<u>MICRO-GRID (STAND ALONE SYSTEM)</u>

A Project report submitted in partial fulfillment
of the requirements for the degree of B. Tech in Electrical Engineering

by

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CERTIFICATE

TO WHOM IT MAY CONCERN

This is to certify that the project work entitled **MICRO-GRID** (Stand Alone System) is the bona fide work carried out by **Rahul Rakshit (11701617008), Shaheen Wasif (11701616032), Debarati Chowdhury (11701617017) And Neelotpal Sharma (11701617012),** are student of B.Tech in the Dept. of Electrical Engineering, Rcc Institute of Information Technology (RCCIIT), canal south road, Beliaghata, kolkata-700015, affiliated to Maulana Abul Kalam Azad University Of Technology (MAKAUT), West Bengal, India, during the academic year 2016-17, in partial fulfillment of the requirements for the degree of Bachelor of Technology in Electrical Engineering and that this project has not submitted previously for the award of any other degree, diploma and fellowship.

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Respected Sir,

In accordance with the requirements of the degree of Bachelor of Technology in the Department of Electrical Engineering, RCC Institute of Information Technology, we present the following thesis entitled “MICRO-GRID (STAND ALONE SYSTEM)”. This work was performed under the valuable guidance of **Mr. Nijam Uddin Molla,** Assistant Professor in the Dept. of Electrical Engineering. We declare that the thesis submitted is our own, expected as acknowledge in the test and reference and has not been previously submitted for a degree in any other Institution.

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ABBREVIATIONS AND ACRONYMS

IC - Integrated Circuit

PCB – Printed Circuit Board

μC – Micro Controller

BJT - Bi-polar Junction Transistor

SPDT - Single Pole Double Throw

NO - Normally Open

NC - Normally Closed

COM – Common

LCD – Liquid Crystal Display

LED - Light Emitting Diode

POT – Potentiometer

AT – Attention Command

SMPS – Switch Mode Power Supply

RF – Radio Frequency

USB – Universal serial bus

SPI – Serial Peripheral Interface

GPIO – General Purpose Input Output

API – Application Program Interface

ABSTRACT

The Micro–Grid concept assumes a cluster of loads and micro–sources (<100 kW) operating as a single controllable system that provides both power and heat to its local area. This concept provides a new paradigm for defining the operation of distributed generation. To the utility the Micro–Grid can be thought of as a controlled cell of the power system. For example, this cell could be controlled as a single dispatchable load, which can respond in seconds to meet the needs of the transmission system. To the customer the Micro–Grid can be designed to meet their special needs; such as, enhance local reliability, reduce feeder losses, support local voltages, provide increased efficiency through use waste heat, voltage sag correction or provide uninterruptible power supply functions. This paper provides an overview of the Micro–Grid paradigm. This includes the basic architecture, control and protection and energy management.

Microgrids are intentional islands formed at a facility or in an electrical distribution system that contain at least one distributed energy resource and associated loads. Microgrids that operate both electrical generation and loads in a coordinated manner can offer benefits to the customer and the local utility. The loads and energy sources in a microgrid can be disconnected from and reconnected to the utility system with minimal disruption, thereby improving reliability. Any time a microgrid is implemented in an electrical distribution system, it must be well planned to avoid problems. This paper discusses current microgrid technologies and standards that are being developed to address implementation of microgrids.

Chapter 1. Introduction

Distributed generation (DG) encompasses a wide range of prime mover technologies, such as internal combustion (IC) engines, gas turbines, micro-turbines, photovoltaic, fuel cells and wind- power.
Penetration of distributed generation across the US has not yet reached significant levels. However that situation is changing rapidly and requires attention to issues related to high penetration of distributed generation within the distribution system. A better way to realize the emerging potential of distributed generation is to take a system approach which views generation and associated loads as a subsystem or a "micro-grid".
The CERTS micro-grid concept is an advanced approach for enabling integration of, in principle, an unlimited quantity of distributed energy resources into the electricity grid. The micro-grid concept is driven by two fundamental principles:

1) A *systems* perspective is necessary for customers, utilities, and society to capture the full benefits of integrating distributed energy resources into an energy system;
2) The *business case* for accelerating adoption of these advanced concepts will be driven, primarily, by lowering the first cost and enhancing the value of micro-grids.

Each innovation embodied in the micro-grid concept (i.e., intelligent power electronic interfaces, and a single, smart switch for grid disconnect and resynchronization) was created specifically to lower the cost and improve there liability of smaller-scale distributed generation (DG) systems (i.e., systems with installed capacities in the 10's and 100's of kW). The goal of this work is to accelerate realization of the many benefits offered by smaller-scale DG, such as their ability to supply waste heat at the point of need (avoiding extensive thermal distribution networks) or to provide higher power quality to some but not all loads within a facility. From a grid perspective, the micro-grid concept is attractive because it recognizes the reality that the nation's distribution system is extensive, old, and will change only very slowly. The micro-grid concept enables high penetration of DER without requiring re-design or re-engineering of the distribution system, itself**.**

During disturbances, the generation and corresponding loads can autonomously separate from the distribution system to isolate the micro-grid's load from the disturbance (and thereby maintaining high level of service) without harming the transmission grid's integrity. Intentional islanding of generation and loads has the potential to provide a higher local reliability than that provided by the power system as a whole. The smaller size of emerging generation technologies permits generators to be placed optimally in relation to heat loads allowing for use of waste heat. Such applications can more than double the overall efficiencies of the systems.

1.1 Literature Review:

Microgrids have a long history. In fact, Thomas Edison‘s first power plant constructed in1882 – the Manhattan Pearl Street Station – was essentially a microgrid since a centralized grid had not yet been established. By 1886, Edison‘s firm had installed fifty-eight direct current (DC) microgrids The term Microgrid has been defined by many people in many ways. As recorded at University of Wisconsin, Madison, USA, the term ―MICROGRID‖ has as many as13 compositing definitions. Different definitions of Microgrid:

1. An integrated energy system consisting of distributed energy resources and multiple electrical loads operating as a single, autonomous grid either in parallel to or ―islanded‖ from the existing utility power grid.

2. The term microgrid (μG) refers to the concept of single electrical power subsystems associated with a small number of distributed energy resources (DERs), both renewable and/or conventional sources, including photovoltaic, wind power, hydro, internal combustion engine, gas turbine, and microturbine
together with a cluster of loads

3.International Council on Large Electricity Systems (CIGRE) has a Working Group on DG. It defined DG as all generation units with a maximum capacity of 100 MW usually connected to the distribution network, that are neither centrally planned nor dispatched.

4.International Energy Agency (IEA) views DG as units producing power on a customer site or within local distribution utilities and supplying power directly to the local distribution network.

5.Willis et al. state that ―DG includes application of small generators, typically ranging in capacity from 15 to 10,000 kW, scattered throughout a power system, to provide the electric power needed by electrical consumers. As ordinarily applied, the term DG includes all uses of small electric power generators, whether located on the utility system, at the site of a utility customer, or at an isolated site not connected to the power grid.

6. However, most accepted definition by Dr. Robert H. Lasseter , Professor and Principle Research Scientist, University of Wisconsin, Madison, is ―The Consortium for Electric Reliability Technology Solutions (CERTS) Micro-Grid concept assumes an aggregation of loads and micros-ources operating as a single system providing both power and heat. Most of the micro-sources must be power electronic based to provide the required flexibility to insure operation as a single aggregated system. This control flexibility allows the CERTS Micro-Grid to present itself to the bulk power system as a single controlled unit that meets local needs for reliability and security.

1.2 Emerging Generation Technologies

In terms of the currently available technologies, the micro-sources can include fuel cells, renewable generation, as wind turbines or PV systems, micro-turbines and inverter based internal combustion generator set with inverters. One of the most promising applications of this new concept corresponds to the combined heat and power – CHP – applications leading to an increase of the overall energy effectiveness of the whole system.
Most emerging technologies such as micro-turbines, photovoltaic, fuel cells and gas internal combustion engines with permanent magnet generator require an inverter to interface with the electrical distribution system.

Photovoltaic and wind-power are important renewable technologies that require an inverter to interface with the electrical distribution system. The major issue with these technologies is the nature of the generation. The availability of their energy source is driven by weather, not the loads of the systems. These technologies can be labeled as intermittent and ideally, they should be operated at maximum output. Intermittent sources can be used in the CERTS micro-grid as a "negative load", but not as a dispatchable source.

1.3 Issues and Benefits Related to Emerging Generation Technologies

1.3.1 Control

A basic issue for distributed generation is the technical difficulties related to control of a significant number of micro-sources. For example, for California to meet its DG objective it is possible that this could result in as many as 120,000, 100kW generators on their system. This issue is complex but the call for extensive development in fast sensors and complex control from a central point provides a potential for greater problems. The fundamental problem with a complex control system is that a failure of a control component or a software error will bring the system down. DG needs to be able to respond to events autonomous using only local information. For voltage drops, faults, blackouts etc. the generation needs to switch to island operation using local information. This will require an immediate change in the output power control of the micro-generators as they change from a dispatched power mode to one controlling frequency of the islanded section of network along with load following.

We believe that while some emerging control technologies are useful, the traditional power system provides important insights. Key power system concepts can be applied equally well to DG operation. For example, the power vs. frequency droop and voltage control used on large utility generators can also provide the same robustness to systems of small DGs. From a communication point of view only the steady state power and voltage needs to be dispatched to optimize the power flow.

The area of major difference from utility generation is the possibility that inverter-based DG cannot provide the instantaneous power needs due to lack of a large rotor. In isolated operation, load-tracking problems arise since micro-turbines and fuel cells have slow response to control signals and are inertia-less. A system with clusters of micro sources designed to operate in an island mode requires some form of storage to ensure initial energy balance. The necessary storage can come in several forms; batteries or super capacitors on the dc bus for each micro source; direct connection of ac storage devices (AC batteries; flywheels, etc, including inverters). The CERT micro-grid uses dc storage on each source's dc bus to insure highest levels of reliability. In this situation one additional source (N+1) we can insure complete functionality with the loss of any component. This is not the case if there is a single ac storage device for the micro-grid.

1.3.2 Operation and Investment

The economy of scale favors larger DG units over micro-sources. For a micro-source the cost of the interconnection protection can add as much as 50% to the cost of the system. DG units with a rating of three to five times that of a micro-source have a connection cost much less per kWatt since the protection cost remain essentially fixed. The micro-grid concept allows for the same cost advantage of large DG units by placing many micro-sources behind a single interface to the utility.

Using DG to reduce the physical and electrical distance between generation and loads can contribute to improvement in reactive support and enhancement to the voltage profile, removal of distribution and transmission bottlenecks, reduce losses, enhance the possibly of using waste heat and postpone investments in new transmission and large scale generation systems. Contribution for the reduction of the losses in the European electricity distribution systems will be a major advantage of micro-sources. Taking Portugal as an example, the losses at the transmission level are about 1.8 to 2 %, while losses at the HV and MV distribution grids are about 4%. This amounts to total losses of about 6% excluding the LV distribution network. In 1999 Portugal's consumption at the LV level was about 18 TWh. This means that with a large integration of micro-sources, say 20% of the LV load, a reduction of losses of at least, 216 GWh could be achieved. The Portuguese legislation calculates the avoided cost associated with CO_2 pollution as 370g of CO_2/kWh produced by renewable sources. Using the same figures, about 80 kilo tones of avoided annual CO_2 emissions can be obtained in this way. Micro-generation can therefore reduce losses in the European transmission and distribution networks by 2-4%, contributing to a reduction of 20 million tones CO_2 per year in Europe.

1.3.3 Optimal Location for Heating/Cooling Cogeneration

The use of waste heat through co-generation or combined cooling heat and power (CCHP) implies an integrated energy system, which delivers both electricity and useful heat from an energy source such as natural gas [12]. Since electricity is more readily transported than heat, generation of heat close to the location of the heat load will usually make more sense than generation of heat close to the electrical load. Under present conditions, the ideal positioning of cooling-heating-and-power cogeneration is often hindered by utility objections, whether legitimate or obstructionist. In a micro-grid array, neither obstacle would remain. Utilities no longer have issues to raise regarding hazards. Consequently, DGs don't all have to be placed together in tandem in the basement anymore but can be put where the heat loads are needed in the building. CHP plants can be sited optimally for heat utilization. A micro-grid becomes, in effect, a little utility system with very *pro*-CHP policies rather than objections.

The small size of emerging generation technologies permits generators to be placed optimally in relation to heat or cooling loads. The scale of heat production for individual units is small and therefore offers greater flexibility in matching to heat requirements.

1.3.4 Power Quality/ Power Management/ Reliability

DG has the potential to increase system reliability and power quality due to the decentralization of supply. Increase in reliability levels can be obtained if DG is allowed to operate autonomously in transient conditions, namely when the distribution system operation is disturbed upstream in the grid. In addition, black start functions can minimize down times and aid the re-energization procedure of the bulk distribution system.

Thanks to the redundancy gained in parallel operation, if a grid goes out, the micro-grid can continue seamlessly in island mode. Sensitive, mission-critical electronics or processes can be safeguarded from interruption. The expense of secondary onsite power backup is thus reduced or perhaps eliminated, because, in effect, the micro-grid and main grid do this already.

In most cases small generation should be part of the building energy management systems. In all likelihood, the DG energy output would be run more cost-effectively with a full range of energy resource optimizing such as peak-shaving, power and waste heat management, centralized load management, price-sensitive fuel selection, compliance with interface contractual terms, emissions monitoring/control and building system controls. The micro-grid paradigm provides a general platform to approach power management issues.

It has been found that [13], in terms of energy source security, that multiple small generators are more efficient than relying on a single large one for lowering electric bills. Small generators are better at automatic load following and help avoid large standby charges seen by sites using a single generator. Having multiple DGs on a micro-grid makes the chance of all-out failure much less likely, particularly if extra generation is available.

1.4 Micro-grid Concept

CERTS Micro-grid has two critical components, the static switch and the micro-source. The static switch has the ability to autonomously island the micro-grid from disturbances such as faults, IEEE 1547 events or power quality events. After islanding, the reconnection of the micro-grid is achieved autonomously after the tripping event is no longer present. This synchronization is achieved by using the frequency difference between the islanded micro-grid and the utility grid insuring a transient free operation without having to match frequency and phase angles at the connection point. Each micro-source can seamlessly balance the power on the islanded Micro-grid using a power vs. frequency droop controller. This frequency droop also insures that the Micro-grid frequency is different from the grid to facilitate reconnection to the utility.

Basic micro-grid architecture is shown in Figure 1.1. This consists of a group of radial feeders, which could be part of a distribution system or a building's electrical system. There is a single point of connection to the utility called point of common coupling [14]. Some feeders, (Feeders A-C) have sensitive loads, which require local generation. The non-critical load feeders do not have any local generation. Feeders A-C can island from the grid using the static switch that can separate in less than a cycle [15]. In this example there are four micro-sources at nodes 8, 11, 16 and 22, which control the operation using only local voltages and currents measurements.

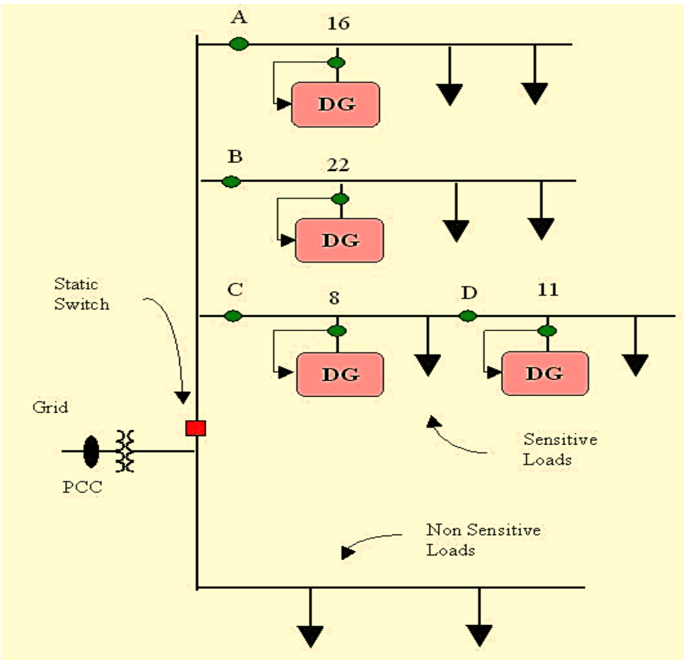


Figure 1.1 Micro-grid Architecture Diagram.

When there is a problem with the utility supply the static switch will open, isolating the sensitive loads from the power grid. Non sensitive loads ride through the event. It is assumed that there is sufficient generation to meet the loads' demand. When the micro-grid is grid-connected power from the local generation can be directed to the non-sensitive loads.

To achieve this we promote autonomous control in a peer-to-peer and plug-and-play operation model for each component of the micro-grid. The peer-to-peer concept insures that there are no components, such as a master controller or central storage unit that is critical for operation of the micro-grid. This implies that the micro-grid can continue operating with loss of any component or generator. With one additional source (N+1) we can insure complete functionality with the loss of any source. Plug-and-play implies that a unit can be placed at any point on the electrical system without re-engineering the controls. The plug-and-play model facilitates placing generators near the heat loads thereby allowing more effective use of waste heat without complex heat distribution systems such as steam and chilled water pipes.

1.4.1 Unit Power Control Configuration

In this configuration each DG regulate the voltage magnitude at the connection point and the power that the source is injecting, P. This is the power that flows from the micro-source as shown in Figure 1.1. With this configuration, if a load increases anywhere in the micro-grid, the extra power come from the grid, since every unit regulates to constant output power. This configuration fits CHP applications because production of power depends on the heat demand. Electricity production makes sense only at high efficiencies, which can only be obtained only when the waste heat is utilized. When the system islands the local power vs. frequency droop function insures that the power is balanced within the island.

1.4.2 Feeder Flow Control Configuration

In this configuration, each DG regulate the voltage magnitude at the connection point and the power that is flowing in the feeder at the points A, B, C and D in Figure 1.1. With this configuration extra load demands are picked up by the DG showing a constant load to the utility grid. In this case, the micro-grid becomes a true dispatchable load as seen from the utility side, allowing for demand-side management arrangements. When the system islands the local feeder flow vs. frequency droop function insures the power balance with the loads.

1.4.3 Mixed Control Configuration

In this configuration, some of the DGs regulate their output power, P, while some others regulate the feeder power flow, F. The same unit could control either power or flow depending on the needs. This configuration could potentially offer the best of both worlds: some units operating at peak efficiency recuperating waste heat, some other units ensuring that the power flow from the grid stays constant under changing load conditions within the micro-grid.

Chapter 2. Static Switch

The static switch has the task of disconnecting all the sensitive loads from the grid once the quality of power delivered starts deteriorating. The static switch does not disconnect the local system from the grid, but it disconnects only the sensitive loads.

There are two main reasons to adopt a static switch to implement the connection and disconnection from the grid: first a static switch does not have mechanical moving parts, therefore its operating life will be extensively elongated compared to a traditional contactor with moving parts. The second reason to use a dedicated switch is because during reconnection with the grid a complex series of synchronization checks need to be performed. A normal interrupting breaker would be able to perform the function of disconnecting to the grid, but a sophisticated static switch is required to properly reconnect to the utility system without creating hazardous electrical transients across the micro-grid.

The static switch plays a key role in the interface between the micro-grid and the utility system. This device needs to be controlled by a logic that verifies some constraints at the terminals of the switch before allowing for synchronization. The same logic applies to the circuitry that controls the action of the contactor, the device used to physically connect a micro-source to the feeder. Disconnection at the static switch is regulated differently than at the contactor. Disconnection at the static switch takes place because of deterioration of quality of electric power delivery from the utility system. More in particular, there are at least five conditions that will enable the disconnection logic and command the transfer to intentional island:

i) Poor voltage quality from the utility, like unbalances due to nearby asymmetrical loads
ii) Frequency of the utility falls below a threshold, indicating lack of generation on the utility side
iii) Voltage dips that last longer than the local sensitive loads can tolerate
iv) Faults in the system that keep a sustained high current injection from the grid
v) Any current that is detected flowing from the micro-grid to the utility system for a certain period of time

Synchronization conditions are detected by verifying two constraints: the first is that the voltage across the switch has to be very small (ideally zero), and the second is that the resulting current after the switch is closed must be inbound from the utility system towards the micro-grid. The second condition needs to be re-spelled for the case of a contactor connecting two micro-sources in island mode: in this scenario the resulting current must always be from the highest frequency source to the lower one (which is by the way the same constraint that is enforced when connecting to the grid, but there it was described using more familiar terms).

2.1 Direction of Current at Synchronization

The first thing that needs to be taken into consideration is that the switch is going to close on an R-L circuit that has no current previously flowing into it. Furthermore, the voltages at each of the two ends of the switch rotate at different frequencies. This implies that the relative phase angle between the voltage of the grid, E, and the voltage on the micro-grid side, V, is constantly changing from a minimum value of zero degrees to a maximum of 180 and back to zero again.

The direction of flow of the resulting current will be determined by the relative placement of these two voltages at the instant of closing.

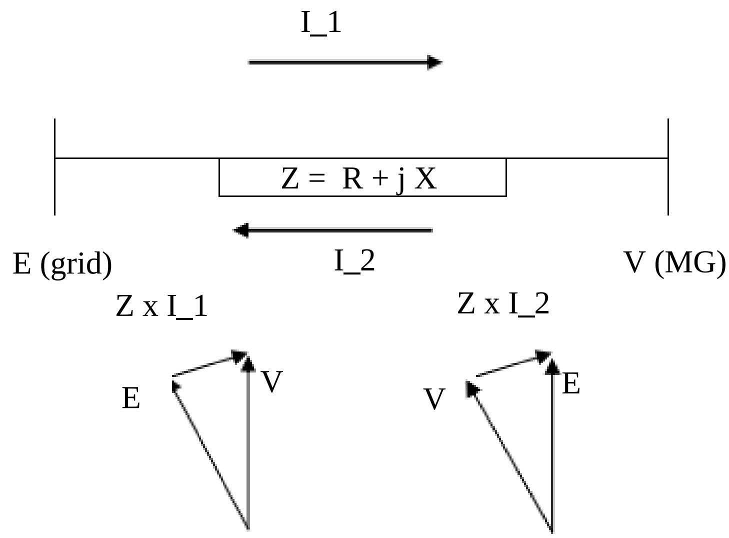


Figure 2.1 Current Direction as the Switch is Closed.

Figure 2.1 shows that with the convention of the angles growing in the anticlockwise direction, if E is ahead of V, then the resulting current I_1 will go towards the micro-grid. Conversely, if V is ahead of E, then the resulting current I_2 will go towards the grid. The condition to be enforced is that when the switch is closed the resulting current must be flowing towards the micro-grid.

2.2 Direction of Current at Steady State

This section proves that the in steady state the active power flows always from the source that has higher frequency towards the other that has lower frequency before the connection takes place. The reason why the previous statement is true has to be sought into the power versus frequency droop. The case of one micro-source connected to the grid is examined. The droop characteristic is reported in Figure 2.2 showing the requested power that is injected during the connection to grid, when operating at system frequency as well as the power injected during island mode, at a reduced frequency. In this chapter no frequency restoration during island mode is assumed, which implies that the frequency will stay at the lower value during the whole time the system operates disconnected from the grid. During island mode the power injected is also the power taken from the load, since no other sources are in the system. Notice that the power that the grid injects is the difference from the load power and what the unit injects. Obviously, the requested power must be smaller or equal than the load demand because if not power would be injected from the micro-grid into the utility system.

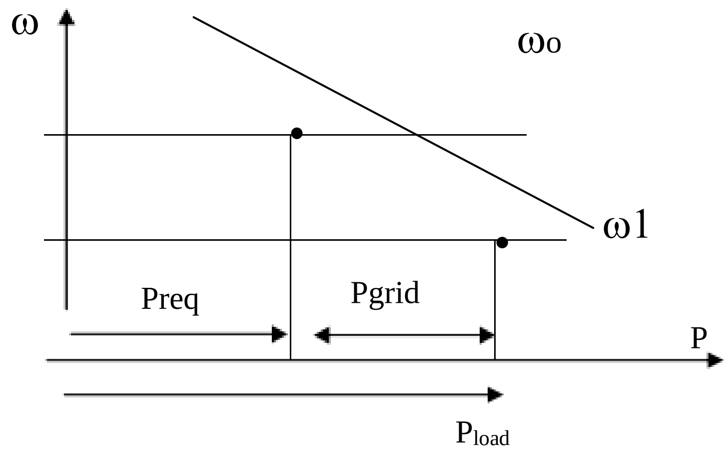


Figure 2.2 Power vs. Frequency Droop.

In island mode the micro-grid is operating at a lower frequency, w1, than the utility system. The micro-source injects the full quota of power to provide the load and the grid injects zero power since it is disconnected. After reconnection the micro-source injects power according to the requested command, while the grid injects the remaining quota to meet the load demand. So, it is apparent that after synchronization, in steady state the power flows from the source that had high frequency (grid) during the island mode towards the source that had lower frequency (micro-grid). It is less obvious to understand why the same principle rules the behavior of the steady state power when two micro-sources are connected while in island.

Figure 2.3 shows the case when two micro-sources are connected in island. Each micro-source was operating in island from the grid on beforehand, and after connection the two sources are interconnected, but still, in island from the utility system.

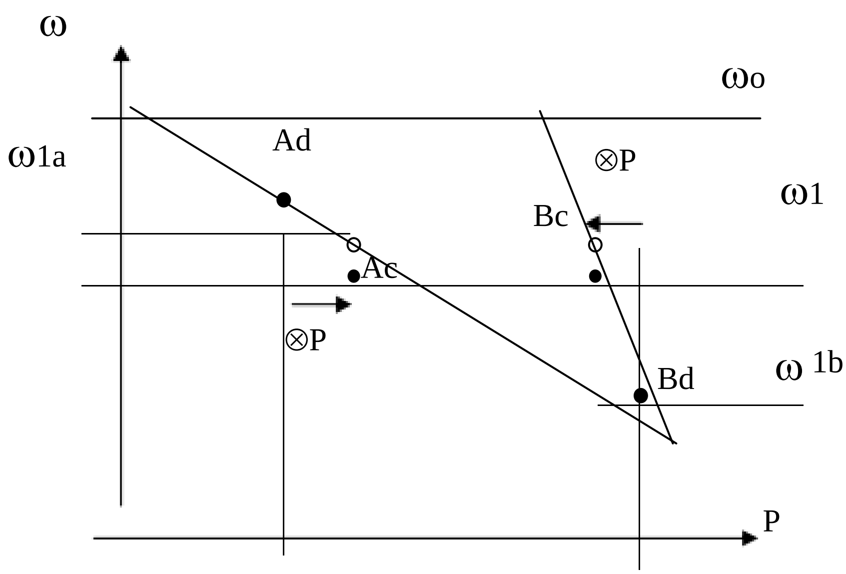


Figure 2.3 Island Connection of Two Micro-sources, A has Higher Frequency than B.

This is the situation that can be encountered during a reconnection procedure of micro-grid sections after they all have been disconnected from each other and the grid because of a nearby fault. All possible cases, two in total, will be examined assuming that unit A is loaded less than unit B since the same process can be repeated without loss of generality inverting the two labels.

In Figure 2.3 the letters “d” and “c” have been used to respectively indicate the condition when the two units are disconnected and connected to each other. When they are disconnected, unit A has a higher operating frequency than unit B. When they are connected, the frequency is one and only, ω1. Each of the two units injects the power requested by their local loads before connection. When the two sources are connected, unit A injects more power, ⊗P, while unit B injects less power, diminished of the very same amount (⊗P) that unit A had increased since none of the loads have changed. Power injection has just been rearranged between the two units, but it still remains that on the point of connection between the two units, in steady state the power flows from source A to source B. That is, the power flows from the source that had higher frequency before connection, towards the one at lower frequency.

To complete the proof, only one more case needs to be described. Figure 2.4 shows the case where unit A has a lower operating frequency, ω1a, than B, ω1b, when the two units are disconnected.

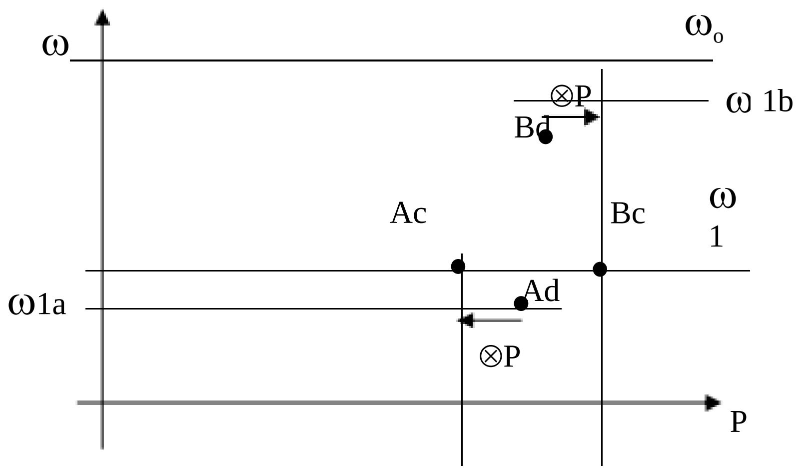


Figure 2.4 Island Connection of Two Micro-sources, A has Lower Frequency than B.

At the steady state after the units are connected, the newly established frequency will be ω1, the same for both units. The power injected by the sources when they are not connected with each other are respectively Ad and Bd, while after connection they are Ac and Bc. There is to notice that as connection takes place, due to the droop characteristic, source a backs off its injection of amount ⊗P and since the overall load is unchanged, source B will increase its output of ⊗P. This means that looking on the line that connects the two sources one would see the flow of power going from B to A and the power flow would be exactly ⊗P. Also in this case the power in steady state flows from the source that was operating at higher frequency when disconnected towards the other source operating at lower frequency.

2.3 Synchronization Conditions

The grid voltage E rotates at 60 Hz in the counter clockwise direction, while the micro-grid voltage V rotates at a frequency *lower* than 60 Hz in the same direction. This means that if the vectors are strobed 60 times a second, the vector E stays motionless, while vector V recedes in the clockwise direction.

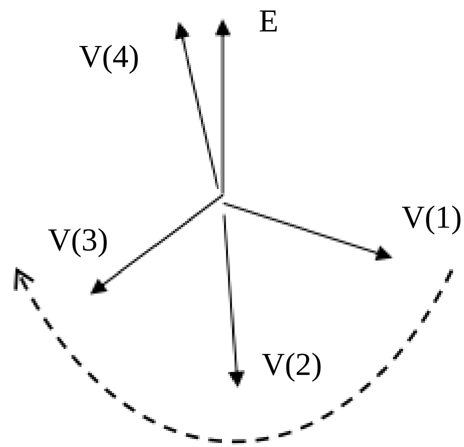


Figure 2.5 Receding Trajectory of Voltage Vector V.

Figure 2.5 shows the vector V rotating slower than E, so at each strobing it loses some angle from E. As time increases, V goes from position 1 to 4. The magnitude of the current resulting when the switch is closed is proportional to the voltage across the switch as the contacts are closed. The voltage across the switch is given by the vectorial difference between E and V. Near position 2 there is the maximum voltage across the switch and it would be a big mistake to close there because large transients in the current will ensue. Position 3 is better, but position 4 is where it is safe to close the switch.

Figure 2.6 shows the behavior in time domain: the difference in frequency has been artificially increased to make the point. In the upper plot, the solid line is the voltage of the grid, E, while the slower voltage, V, with longer period, and is dotted. In the lower plot there is the voltage across the static switch. The best time to close the static switch is when the voltage across the switch is very small and contemporarily, the voltage of the grid is leading the voltage of the micro-source. Therefore, anytime between time scale values of 30 to 35 is a good time to synchronize to the grid and close the switch.

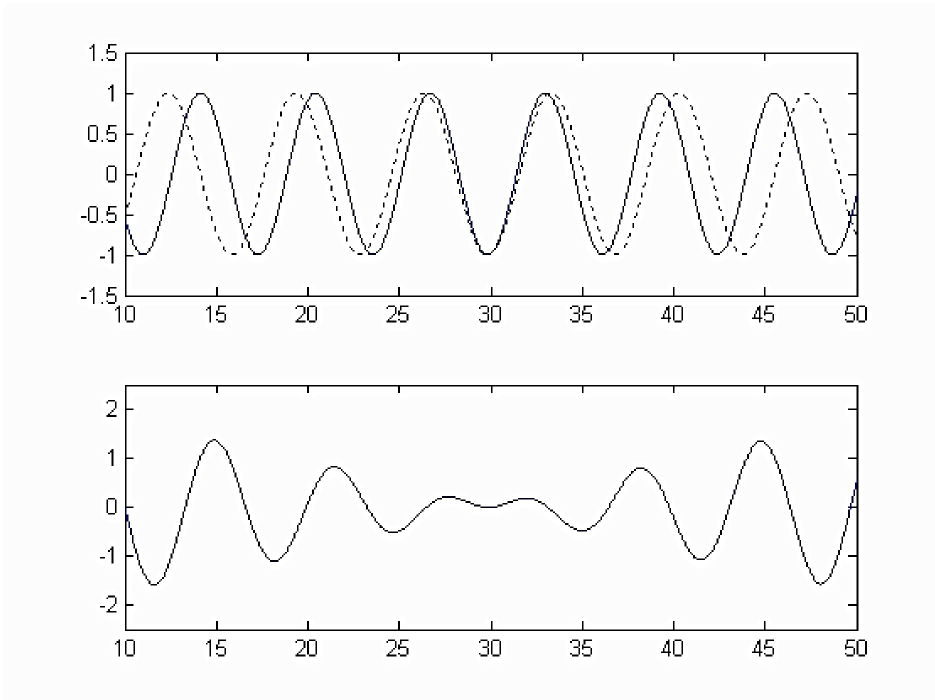


Figure 2.6 Voltages on Either Side and Across the Static Switch.

When connecting two units together in island mode, each of the units is rotating at its own frequency, possibly none of them at 60Hz. The considerations made so far can be applied to a contactor that is responsible to connect the two units as long as the grid voltage is replaced with the voltage of the source that rotates faster and the micro-grid voltage with the voltage of the source that rotates slower. It is possible to review the synchronizing conditions and express them in general terms that can be applied either to a static switch or to a contactor. The conditions that need to be contemporarily satisfied are:

i) The voltage across the switch must be very small

ii) The fastest rotating voltage must be leading the voltage that rotates slower

Condition (i) seems to be self-explanatory: closing with high voltage across the switch would determine an intolerable transient current. Voltage ratings are also at stake: if closing when the position of the voltage is at 2 in Figure 2.5, the initial condition for the current would be dictated by a voltage drop twice the nominal voltage of the system.

Condition (ii) may need some justification. The droop characteristic always determines a power flow from the unit operating at higher frequency to the lower frequency. This implies that when connecting to the grid, power is taken from the grid in steady state. When closing with the voltages across the switch determining a current of the opposite side, the current will grow at first then diminish and have a zero magnitude for a short time and then grow again, in the opposite direction. The power system can be described by differential equations: closing the switch with a certain voltage across it and with sources in the system applies an initial condition to a force system. The voltage across the switch determines the initial condition, while the permanent, forcing terms are provided by the sources that follow the power versus frequency droop. The issue is that it is possible to create an initial condition with a current that grows in the opposite direction from the forced solution that exists in steady state. The current must have only one transient: growing from zero to the final steady state value.

To make a stronger point, some simulation results with a single micro-source connected to the grid will be shown. At first, the simulation will not meet condition (ii). Figure 2.7 shows the currents flowing in the static switch while Figure 2.8 shows the voltage across the static switch on the upper plot and the current injected by the micro-source on the lower plot. Figure 2.9 shows the active power injected by the unit on the upper plot and the frequency of the micro-grid on the lower plot. From all these plots it should be noticed:

a) the current from the grid increasing, going to zero (reversing) and then increasing again on all three phases

b) The micro-source injects even more power than it is injecting in island, to feed the grid, and backs off immediately to the requested level.

c) The load always takes the same amount of power since its voltage is unperturbed, so the extra power that the micro-source generates transiently goes into the grid.

The micro-source power command is 0.2 pu, while the load takes 0.65 pu (all provided by the unit during island mode): transiently the source generates up to 0.9 pu, with the extra power being injected in the grid.

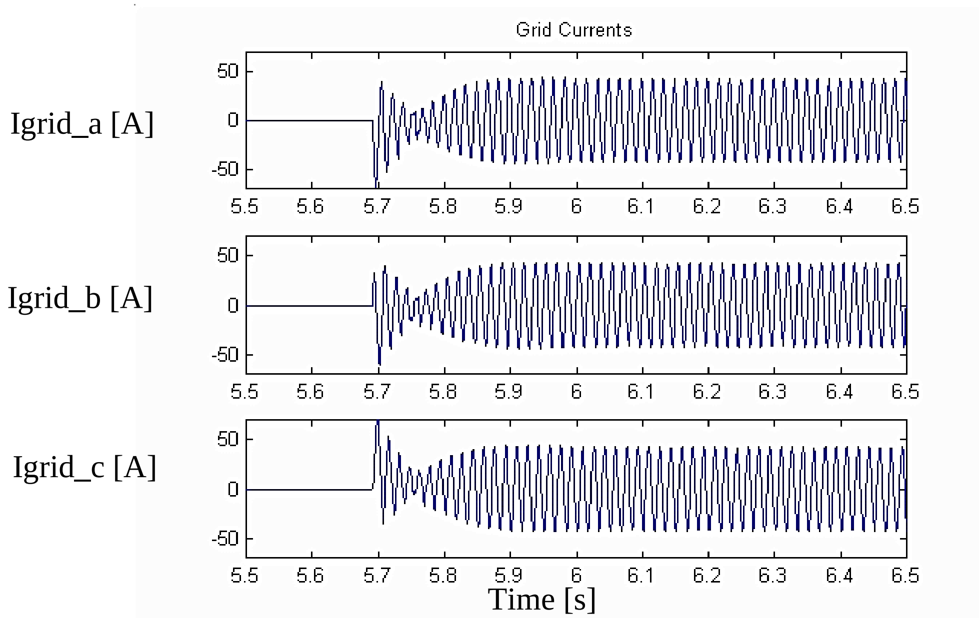


Figure 2.7 Three Phase Currents of the Static Switch, with Condition (ii) not Met.

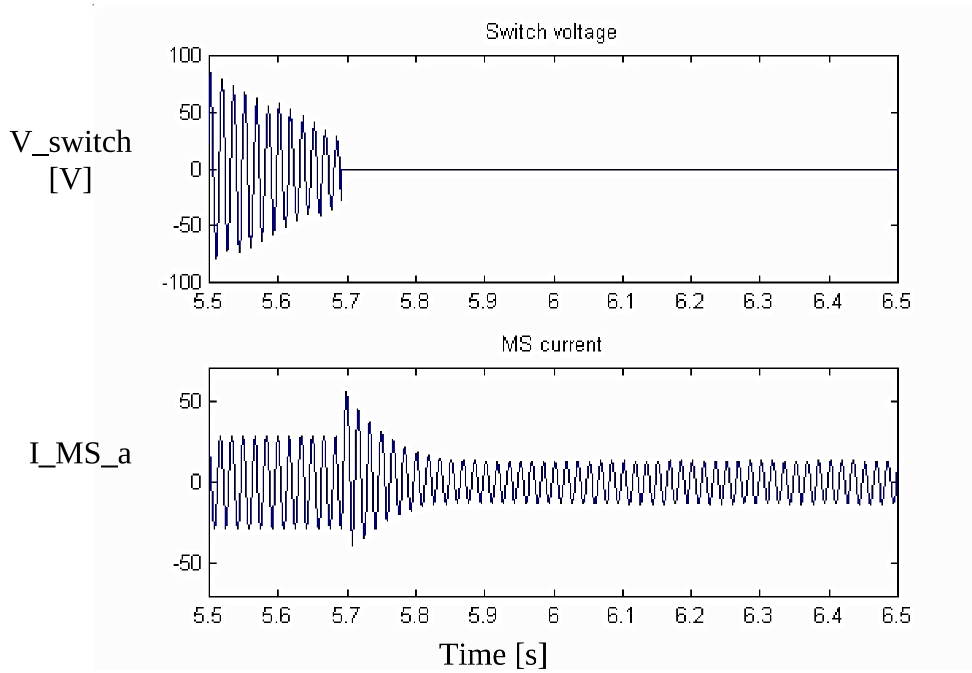


Figure 2.8 Switch Voltage and Micro-source Current, with Condition (ii) not Met.

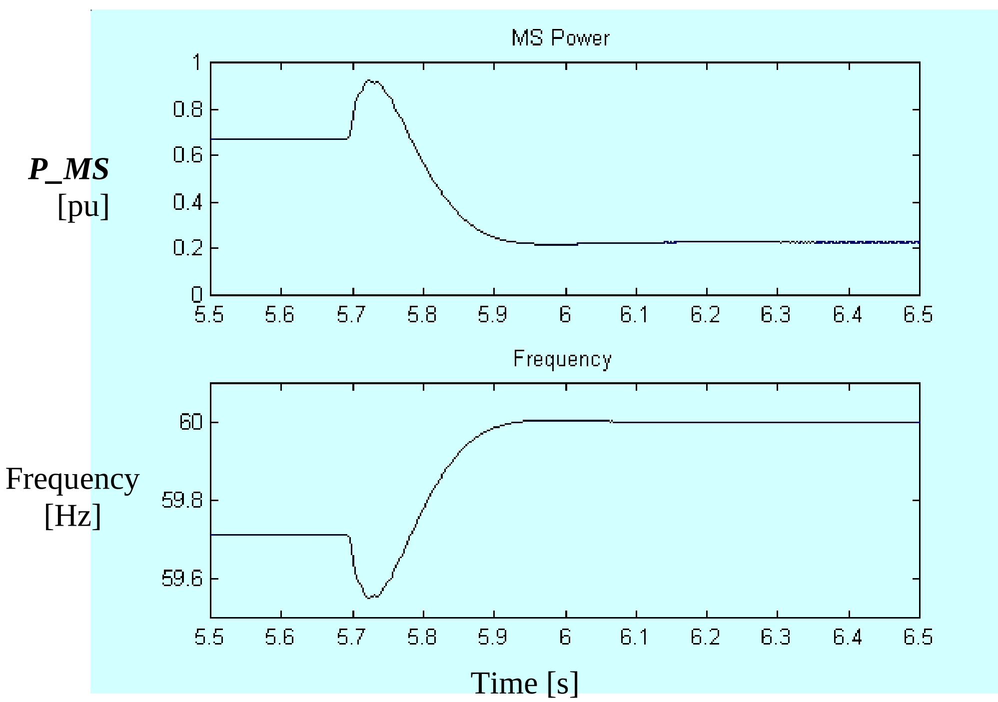


Figure 2.9 Micro-source Power Injection and Frequency, with Condition (ii) Not Met.

This synchronizing behavior is unacceptable because:

1) When the current reverses, also the flux in the magnetic cores of the transformers will change sign, creating a magnetoelectro-dynamic stress on the coils and it is reasonable to assume that every inversion transient will lower the life of the equipment.

2) Due to the fact that the output power of the micro-source overshoots, it is impossible to synchronize when the unit operates near its rated power (say 90%) since this overshoot would bring the operating point beyond the rating of the source and as a result of this the equipment will trip.

It is time to look at a simulation when the switch is closed when the condition (ii) is verified.
Figure 2.10 shows the vector plane with the voltage E and V. Remember that each of the voltages rotates counter clockwise, E at 60Hz and V at a frequency slightly lower. When strobing 60 times a second the vector E is still, while V recedes clockwise. As time increases, the voltage V goes from position 1 to 4. At this very point condition (i) for synchronization is verified, but it is position 5 that contemporarily verifies condition (i) and (ii) to achieve a safe synchronization to the grid.

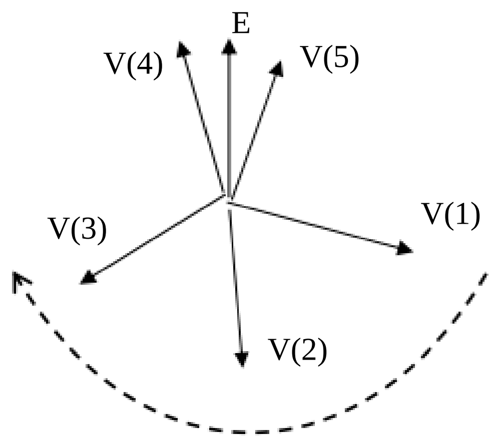


Figure 2.10 Voltage Vector Plane Showing Correct Reclose Timing.

Figure 2.11 shows the three phase currents at the static switch as the synchronization takes place and the switch closes. There is still some transient due to the fact that the closing takes place on an R-L cable, but the current does not go through the reversal of direction.

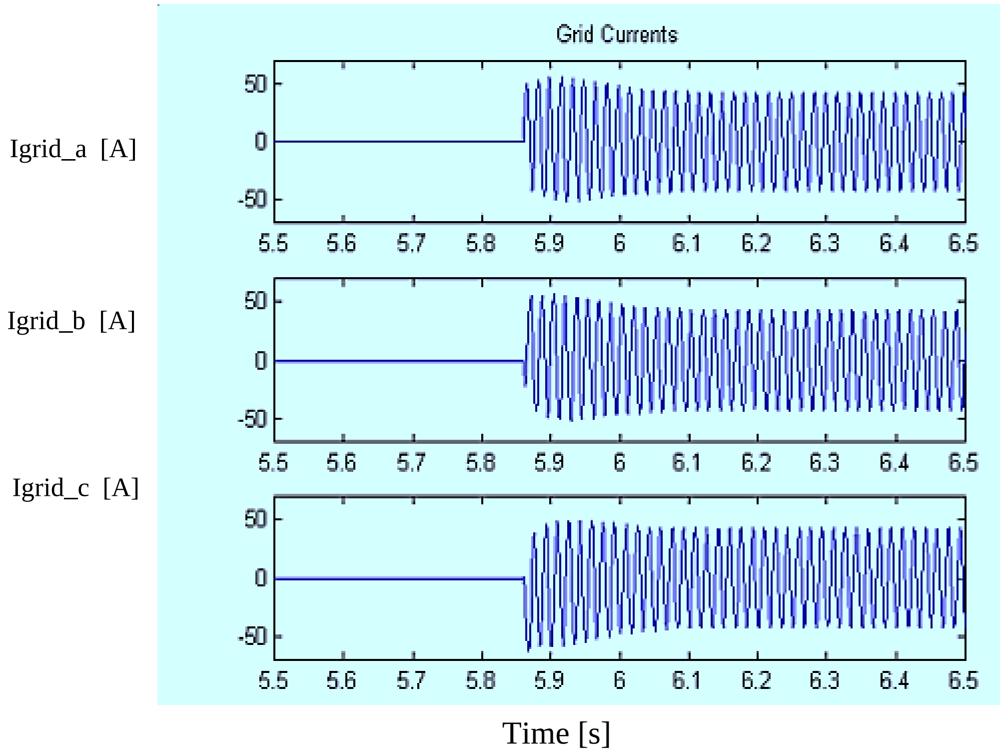


Figure 2.11 Three Phase Currents of the Static Switch, with Condition (ii) Met.

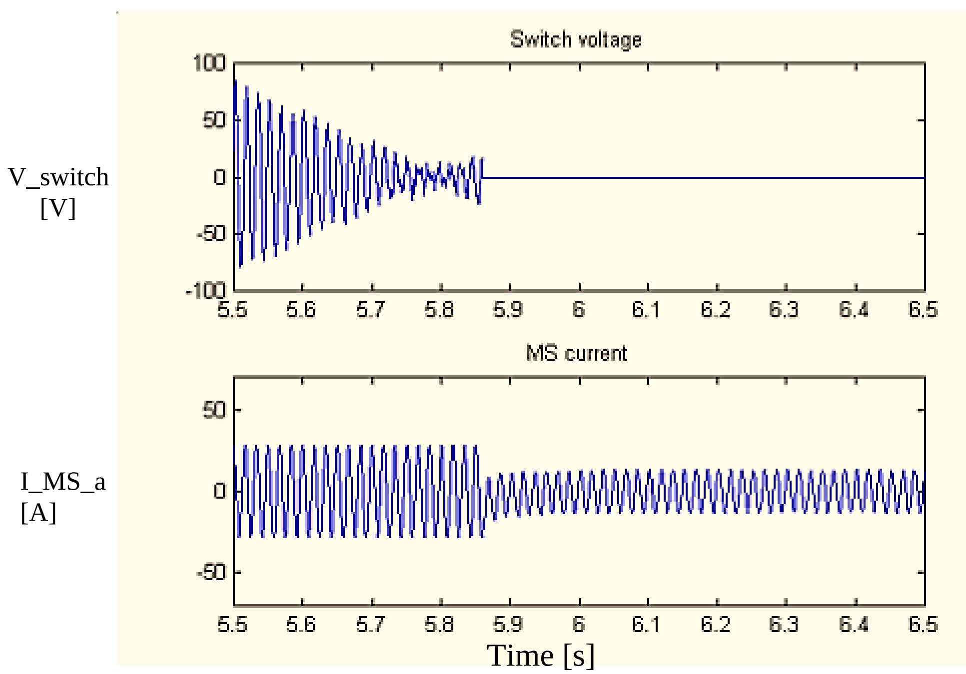


Figure 2.12 Switch Voltage and Micro-source Current, with Condition (ii) Met.

Figure 2.12 shows on the upper plot the voltage across the switch: the envelope of the voltage needs to go past the instant when it reaches the minimum value and then synchronization can take place. The lower plot of Figure 2.12 shows the current in the micro-source, notice also the transient due to reclosing on an inductive network. The current drops to the lower value without any overshoot. The upper plot of Figure 2.13 shows the power of the micro-source going from the full amount required by the load is island mode, 0.65 pu, to the value requested, 0.2 pu, never exceeding the value that it had during island mode. The lower plot of the same figure shows the frequency being locked to the grid value of 60Hz without first sagging towards an even smaller value, as seen in the previous simulation, Figure 2.9

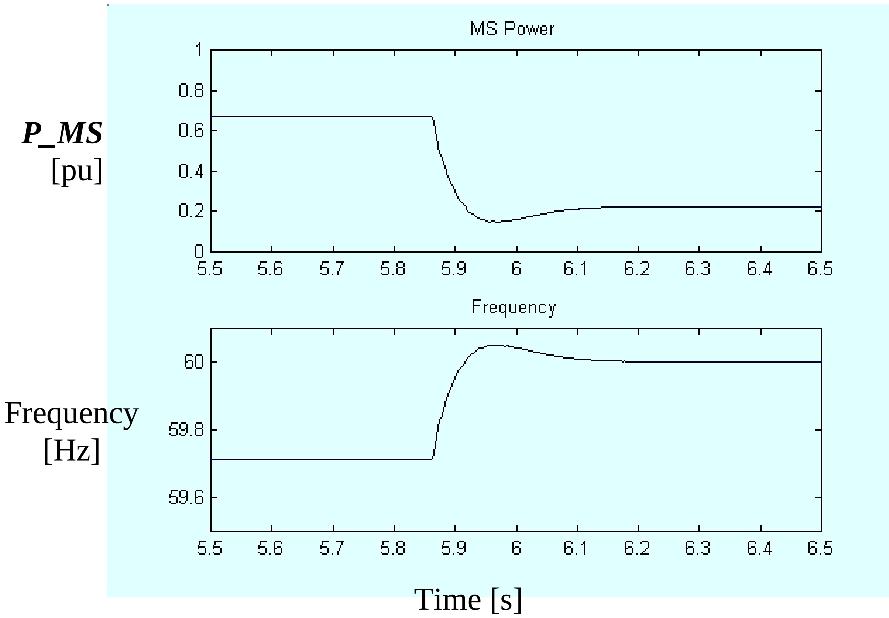


Figure 2.13 Micro-source Power Injection and Frequency, with Condition (ii) Met.

As already described, the synchronizing algorithm applies to the static switch that connects to the grid as well to the contactor that connects the two micro-sources together. To see that it is true, in the previous analysis one only needs to replace the grid voltage with the voltage of the unit that has the highest frequency. Indeed, it does not matter what is the operating frequency: all it matters is that the two voltages are rotating at different speeds. As of today, the hardware configuration of the static switch includes a logic block that enforcers condition (i) but not condition (ii). The current hardware configuration correctly implements the first condition, but does not implement the second. Figure 2.14 shows the voltage across the switch during synchronization. The voltage diminishes in time due to the fact that the voltages at either ends of the switch rotate at slightly different frequencies. As soon as the voltage has reached a minimum threshold the synchronization takes place.

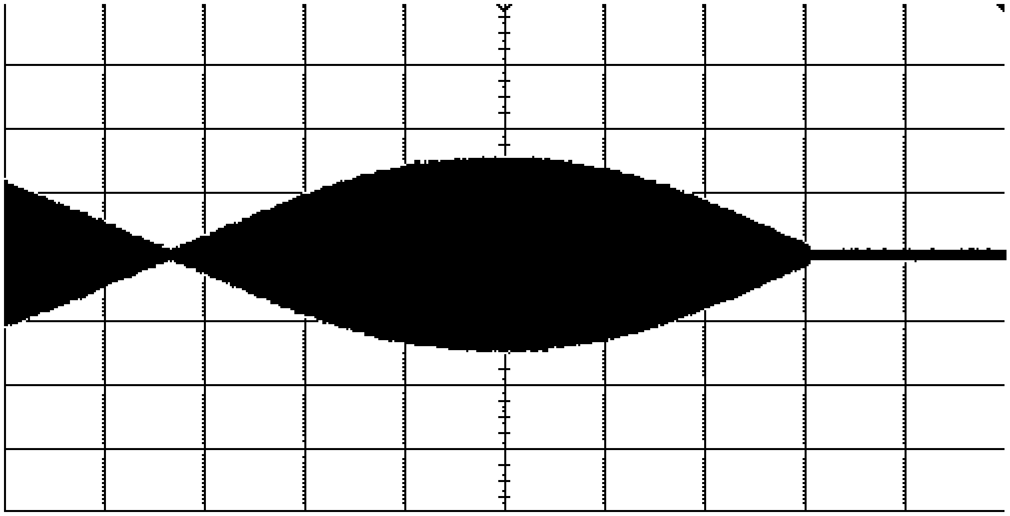


Figure 2.14 Voltage across the Static Switch during Synchronization, 1sec/div, 200V/div.

Figure 2.15 shows the current from the grid (upper plot) and the micro-source (lower plot) when a single unit is connected to the utility. Before synchronization the current from the grid is zero because the static switch is open. As soon as it closes, due to the fact that the second condition is not implemented, the current starts flowing into the grid to immediately reverse after going through a cycle with zero magnitude. The micro-source provides the extra transient current that is injected into the grid and then settles down to a lower value, since the utility is supplementing part of the quota of the load power demand.

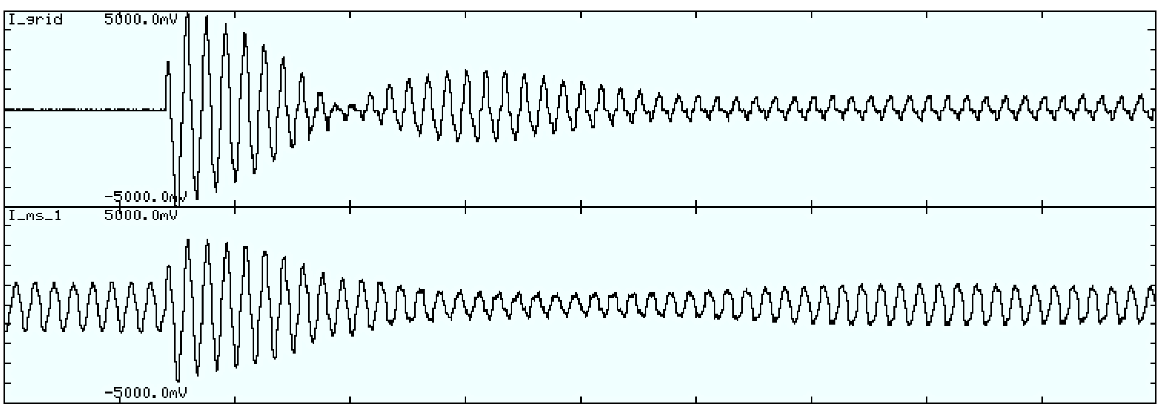


Figure 2.15 Grid and Micro-source Current during Synchronization, 100ms/div, 10A/div.

Chapter 3. Micro-source Details

This chapter gives the details of the system that composes a micro-source. Figure 3.1 shows the micro-source layout implementation. The controller sends the gate pulses to the inverter that generates a three phase 480V line to line voltage. This waveform is rich in harmonic content at the switching frequency, 4 kHz. To filter out these harmonics there is a low pass LC filter immediately connected at the inverter terminals. Then there is the series of the coupling inductance and transformer. The sensed quantities are the voltages at the load bus and the inverter currents. From these quantities it is possible to extract the load voltage magnitude and the active and reactive power injected by the unit. If the unit controls the feeder power flow, then the measures of the currents flowing on the feeder from the side that connects to the grid are also passed to the controller to enable the calculation of this active power flow.

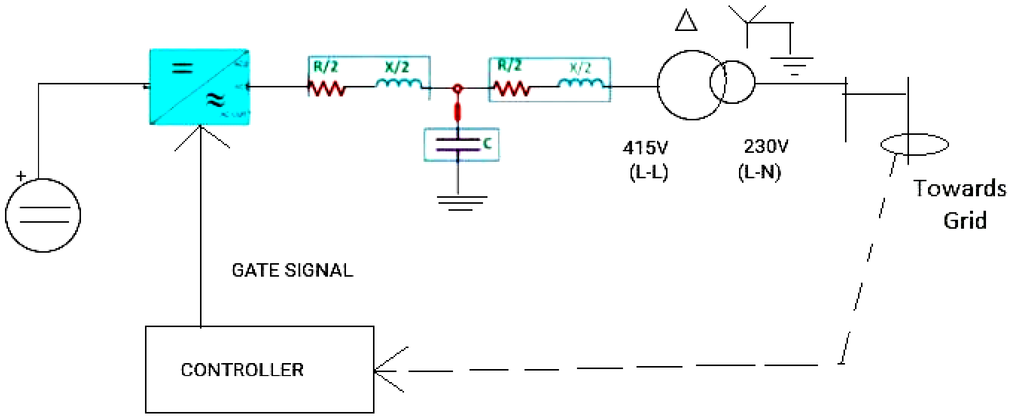


Figure 3.1 Micro-source Diagram.

3.1 Micro-source Controller

This section gives the details of the Micro-source control. The fundamental frequency selective filter is a first tool to handle some of the higher harmonics of the noise, but the calculated values of active and reactive power, as well as the voltage magnitude still suffered from oscillations determined by random spikes in the measured quantities. Two types of controller mainly used in micro-grid are as follows:

- **Local Micro-Controller (MC) :**

The micro-source controller controls the power flow independently without any communications from the central controller (CC). Moreover, micro-controller does not interact independently with other MCs in such a way that it does not override the CC directives and prevents dangerous operation for micro-sources. In response to any disturbance and load changes, MC controls the load-end voltage profile of the micro-source. Each micro-source quickly picks up its generation to supply its share of load in stand-alone mode and automatically comes back to the grid-connected mode by the help of CC. The micro-source controllers quickly respond to the locally monitored voltages and currents irrespective of the data from the neighboring MCs. This control feature facilitates the addition of new micro-sources at any point of Micro-grid without affecting the control and protection of the existing units.

Thus the micro-sources can act as plug-and-play devices. The micro-controller also performs other functions such as economic generation scheduling, load tracking and demand side management by proper control of charging and discharging of electric storage devices in micro-grid system.

- **Central Controller(CC):**

The key function of central controller (CC) is to perform an overall control of micro-grid operation and protection through the MCs. It also provides the power dispatch and voltage set points for all the MCs. Central controller maintains the voltage and frequency through power-frequency (P-f) and voltage control at a specified value at the load end . Besides, it also controls energy optimization for a micro-grid. Though the central controller usually operates in automatic mode but it is designed with a provision for manual intervention as and when required. The central controller (CC) performs its operation by two functional modules, namely, Energy Management Module (EMM) and Protection Co-ordination Module (PCM).

Energy Management Module (EMM):

The Energy Management Module provides specific set points for voltage, frequency, active and reactive power output, to each MC. The specific value considered as the set points are decided on the basis of the operational needs of the Micro-grid. This function is performed either by the techniques of artificial intelligence or by state-of-theart communication. EMM monitors the correct supply of heat and electrical loads to customer satisfaction. It also checks micro-grid's satisfactory operation as per the priori operation in contract with main grid. The module also keeps watch over micro-grid operation with minimum losses and less emissions of greenhouse gases and particulates. EMM also offers micro-sources operation at their highest possible efficiencies.

Protection Co-ordination Module (PCM):

The Protection Co-ordination Module mainly deals with correct protection and coordination of the Micro-grid. It senses and responds to micro-grid and main grid faults and loss of grid (LOG). Changes occurring in fault current levels, during change over from grid-connected to stand-alone mode, are also dealt with by proper communication between the PCM, MCs and upstream main grid controllers

. During the occurrence of minor faults, protection co-ordination module allows the micro-grid to ride through in the grid-connected mode for some time and it continues to operate when the temporary fault is removed. While, on the other hand, when fault occur at main grid PCM immediately switches over the Micro-grid to stand-alone mode for supplying power to the priority loads. Moreover, if any grid fault endangers the stability of the micro-grid, then PCM disconnects the micro grid fully from all main grid loads through the non-priority feeder. This leads to ineffective utilization of the micro-grid in delivering power. In case of faults occurring within a portion of micro-grid feeders, more specifically, the priority feeder, the small faulty zone of that feeder is eliminated to maintain proper supply to the healthy parts of the feeders.

The complete control of the micro-source is shown in Figure 3.2 the inputs are either measurements (like the voltages and currents) or set points (for voltage, power and the nominal grid frequency). The outputs are the gate pulses that dictate when and for how long the power electronic devices are going to conduct. The inverter voltage and current along with the load voltage are measured. The voltage magnitude at the load bus and the active power injected are then calculated. When controlling active power, there is a choice of regulating the power coming from the unit or the power flowing in the feeder where the source is connected. If the power in the feeder is regulated then there is a need to bring in the measure of the current flowing in that branch.

The voltage is calculated from the stationary frame components of the filtered instantaneous voltages. The desired and measured values for the voltages are then passed to a dynamic block that implements the P-I response of the voltage control. The output is the desired voltage magnitude to be implemented by the gate pulse generator block. This version includes low pass filters on the P, Q, and V calculated quantities to reduce the propagation of the effects of noise. These filters have also a secondary desirable effect: they attenuate the magnitude of the 120Hz ripple that exists during unbalanced operation. This allows the control to survive conditions of load unbalance without having to take any corrective action.

This final version of the control focuses on the configuration that regulates the power injected by the unit. This is not a loss of generality, since to implement the load tracking configuration one needs just two modifications: the first is to introduce the measure of the line current to calculate feeder flow, still retaining the inverter current measure to calculate the reactive power injected by the unit. The second modification is to invert the sign of the droop coefficient of the power-frequency characteristic to take into consideration that now it is the line power that is regulated and not the power injected by the unit.

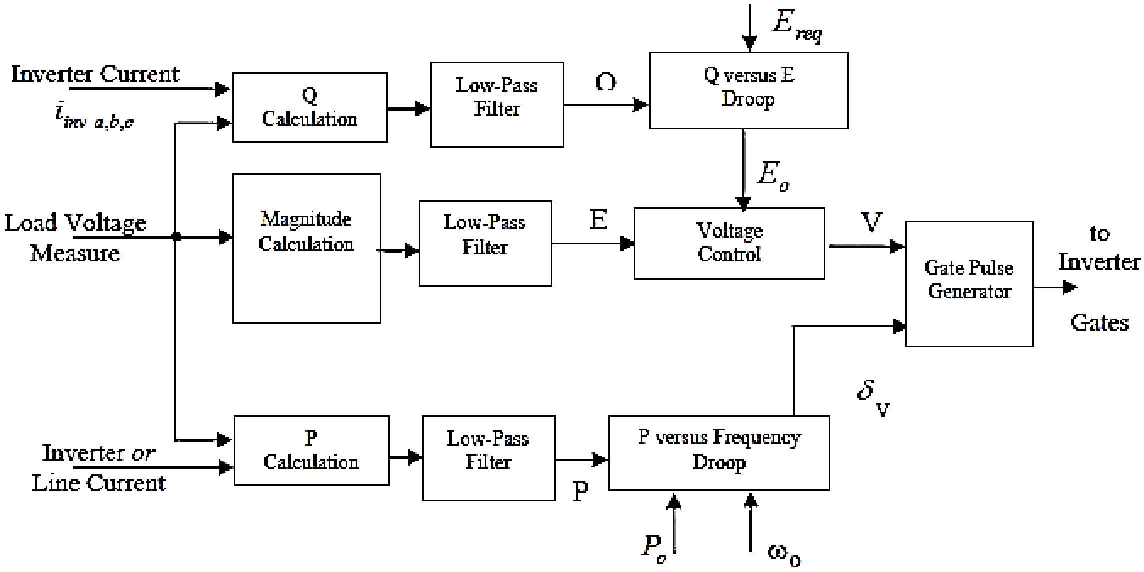


Figure 3.2 Final Version of Microsource Control.

One of the main objectives for the control is portability when adopted in units of different nominal ratings. To satisfy this requirement, the control has been designed so that all the internal quantities are in a per unit system. This implies that whether the size of the unit is 30kW or 200kW, the power is internally represented always as a quantity that is between zero and unity values. The same considerations are applied to the voltage rating of the feeder where the units are installed. Rescaling quantities in a per unit system implies that the PI gains and the droop coefficients do not need to be calculated again each time one decides to use this control on a unit with different size. This control is somewhat universal because of its ability to be used with different hardware configurations without having to change anything internally. Every block will be expanded to show the operations on the variables inside.

The active power is regulated to a desired value during operation in parallel with the grid. During transfer to island operation, the frequency of the network will be allowed to sag slightly, adopting the active power-frequency droop. The characteristic will ensure that all the units will immediately ramp up their output power to match the missing quota from the grid, without the usage of an explicit network of communication between the several units. This P versus frequency block generates the angle that will be tracked by the gate pulse-generator.

3.1.1 P and Q Calculation

The blocks that calculate the values of active and reactive power will use the instantaneous values of line to line voltages and line currents. These are exactly the quantities that are brought in from the sensing equipment. Since there is no ground to refer to, the voltages are always measured across the phases. The count of the sensing equipment is kept to a minimum by measuring only two of the line to line voltages and calculating the third one from the fact that the sum of the three delta voltages must equal zero, in balanced as well under unbalanced conditions. Only two currents are measured and the third one is calculated assuming their overall sum to be zero, which is correct only under balanced conditions.

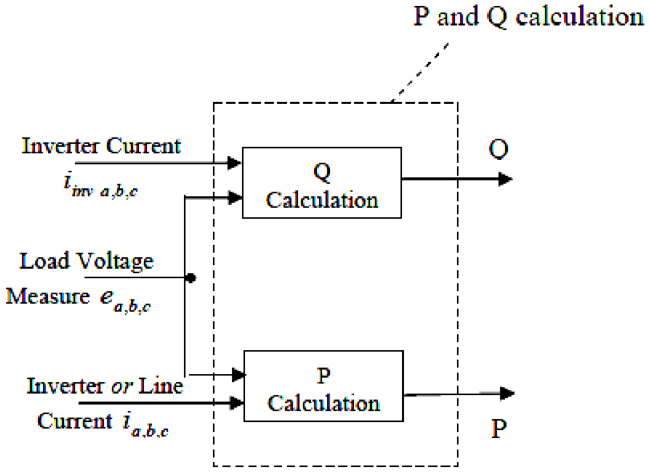


Figure 3.3 P and Q Calculation Blocks

Figure 3.3 shows the input-output layout for the P and Q calculation. Notice that the measure of the voltage at the micro-grid side is passed to both blocks, while the current can either be the inverter current or the feeder current, depending respectively if the output power of the micro-source or the power flow on the feeder is controlled.

The equations used are

$$P = e_{bc} i_c - e_{ab} i_a$$

$$Q = -\frac{e_{bc}(2i_a + i_b) + e_{ca}(2i_b + i_a)}{\sqrt{3}}$$

One advantage of adopting these equations is that they use quantities that are readily available, namely the line to line voltage measure that does not need to be converted to line to neutral. Another advantage is the simplicity of the equations that do not require the extra step of being converted to rotating frame components, since the powers are evaluated from the immediately available time domain quantities obtained from the sensing equipment.

3.1.2 Voltage Magnitude Calculation

The block of Figure 3.2 labeled Magnitude Calculation is expanded in Figure 3.4. It uses information on the time domain line to line voltage to calculate the magnitude for the load side voltage.

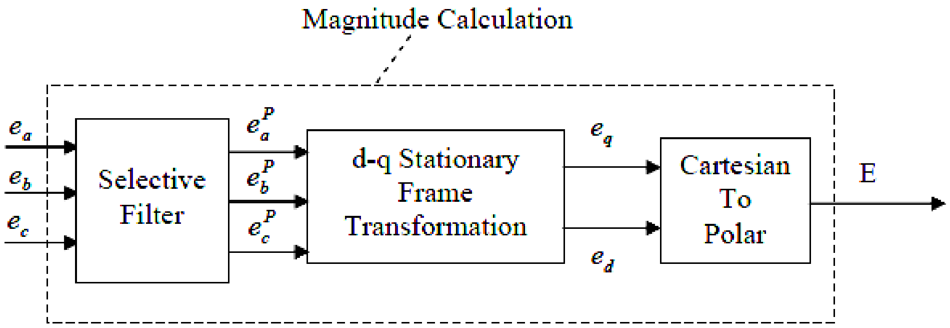


Figure 3.4 Voltage Magnitude Calculation

The selective filtering of the voltage components has the desirable effect of removing the high frequency random noise components that inevitably creep in the real world of sensing equipment. The overall output of this block is the magnitude of the voltage.

The selective filter, shown in Figure 3.5 is achieved with two integrators that implement an oscillator, removing any component that is not at the specified frequency. This frequency is obviously chosen to be the system nominal frequency. This selective filtering has two possible outputs: u^P is the output in phase with the input signal, u, while u^Q is the output that is behind, in quadrature with respect to the input signal.

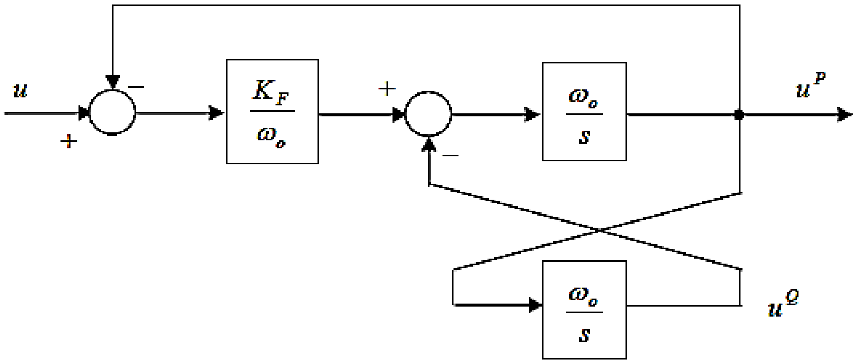


Figure 3.5 Selective Filter Diagram.

Figure 3.6 shows the magnitude and phase response of the filter. The magnitude shows that the frequency 60Hz is passed without any alteration, i.e. unitary gain (zero dB) and zero phase shift. For frequencies very near to 60Hz the gain is a little lower than one and phase shift is non-zero. That is not a problem: by choosing an appropriate value for K_F, it is possible to ensure that the gain is lowered only of a fraction of a percent for the range of frequencies expected during island operation. The phase shift is also not a problem: since all components are shifted of the same amount, the shift can assume any arbitrary value. The calculation of P and Q is a function of the relative shift of voltages and currents, not their absolute value. As long as both voltages and currents are shifted of the same amount (and they are, since the frequency of voltages and currents are the same), then their relative phasing will remain unaltered

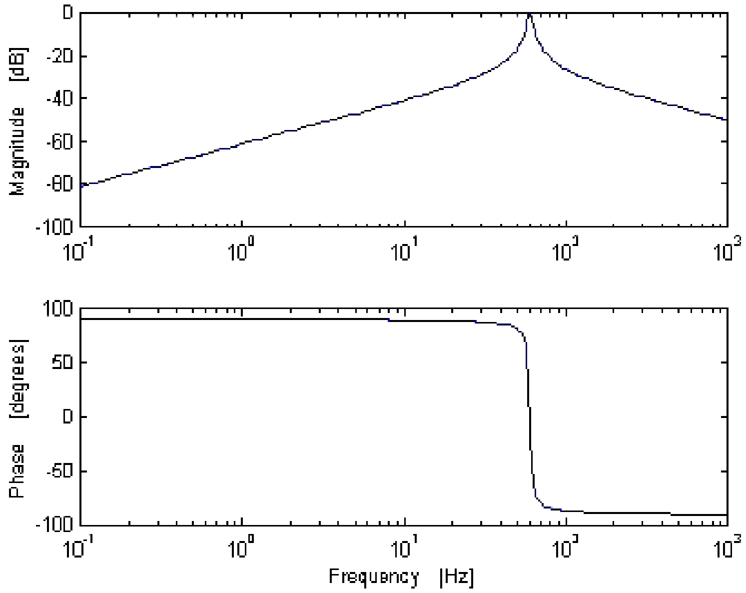


Figure 3.6 Selective Filter Response.

The‘d-q’ axis components are found by projecting the rotating phase voltages over a fixed reference frame with two axis in quadrature. The equations are:

$$e_{ds}(t) = \frac{e_c(t) - e_b(t)}{\sqrt{3}}$$
$$e_{qs}(t) = \left(\frac{2}{3}\right)\left(e_a(t) - \frac{1}{2}e_b(t) - \frac{1}{2}e_c(t)\right) \qquad \text{Eq. 3.1}$$

These components are then converted to magnitude and phase by a change of coordinates, from Cartesian to Polar:

$$E = \sqrt{e_d^2 + e_q^2} \qquad \text{Eq. 3.2}$$

3.1.3 Voltage Control

The Voltage Control block is shown in detail in Figure 3.7. The output of this block interfaces with the inverter that implements the space vector technique synthesizing directly this desired voltage magnitude. The inputs of this block are the requested value adjusted from the Q-voltage droop and the measure of the magnitude of the voltage at the feeder bus. This block is the core of the voltage control: the voltage at the load is regulated by creating an appropriate voltage at the inverter terminals.

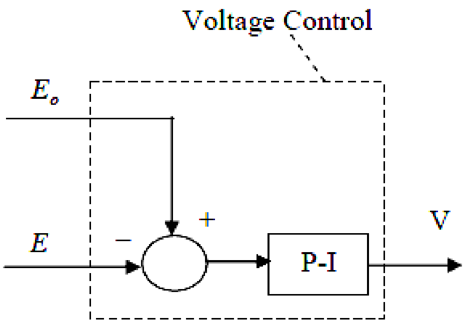


Figure 3.7 Voltage Control Block.

This block compares the measured and the desired voltage magnitudes. This error is passed inside a P-I controller to generate the desired voltage magnitude at the inverter.

3.1.4 Q versus E Droop

Fig. 3.8. is voltage control block that use Q-E droop control. Where Ereq. is voltage reference of node. Applying Q-E droop control, make new voltage reference and voltage control [3]. This can be possible to reduce large output of reactive power by allowing some voltage changes (ΔV/Qmax) from reference voltage. Voltage controller and Active power model in droop control using EMTP is illustrated in Fig. 3.8.

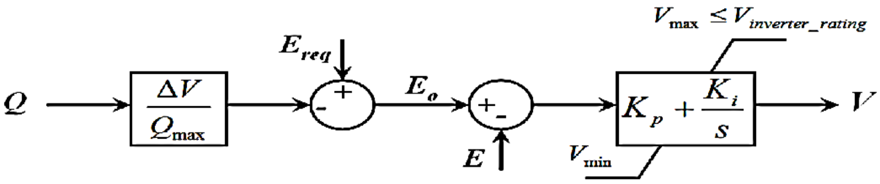


Figure 3.8 Q versus E droop and voltage controller

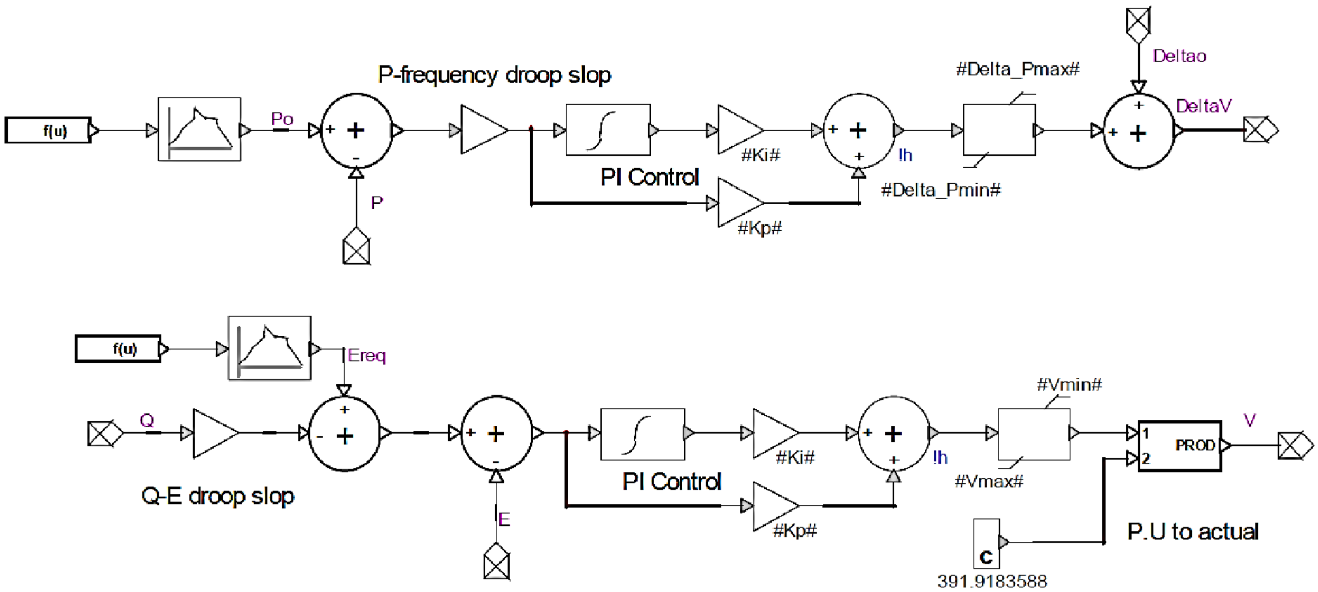


Figure 3.9. EMTP/RV module development for P and Voltage magnitude. (Droop)

$$E_0 = E_{req} - \left(\frac{\Delta V}{Q_{max}}\right).Q$$

Figure 3.10 shows the details of the operations taking place inside the block called “Q versus E droop” in Figure 3.2. This block implements the reactive power versus voltage droop, its main action is to adjust the externally requested value of voltage to a value that will require less injection of reactive power to be tracked.

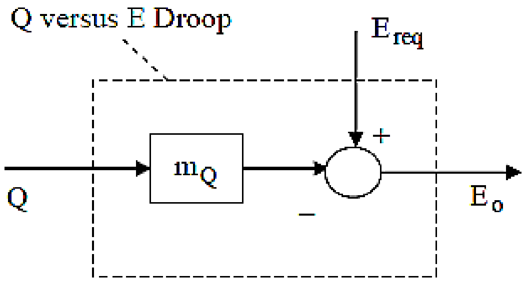


Figure 3.10 Q versus Load Voltage, E, Droop Block.

The inputs of this block are the desired voltage at the regulated bus and the current injection of reactive power from the micro-source. The output is the new value of voltage request that replaces the one commanded from outside. This new value is obtained from the linear characteristic of the droop.

Figure 3.10 expands the block labeled as “Q versus E droop” in Figure 3.2 to allow to see the details. This block is responsible for modifying the value of the reference voltage that is commanded from outside. When two units are located electrically near each other and given two voltage setpoints, they will try to achieve those requested voltages by injecting reactive power. If the two setpoints are somewhat different from each other, then one machine will inject a large amount of capacitive power, while the other will inject inductive power.

This situation comes as a consequence that the units will have to create the requested difference of voltage by injecting a large current over the small impedance that there is between the units. In this scenario reactive current will flow from one unit to the other, creating the problem of the circulating currents. These currents flow in the machines, reducing the amount of ratings available to face new load requests.

To mitigate this problem, a reactive power versus voltage droop is adopted. This characteristic is designed to convert the external command of the voltage E_{req} into the value E_o. The larger is the amount of capacitive power that is injected, the lower this value is allowed to sag compared to the external request. Conversely, E_o is allowed to swell as inductive current is injected. In this way, if two neighboring units have voltage set points E_{req} that are too far apart, then the actual commands E_o of the units will result nearer to each other. This correction successfully limits the circulating reactive currents because it limits the reactive power injections to achieve the adjusted voltages. The characteristic is represented in Figure 3.10 where it is possible to see how the block corrects the reference voltage according to the sign of the injected reactive power.

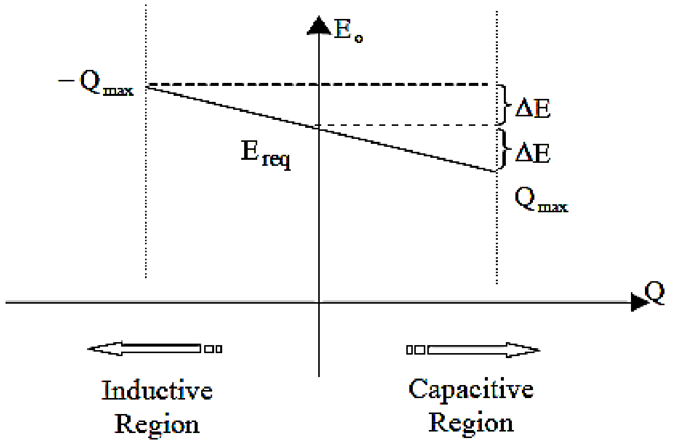


Figure 3.11 Q versus Load Voltage, E, Droop Characteristic

There is a physical limit, determined by the ratings of the inverter, for how much reactive power it is possible to inject. This amount is shown as Q_{max} in Figure 3.11. It is also possible to decide on beforehand how much the voltage is allowed sag (or swell) corresponding to that amount of maximum reactive power,

$$E_o = E_{req} - m_Q Q$$

$$m_Q = \frac{\Delta E}{Q_{max}}$$

E. From the characteristic, it is possible to write the equations:

$$m_Q = \frac{\Delta V}{\Delta Q} = \frac{0.05}{1.0} = 0.05$$

The value E_o will match the externally requested value, E_{req}, only when the injection of reactive power is zero. The quantity m_Q is the slope coefficient of the droop curve. In this case, the coefficient is such that the voltage is allowed to drop of 5 per cent for every 1 pu of reactive power that is injected.
For instance, when injecting 0.1 per unit of capacitive power the voltage will be allowed to sag 0.5 per cent. This seems such a small correction, but it goes a great deal to limit the amount of reactive power that is injected.

3.1.5 P versus Frequency Droop

This block is responsible for tracking the power command during grid connected mode and allowing for the units to redispatch their output power to match the load requests during operation in island mode. When the micro-grid transfers to island, Ohm's law demands larger currents from the micro-sources increasing their measure of output power, and as a consequence of the droop the units will operate at a frequency slightly smaller that nominal system value.

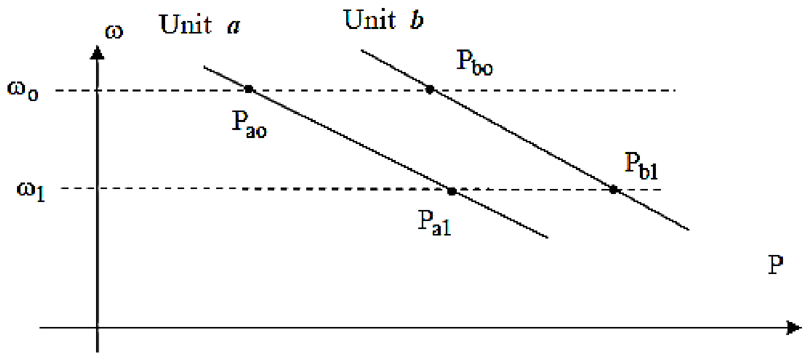


Figure 3.12 Power – Frequency Droop Characteristic.

Figure 3.12shows the characteristic of the power versus frequency droop. Two units, *a* and *b* are shown here: their power setpoint when connected to the grid are respectively Pao and Pbo. Both characteristics allow power to increase as the frequency decreases. During islanding the frequency sags to a new value, ω_1, and the micro-sources respectively generate Pa1 and Pb1 power. Two things need to be pointed out: the difference of the sum of generation in island (Pa1+Pb1) and during grid connection (Pao+Pbo) is the missing quota of power from the grid. The second important point is that since the slopes of the droops are constant, the two units pick up power in the same amount that is one ramps up of as much in per unit as the other does.

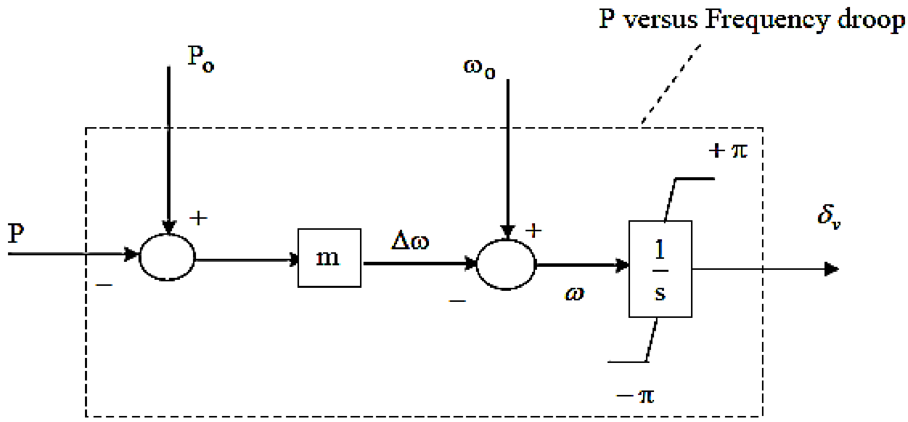


Figure 3.13 Block Diagram of the Active Power Droop.

The control block that realizes the droop is represented in Figure 3.13: there are only three inputs to the block: the desired and measured injected power and the nominal system frequency. The measure of the angle of the voltage at the regulated bus is not needed because that information is already implicitly fed back through the value of the measured power injected by the micro-source. The output of this block is the desired angle of the voltage at the inverter bus: this is because the gate pulse generator based on the space vector synthesizes directly the angle of the desired voltage.

The droop characteristic is realized by multiplying the coefficient '*m*' with the error for power. The droop coefficient '*m*' represents the slope of the characteristic, and it depends on the values of Pmax, ωmin and current power setpoint. The expression for '*m*' is:

$$m = -\frac{\omega_o - \omega_{\min}}{P_{\max}}$$

The angle is obtained by integrating the instantaneous quantity ω wrapped around +π and –π.
This is because the command δv_{req} is constantly increasing with rate at or near ω_o, so to avoid overflow of this variable inside +π, therefore the quantity $\delta v_{req}$the DSP register, the angle is reset to –π each time it reaches will look like a saw tooth.

3.2 Power Control Mode with Limits on Unit Power

This section gives a general view of the issue of limits in distributed generation. Each unit is composed of a prime mover, an energy storage device and an inverter that interfaces with the system as shown in Figure 3.14

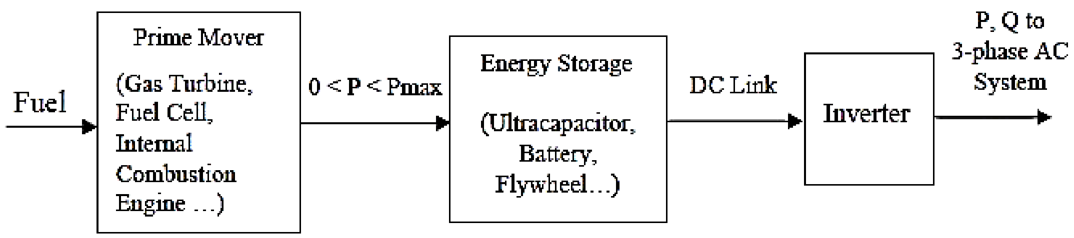


Figure 3.14 Micro source Elements: Prime Mover, Storage and Inverter.

The problem of reaching maximum output power needs to be addressed to avoid that the energy storage is either depleted or filled up over capacity. The prime mover does not have a problem exceeding the maximum power because it simply cannot do it. The maximum power exists because of the fact that the prime mover is not able to generate more power than that. The inverter ratings are slightly larger than this maximum active power limit because of the need to provide reactive power as well as active power at the same time.
Reactive power injection is required to perform voltage regulation.
As soon as the load conditions (P and Q combined) determine an overall output that is above the ratings of the inverter, then protections will ensure survival of the silicon devices by tripping the unit off.

The basic difference between limits in the prime mover and limits in the inverter is that the prime mover cannot physically give more than its maximum power, so it would reach this limit and hold it. The inverter could inject more than its own power rating (nothing physical prevents it from doing it), so to prevent damage the protections would intervene. Reaching this kind of limit that requires intervention of protections has nothing to do with this section. Overshooting the inverter ratings limits (in kVA) can only result in shutdown and is the topic of protection analysis. This report is about preventing the inverter from injecting a steady state output power that is larger than maximum prime mover output. If that were to occur, the storage would deplete all its energy. This suggests that as long as the inverter is within its apparent power ratings (kVA) it is possible to overshoot the maximum power limit (kW) without compromising equipment safety. Some action must be taken to avoid that this overshoot is sustained in steady state, by enforcing the behavior of the unit to belong to some particular characteristic.

This report is also about preventing the inverter from injecting a steady state output power with a negative sign: if that were to occur, the storage would overshoot its maximum capacity. This limit is defined by the fact that the prime mover cannot behave like a load. For instance, microturbines are thermodynamic machines that convert chemical energy of the fuel into mechanical power. This machine will not be able to perform the opposite task of using mechanical power to convert it to some other form. It follows that the prime mover has the value of P = 0kW as the lower limit of power. The inverter does not have such an issue. It can legally operate in all four quadrants of the P, Q plane as long as its ratings are not exceeded. In practice, the voltage and current flowing in the inverter could have a phase displacement so that the overall active power injection is negative. This power cannot be transferred to the prime mover and would be stored in the battery. A steady state operation in this condition would overfill the energy storage. To avoid this situation there is the need to prevent the inverter from ever exceeding minimum power during steady state, acknowledging the fact that it would be legal to overshoot this limit for a short period of time.

3.2.1 Steady State Characteristics with Output Power Control

This section describes the configuration with the control regulating the voltage and the power injected by the unit at the local point of connection with the feeder to a desired amount. To this end, the active power injected, and the feeder voltage are measured and passed back to the control loop. Figure 3.15 shows the diagram of this configuration: the measure of power injected by the unit, P, is calculated from the current injected by the source and the voltage E measured at the point where the unit is installed.This chapter shows the steady state characteristics on the power vs. frequency plane that allow to enforce limits for the output active power and frequency. This chapter describes the characteristics to be used when the units are configured to regulate their output active power. Figure 3.15 shows that when connected to the grid, load changes are matched by a corresponding power injection from the utility. This is because the unit holds its injection constant. During island mode all the units participate in matching the power demand as loads change.

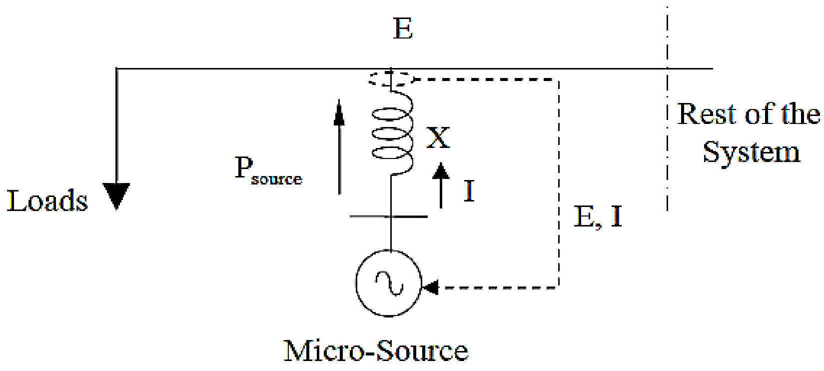


Figure 3.15 Diagram of a Unit Regulating Output Active Power.

In this case there is no mean of controlling the power that comes from the grid: it can indirectly be changed by choosing different setpoints for the power of the unit, but the amount of power that is drawn from the AC system cannot be planned ahead. With this system of regulating active power, it is impossible to sign a contract with the utility agreeing on a determined amount of power to be taken: the units can only control their power output, without any notion of the power from the grid. The amount of power dispatched by the units when the grid is connected is arbitrary and dependent on the choices of the managers of the units inside the micro-grid.

This configuration can take full advantage of the Combined Heat and Power (CHP) applications, where total (electric + heat) system efficiency is maximized when the waste heat from power production is also used. In this way, electricity production is only requested when there is also heat load demand resulting in great levels of total efficiency.

The system can operate in island mode because of the power-frequency droop that allows the units to share the extra power demand. The minimum requirement for every micro-source is to regulate power and voltage to desired values when connected to the grid. During island mode, the power must automatically and independently readjust in every machine so that the new level of power output matches the demand from all sensitive loads present in the micro-grid.

The voltage is regulated at the bus where the source is connected to the feeder belonging to the micro-grid. Figure 3.16 shows the unit power configuration, where the source directly regulates the power injected by the unit.

When all the sources have their own power commands set, any load change taking place within the micro-grid will be matched by a corresponding amount of power imported from the utility. This mode of operation is the most traditional because it follows directly from the operation of any existing power plant.

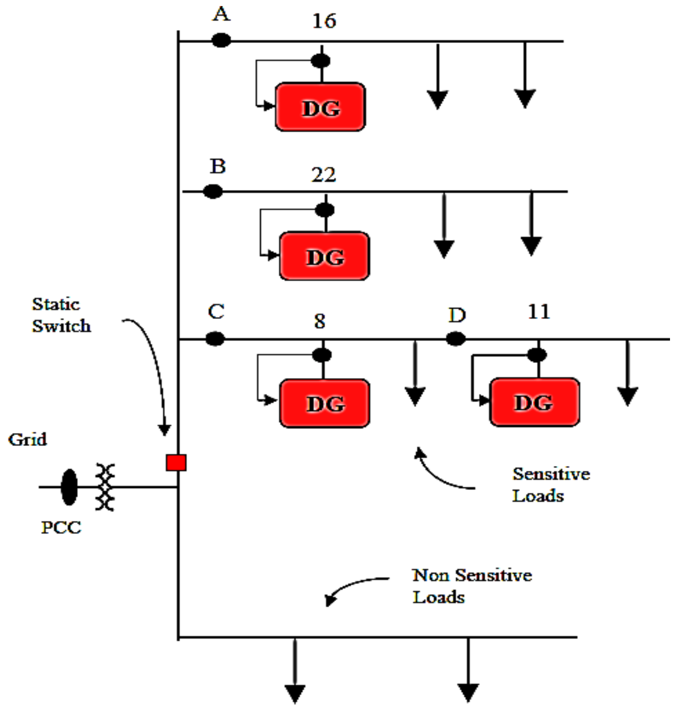


Figure 3.16 Unit Power Configuration.

Figure 3.17 shows the steady state P-ω characteristics for two units when using the constant minimum slope:

$$m = -\frac{\Delta\omega}{P_{max}} \qquad \text{Eq. 3.3}$$

This slope allows power to change between P=0 and P=Pmax as frequency changes of Δω,shown in Figure 3.16 with the thick dashed line. All the other characteristics are simply parallel to this one. If the system is importing from the grid before islanding, then the resulting frequency, ω_imp is smaller than the system frequency ωo, as already seen. It is possible that one of the units reaches maximum power in island mode, as shown by unit 2 at frequency ω_imp. The steady state characteristic slope switches to vertical as soon as the maximum power limit has been reached and the operating point moves downward vertically as shown by the arrows in Figure 3.16 as load increases. Opposite considerations take place when unit is exporting and new frequency ω_exp is larger than nominal. It is possible that if the load is very small that one of the units has

Reached the limit P=0. At that point, the slope of the characteristic is switched to vertical and as load decreases, the operating point moves upwards, as shown by the arrows in Figure 3.16.

The minimum and maximum power limits are enforced by the fact that the characteristic with constant slope are switched to a vertical steady state characteristic.
The minimum and maximum frequency limits cannot be overshoot because it would imply, respectively, that the loads have exceeded the overall generation capability or that the load is actually injecting power into the system. These last two limits do not need to be explicitly enforced since the assumption on the load (smaller than sum of all generation, but never smaller than zero) automatically implies behavior within frequency limits.

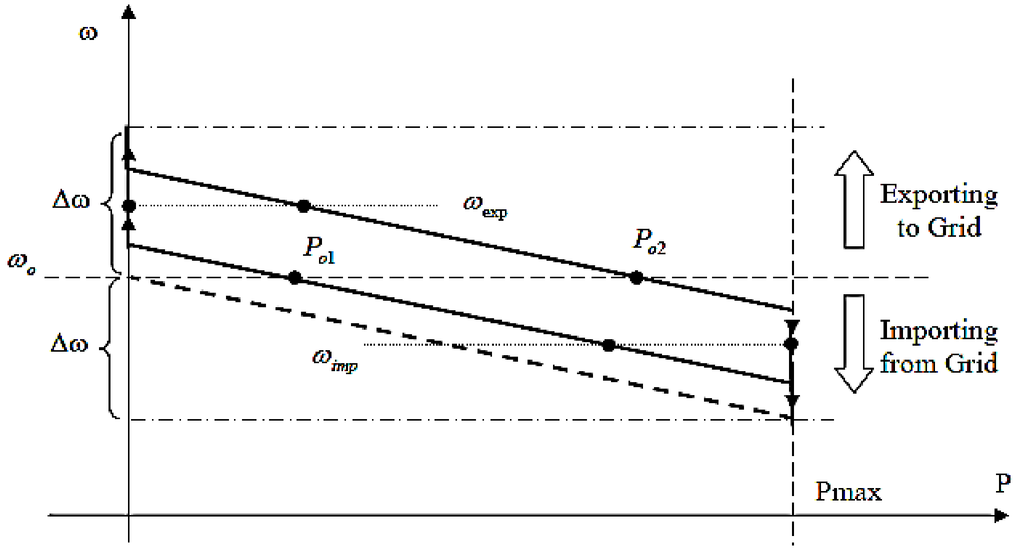


Figure 3.17 Steady State P-ω Characteristics with Fixed, Minimum Slope.

This approach has the advantage of being able to enforce both limits in power and frequency while adopting a fixed value for the slope. Only power limits need to be enforced, frequency limits come as a consequence.

The fundamental idea is that the control needs to be augmented with some blocks responsible to enforce limits. To prevent changing the system behaviour as we know it, these blocks shall be inactive at any time the unit is not exceeding the limits. Figure 3.18 allows to understand what these added blocks need to change and how.

Where in this case $\Delta\omega min=(\omega 2-\omega 1)$, positive number, in steady state. $\Delta\omega min=0$ each time the power output is larger than zero to ensure that the behavior of the unit follows the desired characteristic of Eq. 3.4. Notice that $\Delta\omega min$ translates upwards the original characteristic enforced when no limit is exceeded. Next paragraphs deal on how to generate the offsets for maximum and minimum power excursions.
It is possible to take advantage of two assumptions:

1) The prime mover will never give a fraction of extra power over P_max, but because of the storage interface, there is some extra power available transiently. Furthermore, the inverter is rated to be able to inject over P_max as stated in Section 3.4. Therefore it is assumed that there is enough stored energy available and silicon ratings to deliver it so that the inverter can transiently sustain overshoots of the value P_max for short periods of time.

2) As soon as the inverter is absorbing power, (P<0), the power electronic devices behave like a bridge of diodes due to the reversed current polarity. Energy is transferred from the feeder to the DC storage. It is assumed that the storage device can transiently sustain the condition of P < 0 for brief periods of time.

When preventing injections of power exceeding maximum value, the first step to obtain the frequency offset is to generate a power error with the reference set to Pmax, and obtain the quantity errP_max as shown in Figure 3.19.

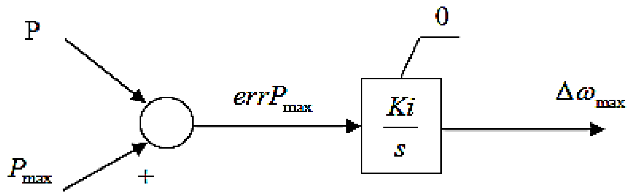


Figure 3.18 Offset Generation to Limit Max Power with Integral Block.

This error is passed it to an integral block that has a dynamic limiter which prevents its output to ever become positive. This limiter makes this integral path non-linear. The integral can always integrate up and down (depending on the sign of errP_max) but its output will be truncated to zero and never allowed to become positive. With this approach, Δω_max is either a zero or a negative quantity only. As long as power is lower than max, errP_max is positive and the output of the integral is dynamically limited to zero, correctly generating a zero offset when the unit is operating below Pmax. If power is larger than maximum, errP_max is negative and the integral would start generating a negative value for the offset. This offset in turns translates the characteristic down (see Figure 3.17). It will keep on translating down up until the offset exactly matches the value for which errP_max = 0. As long as it is not, the integral would keep on increasing the offset. When power output matches maximum power the error would become zero and the integral would stop increasing the offset: a new steady state has been reached at the frequency ω2 (Figure 3.17) with offset Δωmax = ω2-ω1. This control proved to be effective to limit power, but the analysis would not be complete without showing that the process of reaching a maximum is reversible. To understand this concept, consider the following series of states and actions:

i. Steady State: units within limits,

ii. Action: load increase

iii. Steady State: a limit is reached is held

iv. Action: load decrease

v. Steady State: units within limits

The system is considered memory less or reversible if the state (i) is identical to the state (v), that is, the system has no memory that it went through states (ii) through (iv).

To verify reversibility, consider the following: at first the system on state (i) operates on the characteristic “Unit 2” in Figure 3.18. After a load increase (that engages max power output regulation) the characteristic has been effectively changed from “Unit 2” to “Unit 2 Max”, represented by state (iii). When the load

decreases (iv) then the unit would continue to operate on this second characteristic and power will become smaller than maximum. But as soon as this happens, the errP_max of Figure 3.18 becomes positive and the negative offset Δω max becomes smaller and smaller. The dynamic limiter in the integral will prevent it from ever assuming a positive value. When this value has been reached, the unit is operating again on characteristic "Unit 2" of Figure 3.17 and this would be state (v), which is identical to state (i): the memoryless feature has been proved.
When preventing injections of power exceeding minimum value, the approach used to calculate the offset Δωmin is very similar and mirror-like in many aspects, to the approach used to calculated Δωmax. Figure 3.19 shows that the first step is to calculate the error errP_min using as a reference the minimum power setpoint, zero.

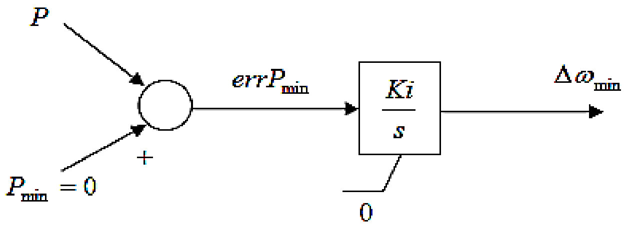


Figure 3.19 Offset Generation to Limit Minimum Power with Integral Block.

This error is passed to an integral that has a dynamic limiter to prevent the output from ever becoming negative. As soon as the power injection becomes negative, the quantity errP_min becomes positive and the offset increases, from a value of zero to larger positive values. As soon as the power injection is zero the integral will stop increasing the value of the offset and will hold it exactly to the value Δωmin=ω2-ω1, positive, (in Figure 3.16) that is needed to translate the characteristic from "Unit 1" to "Unit 1 Min". To verify reversibility, one needs to consider that as soon as load increases, the characteristic for unit 1 would be "Unit 1 Min". The power would increase to a value larger than zero, generating a quantity errP_min negative. The integral would then start decreasing the value of the offset up until zero, then the dynamic limiter would lock it to the null value. At that point the offset has been completely removed and unit 1 is correctly operating again on the original characteristic labeled "Unit 1" on Figure 3.16.
Figure 3.20 shows the full control diagram, where it is possible to see that the blocks on the upper part belong to the original control structure (as shown in Figure 3.11). The blocks that generate the frequency offsets are in the lower part and represent the change needed to enforce power limits.

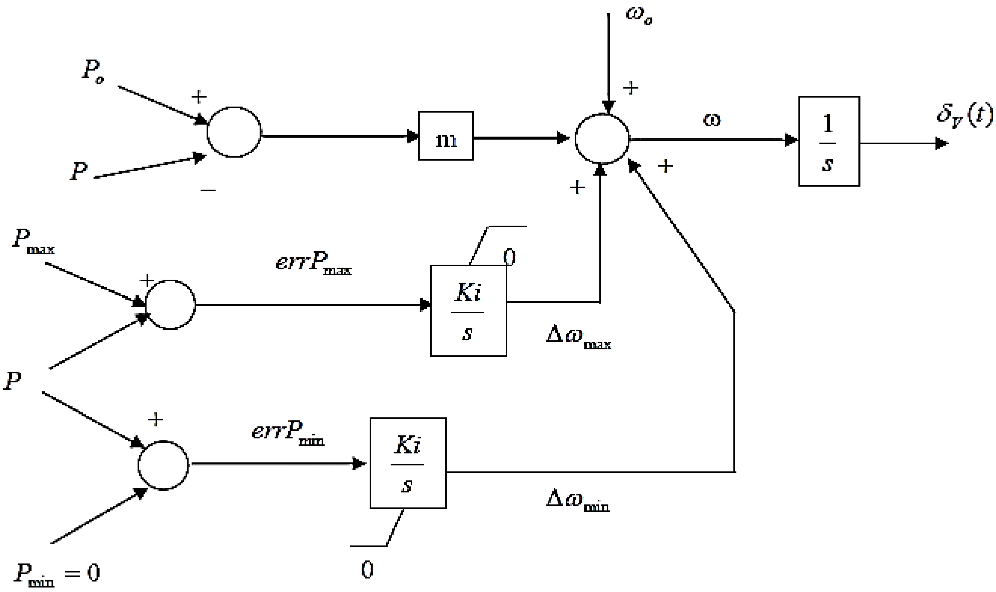


Figure 3.20 Control Diagram to Enforce Limits with Unit Power Control.

The equation that governs this control has been formally changed from Eq. 3.4 to an equation that keeps into account of changes made in Eq. 3.5 and Eq. 3.6 when respectively dealing with maximum and minimum power limits. The final equation is:

$$\omega_i = \omega_o - m\left(P_{o,i} - P_i\right) + \Delta\omega\max + \Delta\omega\min \qquad \text{Eq. 3.7}$$

The quantities Δωmax and Δωmin are added to the frequency as calculated in Eq. 3.4. Both quantities are zero when the unit operates within power limits. When Pmax is exceeded, then Δωmax becomes negative (never positive) to enforce the limit. Conversely, when Pmin = 0 is exceeded, then Δωmin becomes positive (never negative) to enforce the limit. This control has been implemented in simulation and hardware and the results obtained prove the effectiveness of the control design.

3.2.2 Steady State Characteristics with Feeder Flow Control

Another possible option for controlling power is to regulate to a constant the flow of active power in the feeder where the unit is installed. The main reason why there is an interest in exploring the load tracking configuration is because when regulating power on the branches to a constant value, then the power supplied from the grid will remain unchanged when a load changes inside the micro-grid. There are cases when the utility is interested in having large customers to draw a constant amount of power from the grid, regardless of their changing local needs of power. This solution would solve this problem and the grid would see a constant power demand from the micro-grid.

The basic requirement for the load dispatch configuration is the need for a measure of the power flowing in those branches so that the control can compare it against the desired reference amount. Figure 3.21 shows this configuration, where it is possible to see that the power from the line and the power from the unit always add up to the load request. When a load increases the unit increases its power output to maintain a constant branch power flow. This configuration implies feedback of the line current and the voltage at the point where the unit is installed to calculate the power flow in the feeder.

This section shows the steady state characteristics on the F-ω plane that allow to enforce limits on frequency and unit power output, P. In this case the units are configured to regulate the flow of power in the feeder that connects to the utility, F. Figure 3.21 shows the setup: when connected to the grid, every load change is matched by a different power injection from the unit since the control holds the flow of power coming from the grid, F_ line, to a constant value.

During island mode all the units participate in matching the power demand as loads change.

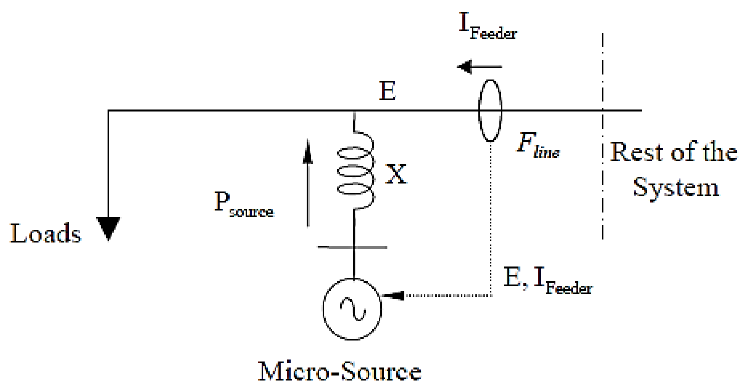


Figure 3.21 Diagram of a Unit Regulating Feeder Power Flow.

The case when the grid fails while operating in the load dispatch mode can be handled by changing the sign of the power-frequency droop characteristic. During island mode there is less need to import power from the feeders so that the characteristic is designed to reduce power as the frequency reduces. Figure 3.22 shows the load tracking configuration for the whole micro-grid. This mode of operation earned this name because once the required level of power requests are set, any change in load within the micro-grid will be matched by a corresponding amount of power injected by the units to keep the flow in the feeder constant. This configuration has the advantage that the micro-grid looks exactly like a dispatchable load from the utility point of view. New agreements in electric contracts can be signed with the utility: for instance the micro-grid could agree to behave like a constant load during a determinate period of time of the day since it can automatically track all its internal changes of load with the local generation.

This creates advantages on both sides of the meter: the utility is guaranteed a limit on the amount of power taken by a certain region where multiple micro-grids are present, while due to this restriction on the power usage, micro-grids could enjoy lowered electricity rates during those periods of times when the restriction applies.

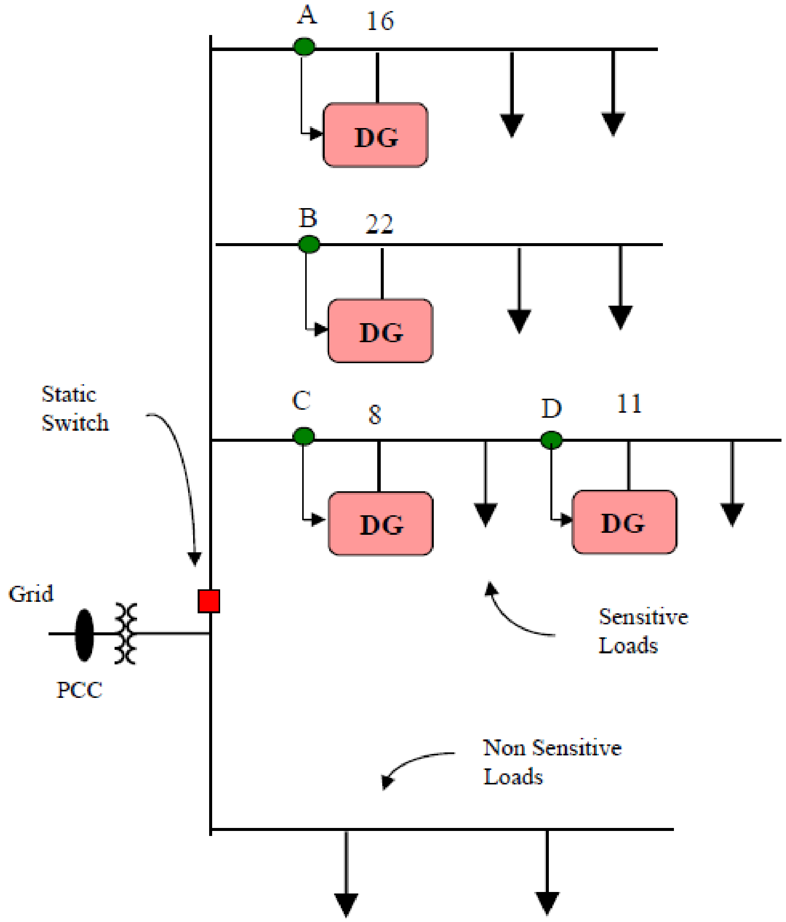


Figure 3.22 Load Tracking Configuration

The fact that the power on the feeder needs to be regulated implies that there is a need to install sensing equipment on that feeder to evaluate the power and feed it back to the micro-source controller. In short, this implies an increase in the component count for the sensing equipment. The advantages that load tracking offer may be more than enough to offset the nuisance of having to install measuring equipment directly on the feeder of the micro-grid floor, rather than having them nicely encased within the chassis of the micro-source.

Figure 3.23 shows the characteristics of two units adopting the feeder power flow control. The characteristics enforce the following relation:

$$\omega_i = \omega_o - m_F\left(F_{o,i} - F_i\right) \qquad \text{Eq. 3.8}$$

This expression is very similar to Eq. 3.4 used for unit output power control. The slope has fixed identical magnitude of the minimum slope of Eq. 3.3, but has a reversed sign ($m_F = -m$, the characteristics are slanted the opposite way). The sign needs to be reversed because
of the relation between the output power, P and the feeder flow F. This relation can be derived by inspection of Figure 3.21:

$$Fi + Pi = Li \quad \text{for unit 'i'} \qquad \text{Eq. 3.9}$$

Fi is the power (imported means positive) from the rest of the system
Pi is the power injected by the unit (subjected to belong to [0, Pmax] interval) Li is the overall loading level seen by the unit
The above relation implies that to increase F one needs to decrease P (assuming no change in the load) and vice-versa, hence the reverse sign in the slope when moving from the P-ω plane to the F-ω plane.

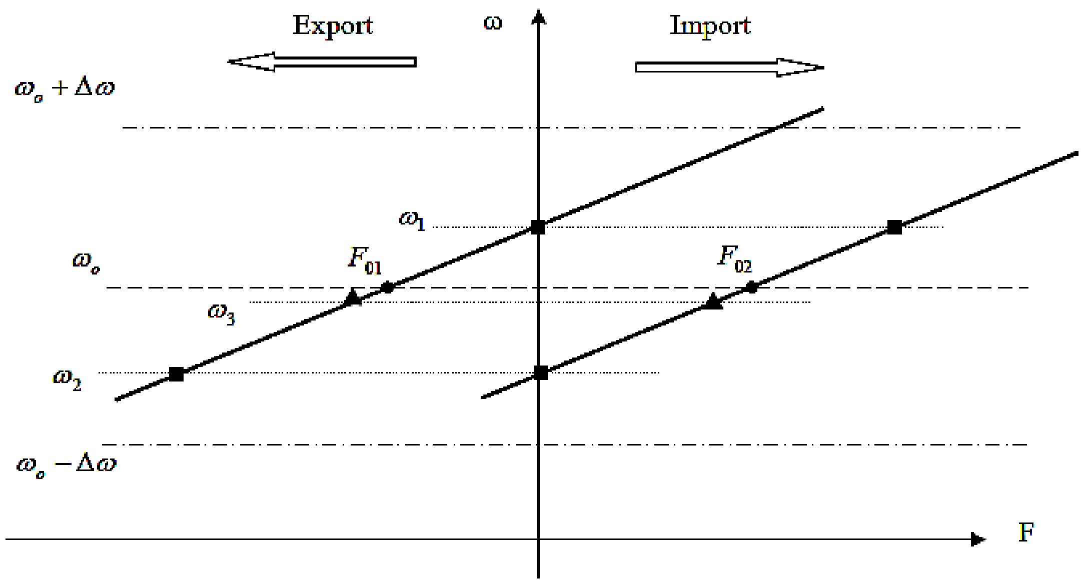


Figure 3.23 Steady State Characteristics on the F-ω Droop with Feeder Flow Control.

During connection with the grid the flows in the feeders track the requested values, Foi, at the system frequency, ωo. When the micro-grid transfers to island, the two units readjust the flow dispatch depending on the geometrical configuration of the units on the field. Figure 3.24 shows the two basic connectivity choices: sources installed on a single feeder (a) and installed on a multiple feeders (b). These two base cases also cover hybrid configurations of (a) and (b) in the micro-grid.

From inspection of Figure 3.24(a), during island the frequency will match the value where the flow nearest to the utility is zero. This is because during island the power exchanged with the grid is always zero. Figure 3.24(a) shows that since flow of unit 1 is the on nearest to the grid,then in island the system will operate at the frequency ω_1 , where flow of unit one is zero. The operating points are shown with squares at that frequency. Frequency ω_1 is larger than the nominal system frequency because the system was exporting to the grid (Fo1 is negative) prior to disconnection, which is the same behavior seen with unit output power control. If, for instance, the two characteristics of Figure 3.23 are swapped (i.e. replace Fo1_new =Fo2 and Fo2_new =Fo1), then the frequency in island would be ω_2 . At this frequency the flow at the feeder 1 will be zero (on Figure 3.23 it is where unit 2 reaches zero, remember the swapping). This time the frequency is lower than nominal, and that is because the micro-grid was importing power from the grid (Fo1_new=Fo2>0) prior disconnection. This is consistent with what was already seen with the other power control configuration.

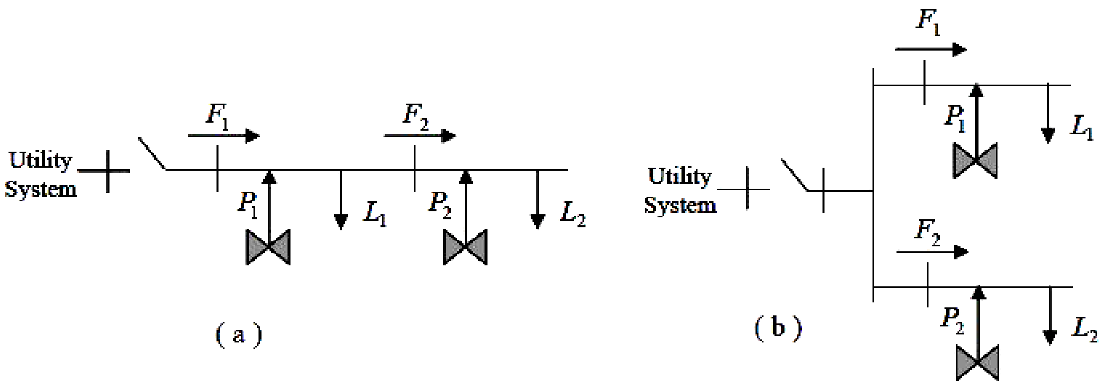


Figure 3.24 Single (a), and Multiple (b) Feeders Source Connectivity.

From inspection of Figure 3.25(b), during island the frequency equals to the value where the sum of the flows is zero. This is because the sum of the flows equals the power exchanged with the grid. On Figure 3.23, the frequency in island is ω_3, exactly where F1 = -F2. The operating points are shown with triangles at that frequency. Notice that this frequency is lower than nominal. From the intuition developed so far, it must be because the system was importing from the grid prior disconnection. In fact, the exchanged power with the grid is by definition Fo1+Fo2>0 which implies importing from the grid (notice that algebraically, Fo1 has a negative sign). It follows that if the system was exporting to grid (i.e. Fo1+Fo2<0), then the resulting frequency (where F1 = -F2) would have been larger than nominal.
So far it was assumed that all the units operate within their limits of power and frequency. As seen in Figure 3.16, the choice of the minimum slope value guarantees operation within frequency limits across the whole operating range of output power but it requires the unit output power limits to be actively enforced.The limits on output power variable, P, are projected on the feeder flow variable, F, as shown in
Eq. 3.11. That equation has been rearranged below to show the point:

$$Fi = Li - Pi \qquad \text{for unit 'i'} \qquad \text{Eq. 3.10}$$

and since 0<Pi<Pmax, then the limits Fmin<F<Fmax can be written as follows:

$$Li\text{-}Pmax < Fi < Li \qquad \text{for unit 'i'} \qquad \text{Eq. 3.11}$$

Notice that:

F=Fmin=Li-Pmax is reached when P=Pmax and F=Fmax=Li is reached when P=Pmin=0
This is due to the minus sign in front of the power term “Pi” in Eq. 3.10. The limits for the feeder flow, F, as expressed in Eq. 3.11 can be visualized on the F-ω plane as a rigid window whose width (Fmax-Fmin), is the whole range of the unit output power: Pmax-Pmin=Pmax.

Figure 3.25 shows the full control diagram, where it is possible to see that the blocks on the upper part belong to the original control structure (as shown in Figure 3.12). The blocks that generate the frequency offsets are in the lower part and represent the change needed to enforce power limits.

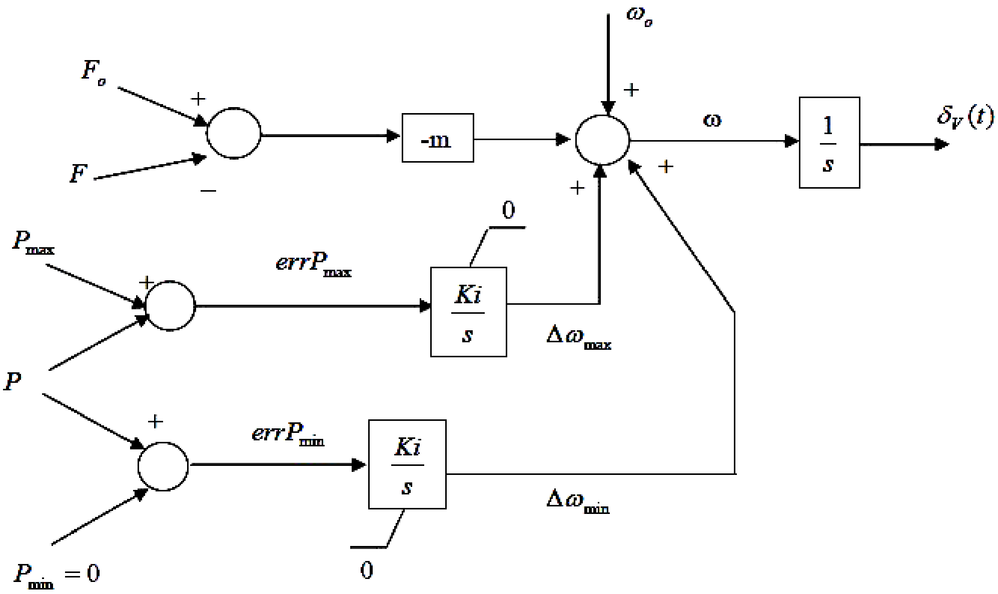


Figure 3.25 Control Diagram to Enforce Limits with Feeder Flow Control.

The equation that governs this control has been formally changed from Eq. 3.4 to an equation that keeps into account of changes made in Eq. 3.5 and Eq. 3.6 when respectively dealing with maximum and minimum power limits. The final equation is:

$$\omega_i = \omega_o + m(F_{o,i} - F_i) + \Delta\omega\max + \Delta\omega\min \qquad \text{Eq. 3.12}$$

The quantities Δωmax and Δωmin are added to the frequency as calculated in Eq. 3.8. Both quantities are zero when the unit operates within power limits. When Pmax is exceeded,
Δωmax becomes negative (never positive) to enforce the limit. When Pmin = 0 is exceeded, then Δωmin becomes positive (never negative) to enforce the limit.

3.2.3 Mixed System

This Section describes the steady state characteristics for a mixed system consisting of some units that regulate their output power and some other units that control the feeder power flow.

Figure 3.26 shows a possible configuration. The combinations of different configurations could swell to a large number even with few units. For instance, with two only units (one controlling P, other F to have mixed system) there are three independent configurations. The first is with both units on the same feeder, unit controlling F nearest to the utility (as in Figure 3.26), the other case is when the unit controlling P is the nearest to the utility. The last case is when the two units are in two separate feeders. The island condition is that grid power is zero, which means that the overall flow in the feeder(s) converging to the utility must be zero. This statement translates on Figure 3.26 with the condition that F1=0 in island, since that is the only one feeder connecting to the grid. This implies that for the unit configuration shown in Figure 3.26, in island mode the operating point is at frequency ω1 , lower than the system frequency only because the flow Fo1 is positive (importing power during grid connection). A negative value for Fo1 would have generated an intersection with the axis F=0 at a frequency higher than nominal.

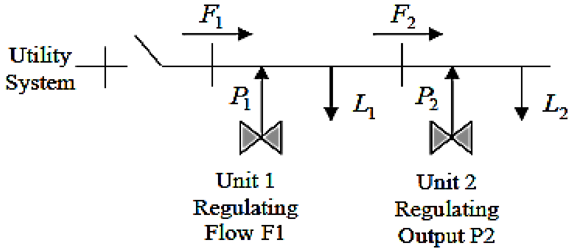


Figure 3.26 Mixed System on a Single Feeder, with Flow Control Near the Utility.

Chapter 4. Interface of Inverter to Local System

This chapter describes how the ratings of the several components within a micro-source need to be coordinated to achieve the desired operation. Figure 4.1 shows the full layout of every component that appears in a micro-source: from left to right, there is the prime mover responsible to generate a DC voltage, then there is the DC bus that needs to include some storage. The inverter is the interface between the DC bus and AC system and is responsible for the operations of the micro-source. Immediately connected to the inverter terminals there is an L-C filter bank to eliminate the higher harmonic from the voltage waveform and then there is the inductor that determines how active and reactive power can be dispatched. The final connection with the feeder is achieved by means of a delta-wye transformer with a neutral connection to allow for single phase loads to be connected to the system.

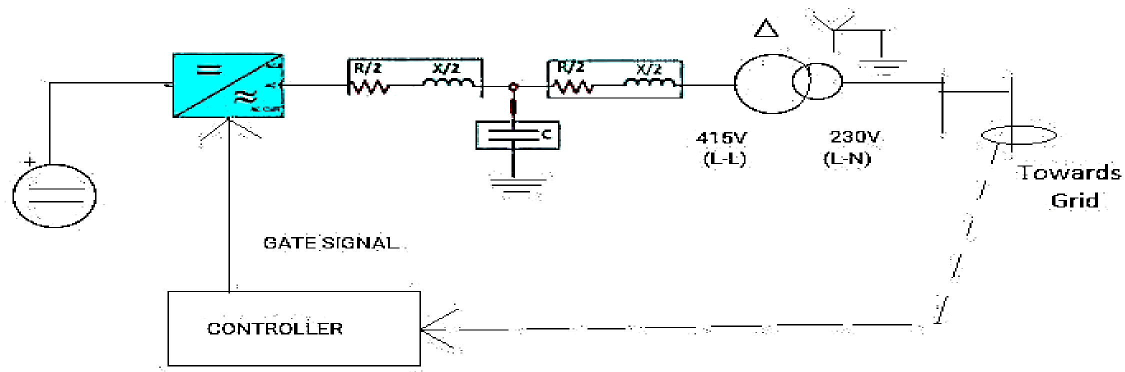


Figure 4.1 Micro-source component parts

All these components need to be coordinated and selected in such a way that their ratings are compatible with the capabilities of the other components of the chain.

4.1 Prime Mover Dynamics and Ratings

The prime mover is the block that converts the chemical energy of the fuel in DC electric power. Some examples of prime movers are micro-turbines and fuel cells. Each prime mover has a dynamic response to changes in power command that depends on the technology adopted. In general the dynamic response takes from few seconds to few minutes to track a step change in the power command, for example Capstone micro-turbine shows a time constants in the order of 10-20 seconds to follow a step change in the power command, while a fuel cell stack takes minutes to track the power command. There is the need to provide some form of energy storage to ensure that the energy for the loads is immediately available. The storage will be located at the DC bus. The rating on the prime mover is given in terms of maximum active power output, which is the largest amount of power that the generator can convert to electric form. This is an upper limit that will influence the choice of the ratings for other components of the micro-source such as the inverter and the transformer. Usually, the prime mover has also generating on the voltage output, establishing the maximum voltage level at which that the power is produced.

Micro-turbines have a two pole permanent magnet generator that converts the mechanical power of the shaft into electric power at variable frequency, depending on the speed of rotation. The variable frequency voltage is rectified to a DC voltage that is almost independent of the variable AC frequency.

Each time the electrical load is diminished, the DC bus voltage immediately increases due to the lower power demand: at that point the fuel valve controller decreases the fuel to the microturbine to reduce its output power and regulate the DC voltage. When the load is increased, the DC voltage decreases because the storage is providing immediately power to the load: at this point the controller increases the fuel injection to the microturbine to increase its output power and restore the DC voltage. DC bus voltage is 12V .

We are using a system where the speed of the turbine shaft is 100 rpm and the DC voltage produced is 5V.

4.2 DC Bus and Storage Ratings

The DC bus has two ratings, one is on the voltage, the other is on the amount of energy that can be stored in it. The DC bus voltage rating is the voltage level from the prime mover.

Microturbines have a 5 Volts range on a 12-23V, while fuel cells need to be interfaced with a DC/DC converter to obtain such a small range of change in the output voltage as the loading conditions change.

Since the prime mover does not have instantaneous tracking capability of the power command, the DC bus needs to store enough energy to be able to supply the load immediately while the prime mover ramps up. The worse case is during island operation when the grid is not available to supplement that transient energy. The amount of rated stored energy should be enough to guarantee tracking load requests in the face of the slow dynamics of the prime mover. This implies that the ratings on the storage are dependent on the technology of the prime mover, for instance, a micro-turbine that takes ten seconds to ramp up output power should have less storage than a fuel cell that takes over a minute to ramp up.

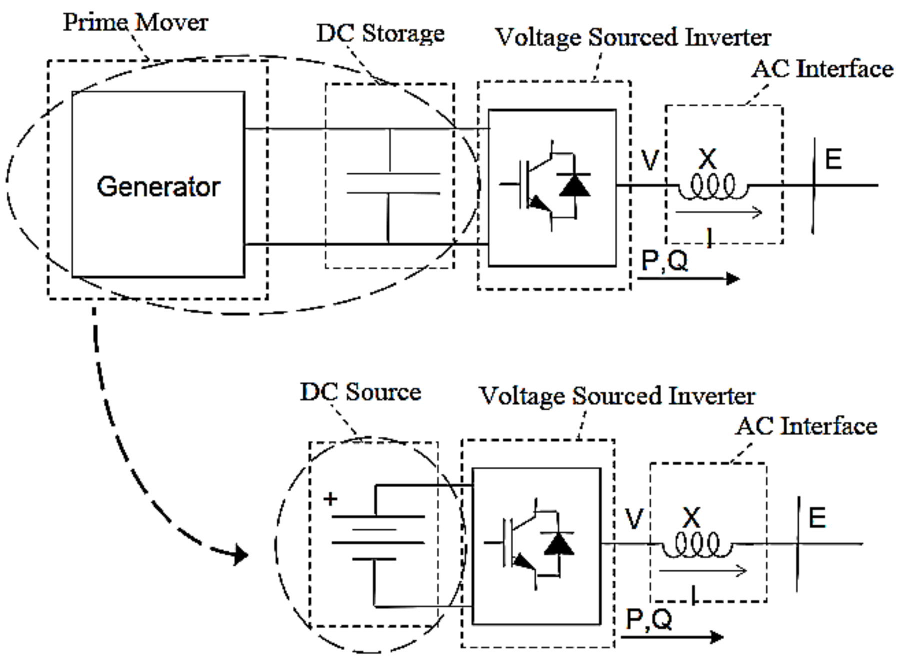


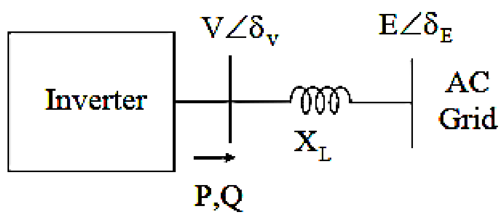
Figure 4.2 Replacement of Prime Mover + DC Storage with DC Source.

With storage, the value of the voltage at the DC bus is quite stiff because it is regulated by the prime mover. Since there is a need for some sort of available storage, then it is possible to eliminate the prime mover altogether from the model, without loss of generality. Figure 4.2 shows how the prime mover + DC storage blocks can be replaced by a DC voltage source. This simplification is legal because the two parts in the dark dashed ovals behave essentially the same. This simplification allows to obtain conclusions on the behavior of inverter based sources, without having the need to use an actual prime mover. The hardware tests that will be described in the following chapters adopt a micro-source that takes advantage of this simplification.

4.3 Sizing the Coupling Inductor, Inverter Voltage and Power Angle

Micro-sources need a power electronics block to perform the DC/AC conversion to interface with the local grid where they are installed. The inverter terminals are ultimately connected to the AC system by means of an inductance. Figure 4.3 shows the details of the interface with the grid.

Measurements are taken from both sides of the inductance and a controller generates desired values for V and δ_V to track the externally commanded values for active power injection P, and voltage magnitude E at the point of connection with the grid.



$$\delta_p = \delta_v - \delta_E$$

$$P = \frac{VE}{X_L}\sin(\delta_p)$$

$$Q = \frac{V^2 - VE\cos(\delta_p)}{X_L}$$

Figure 4.3 P and Q as a Function of the Voltages and their Angles.

The size of the inductor is derived from the inverter voltage ratings, the regulated bus voltage and the limits on the power angle. The power angle is the angle difference between the voltages at the inverter and the regulated bus. Typical limits can be:

Limit on V (such as $V_{max} \leq 12.$ pu). This condition is dictated by the value of the voltage at the DC bus and by the kind of power electronic bridge used in the inverter.

Limit on δ (such as $\delta_{max} \leq 30$ deg *rees*). This condition derives from the need for the controller to operate in the linear portion of the P(δ_p) characteristic: as Figure 4.4 shows, 30 degrees is a reasonable choice for the maximum value for δ_p .

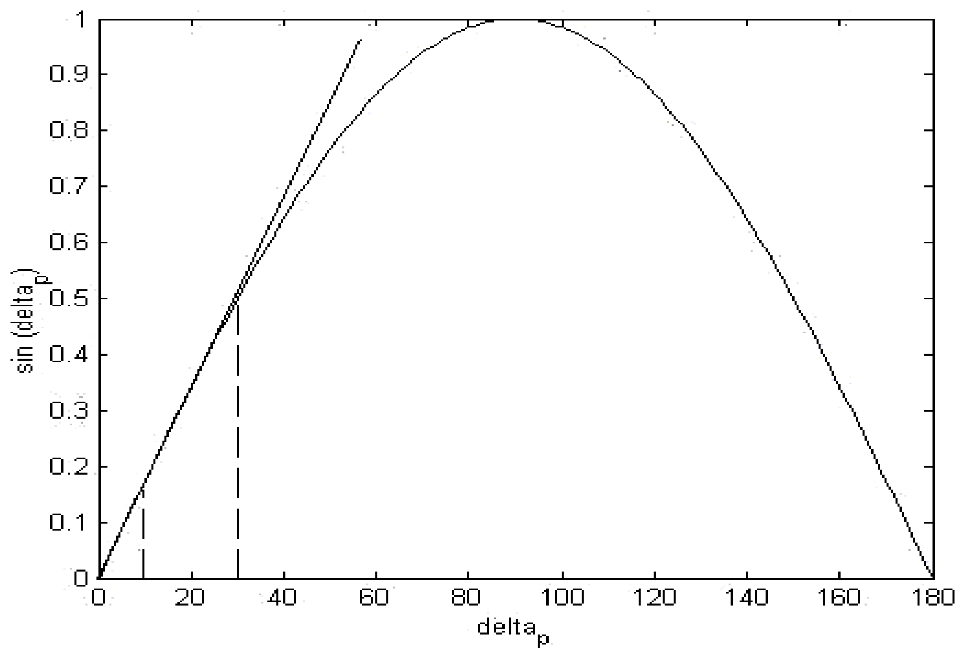


Figure 4.4 Power-Angle Characteristic

The power angle characteristic is already a great place to start to limit the size of the inductor, because it provides some upper and lower boundaries for its value. If the value of the inductance is too large, then the resulting angle at maximum power would not satisfy the condition of linearity. A value of 30 degrees provides a 4% error in the linear approximation, but a maximum power angle value of 10 degrees implies that the largest error in the approximation would be 0.5%. A smaller range for the power angle would require too much precision in the synthesization of the angle at the inverter terminals. The inverter synthesizes the voltage angle with a certain tolerance depending on the switching frequency. The higher is the operating frequency the lower is this tolerance. If a large range for the power range is chosen, then the relative size of the error is small and there are no problems in injecting power. If a small range is chosen, then the same absolute value of the tolerance becomes relatively large compared to the range of delta, implying problems in achieving constant power injection. The power would oscillate, and if the range for the angle is chosen really small, say a fraction of a degree, then it would be nearly impossible to regulate power due to the fact that the angle would need to be held with a very high precision.

4.3.1 P versus Q Area of Operation

When designing the inverter, the choice of ratings of the devices plays a key role. The power electronic block at the minimum has to be rated as the prime mover. If the ratings of the prime mover exceed the inverter ratings then when the prime mover operates at peak power it would be impossible to transfer its full power. Each inverter has limits dictated by the ratings on the silicon devices. These limits appear in the form of maximum voltage that the power electronic device can safely sustain and the maximum current that it can carry. Based on these considerations, each designer provides a range of active and reactive powers that the inverter can safely operate at. At this point there is the first formulation of the answer for the problem of the size of the inductor:

The size of the inductor must be such that it enables delivery of the active and reactive power that the inverter can provide.

Figure 4.5 shows the plot of the active and reactive power obtained from the formulas included in Figure 4.3 as a function of the inverter and bus voltage, their angle difference and the impedance. All quantities are in per unit to maintain generality and the plot is obtained for the power angle equal to 15 degrees. Smaller inductances allow larger power flows. The inductor should be chosen small enough to guaranteed delivery of the specified amounts of power: if the inductor is chosen too large the power may no longer be deliverable. The optimal inductor size can be seen as the maximum size that the inductor can have, and still being able to satisfy the delivery requirements.

To develop some intuition on how to solve the problem it is useful to build some maps of the power that it is possible to deliver given the limits that need to be satisfied.

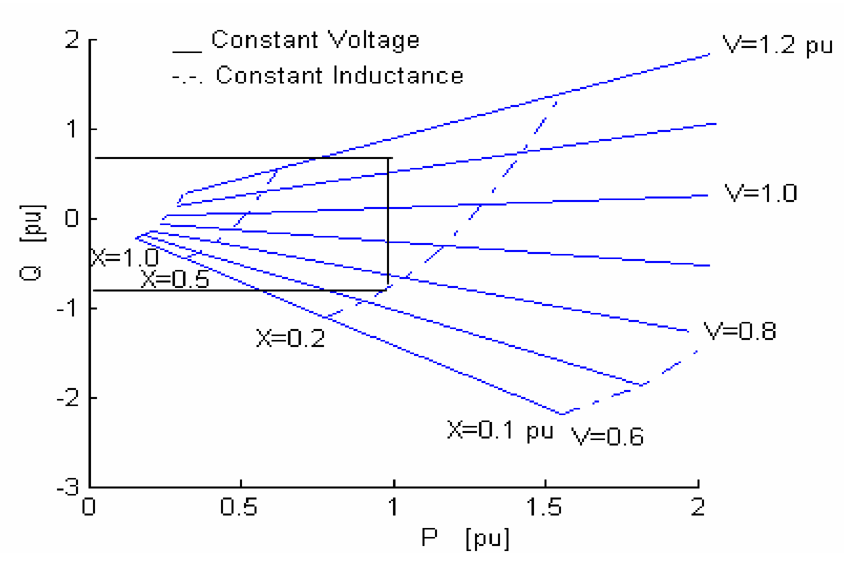


Figure 4.5 P and Q Plane Capability with Constant Voltage and Impedance.

Figure 4.5 plots P and Q from the formulas inside Figure 4.5 assuming that
$\delta p = \delta p$ max = 15 degrees and E=1pu. Then, the values for V ∈[0.6, 12.] pu and X ∈ [0 .1, 1.0] pu are separately spanned. The result of overlapping the plots yields a map: positive values for Q imply capacitive power while negative values imply inductive injection. Assuming as an example a power factor of

0.8 it is possible to calculate Qmax as 0.75 pu when P=Pmax is 1.0 pu. This means that there is a region between P=[0, 1.0] pu and Q=[-0.75, 0.75] pu that is identified in Figure 4.5 as a rectangle. This rectangle is just a simplification of the shape of the region describing the capability of the inverter to inject active and reactive power. The impedance must be such that the points inside this region are reachable. A value of the impedance around 0.2 pu would fulfill the requirement, but if one chooses a larger impedance some of the values inside the rectangle would not be reachable.

Each value of the inductance defines a certain region in the space that can be reached: Figure 4.6 shows this region for X=0.2 pu while δ is spanning from 0^{o} to 30^{o} . Figure 4.6 shows that with the inductor of size X=0.2 pu it is possible to reach the coordinate P=1.0 pu and Q=0.75 pu with an inverter voltage of about 1.12 pu and a power angle of 10 degrees.

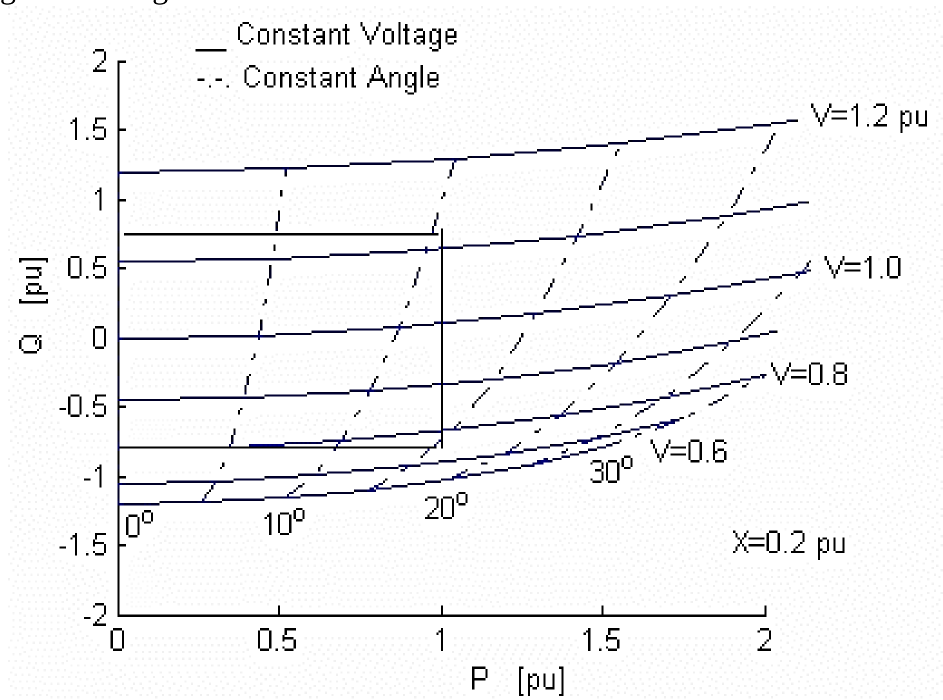


Figure 4.6 P and Q Plane Capability with Constant Voltage and Angle X=0.2 pu.

The value P=1.0 pu and Q=-0.75 pu can be reached with an inverter voltage as low as 0.76 pu and a power angle of 15 degrees. This is the largest inductance value to reach these values as of Figure 4.5, but one could choose a smaller inductor for economic reasons. Figure 4.7 is the map drawn for X=0.1 pu and it shows that with this smaller impedance it is possible to reach a larger region in the plane P-Q. The example values of P=1.0 pu and Q=0.75 pu can be reached with a value of the inverter voltage near 1.06 pu and a power angle of 6 degrees. The values P=1.0 pu and Q=-0.75 pu can be reached with inverter voltage of 0.92 pu and power angle of about 7 degrees. This solution with the smaller impedance is also more appealing because of the reduced cost of the inductance, but it implies that the inverter control must have a good resolution in angle. There is always a given constant error in the angle because of resolution due to the truncation effects of the digitalization inside a DSP environment or the capability of the inverter. This error propagates as an error in the power delivered and there will be larger errors in power the smaller is the range of the power angle from zero to maximum rated power: that is why it would be a bad idea to choose an impedance that determines a very low value of the maximum delta, such as one degree. The design of the inductor size must also factor in this consideration to avoid unacceptable errors in the power delivery.

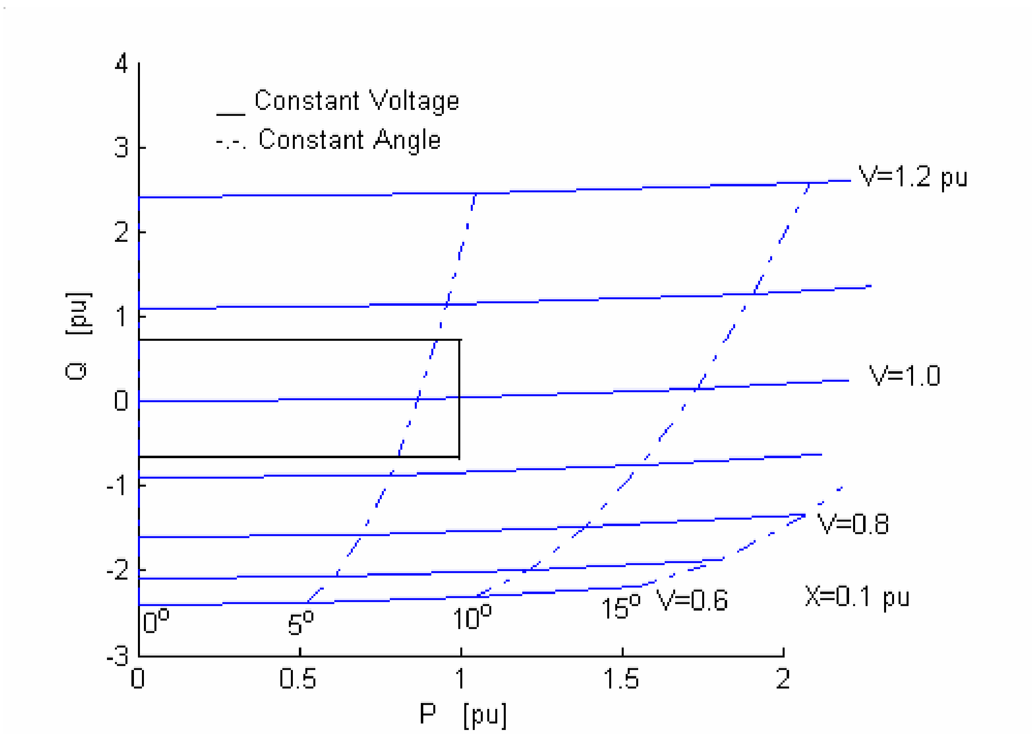


Figure 4.7 P and Q Plane Capability with Constant Voltage and Angle X=0.1 pu.

It must be noticed that there are several choices of the impedance that allow to deliver the P and Q inside the region, but each choice corresponds to a different inverter voltage and power angle. For what concerns the maximum inverter voltage, it can be noticed that with X= 0.2 pu, in Figure 4.6, there is a need to have a 1.12 pu inverter voltage to reach the coordinate P=1.0 pu, Q=0.75 pu. With X=0.1 pu the inverter voltage needs to be only 1.06 pu. It is manifest how the choice of the impedance affects the requirements on the inverter to reach the P and Q coordinates. For instance a lower DC bus voltage can be afforded when using X=0.1 pu rather than X=0.2 pu. The ideal design must keep into consideration the issue of DC bus magnitude because it is directly connected to the maximum voltage that the inverter can achieve. The inductance also affects the value of the minimum voltage that the inverter may need to synthesize when trying to reach high values of inductive reactive power. But this value is less critical because it can always be reached by means of a thinner modulation of the voltage waveform: on the contrary, the maximum voltage represents a real issue because its value determines the rating that the DC bus must have.

In summary, a smaller size of the inductor corresponds to a lower cost, a lower requirement on the DC bus rating and a smaller range of power angle. The range of the power angle cannot be allowed to get too small to avoid errors in the power to become unacceptable. A compromise between angle resolution, inductor price and DC bus rating is key to obtain an ideal match between inverter capabilities and inductor.

4.4 System Ratings

The inverter performs the task of converting the voltage from a DC level to the AC utility frequency. The output voltage level of the inverter is a free variable that can be changed with an appropriate choice of the turn ratio of the transformer. The inverter allows the flexibility of adopting a wide variety of prime movers. The output voltage of the inverter depends on the DC bus voltage and the modulation technique adopted.

The inverter needs at the minimum to have enough ratings to supply the active rated power of the prime mover, but the final ratings need to be somewhat higher to be able to supply the reactive power necessary for voltage regulation. The silicon devices inside the inverter have thermal limits that need to be observed to guarantee their operation. These thermal limitations are translated in a maximum amount of continuous operation current that the devices can withstand without incurring in thermal runoff and being damaged. During faults the silicon can transiently sustain a 2 pu current for those few cycles that the protection takes to intervene and disconnect the source.

It is possible to show how the maximum current on the device impacts the AC side rms current value. Assuming a power factor of 0.8 it is possible to calculate that the maximum reactive power injection is:

$PF = \cos(\phi)$

$Q = P \tan(\phi) = P \tan(a \cos(PF)) = 0.75\ P$

When the inverter is operating at the maximum current output the voltage of the inverter will also be nearest it maximum possible value. This means that the modulation of the DC voltage has become very wide: to greatly simplify the analysis a six pulse operation of the bridge is assumed. This implies that each of the devices conduct for a half of the fundamental frequency period. Figure 4.8 shows the voltage source inverter that interfaces the DC bus voltage with AC sinusoidal current sources. These sources are assumed to be 120 degrees apart in each phase.

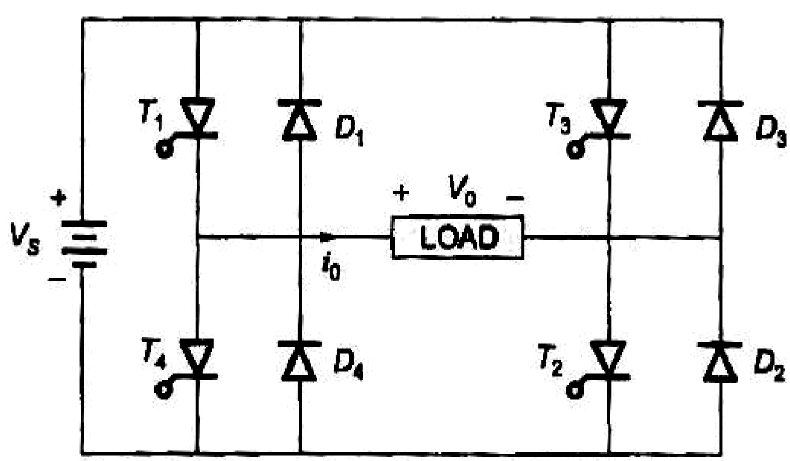


Figure 4.8 Voltage source inverter

Chapter 5. Unbalanced Systems

This chapter addresses the fact that unbalanced conditions of small magnitude are a relatively common operation of the system and the micro-sources need to be able to operate in this environment. The reasons that determine unbalance are first given. An active approach at eliminating unbalance determines higher requirements in the ratings of the source. The micro-source needs to operate in the unbalanced environment without attempting to restore balanced conditions.

5.1 Reasons that Determine Unbalanced:

Any deviation in voltage and current waveform from perfect sinusoidal, in terms of magnitude or phase shift is termed as unbalance. In ideal conditions i.e. with only linear loads connected to the system, the phases of power supply are 120 degree apart in terms of phase angle and magnitude of their peaks should be same. On distribution level, the load imperfections cause current unbalance which travel to transformer and cause unbalance in the three phase voltage. Even minor unbalance in the voltage at transformer level disturbs the current waveform significantly on all the loads connected to it. Not only in the distribution side but through the transformer, voltage unbalances disturbs the high voltage power system as well.

Causes of unbalance

Practical imperfections which can result in unbalances are:-

1. A three phase equipment such as induction motor with unbalance in its windings. If the reactance of three phases is not same, it will result in varying current flowing in three phases and give out system unbalance.

– With continuous operation, motor's physical environment cause degradation of rotor and stator windings. This degradation is usually different in different phases, affecting both, the magnitude and phase angel of current waveform.

– A current leakage from any phase through bearings or motor body provides floating earth at times, causing fluctuating current.

2. Any large single phase load, or a number of small loads connected to only one phase cause more current to flow from that particular phase causing voltage drop on line.

3. Switching of three phase heavy loads results in current and voltage surges which cause unbalance in the system.

4. Unequal impedances in the power transmission or distribution system cause differentiating current in three phases.

.

$$\%\text{ of voltage unbalance} = 100\,\frac{\text{maximum deviation from average voltage}}{\text{average voltage}}$$

5.2 Unbalance Correction

When a voltage unbalance exceeds the nominal value that can be tolerated within a system as stated by the ANSI standard, some corrective action must be taken to prevent this unbalance from creating problems in the operation of the equipment inside the micro-grid.

One approach could be to inject sequence currents from the inverter to rebalance the system. The inverter can only generate voltages on a line to line basis, so the scope of the correction would only be limited to the negative sequence. The measures of voltages and currents that are passed to the control need to be conditioned to identify the positive and negative sequence components.

Each of the components is then separately controlled: the positive sequence quantities are regulated to the externally requested values while the negative sequence quantities are regulated to zero. The structure of the control needs to be more complex and the ratings of the inverter need to be augmented to be able to carry the negative sequence currents.

Another approach is to transfer to intentional islanding mode by separating the micro-grid from the utility in the case that the unbalance exceeds the tolerable levels. This solution does not require any modifications in the control and the micro-sources only need to be able to correctly operate under unbalanced conditions as long as the level of unbalance is below a determined threshold. In this case the sensing equipment at the point of interconnection with the grid needs to be able to evaluate the unbalance and send a tripping signal to the static switch when limits are exceeded. This solution does not require any extra rating of the inverter to allow for the negative sequence current injection.

5.3 Operation under Unbalance

The inverter ratings need to be increased by a large factor to correct for sustained voltage unbalances. Avoiding the active cancellation of negative sequence implies that the static switch needs to be able to selectively disconnect the micro-grid when unbalances exceed the tolerance level of 3 percent as recommended by the ANSI standard. This approach implies that the basic control of the micro-source needs to be able to correctly operate in an environment that may contain unbalances up to that tolerance. Unbalances affect the basic control because the opposite rotating negative sequence introduces 120Hz oscillations in the measure of power and voltage magnitude. The measurement system assumes quantities with positive sequence component only when unbalances are present some calculations are affected. For instance, the d-q stationary components will no longer be represented by two vectors of same magnitude and phase. When plotted on the d-q plane these components will not describe a circle but an ellipse. The instantaneous calculation of the radius of the ellipse (the magnitude of the voltage) will yield quantity pulsating at twice the nominal system frequency. If the unbalance is less than 3 percent, the magnitude of the pulsation can be very small. The active power measure will have the same issue, showing a small amplitude ripple at twice the system frequency superimposed over the traditional value.
Filtering the signals of voltage magnitude and power is the solution that can eliminate the presence of the small ripples. In the hardware realization measures are brought in by sensing equipment and translated to digital values. These values are plagued by noise coming from the sensing devices and from the connecting cables that carry those measurements. The digital values inside the DSP environment need to be filtered to minimize the effect of these noises. It turns out that those filtering levels may also be enough to eliminate the 120Hz ripples in the measures due to low levels of unbalance present in the system. In the hardware laboratory setup the voltage supply is rather well balanced, showing a 0.2 percent level of unbalance at the 240V point of common coupling. The values of P,Q and regulated voltage magnitude, V are filtered before being introduced in the controller. The filter is a low pass, single time constant transfer function:
The time constant τ is worth 30ms, for P, Q and V. Figure 5.1 shows the frequency response of this filter.

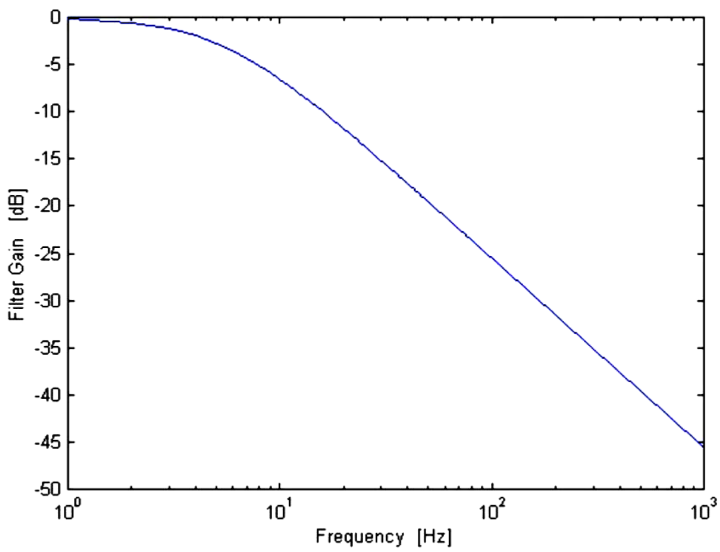


Figure 5.1: Filter Gain as a Function of Frequency

The test system is one micro source in island connected to an unbalanced load. The load is unbalanced by removing the connection at one of the three phases. As a consequence, the current in that particular phase will be zero. The resulting unbalance in the voltage is 5.12%.
Figure 5.2 shows the plots for P,Q and V as the unbalance is applied. It is possible to notice the 120Hz component superimposed to the balanced value on each of the three quantities. The voltage magnitude, V, shows a very small magnitude in the double frequency component, that is because the unbalance driving it is 5.12%. The values of P and Q show a relatively larger magnitude in the double frequency component because they are calculated using voltage and as well as the current, which has a 100% unbalance.
Figure 5.3 shows the three line to line voltages at the load terminals (upper traces) and the currents (lower traces).

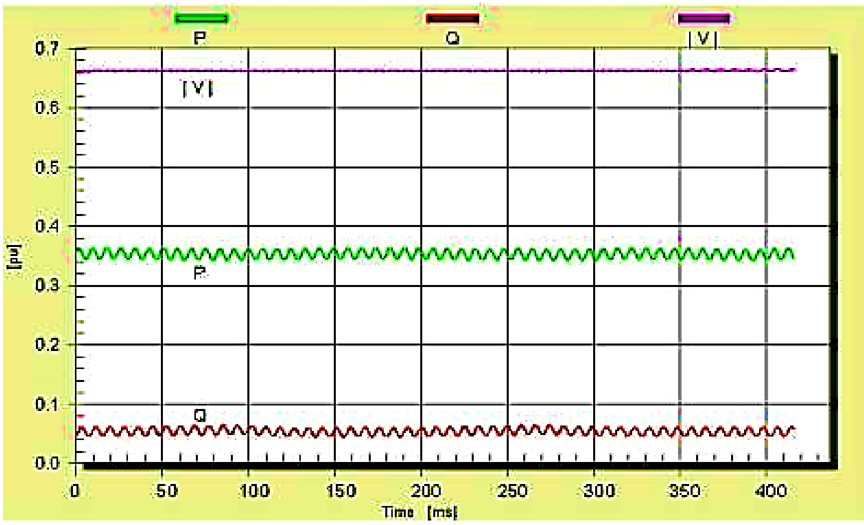


Figure 5.2: P,Q and Magnitude of V.[50 ms/div]

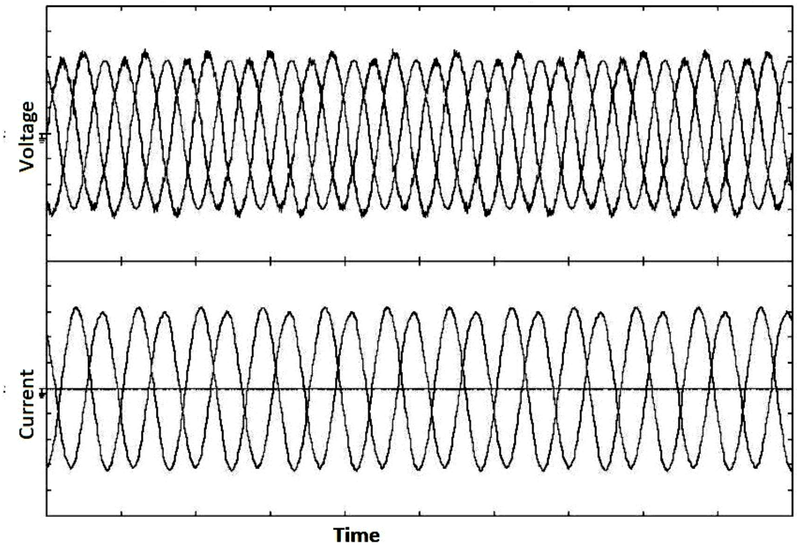


Figure 5.3: Load Line Voltage 100v/div (upper traces) & Unit currents,(lower traces)[20ms/div]

Figure 5.5 shows the measures of P and Q as well as the measure of V at unit 1 when unit 1 is operating in parallel to unit 2. The unbalance is determined by a phase on the load of unit one being open. The overall voltage unbalance at the terminals of unit 1 is reduced to 3.97% due to the presence of unit 2. Figure 5.6 shows the same quantities for unit 2. Being that this second unit is farther away from the unbalanced load, the amplitudes of the oscillations at 120Hz are reduced.

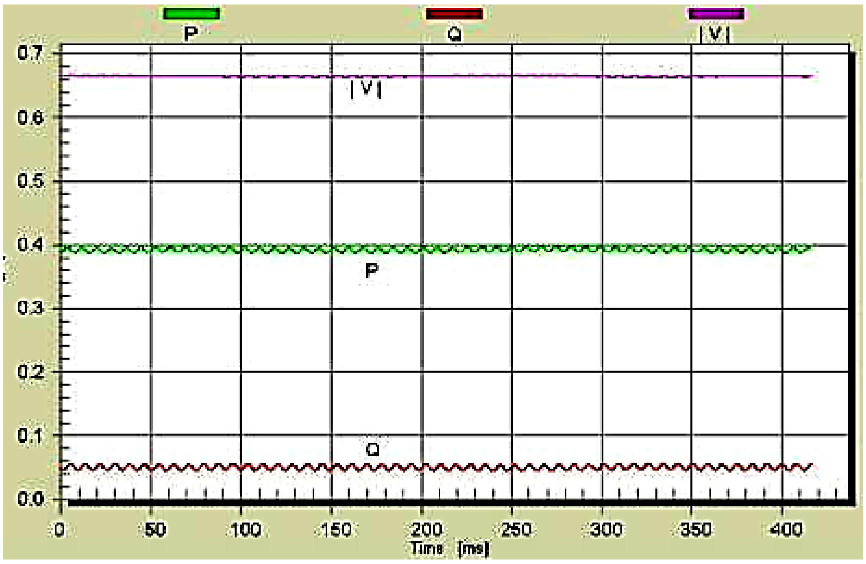


Figure 5.4 Unit 1 – Two Units in parallel.[50ms/div]

Figure 5.4 shows the measures of P and Q as well as the measure of V at unit 1 when unit 1 is operating in parallel to unit 2. The unbalance is determined by a phase on the load of unit one being open. The overall voltage unbalance at the terminals of unit 1 is reduced to 3.97% due to the presence of unit 2. Figure 5.5 shows the same quantities for unit 2. Being that this second unit is farther away from the unbalanced load Amplitudes of the oscillations at 120 Hz are reduced.

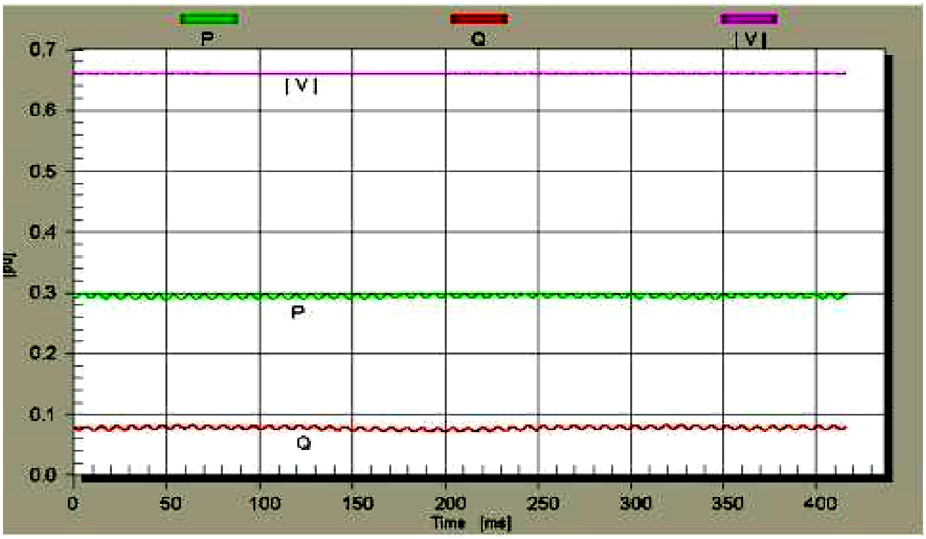


Figure 5.5 Unit -2 Two Units parallel[50mis/div]

Figure 5.6 shows the 120Hz ripple at the measured quantities of the micro source when this unit is connected to the grid and the unbalance is created by the opening of one phase. In this case the voltage unbalance measured at the terminals of the unit is of 2.82%. This is because of the stiff Thevenin impedance of the utility system being in parallel to the unbalanced load at the source.

The oscillations on P and Q have a very low magnitude, while the oscillations on V have nearly completely disappeared. This allows to conclude that the source does not require any active action to compensate for negative sequences, as it has been shown that it can safely operate under the voltage unbalances below the threshold of tripping.

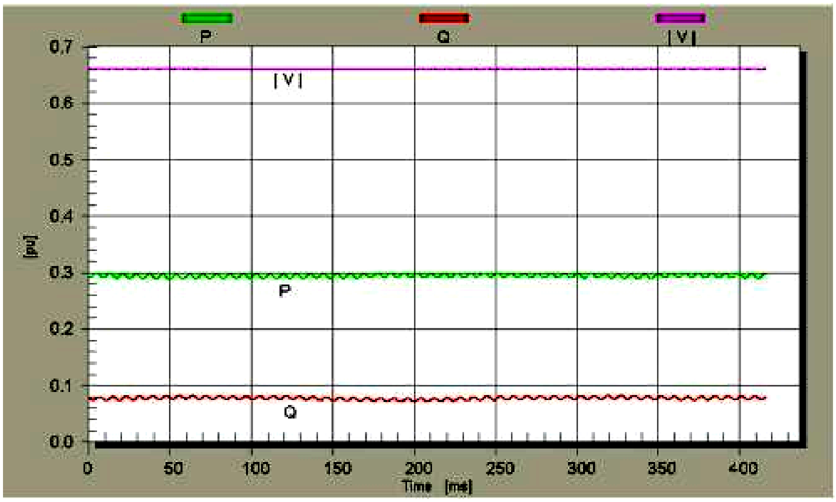


Figure 5.6 One Unit Connected to the Grid [50ms/div]

Chapter 6. Hardware Implementation

The ultimate validation of the control capabilities is a successful series of tests carried on a hardware level. Steady state and dynamic analysis can give many insights on the performance of the control, but it is only after realizing a scaled down version of a micro-grid that it is possible to assess the actual quality of the design.
The details of the hardware setup that implements the proof-of-concept for the micro-grid will be given in this chapter.

6.1 Basic System

A scaled down version of a micro-grid has been reproduced in the lab to test micro-source operation and control. This system incorporates the typical components that can be found in a local load center: there is one transformer that connects to the utility system and a radial network with feeders that delivers the electric power to all the loads. Figure 6.1 shows the network configuration. The point of delivery of power from the main grid is at 240 V, while inside the system all the loads and the feeders are operating at 220 V. The micro-sources generate power at the voltage level of 240 V appropriately lowered to the network voltage by a separate transformer. On the inverter side of the transformer there is a low pass LC filter to smooth out the voltage waveform. In series to the filter there is an inductance to allow for power transfers. There are two load centers located near the two micro-sources and another load electrically installed between the two units: this allows to test the power sharing during operation in island mode.

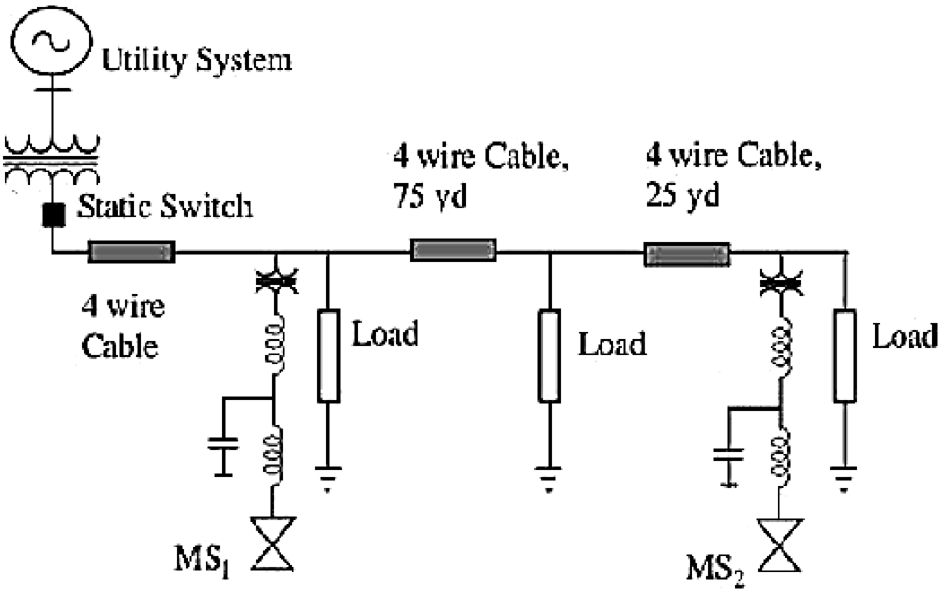


Figure 6.1 Single Phase Test System Diagram

The three phase passive loads are connected at star and are purely resistive, while the cables consisting of four conductors, three phases and a neutral, that run in parallel from a bus to the next representing the feeder. Micro-sources are connected to the local feeder with a transformer in series to an inductance. The connection is at delta on the inverter side and at wye on the feeder side with the center star connected to the neutral wire of the feeder cable. The voltage level of the feeder is 220V, while the inverter operates with voltages of 240V. In summary, operations are on a three-wire environment on the inverter side of the transformer, while they are on a four wire environment on the micro-grid.
Figure 6.2 shows the basic equipment that appears in a micro-source: the inverter is connected to an ideal DC source and creates the AC voltage at its three phase terminals. The inverter is controlled by the gate signals that are generated by the control blocks. The controller uses the measures of voltage and current at the feeder, where the unit is installed. When the unit is controlling the feeder power flow, then the current

from the feeder on the side leading to the grid are also fed back to the control.
The inverter side is connected to delta, while the lower voltage side is star connected, with the neutral of the transformer carried on in the feeder to allow for single phase loads to be connected

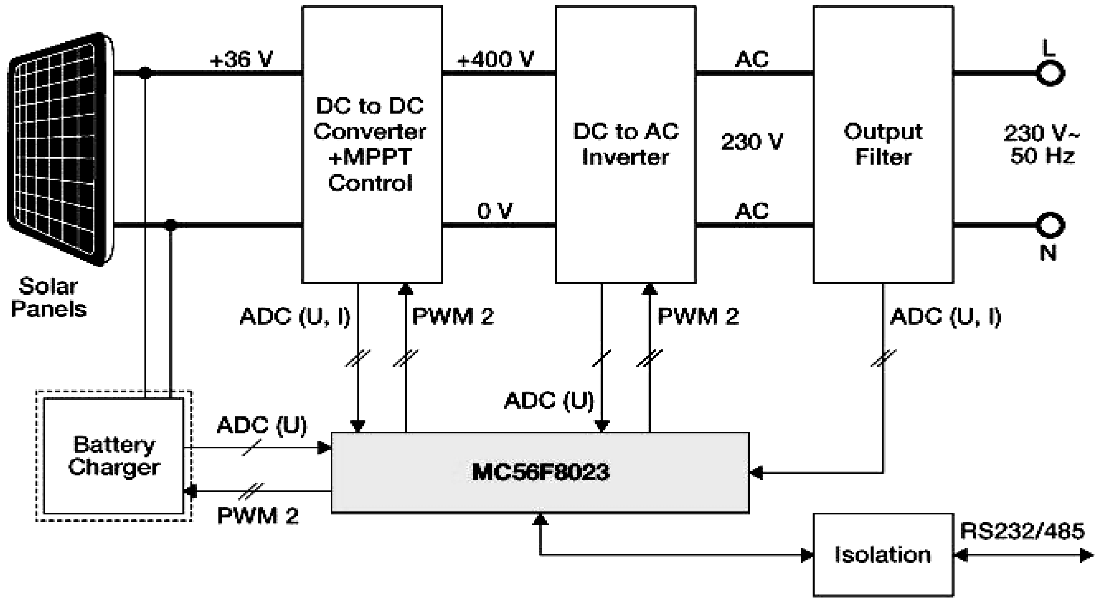


Figure 6.2 Single Phase Diagram of Inverter Connection to the Feeder

6.2 Description of the Laboratory System

This section describes in detail the constituent parts present in the hardware circuit. The overall single phase circuit diagram is represented in Figure 6.3. Somewhere in the building there is a connection that can be considered a stiff voltage source, representing the utility system. From that connection, there is a three-wire cable (Z1) that reaches the transformer T1, located in the laboratory. This transformer has the neutral connected to the fourth wire of the system that runs in parallel to every feeder. On the micro-grid side of the transformer there is the static switch to connect and disconnect from the grid. Then there is a short 4 wire cable (Z2) that connects to the first micro source (MS1) and load center (L1).

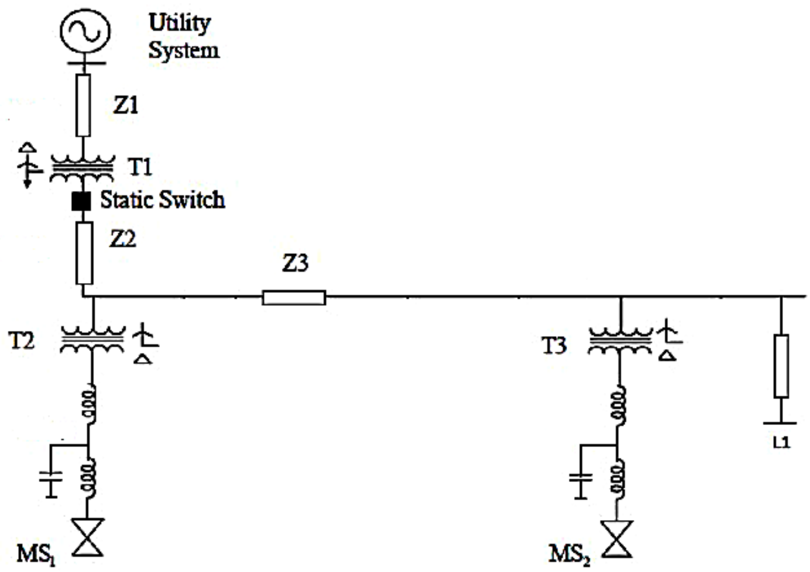


Figure 6.3 Single Phase Laboratory Circuit Diagram

Each micro-source is connected to the feeder by a series of low pass LC filter, an inductor and a transformer. The 220V low side of the transformer is connected at wye with the neutral cable connected the fourth wire inside the system. The 240V high side of this transformer is on the micro-source side where there is a 3 wire system. The supply voltage from the utility is also at 240V, while the rest of the micro-grid operates at 220V.
Every component of the network is described in detail in the following paragraphs.

6.2.1 Transformers

This section describes the transformers used in the systems. The transformer that is used to connect with the utility system has larger ratings than the transformer used to interface with the micro-source. The two micro-sources are twin systems, therefore their transformers will be identical.

Transformer T1

Nameplate Data:
150VA, 240/220
24 V, 8 amp,
so,8 X (24/220) = 0.872 Amp

P_{oc} =8.64 watts
Psc = 50 watts
CosΦ =(8.648 / (24X8)) =0.045
Then, Io = 0.0436 Amp
Ic = 0.0436 X0.045 = 0.001965 Amp
Im =0.0436 $\sqrt{1 - (0.045)^2}$ =0.0435 Amps.

R_c = (220/0.001962) =112130.47 Ω =112.130 KΩ

X_m = (220/ 0.0435) = 5057.47Ω = 5.057 KΩ

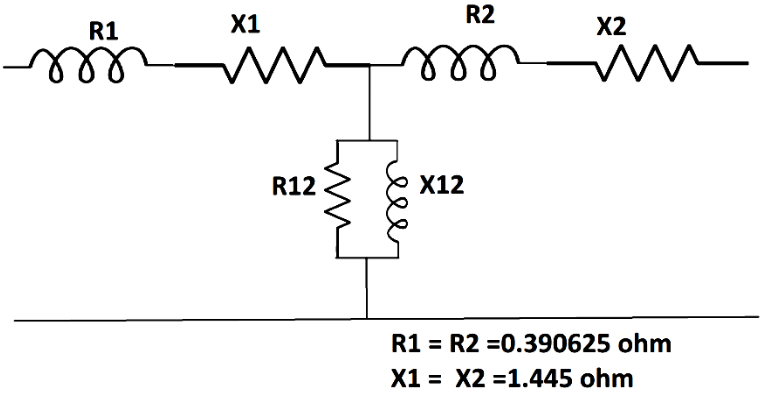
From SC Circuit

R_{ch} =(50/82) = 0.78125 Ω

Z_{ch}= 24/8 = 3Ω

$X_{ch} = \sqrt{3^2 + 0.78125^{\ 2}}$ =2.89 Ω

R_1= R_2= 0.390625 Ω
X_1=X_2= 1.445 Ω



6.2.2 Cables

This section gives the details for all the cables used in the system. All the data for the cables are Specified.
Data
Size 4mm^2, 1.5 mm ^{2},1mm^2, 2.5mm^2
Ac cable carries 150A and has the following parameters,
4mm^2 = R0 = 4.3(Ω/km), 1.5 mm^2 = 11.5(Ω/km),1mm^2=17.2(Ω/km), 2.5mm^2=6.9 (Ω/km)

Must be able to carry the current generated by the plant load demand of 192 W and its reactive part, plus all the losses in the lines. All the cables are at 220 V, with neutral cable having the same size of the a phase conductor.
The first thing to do is to estimate the VA request from the active load and the expected power factor.
With PF = 0.9 S = $\frac{P}{PF} = \frac{150}{0.9}$ = 166.66 VA
With a very poor power factor such as PF=0.7 then S ≈ 214.28 VA. To get the current rating per phase from VA:

$$I_L^{rms} = \frac{S_{1\Phi}}{V_{LN}^{rms}} = \frac{\left(\frac{S_{3\Phi}}{3}\right)}{\frac{V_{LL}^{rms}}{\sqrt{3}}} = \frac{214.28}{220X\sqrt{3}} = 0.562\ A$$

Size	S [VA]	Type & Rated	Rated I[A]	R[Ω]
4mm^2	220	YWY 1000/600V	-	4.3[Ω/km]
1.5mm^2	220	YWY 1000/600V	-	11.5[Ω/km]
1mm^2	220	YWY 1000/600V	-	17.2[Ω/km]
2.5mm^2	220	YWY 1000/600V	-	6.9[Ω/km]

Table 6.1 Cable Data Summary

6.2.3 Loads
This section describes the details of the loads present in the laboratory system.
Data:
The sum of the three loads must be smaller than the total output of the micro sources, so that they can be supplied also in island mode. All loads are wye connected. Load L1 is made of two loads in parallel, one of which has the center of the star connected to the neutral, while the remaining loads have the center of the star floating. All loads have rated voltage of 220V and their overall rating is about 50Watt.

Micro sources
This section describes the details of the micro sources present in the laboratory system.
Data:

Rated active power P =214.28 VA, rated voltage 240V, rated power factor PF = 0.8.
Power angle at full rating: 7 degrees.

Minimum operating frequency: ½ Hz below nominal frequency.
From this data it is possible to calculate every other quantity of interest.

The inverter is fed by a DC bus voltage source of 12V. This DC source emulates the combined effects of a prime mover combined with an energy storage on the DC bus.
The size of the inductance X is calculated from the choice that the power angle at full power output is about 7 degrees. This choice guarantees operation in the linear region of the sinusoidal characteristic. Given that E is the voltage at the inductor X on the inverter side and V is the voltage at the inductor on the micro grid side and δs are their respective angles, then the active power transferred over the inductance is:

$$P = \frac{VE}{X} \text{Sin} (\delta_E-\delta_V) = \frac{240x220}{214.28} \text{Sin} (7^0) = 30\Omega$$

The fact that there is a power factor 0.9 implies that:
Q = P (tan(a cos(PF)) = 214.28*(tan(acos(0.9)) =166 VA
This is the maximum Q that the micro source may be requested to inject. It follows that the overall rating of the micro source is:
$S=\sqrt{p^2+q^2} = \sqrt{214.28^2+166^2}$ = 271.057 VA

These are the ratings that the silicon power electronic devices in the inverter must be able to withstand.
P - W droop with slope
The values of Pmax=192W and Δw min=0.5Hz define range of operating values on the P,ω plane shown on figure 6.4.

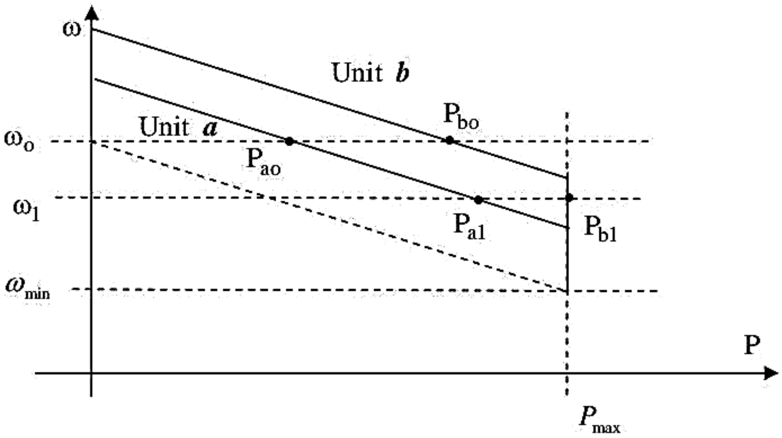


Figure 6.4 The Active versus Frequency Drop

The value for the fixed slope '*m*' of the droop is chosen to be corresponding to the value of the slope obtained for Po=0 when using the fixed slope Eq. below:

$$m = \frac{\omega 0-\omega min}{Pmax} = -\frac{2\pi^1/_2}{214.28VA} = -\frac{\pi}{214.28\,VA}$$

Q-E droop slope and set point

The value of Qmax helps to determine the slope for the Q-E droop, once the value of the maximum excursion expected for the voltage, ΔE, is known. The maximum excursion in voltage can be thought to be the difference in voltage between the best and worst case scenario.
The best case scenario is represented by the micro-grid fully energized from the grid, without micro-sources and without any load attached to it. The voltage profile is to be expected to be absolutely flat, since no

current are flowing in, and the voltage equal to the rated voltage of the system. The worst case scenario is represented by the micro-grid energized from the grid, without micro-sources and with all the possible loads inserted into the system. From an EMTP simulation of the system as described above it is possible to obtain the results shown in Figure 6.5.

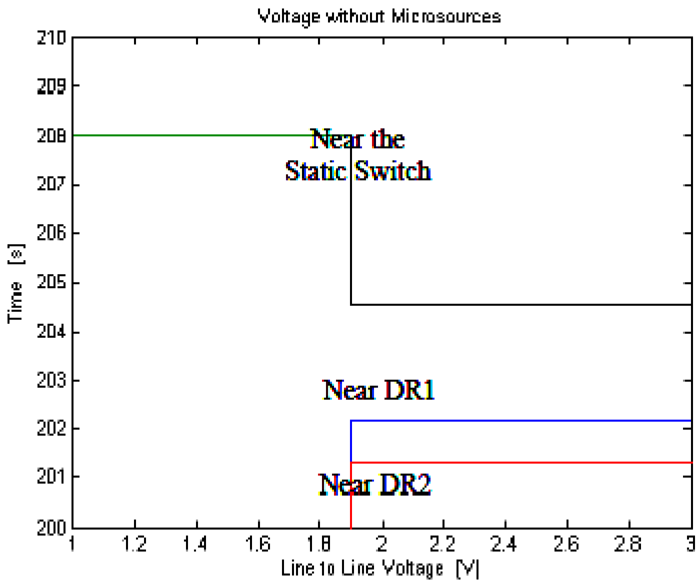


Figure 6.5 voltage Profile in the Micro-grid without Micro-sources

Figure 6.5 shows the magnitude of the line to line voltages as the static switch is closed, energizing the micro-grid, with full load but without micro-sources. From top to bottom, the first trace is the voltage immediately before the static switch, on the utility system side. It has a full value of 220V before the switch is closed. As soon as connection takes place, the voltage on this location falls to about 204.6V. The second trace is the magnitude of the voltage where micro-source 1 would be connected. The voltage is zero previous to connection and it is 202.2V afterwards. The third trace is the magnitude of the line to line voltage at the location where micro-source 2 would be connected. The resulting voltage is 201.3V.
With this information in hand, it is possible to look at the Q-E droop and find all the required values. The droop is reported on Figure 6.6 for case of inspection.

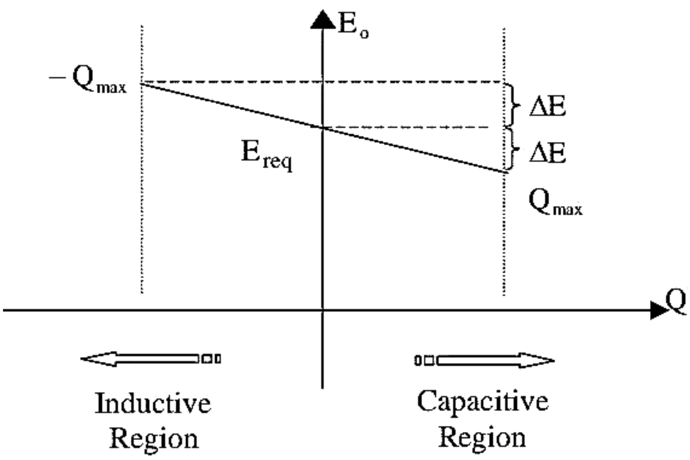


Figure 6.6 Q versus E Drop

For Micro-source 1:
The total drop is (240-220) = 20V = 2 ΔE.
It means that ΔE = 10V, so the setpoint for the voltage is:
Ereq = 220-ΔE = 240-10= 210 V
Qmax was already calculated as VA, so the slope for this droop is:

$$m_Q = \frac{\Delta E}{Qmax} = \frac{10}{166} = 0.0602 \text{ V/VA}$$

That is, the voltage is allowed to change of 0.0602 Volts for every VA that is injected.

6.3 Control Implementation

Micro-source control can be implemented with a limited number of measurements passed to a hardware block that creates the pulses for the gates of the power electronic devices inside the inverter. The hardware block consists of three distinct boards. The first board is responsible for conditioning the values of the measured quantities to voltage levels that allow the interface with the second board, the DSP. The DSP implements the control block, constantly comparing desired and measured quantities to generate the gate pulses. These pulses are then passed to the third board that amplifies the low voltage pulse signals coming out from the DSP to the voltage level needed to operate the actual power electronic devices.
The control blocks are encoded in Assembly language and compiled with Metrowerks CodeWarrior software. The executable code is then passed to the program memory of the DSP board.
The Digital Signal Processor (DSP) is a versatile hardware device that uploads an executable code with the information on how to manipulate inputs to generate outputs. The DSP is the ideal environment to code the control of the micro-source. The input of this board are the signals coming from the sensing devices and the outputs are the firing pulses that are sent to the gates ofthe power electronics inside the inverter.
The code is uploaded in the DSP memory through a connection with a computer, where the program is compiled to an executable format. It is possible to debug the code by executing it on the DSP and sending some of the internal variables to dedicated pins where it is possible to connect with oscilloscope probes. The sensing signals reach the board as analog signals and are converted into digital form to be processed inside the integrated circuit. It is also possible to debug the code by means of a special application called PC Master, a program written by Motorola to support the code builders for their DSP products.

The DSP is an integrated chip mounted on a board that handles several peripherals for interfacing with the external world. Figure 6.7 shows the block schematic highlighting these peripherals:
i) Analog to Digital Conversion (ADC) to import measurement from the outside world as a string of bits stored in a mapped data memory
ii) Crystal oscillator clock that generates the square wave pulses to operate the CPU inside the integrated circuit
iii) Parallel pins to allow the gate signals to be passed to the signal amplifying board
iv) Digital to Analog Conversion (DAC) that is very useful when debugging the control routine allowing output signals to be displayed on the oscilloscope
v) Parallel connection to connect to the computer card that sends the compiled code to be stored in the program memory of the integrated circuit
vi) Interrupt request controller to be able to set up priorities in hardware and software queues of tasks that are waiting to be processed by the DSP
vii) Timer controller that can be used to generate any triangle or square wave that may be needed
viii) Serial port to allow to exchange values from and to the board with the computer.

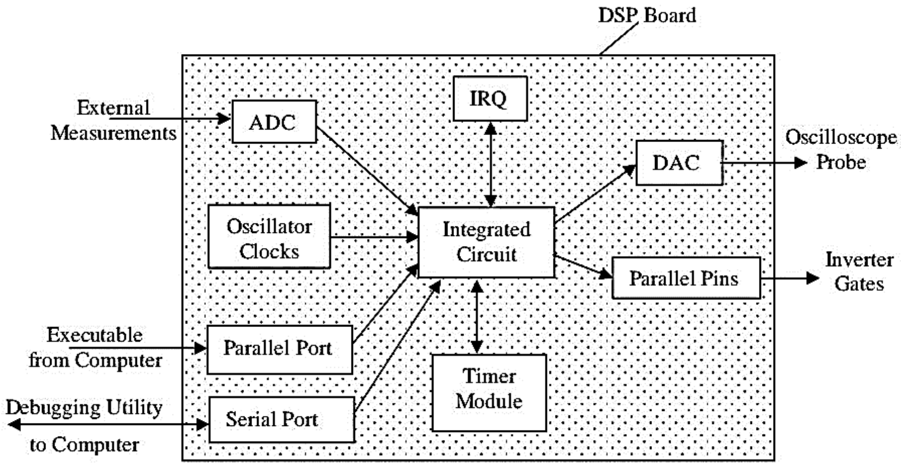


Figure 6.7 DSP Peripherals

The DSP is a Motorola DSP56F805EVM board. Internally, this board handles every signal as a 16 bit word, and uses the fractional integer Arithmetic Logic Unit (ALU), a mathematical processor that supports only two kind of operations between register values: sum and multiplication. The ALU can only represent and use numbers between -1 and 1, demanding extra care when coding the control blocks. Every variable will have to be rescaled so that its value will never exceed the absolute value of unity, not even during overshooting transients. This board works with an internal voltage level that can be ± 3.3 V or below and the internal oscillator can generate a frequencies up to 40MHz.

The basic concept in the DSP implementing architecture is that there is a main routine that is executed once every period of the switching frequency, 4kHz. This routine implements the control and the gate pulse generator. The Interrupt controller is the overseeing scheduling manager that decides when a program starts running according to a preassigned priority.

Figure6.8 shows the priority of the programs that are running inside the DSP.

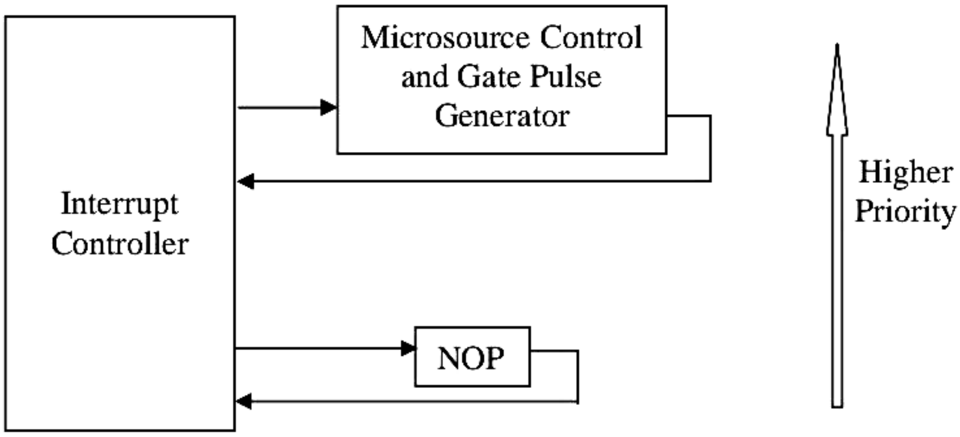


Figure 6.8 Interrupt Routine Queue

The lowest priority program is a No Operation (NOP) routine, substantially it is a main function with an empty body. The higher priority program returns control to the Interrupt controller after it is done. When the NOP routine ends, the Interrupt controller immediately starts it again: in this case the processor is kept in a stand-by, or busy-wait state. NOP has the lowest priority and can be interrupted at any time.

The Interrupt control will generate a request to run the control block operation and gate pulse generation routine four thousand times every second. In this way, gate pulses are generated at a frequency of 4 kHz: this is the frequency at which switching positions change. As soon as the gate pulses calculation is active the NOP is frozen in time and the processor stores the position inmemory from where it was interrupted. The

Interrupt control will generate a request to run the NOP routine from exactly the point where it was stopped as soon as the routine that implements the control and pulse generation has returned from execution.

6.4 Gate Pulse Implementation with Space Vector Modulation

This section describes the implementation based on the synthesization of a desired voltage vector. This operation results in a constant switching frequency and is typically referred in the literature as space vector modulation technique. The inverter is represented in Figure 6.8: it is the simplest configuration possible, with one single level of six power electronic devices connected to a DC ideal voltage source. The gates of the silicon devices can be controlled independently, but there are some constraints that limit the choices on the possible positions. For instance, two switches on the same leg (such as g1 and g4) can never be closed at the same time to avoid shorting the DC voltage source and one switch per leg must always be closed to provide a path for the AC current to flow.

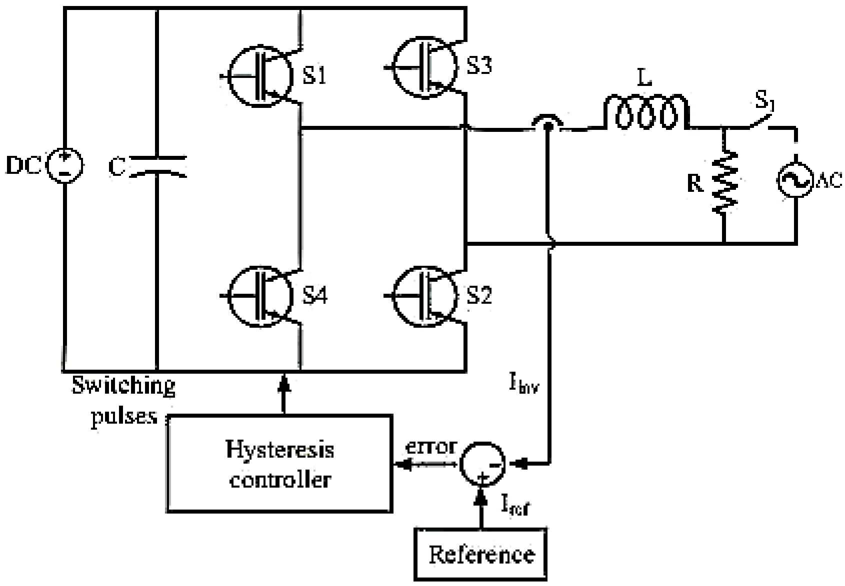


Figure 6.9 Inverter Switch Topology

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This section shows the implementation of the space vector modulation technique to synthesize the voltage at the terminals of the inverter.

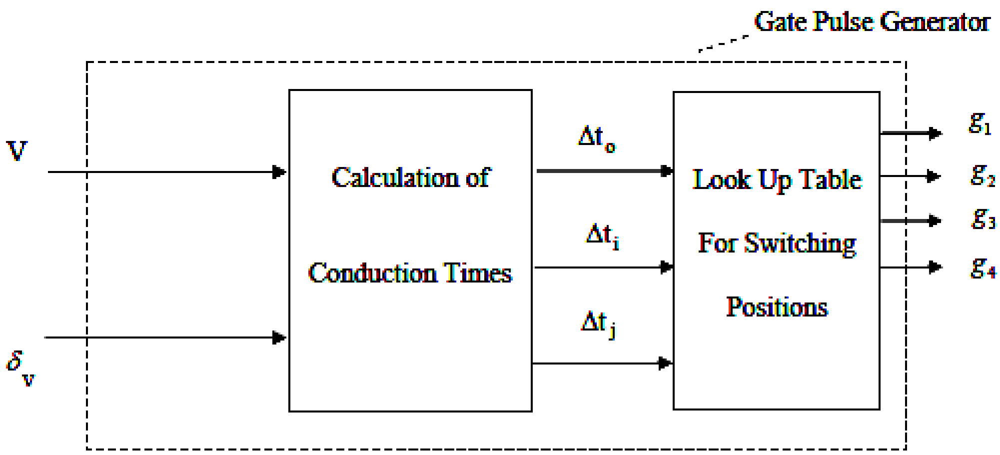


Figure 6.10 Voltage Control Blocks, Hardware with Space Vector Modulation.

Figure 6.10 summarizes the operations of the gate pulse generator as included in Figure 3.2. The gate pulse generator is composed of a cascade of two blocks. The first block is responsible for calculating the real and imaginary components of the voltage vector, starting from the magnitude and angle. From the Cartesian components of the voltages the conduction times for each of the tree voltages are calculated. Two of these voltages are active voltages, while the third one is the zero vector. The conduction times will determine how long each vector will need to be applied for ultimately synthesizing the requested voltage. The information on the conduction time is then passed to another block that reads on a look up table the switching sequence to apply at the gate. Terminals to achieve each of the three vectors. The DSP has an internal read-only routine that interfaces with the external pins that carry the gate signals. Once it is fed with the conduction times and the switching sequence, this routine takes care of sending the proper gate signals at the right time.

The space vector modulation technique applies the time averaging concept by synthesizing a voltage vector as a rapid succession of discrete voltages so that their average over a small interval of time matches the desired voltage vector magnitude and phase. The inputs are the seven operation points of a six step inverter.

6.5 SINGLE PHASE INVERTER OUTPUT VOLTAGE

The output voltage v_o is for a single phase half-bridge inverter and in Fig 6.12 for a single –phase full bridge inverter. These output or load voltage wave from do not depend on the nature of load .Voltage wave shapes of Fig. 6.12 can be resolved into Fourier series as under.

For single phase half bridge inverter,

$v_0=\sum_{n=1,3,5...}^{\infty} \frac{2V}{n\pi} \sin n\omega t$ volts (1)

And for single phase full –bridge inverter,

$v_0=\sum_{n=1,3,5....}^{\infty} \frac{4V}{n\pi} \sin n\omega t$ volts (2)

Here n is the order of harmonic and $\omega = 2\pi f$ is the frequency of output voltage in rad/s.

R_{ms} value of fundamental component V_{01} can be obtained from Equ(2) by putting n=1.

$V_{01}=\frac{2Vs}{\sqrt{2}\pi} = \frac{\sqrt{2}}{\pi} .V_S = 0.45\ V_S$ (3)

For single phase half bridge inverter

For a single phase full ridge inverter, from Eq. (3), we get

$$V_{01}=\frac{4Vs}{\sqrt{2}\pi} = 0.9V_s \quad (4)$$

The load current i_0 can , therefore , be expressed as

$$i_0 =\sum_{n=1,3,5...}^{\infty} \frac{4Vs}{n.\pi.Zn} \sin(n\omega t - \Phi n)\text{Amps} \quad (5)$$

Where,Z_n = load impedance at frequency n.f

$$=[R^2+(n\omega L-\frac{1}{n\omega C})^2]^{1/2} \quad (6)$$

And phase angle Φ_n is given by

$$\Phi n = \tan^{-1} \frac{\left[n\omega L-\frac{1}{n\omega C}\right]}{R} \text{ rad} \quad (7)$$

The output,or load ,current at the instant of communication is obtained from Eq. (5) by putting ωt=π, . Its value is

I0 = I0 at ωt = π Rad

In thyristor based inverters, if I0 > 0, forced commutation is essential. If I0<0, no forced commutation is required and load commutation, as described for RLC underdamped load in can be relied upon.

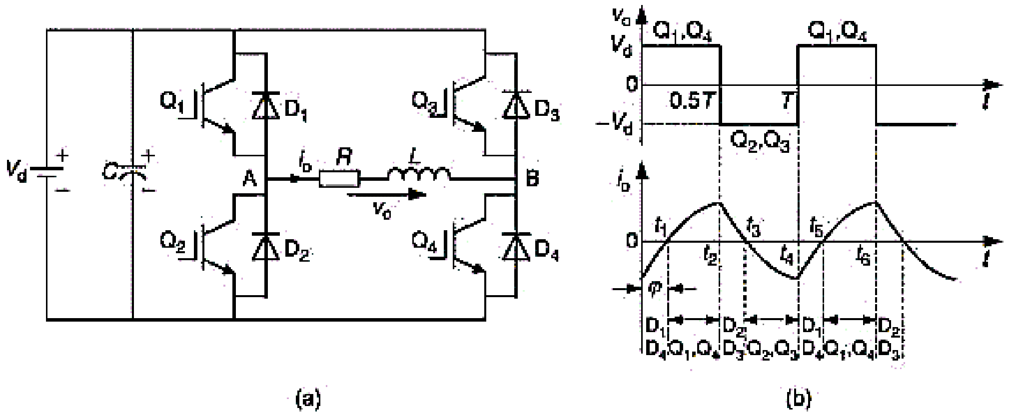


Fig 6.11 Single Phase Full Inverter

Chapter 7. Micro-grid Tests

There are two fundamental different circuits where the test is performed depending on the relative locations of the two units. These two circuits are the series and the parallel configurations. Both configurations are achieved with the same hardware equipment, appropriately rearranged. Each of the five loads may be included or not in every particular experiment. To avoid confusion, every experiment will explicitly show the full circuit diagram used.

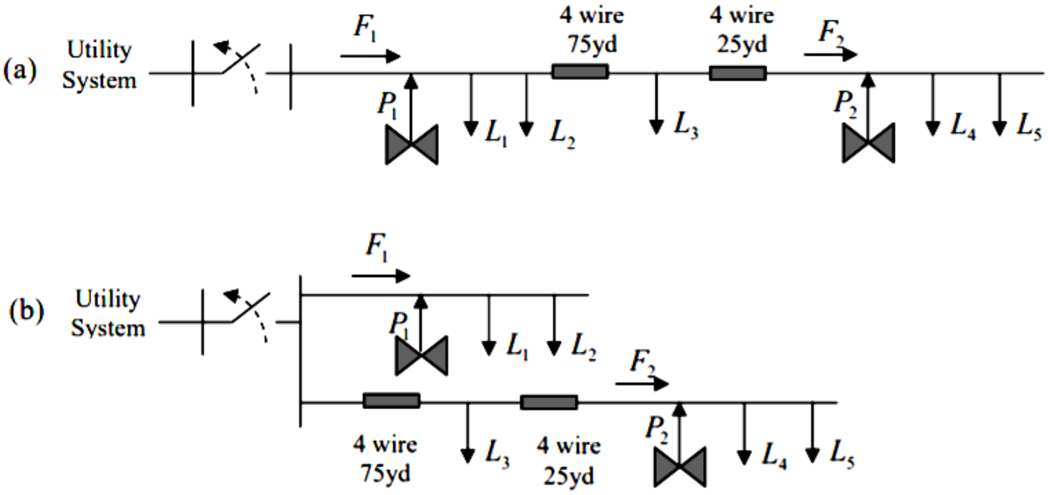


Figure 7.1 Series (a) and Parallel (b) Circuit Configurations.

Each of the two sources can adopt either unit power (P) control or feeder flow (F) control. There are a total of four possible control combinations for the two units: PP, FF, PF, and FP. The circuit with the series configuration will test all these cases, while the parallel configuration will only test FF and FP. This is no loss of generality. The case PF is symmetric to FP and adds no useful insight. The case with PP is non-dependent on the location of the sources and the loads and will give the same exact results already obtained for the series configuration. In conclusion, these are the six groups of tests:

Series configuration
Unit 1 controls P, Unit 2 controls P
Unit 1 controls F, Unit 2 controls F
Unit 1 controls F, Unit 2 controls P
Unit 1 controls P, Unit 2 controls F

Parallel Configuration
Unit 1 controls F, Unit 2 controls F
Unit 1 controls F, Unit 2 controls P

Each test groups is configured as follows:

Import from grid:
− Unit 1 at 50% of its ratings, Unit 2 at 50% of its ratings – transfer to island
− Unit 1 at 10%, Unit 2 at 90% – transfer to island (i), usually Unit 2 reaches maximum output
− From this (i) island operating point, remove a load, this backs off the unit from maximum output
− Again, from (i) reduce setpoint of Unit 2, this backs off the unit from maximum output
− Unit 1 at 90%, Unit 2 at 10% – transfer to island, usually Unit 1 reaches maximum output

Export to grid:

− Unit 1 at 50% of its ratings, Unit 2 at 50% of its ratings – transfer to island
− Unit 1 at 10%, Unit 2 at 90% – transfer to island, usually Unit 1 reaches zero output
− Unit 1 at 90%, Unit 2 at 10% – transfer to island (e), usually Unit 2 reaches zero output
− From this (e) island operating point, insert a load, this backs off the unit from zero output
− Again, from (e) increase setpoint of Unit 2, this backs off the unit from zero output

Every group has five experiments while importing and five while exporting. When at least one of the units regulate feeder flow (all but the very first test group, series PP), then there are two added experiments when importing from the grid:

− Unit 1 at 10%, Unit 2 at 90% - the unit regulating F is switched to a wrong set point that will determine either max or zero power output.
− Unit 1 at 90%, Unit 2 at 10% - the same unit regulating F is switched to a wrong setpoint that will determine max (if before it was zero) or zero (if before it was max) output. If both units are regulating F, then one unit is arbitrarily picked up to test the wrong setpoint feature. In summary, in each test group the experiments will be carried in the order shown in Table 7.1.

mport Export Group Test	Unit 1	Unit 2	Activities
Import Power From the Grid	50%	50%	Islanding
	10%	90%	Wrong Setpoint at One of the Units Controlling F (*)
	10%	90%	Islanding, to Operating Point (i)
	10%	90%	From Island, (i), Remove a Load
	10%	90%	om Island, (i), Reduce Setpoint of Unit at Maximum Power
	90%	90%	Wrong Setpoint at One of the Units Controlling F (*)
	90%	10%	Islanding
Export Power the Grid	50%	50%	Islanding
	90%	10%	Islanding, to Operating Point (e)
	90%	10%	From Island, (e), Insert a load
	90%	10%	From Island, (e), Increase Setpoint of Unit at Zero Power

Table 7.1 Summary of Experiments for Each Group of Tests.

7.1 Choice of Setpoints for the Series Configuration

There are four possible control choices in the series configuration:
i) Unit 1 controlling P, unit 2 controlling P
ii) Unit 1 controlling F, unit 2 controlling F
iii) Unit 1 controlling F, unit 2 controlling P
iv) Unit 1 controlling P, unit 2 controlling F

For each choice (see Table 7.1), there is an experiment when unit 1 is at 10% of its output power, while unit 2 is at 90% of its output power and the system transfers to island. Figure 7.2 shows the series configuration with all the loads, highlighting the fact that the only event taking place is the transition to island. The system is importing from the grid.

Maximum power corresponds to 0.8 pu in the source because of the DSP capability of handling only quantities that are in the –1, +1 interval. To leave room for overshoot, the value of P_max has been chosen to correspond to 0.8.

After the system transfers to island, unit 2 will be sitting at 100% of power (0.8 pu), while unit 1 will be sitting at 50% (since overall loading is 150%) of power (0.4 pu), in all of the four configurations. What really changes, is how they get there. figures show simulation results when P1 and P2 are controlled: both units.

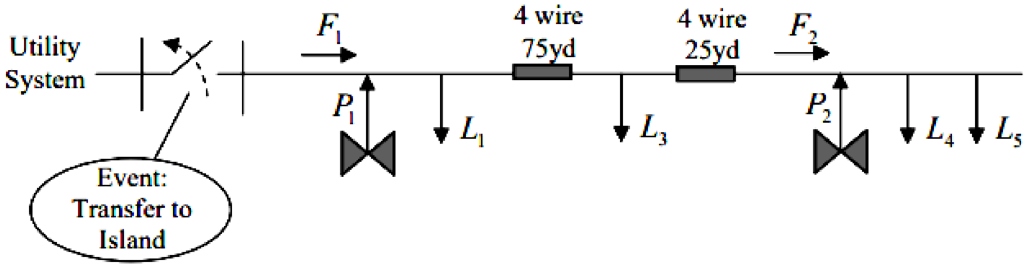


Figure 7.2 Series Configuration Diagram.

Ramp up their power output (P) at the unison. Overshoot at unit 2 is near 0.89 pu (110%).
Figure 7.5 and Figure 7.6 show that when F1 and F2 are controlled, then as P2 ramps, P1 actually, backs off, after rising a little. This means that the resulting overshoot on P2 is about 1.04 pu (130%). This implies tripping of the units, since nearly above 0.9 pu is the threshold value for power, and besides, a value larger than 1.0 is also beyond the overflow value of the bit representation inside the DSP. Figures show that when F1 and P2 are controlled, then an unacceptable overshoot also occurs. Figures show that when P1 and F2 are controlled, the overshoot is manageable again.
This implies that the choice of control configurations bears a consequence on the ratings of the inverters that need to be available, or the gains may need to be readjusted (when possible) to improve response. For this lab case, the above considerations implied that the test for 10% and 90% could not be carried under those cases that generated very large overshoots. To avoid tripping of the units, the setpoint corresponding to loading of respectively 30% and 70% for unit 1 and 2 have been chosen only for the cases with larger overshoot. This problem was only encountered during 10%, 90% setup, never during 90%, 10%, hence this latter configuration has never been changed. Also, these problems are only encountered at high Load levels (importing to grid). Therefore, during exporting no changes were necessary to 10%, 90% setup. Finally, no problems were encountered during the parallel configuration, so no changes had to be made there as well.

ol of Unit 1	ol of Unit 2	hoot of Unit 2
P	P	0.89 pu ~110%
F	F	1.04pu~130%
F	P	1.04pu~130%
P	F	0.89pu~110%

Table 7.2 Series Configuration Control Combinations. Importing from Grid.

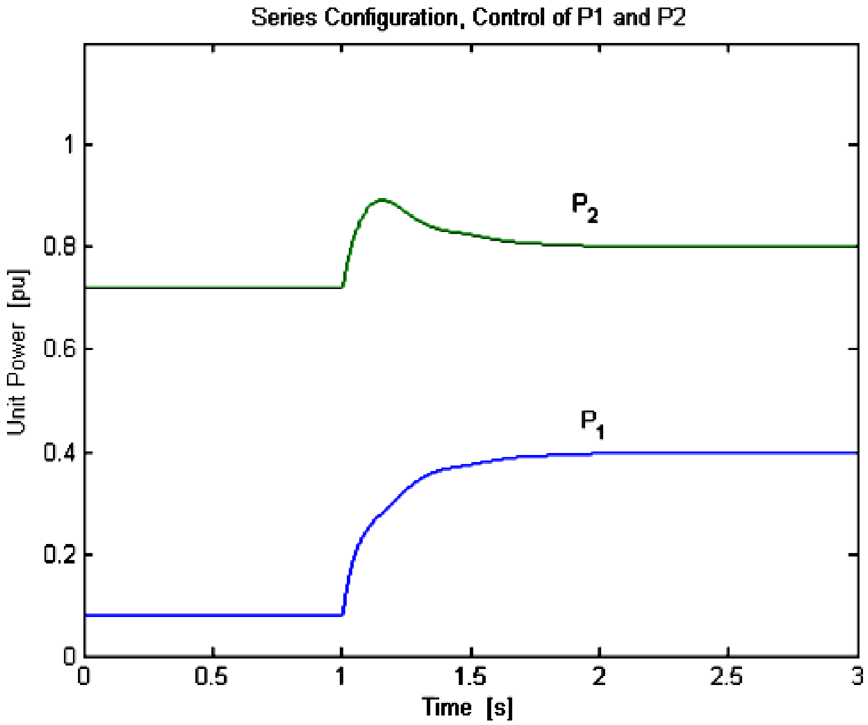


Figure 7.3 Control of P1 and P2, Unit Power.

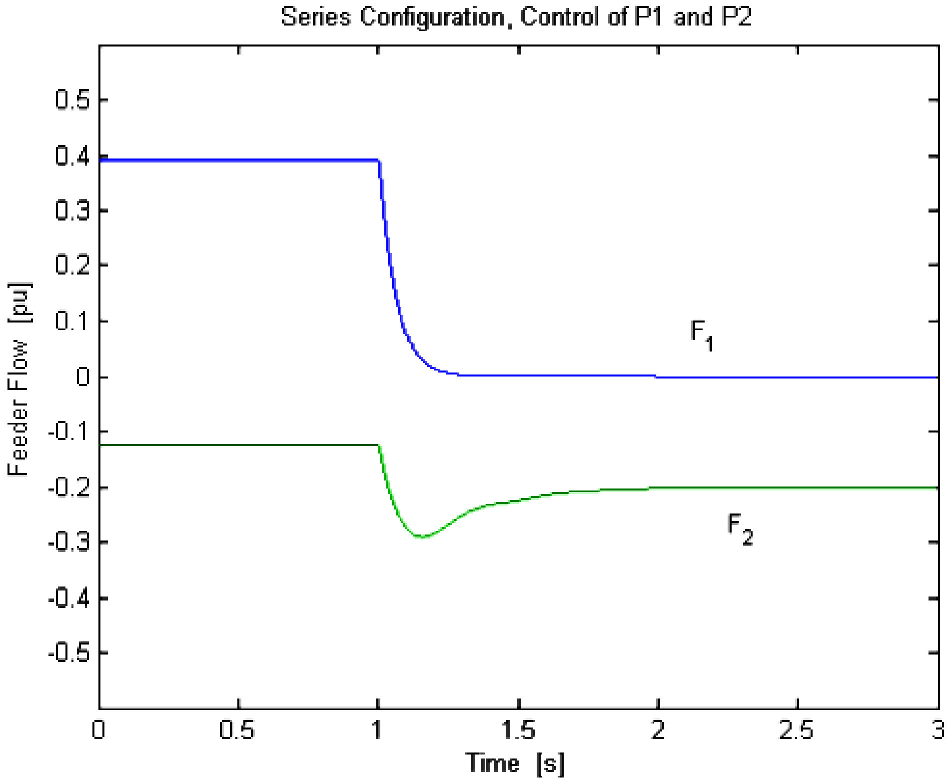


Figure 7.4 Control of P1 and P2, Feeder Flow.

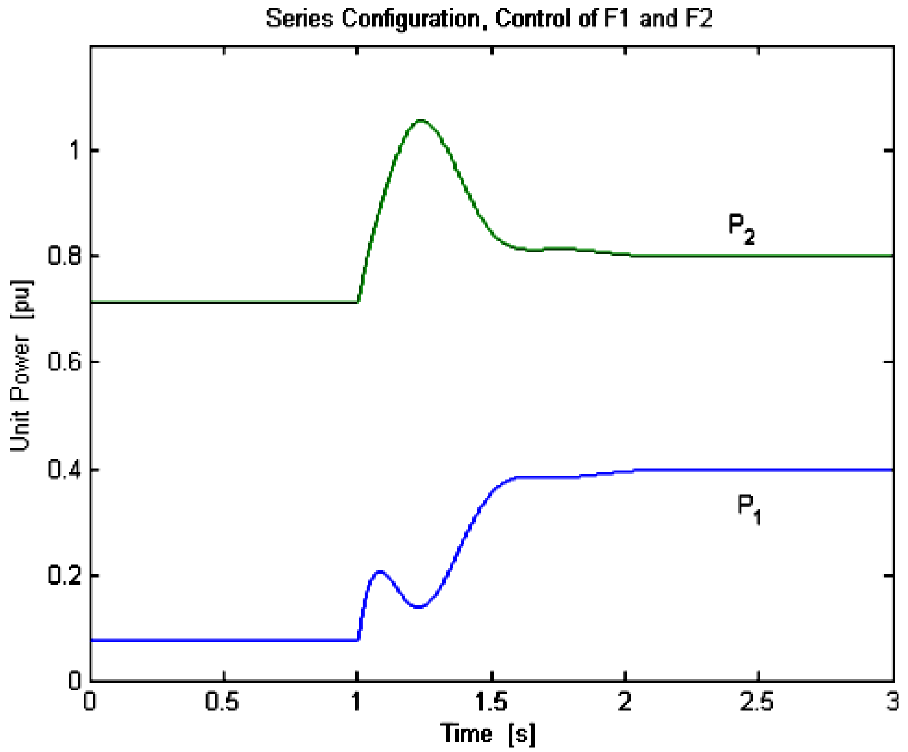


Figure 7.5 Control of F1 and F2, Unit Power.

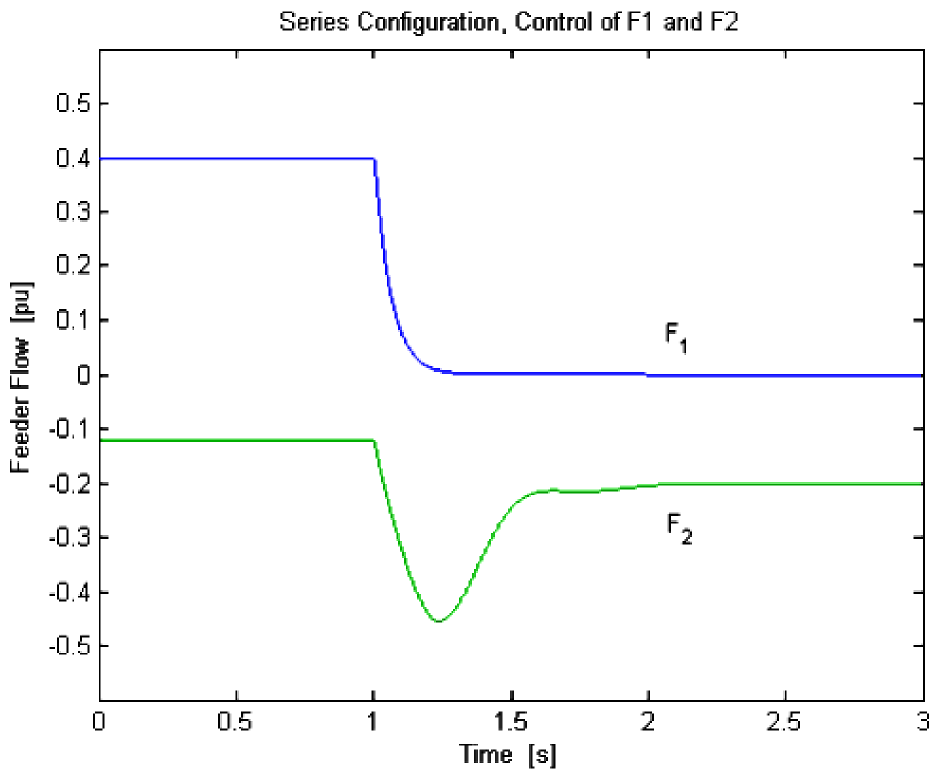


Figure 7.6 Control of F1 and F2, Feeder Flow.

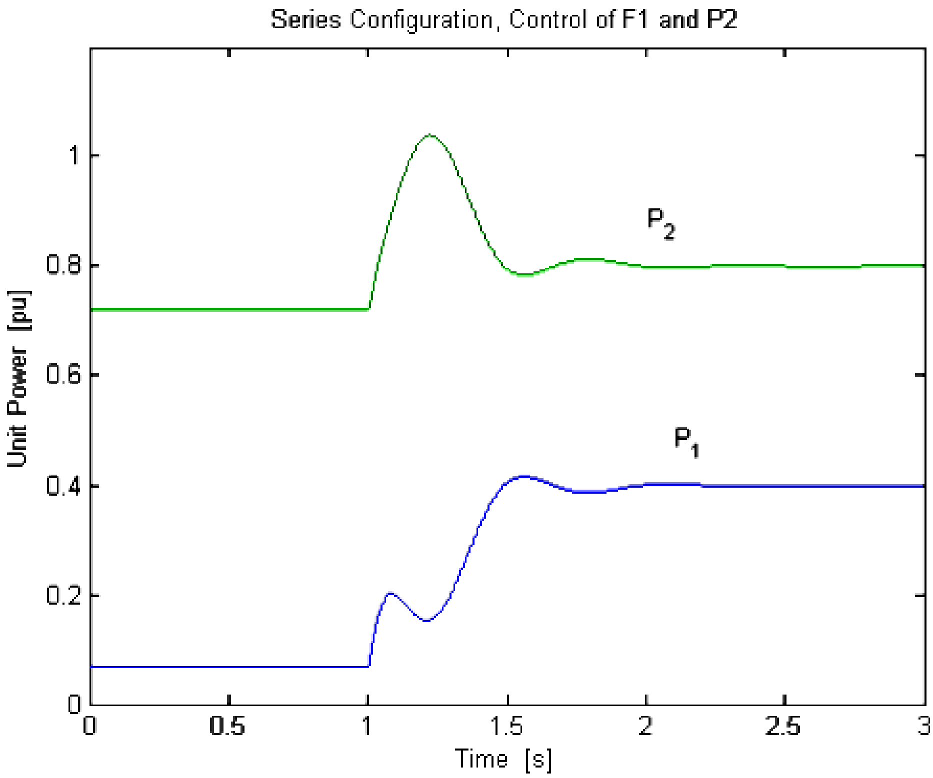


Figure 7.7 Control of F1 and P2, Unit Power.

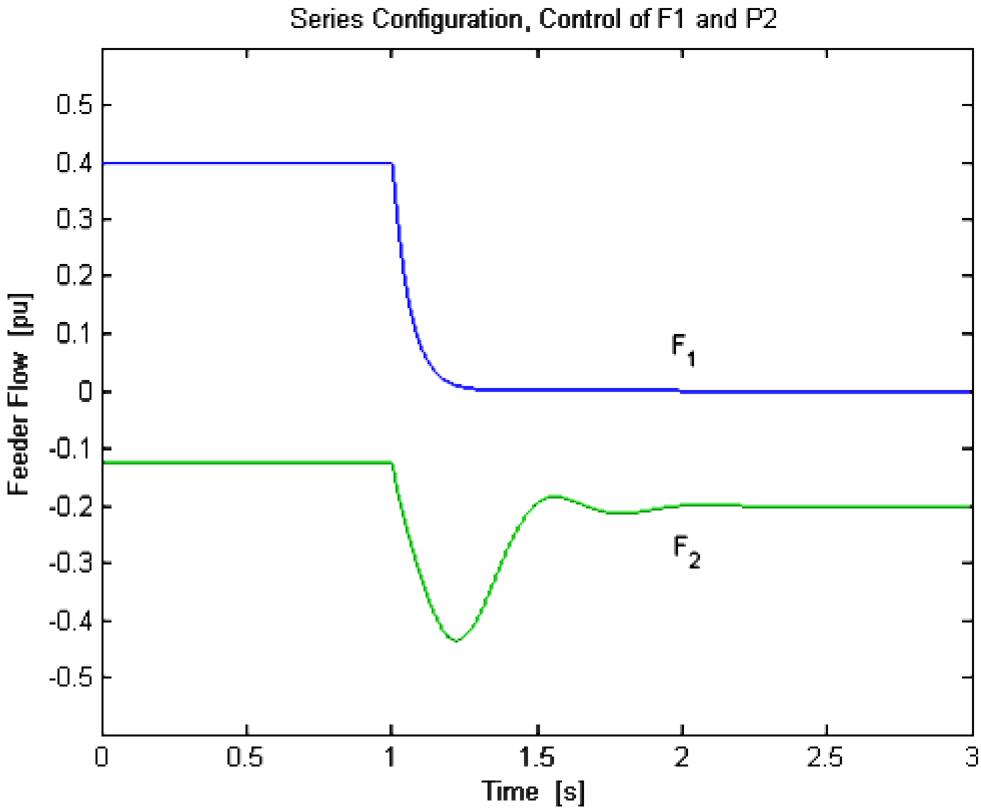


Figure 7.8 Control of F1 and P2, Feeder Flow.

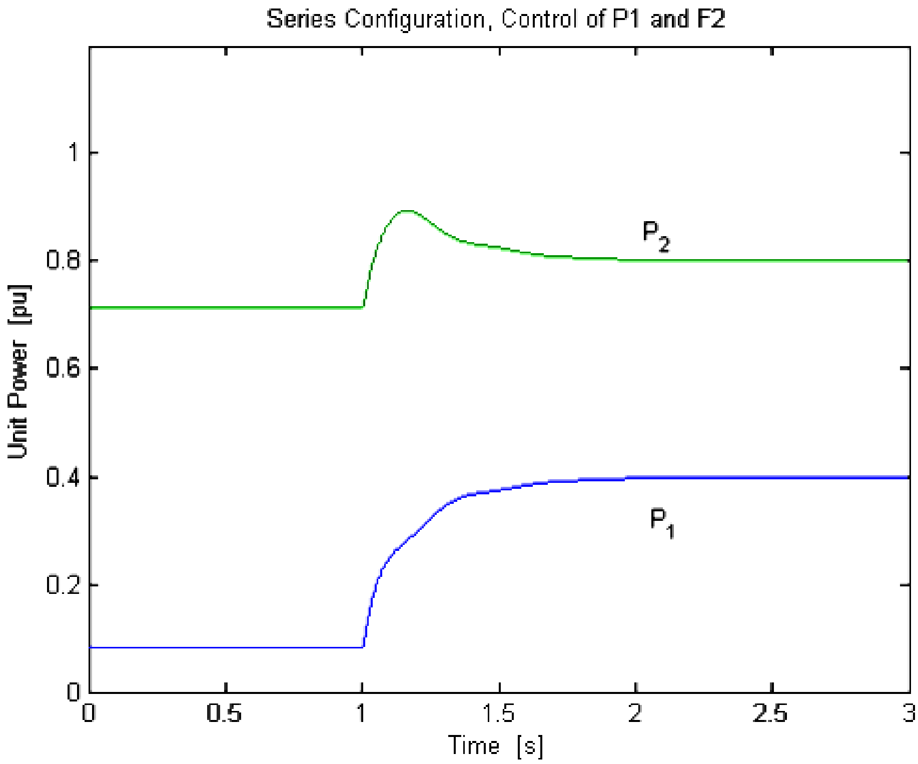


Figure 7.9 Control of P1 and F2, Unit Power.

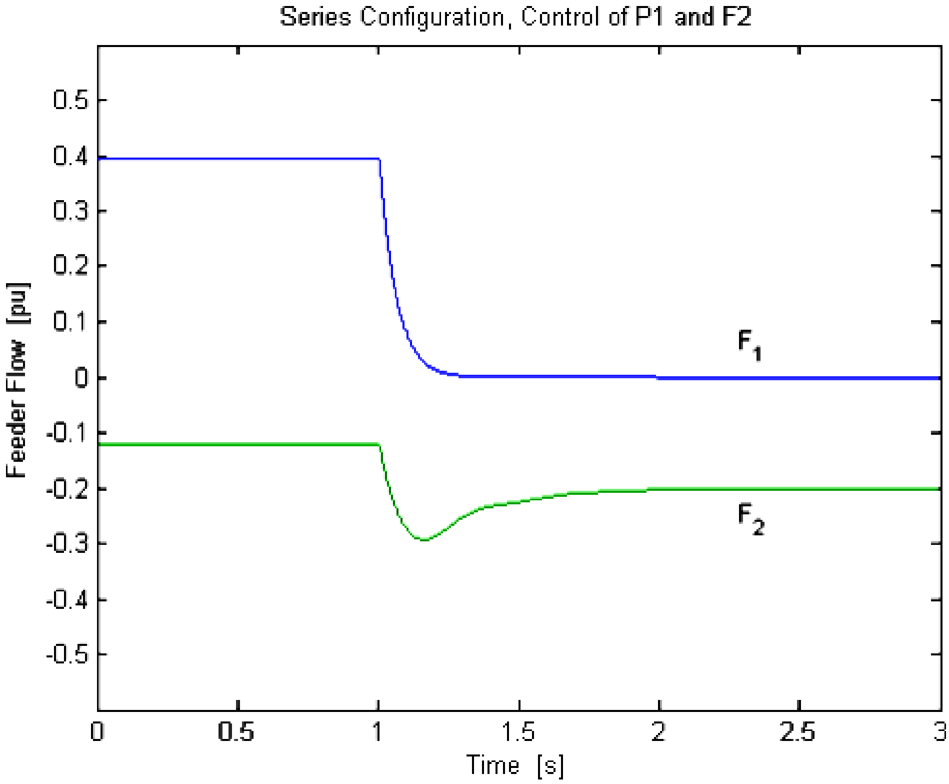


Figure 7.10 Control of P1 and F2, Feeder Flow

7.2 Grid Fluctuations:

This paper discusses the issue of modelling a micro-grid renewable energy system for a selected micro-grid which is connected to the public distribution system. The subject of the study is a hybrid of solar panels, wind turbine and generalized energy storage. Presented model uses statistical indices of solar irradiation and wind speed data to simulate power flow in the system. The voltage variations character has been analyzed considering possible modes wind generator reactive power control. Optimal reactive power control requirements are shown in consideration of voltage variation mitigation. The objective of the work is to create a tool for feasibility assessment of the energy hybrid system component operation and appropriate control strategy to provide its efficiency.

Figure 7.11 Actual Grid Frequency Samples.

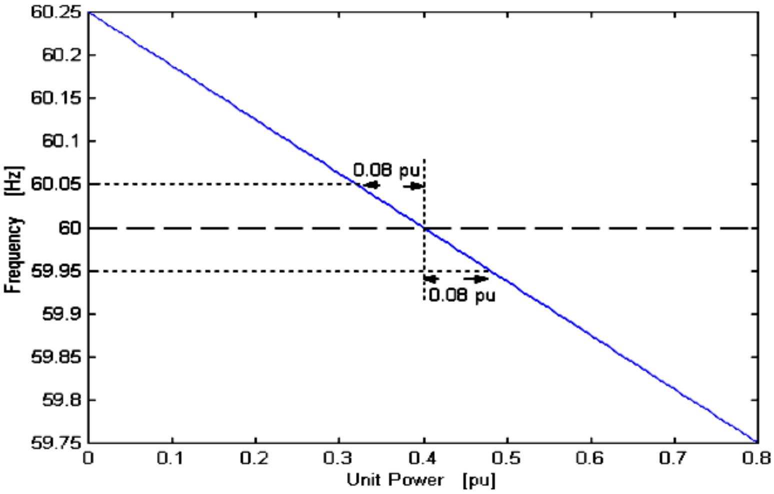


Figure 7.12 Impact on the Power Set-point of a Frequency Deviation of 0.05 Hz.

The voltage also fluctuates of nearly 0.6 V in either direction. The setpoint of 208V is to be intended "on the average". The frequency and voltage fluctuations combined determine conditions of non-repeatability on any of the following grid connected waveforms. Different values of frequency will determine different power injections (and the following plots are recording the actual grid frequency), while different voltages at the point of connection will determine different reactive power injections. Although none of these differences are outstanding, the fact that they exist must not be forgotten when trying to reproduce "exactly" these same results. The load active power demand is 0.3 pu for every load. But this number does not include the losses in the network. The same load, when fed from a neighboring source has a demand of 0.3 pu, but when it is fed from a remote source (or the grid) may demand as much as 0.31 or bigger, usually never above 0.32 pu. Three remote loads may show up as 0.95 pu, rather than 0.9 pu.

7.3 Series Configuration

This configuration represents the classic radial distributed system: there is a single feeder with two sources in series and loads scattered: some of them are near each of the two sources, a load in an intermediate location between the sources. The overall length of cable between the sources is 100yds.

Figure 7.13 shows the general layout of the system with the series configuration.

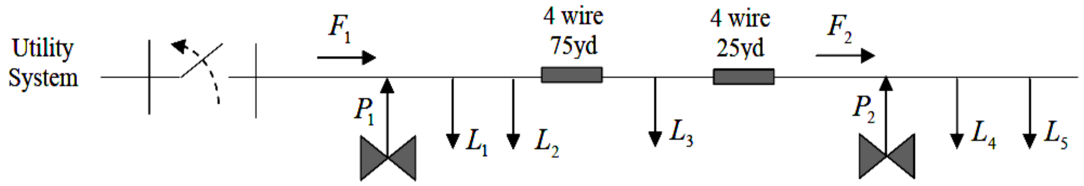
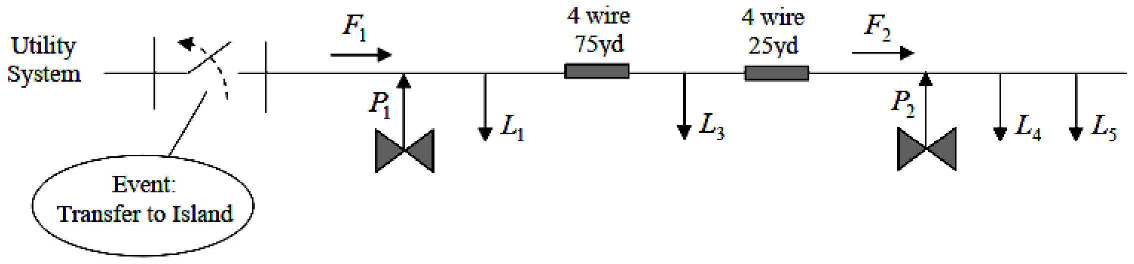


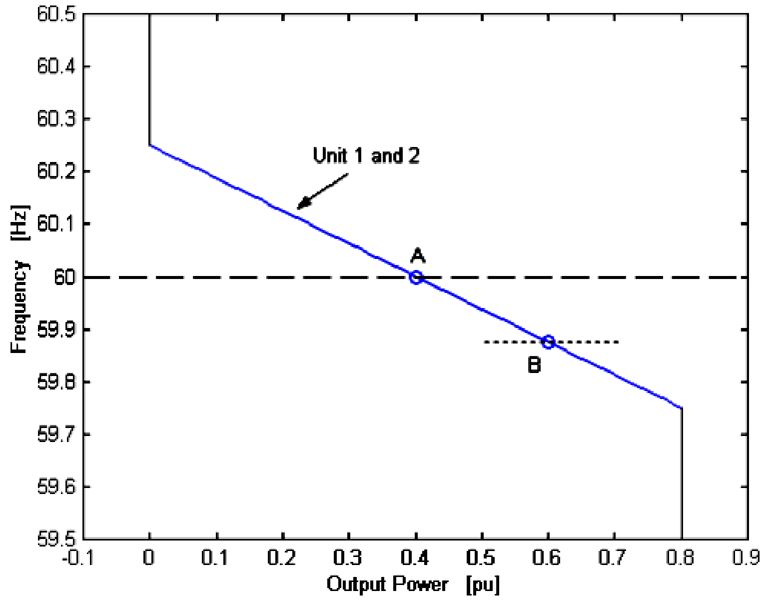
Figure 7.13 Units in Series Configuration.

7.3.1 Unit 1 (P), Unit 2 (P), Import from Grid

Import from Grid, Set points are 50% and 50% of Unit Rating, Islanding



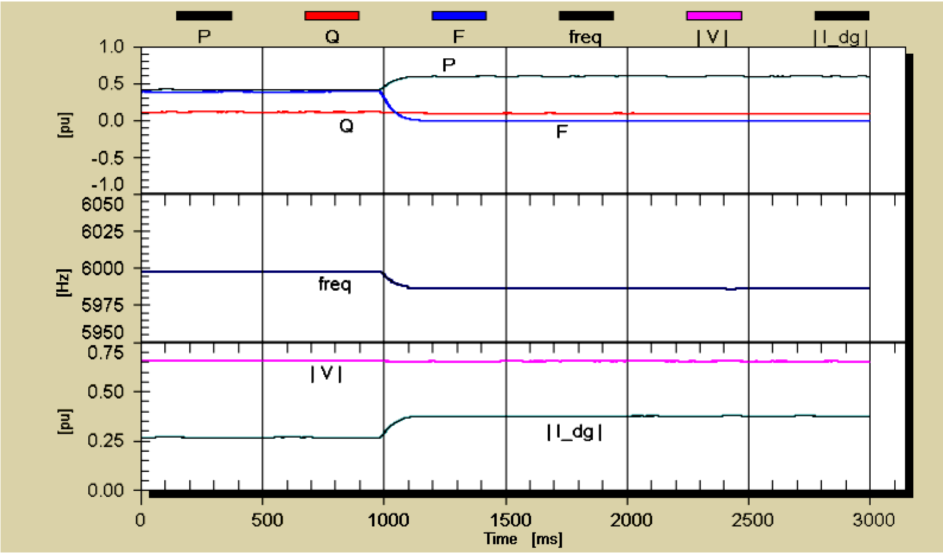
Event shows Unit 1 and 2 meeting the load request after islanding.



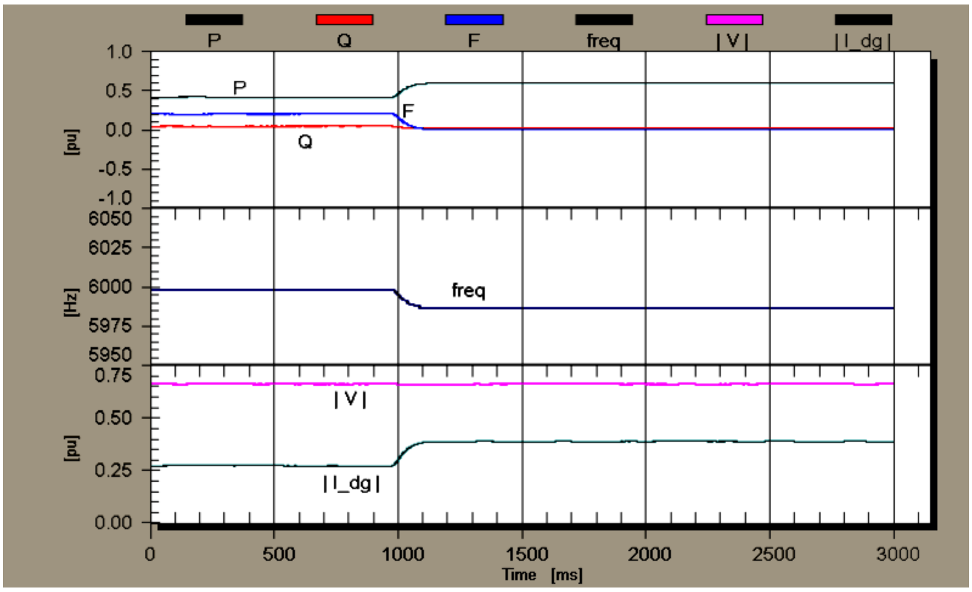
Series Configuration, Control of P1 and P2

	A-GRID	B-ISLAND
P1[p u]	0.4=50%	0.6=75%
P2[p u]	0.4=50%	0.6=75%
Frequency [Hz]	60.00	59.875
Load level [p u]	1.2=150%	1.2=150%
Grid flow[pu]	0.4=50%	0.0%

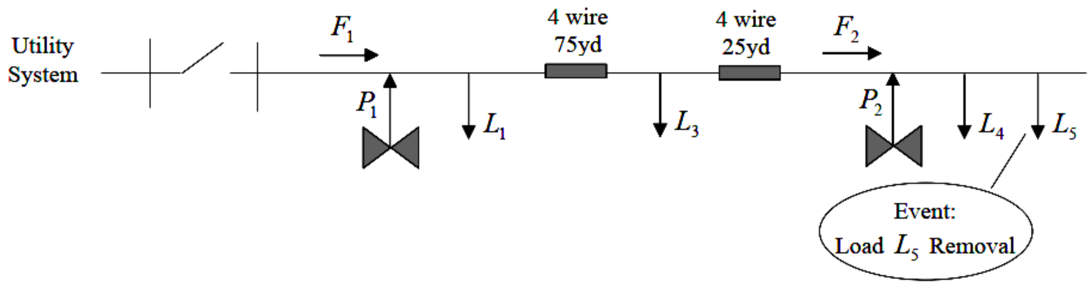
The inverter has to be running at a higher voltage than the grid so it can push power out. The problem is every solar installation pushing power into the system lifts the network voltage just a little. Overvoltage problems are a big contributor to consumers. They are not getting value for money out of the grid connected solar power system. The network is also working with other providers to produce a standard set of solar inverter setting. So, at some point solar installer have a standard configuration profile.



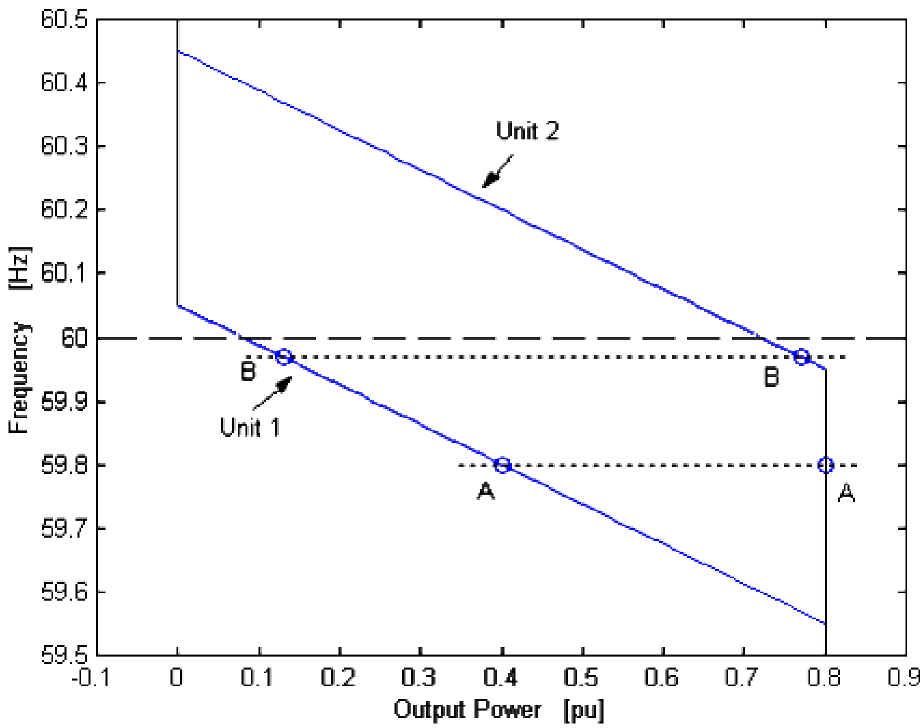
Unit 1: P, Q, F, Frequency, Voltage Magnitude, Current Magnitude, 500ms/div.



Unit 2: P, Q, F, Frequency, Voltage Magnitude, Current Magnitude, 500ms/div.

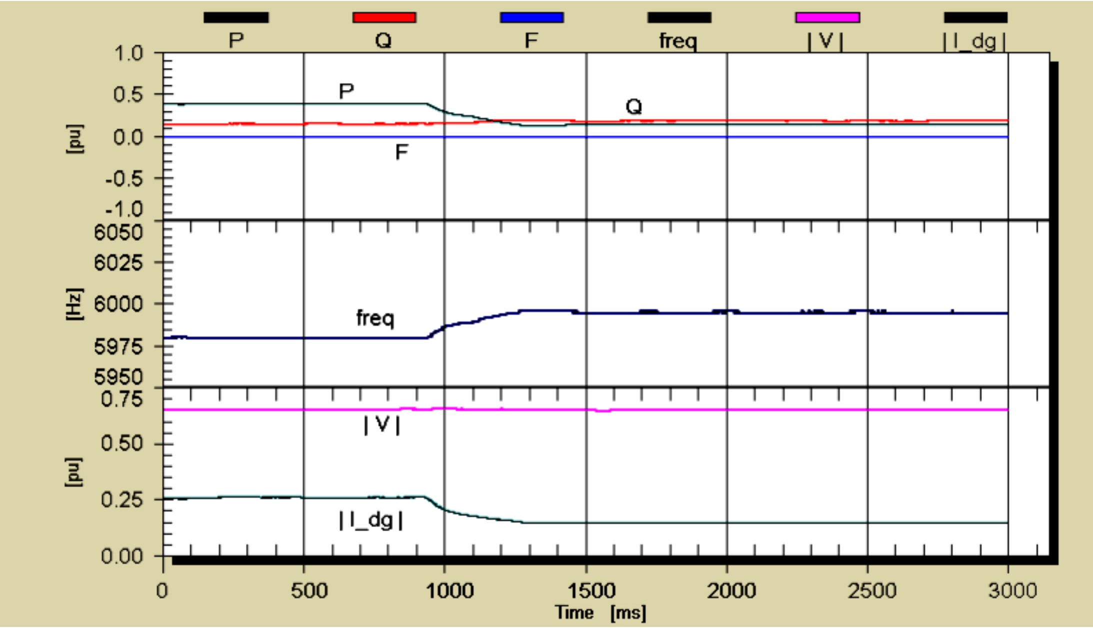


Event shows Unit 2 backing off from maximum output power after a load is removed.

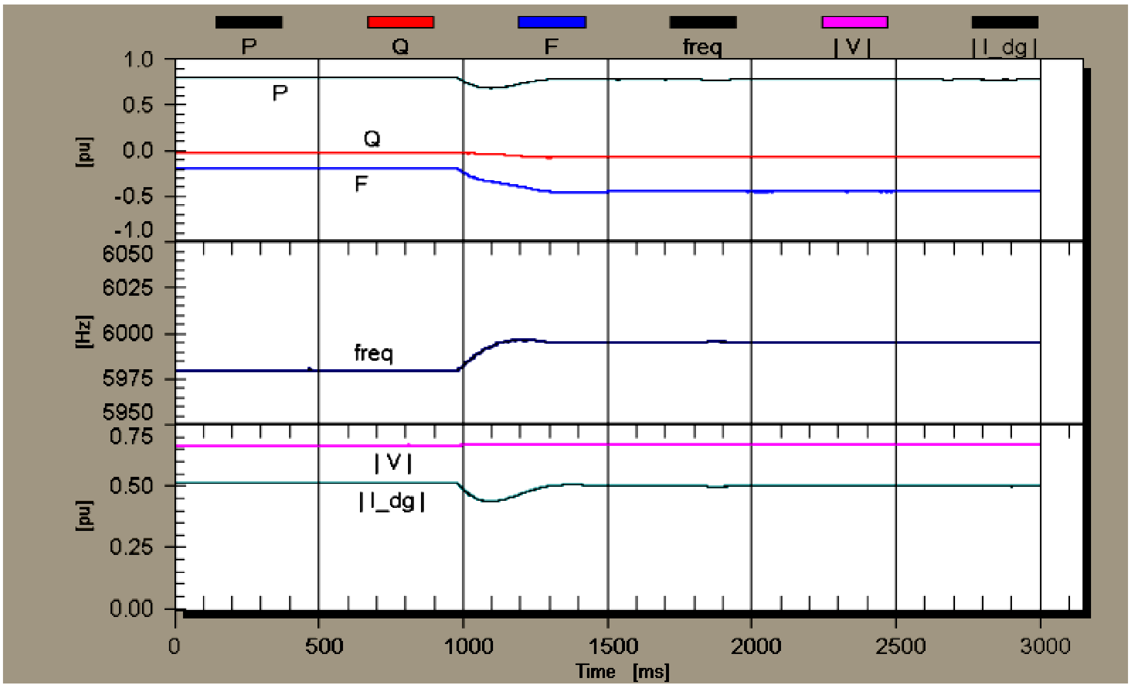


Series Configuration, Control of P1 and P2

	A-L5 ON	B-L5 OFF
P1[pu]	0.4=50%	0.13=16%
P2[pu]	0.8=100%	0.77=96%
Frequency[hz]	59.8	59.968
Load level[pu]	1.2=150%	0.9=112%
Grid flow[pu]	0.0	0.0



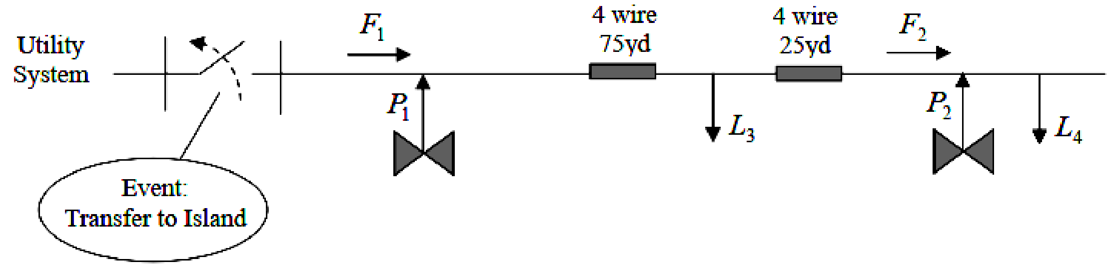
Unit 1: P, Q, F, Frequency, Voltage Magnitude, Current Magnitude, 500ms/div.



Unit 2: P, Q, F, Frequency, Voltage Magnitude, Current Magnitude, 500ms/div.

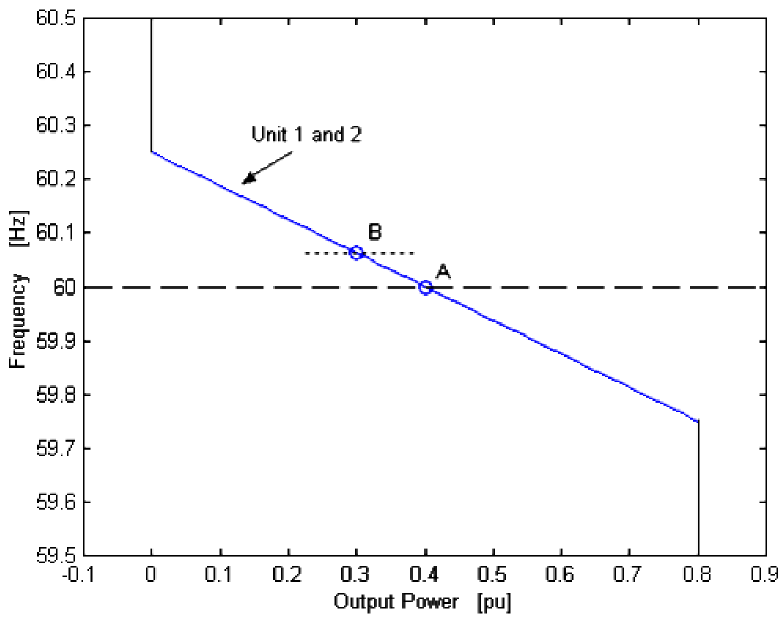
7.3.2 Unit 1 (P), Unit 2 (P), Export to Grid

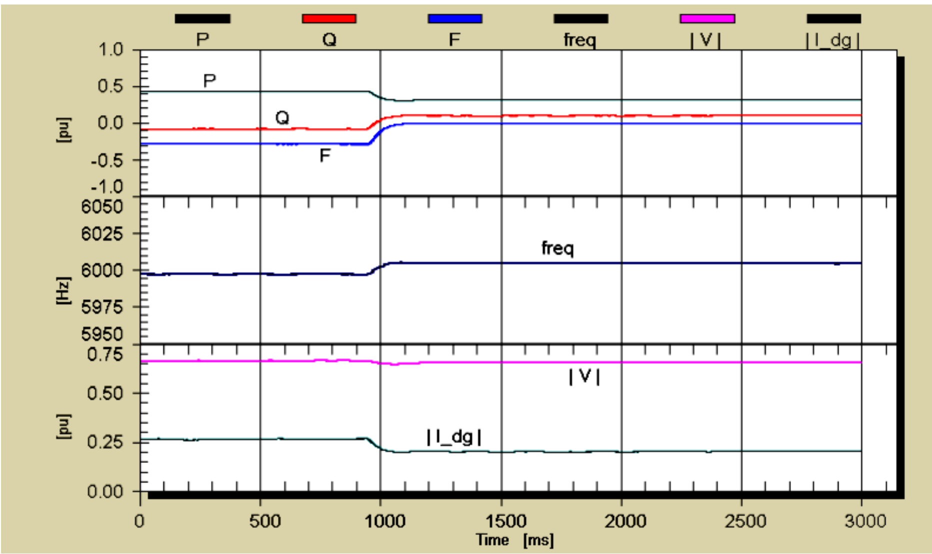
Export to Grid, Setpoints are 50% and 50% of Unit Rating, Islanding



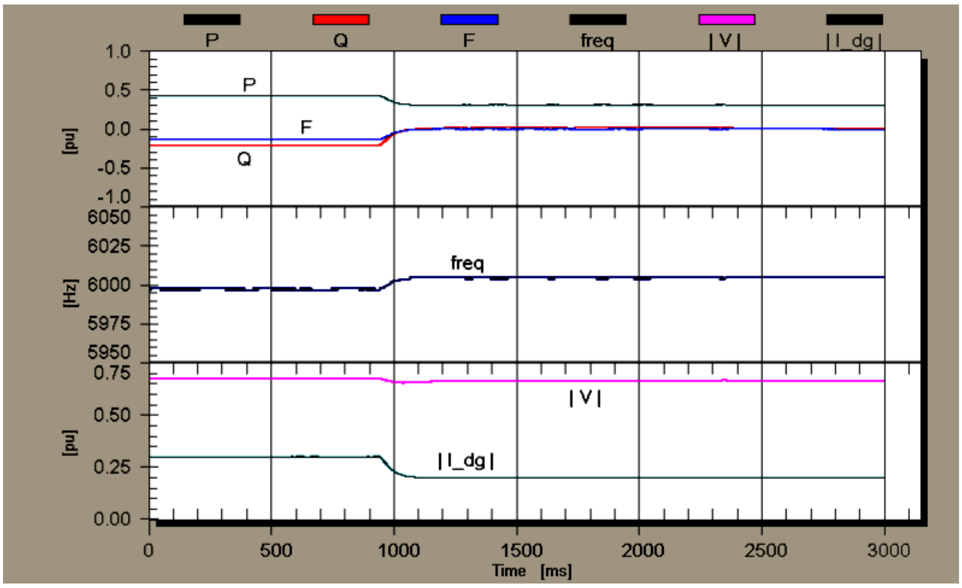
Event shows Unit 1 and 2 meeting the load request after islanding.

	A – Grid	B – Island
P_1 [pu]	0.4 = 50%	0.3 = 37%
P_2 [pu]	0.4 = 50%	0.3 = 37%
Frequency [Hz]	60.00	60.062
Load Level [pu]	0.6 = 75%	0.6 = 75%
Grid Flow [pu]	-0.2 = -25%	0.0





Unit 1: P, Q, F, Frequency, Voltage Magnitude, Current Magnitude, 500ms/div.



Unit 2: P, Q, F, Frequency, Voltage Magnitude, Current Magnitude, 500ms/div.

Chapter 8. DESIGN OF MICRO-GRID

In that projects we are Design Micro-Grid in Different Software:

8.1 Design Software: -

8.1.1 E-plan P8 Electrical: Electrical Engineering Design Software

EPLAN Electric P8 is an electrical engineering design software program that offers unlimited possibilities for project planning, documentation, and management of automation projects. The automatic production of detailed reports based on wiring diagrams is an integral part of a comprehensive documentation system and provides subsequent phases of the project, such as production, assembly, commissioning, and service with the data required. Engineering data from other project areas, such as fluid and pneumatic engineering, can be exchanged via interfaces within our CAE software. This therefore guarantees consistency and integration throughout the entire product development process.

Benefits of EPLAN over traditional CAD packages EPLAN develop solutions for greater efficiency, putting integration and automation at everything it does by providing end-users with all the core functions required of an electrical design package, and easily-integrated additional tools that can be adapted for industry-specific processes; from fluid and pneumatic engineering to enclosure design.

As a result, EPLAN offers many advantages over traditional CAD packages. The main benefits include:

- ✓The ability to automatically connect, mend or break lines
- ✓Instantaneous device tagging and wire numbering
- ✓Provision of point to point wire lists
- ✓Automatic creation of reports and BOM's

Provisions that go far beyond providing the software itself, for example, by offering our Data Portal which delivers online device data on over 500,000 components from leading manufacturers such as ABB, B&R, Mitsubishi Electric, Omron, Phoenix Contact and Schneider Electric.

8.1.2 Auto-Cad (Electrical): CAD, or computer-aided design and drafting (CADD), is technology for design and technical documentation, which replaces manual drafting with an automated process.

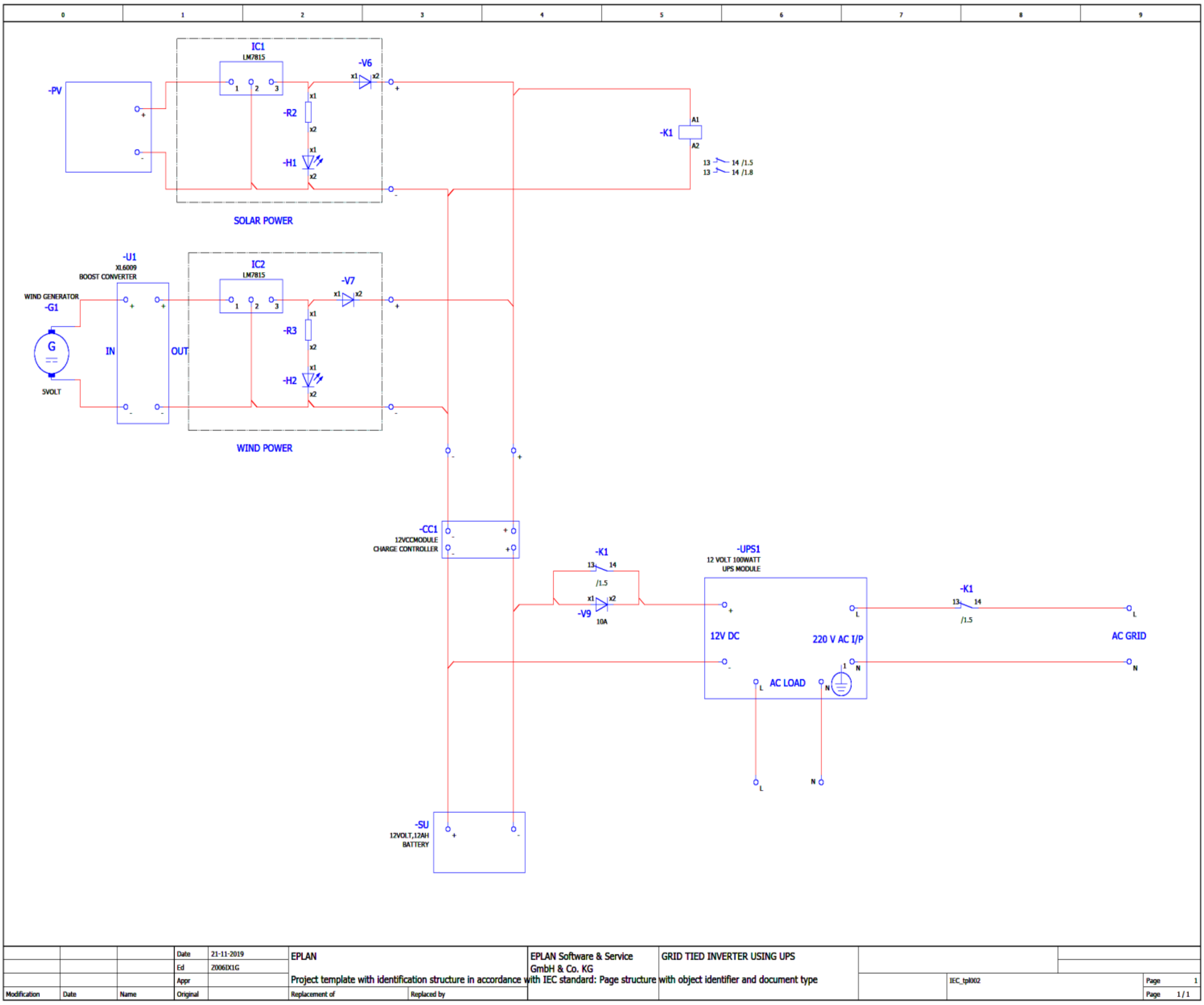
If you are a designer, drafter, architect or engineer, you have probably used 2D or 3D CAD programs such as AutoCAD or AutoCAD LT software. These widely used software programs can help you draft construction documentation, explore design ideas, visualise concepts through photorealistic renderings and simulate how a design performs in the real world.

AutoCAD is a commercial computer-aided design (CAD) and drafting software application. Developed and marketed by Autodesk, AutoCAD was first released in December 1982 as a desktop app running on microcomputers with internal graphics controllers. Before AutoCAD was introduced, most commercial CAD programs ran on mainframe computers or minicomputers, with each CAD operator (user) working at a separate graphics terminal. Since 2010, AutoCAD was released as a mobile- and web app as well, marketed as AutoCAD 360.

8.2 Drawing of Micro-Grid System: -

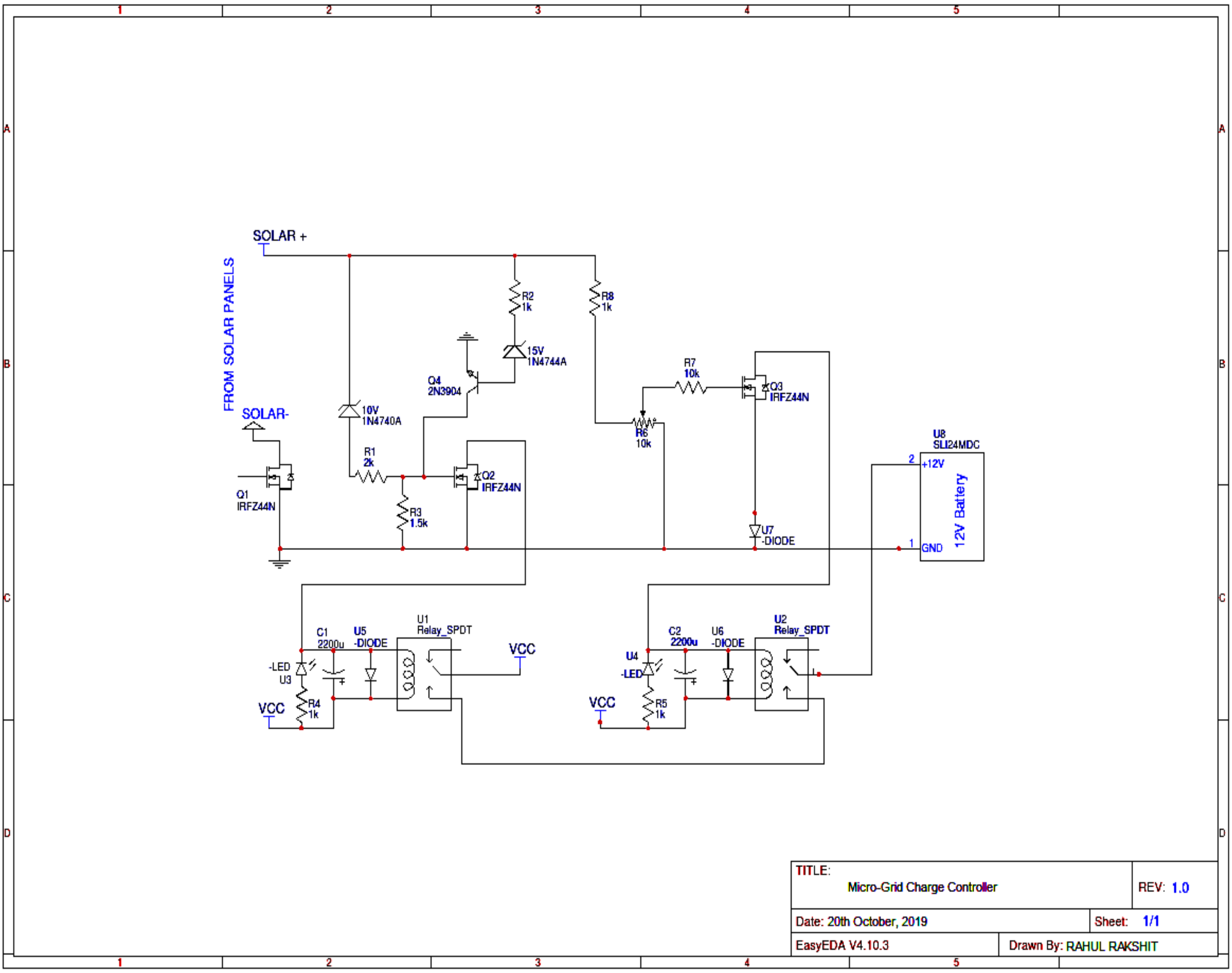
In that project we use E-plan and Auto-Cad for Drawing the different parts and Schematic Diagram.

8.2.1 Schematic Diagram of Micro-Grid:

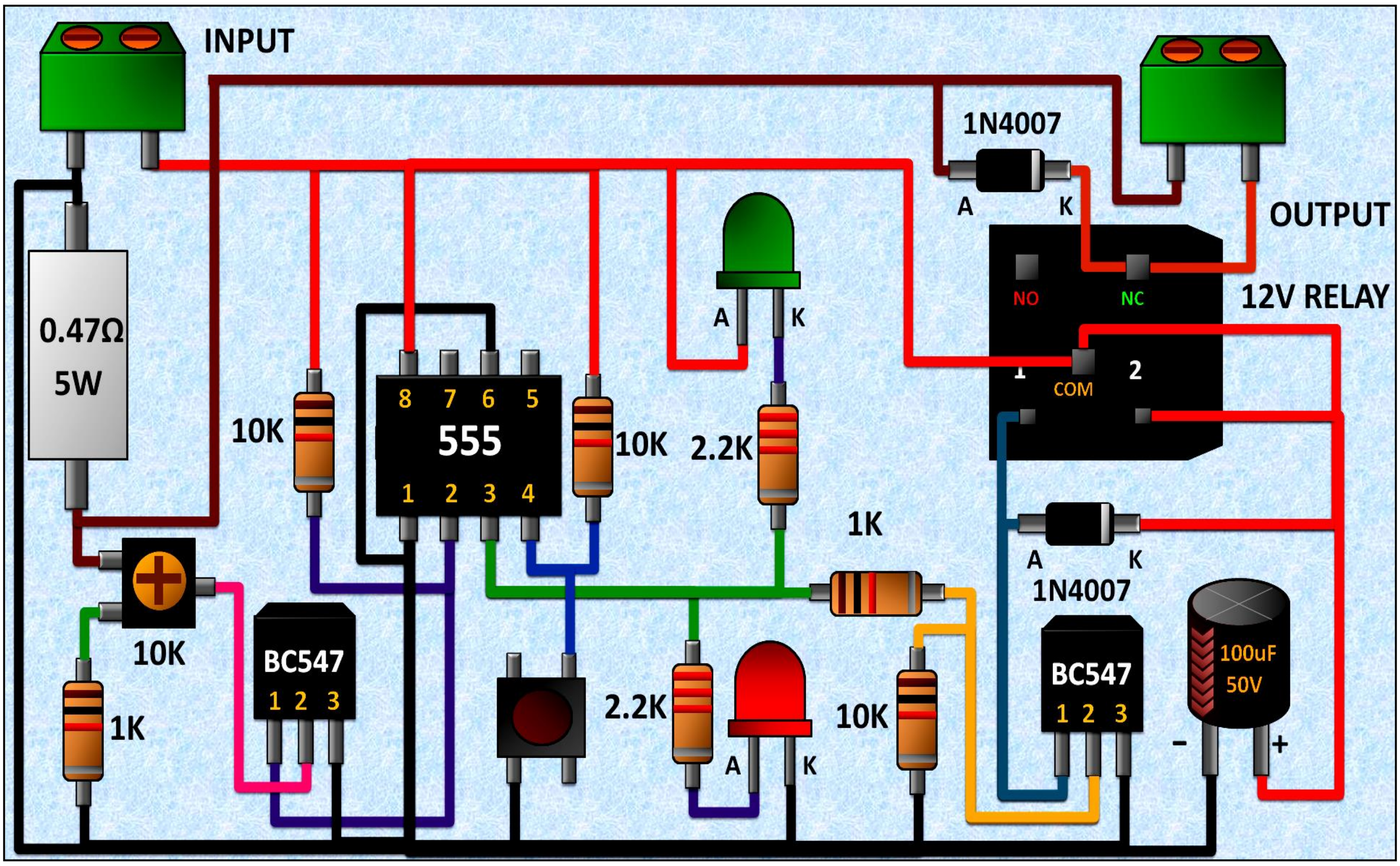


Note: - All this Diagram are Draw in E-plan, so all the Equipment's are IEC Standards**

8.2.2 Circuit of Charge Controller:



8.2.3 Circuit of Automatic Load Controller:



Chapter 9. Cost Estimation or Bill of Materials (BOM)

9.1 Cost Estimation/BOM:

Department of Electrical Engineering
RCC INSTITUTE OF INFORMATION TECHNOLOGY
CANALSOUTHROAD,BELIAGHATA,KOLKATA–700015, WESTBENGAL
PHONE: 033-2323-2463-154, FAX: 033-2323-4668
Website: http://www.rcciit.org/academic/ee.aspx

BILL OF MATERIALS

SL No	Item	DESCRIPTION	QUANTITY	ESTIMATED AMOUNT
1	Solar Panel	Rating- 18Volt, 40 watt, Make- Vikram	1	1800
2	Dc Generator	Rating-5 Volt, 8watt	1	150
3	Charge Controller	Rating-12 Volt, 10 Amp (PWM) Make- BE	1	350
4	Inverter(PWM)	Rating-50Watt,12volt Dc to 220Volt Ac 50Hz	1	510
5	Boost Converter	Rating- 5Volt to 18 Volt Range	1	180
6	Wind Propeller	Medium	1	80
7	Battery	Rating-12 Volt, 12Ah(SLB) Make- Sigma	1	500
8	Diode	1N4007 p-n Diode	4	5
9	Voltage Regulator	IC7815, 15Volt Series Regulator	2	6
10	Schottky Diode	1N5822MIC, 10amp	2	30
11	Static Relay	10amp double no double nc	2	120
12	3 pin Plug	5 amp. 220 Volt Ac	1	20
13	PVC Switch Box	For 1 Plug & Switch	1	20
14	SPST Switch	5 amp. 220 Volt Ac	1	20
15	Bulb Holder	5 amp. 220 Volt Ac	1	10
16	LED Bulb	20Watt. 220VAC	1	110
17	Cable	4 mm Sq, 2.5 mm Sq, 1.5 mm Sq, 0.5 mm Sq.	As per Requrement	100
18	Plywood	Plywood for Structure	As per Requrement	250
19	Vero Board	KS100	1	40
20	IC555	TIMER IC	1	10
21	BC547	NPN TRANSISTORS	2	5
22	POT	VARIABLE RESISTORS 10K	1	25
23	CAPACITOR	Electrolitic 100uF, 30v	2	10
24	RESISTORS	2X1K, 2X 2.2K, 3X10K,	-	10
25	LED	1X RED LED 3X GREEN LED Rating-1/4 Watt	-	5
26	PUSH BUTTON	MICRO Size, 2 Terminal	1	5
27	RESISTOR	0.47 OHM 5W RESISTOR	1	20
28	TERMINAL BLOCKS	2 PIN TERMINAL BLOCKS	2	10
29	Decoration	Chart paper & others	-	50
TOTAL Amount				4451

Chapter 10. CONCLUSION

Solar power is dependent on Sun, so natural energy is a variable energy source. Solar facilities may produce no power at all sometimes. So, as a backup solar low powered battery is used. Power transmission losses will be high. So overall efficiency will be hampered. For wind power generation the amount and direction of air flow is not equally available throughout the year. So, grid operating voltage may fluctuate. Frequency may not be synchronized with 50Hz (tolerance level 49.7Hz-51.3Hz) operating frequency.

Operational amplifier (differential amplifier), boost convertor, high powered solar panel, etc. all are used to improve efficiency. Grid coupling is required to keep the micro-grid voltage level same as main grid voltage level. Inverter is used to control exact frequency. For the detailed analysis of micro-grid system, different articles have been read, e.g. “IEEE Transactions on Industry Applications” & “The CERTS Micro-grid and the future of the Micro-grid” (details can be found in the Reference section).

Renewable energy like solar and wind power are used in the project. All the group members have tried to give their best to reduce grid coupling problem to maintain proper synchronization. Different components like OP-AMP, IC555, potentiometer, battery, solar pannel, boost converter, inverter, transistor, led, resistor, capacitor, ac & dc cable, transformer, etc. all are used as & when are required in the project. Detailed study of such components is made by the group members earnestly.

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CENTSYS

40W Solar panel specifications

Our range of solar panels are constructed from ultra-efficient polycrystalline and have been designed to provide a reliable and cost-effective alternative energy solution for applications where mains power is either not available, or not desirable.

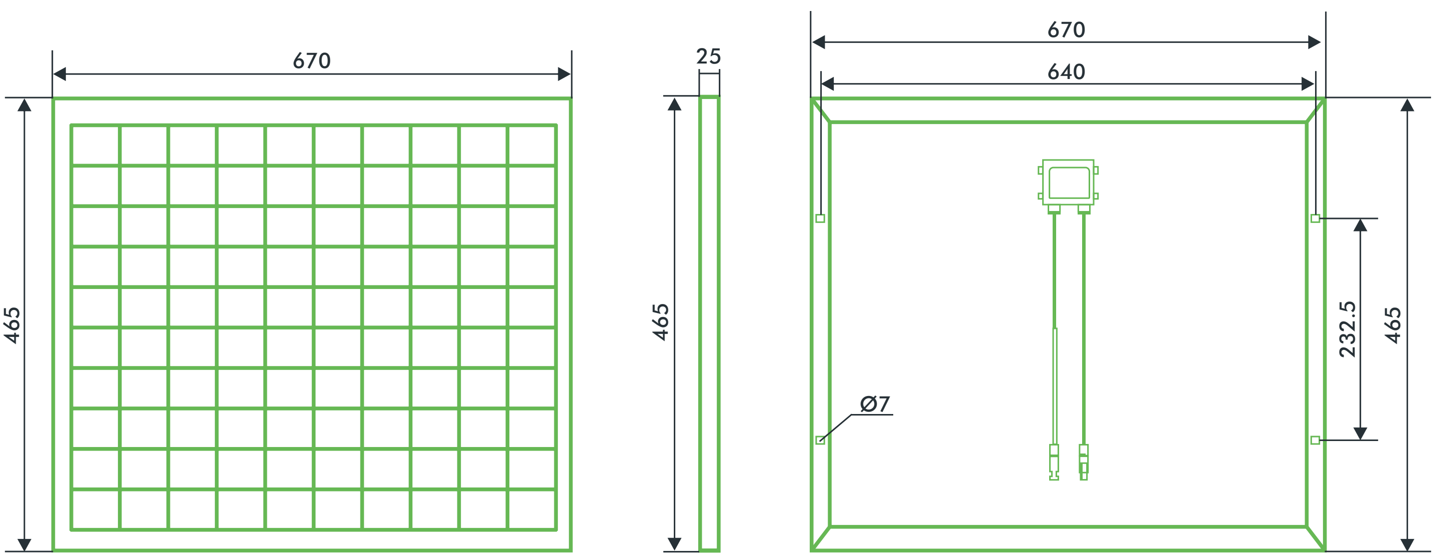
Main features:

- Clever engineering makes for minimal power losses during prolonged periods in shade
- Fully weather-resistant - durable white tempered glass, EVA resin and weather-resistant film enclosed in anodised aluminium frame

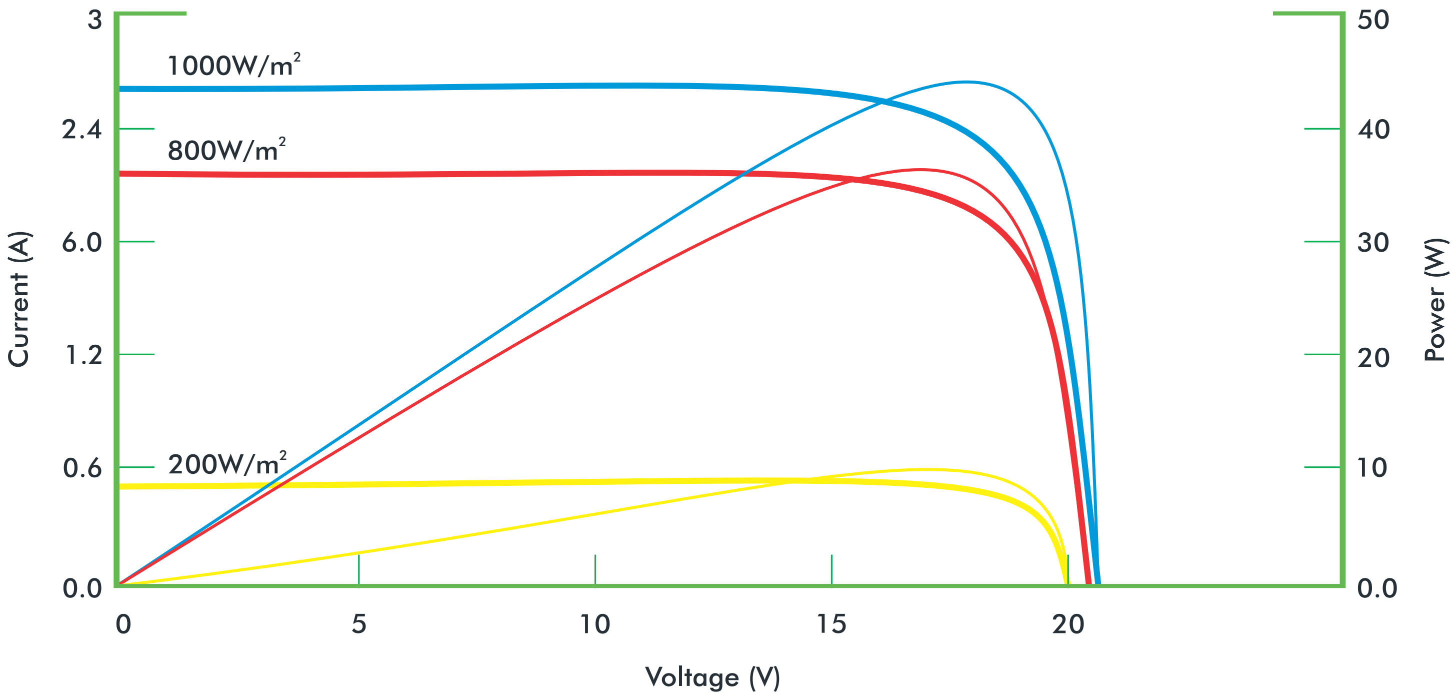
Technical specifications

Type Of Module	**40W**
Maximum Power	40W
Tolerance	± 3%
Open Circuit Voltage	22.2V
Short Circuit Current	2.37A
Maximum Power Voltage	18.2V
Maximum Power Current	2.2A
Module Efficiency	12.84%
Solar Cell Efficiency	17.3%
Series Fuse Rating	15A
Terminal Box	IP65
Maximum system voltage	1000V DC
Operating Temperature	-40°C - 85°C
Dimensions	465mm x 670mm x 25mm
Weight	4kg

Physical dimensions



Current-voltage and power-volatge characteristics - various irradiance levels



Current and voltage — Power and voltage

Electrical characteristics

Electric performance typical performance characteristics	
Current Temperature Coefficient %/°C	+0.06
Voltage Temperature Coefficient %/°C	-0.34
Power Temperature Coefficient %/°C	-0.47
Performance Warranty: 90%output, 12 year 80%output, 25 years	

D. C. GENERATORS

D. C. PERMANENT MAGNET TACHOMETER GENERATORS • D. C. WOUND FIELD GENERATORS

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"The manufacturer shall not be responsible for any damage resulting from improper storage or handling prior to placing the apparatus in service, and the manufacturer shall not assume any expense or liability for repairs made outside his works, without his written consent.

"The manufacturer shall not be liable for consequential damage in case of any failure to meet the conditions of any guarantee."

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D.C. WOUND FIELD GENERATORS

A.C. PERMANENT MAGNET GENERATORS

A.C. LOW INERTIA SIGNAL GENERATORS

A.C. SINE WAVE PERMANENT MAGNET GENERATORS

DC PM TACHOMETER GENERATORS

"ELINCO" D.C. Permanent Magnet Tachometers are used mainly as speed indicating devices. The primary requisites of a speed indicator are: good linearity, minimum temperature variations, minimum ripple voltage, minimum driving torque, variation due to slot lock, repeatability, no aging effects and good life. "ELINCO" D.C. tachometers incorporate the best of all these features and still remain in an economic price range.

CHARACTERISTICS

ELECTRICAL

VOLTAGE RANGE

CB frame 0.25 to 25 volts per 1000 RPM.
B frame 1.0 to 47 volts per 1000 RPM.
BL frame 0.8 to 100 volts per 1000 RPM.
A frame .66 to 170 volts per 1000 RPM.

BRUSHES

The brushes used on tachometers can be either square or rectangular with springs and shunts. Finger brushes with finger type of springs are also used.

A. Finger type brushes recommended when:
   1. Voltage generated must be equal in either direction of rotation.
   2. Speeds do not exceed 3000 RPM.

B. Square or rectangular brushes recommended when:
   1. Speeds are in excess of 3000 RPM.
   2. Lower driving torque.
   3. High currents are required.

COMMUTATORS

For severe environments and for most stable output, silver can be supplied in place of copper.

WINDINGS

The units listed are representative of electrical rating and mechanical configuration which can be furnished.

LINEARITY

Output voltage is linear with speed to ± 1½% between 200 and 500 RPM and ± 1% between 500 and 7000 RPM.

TEMPERATURE COMPENSATED

Tachometers can be temperature compensated to provide outputs proportional to generator speeds over a temperature range of −50°C to +100°C without external temperature compensating networks.

All magnetic materials experience a decrease of flux with increase in temperature. The average flux change in ELINCO Units is .033% per degree C, depending on material, (ie) 150°C change in ambient temperature equals a 5% change in the voltage gradient and accuracy.

Temperature compensation of 1/10% or 1/4% for 150°C temperature range can be furnished at additional cost.

When ordering any of the units listed to be temperature compensated specify the following:
1. % compensation required.
2. Electric load (ohms).
3. Voltage gradient.
4. Temperature range.
5. Operating speed range.

MECHANICAL

FRAME SIZES

Three basic frame sizes with various mounting arrangements are shown in the tachometer section.
CB frame is 1 3/4 inch diameter.
B-F-R-BL-FL-RL frames are 2 1/4 inch diameter.
ASC-ALC frames are 3 3/8 inch diameter.

MOUNTING

Units can be mounted by tapped holes provided in the base on the side of the frame or by tapped or clearance holes on the end of the frame. Ring mounting is provided on some units and special mounting can be provided upon request.

MATERIALS

All frames are aluminum with a black finish. Shafts are machined from steel and ground to size. Laminated stacks are wound with insulated copper wire, impregnated with varnish and baked until cured.

SPECIAL TREATMENT

Treatment for humidity, altitude, high or low temperature, fungus, salt spray, vibration, shock and explosion proof may be provided.

Special lubricant and finish may be furnished if required.

ENCLOSURE

The "A" types of tachometers shown on pages 6, 7 & 8 can be furnished as an open frame or totally enclosed. The other frames are all designed as enclosed units.

PRECISION BALL BEARINGS

All armatures are mounted on ball bearings, lubricated for the life of the unit with appropriate lubrication. The lubrication is selected to match the temperature rise and ambient temperature conditions.

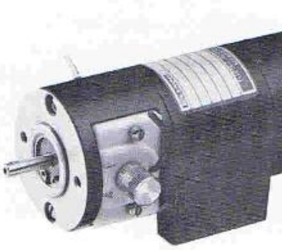
WEIGHT OF UNITS

CB frame 20 ounces.	or	567 grams
B-F-R frame 18.5 ounces.	or	524 grams
BL-FL-RL frames 32 ounces.	or	907 grams
ASC frames 3 to 4 lbs.	or	1360 to 1800 grams
ALC frames 4 to 5 lbs.	or	1800 to 2270 grams

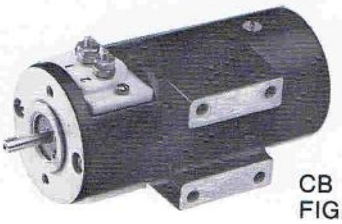
ARMATURE MOMENT OF INERTIA

CB frame .52 oz. in^2 or 95 gm cm^2.
B-F-R frame .52 oz. in^2 or 95 gm cm^2.
BL-FL-RL frames 1.01 oz. in^2 or 185 gm cm^2.
ASC frame 3.0 oz. in^2 or 549 gm cm^2.
ALC frame 4.2 oz. in^2 or 770 gm cm^2.

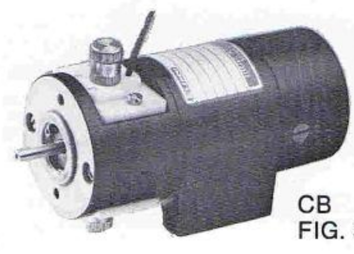
DC PM TACHOMETER GENERATORS



CB FIG. 1



CB FIG. 2

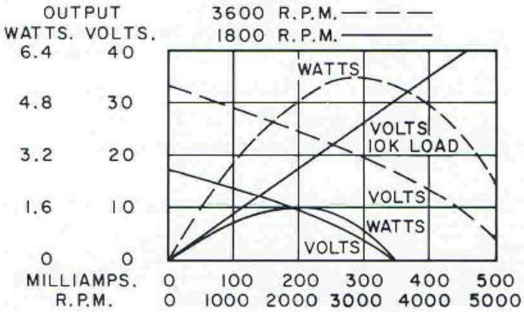


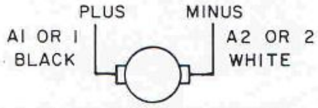
CB FIG. 3

CB FRAMES

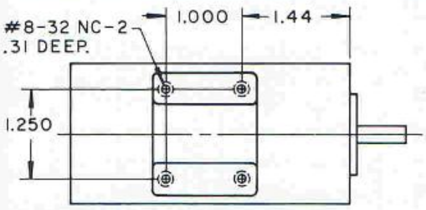
TYPE NO.	*VOLTS PER 1000 RPM	ARMATURE RESIS. OHMS ± 15%	CONT. MAX. AMPS	COMMUTATOR MATERIAL	MAX. RIPPLE %	TYPE OF BRUSH	MAX. SPEED RPM
514	.25	.046	3		7		10000
521	2.5	4	.43		4		10000
597	2.67	4.8	.43		4		10000
616	4.5	12.2	.15		4		10000
549	9	48	.10		4		10000
930	15	286	.05		2		10000
481	15	286	.05	†	2	+	3000
482	15	286	.05		2	+	3000
29	24.3	286	.05		4		10000
47	24.3	286	.05		4	+	3000
247	24.3	286	.05	†	4	+	3000
619	24.3	286	.05	†	4		10000

LINEARITY & REGULATION CURVE CB-549





CLOCKWISE ROTATION AT SHAFT END



STANDARD BASE DIMENSIONS.

1-SYMBOL † INDICATES UNIT WITH A SILVER COMMUTATOR, ALL OTHER ARE COPPER.
2-SYMBOL + INDICATES UNIT WITH FINGER TYPE BRUSHES, ALL OTHER ARE SQUARE.
3-SYMBOL * INDICATES DATA OF VOLTS PER 1000 R.P.M. WITH 10000 OHM LOAD.
4-STEEL SHAFT.
5-BALL BEARING UNITS.
6-SHAFT RUNOUT, .001 T.I.R.
7-ENCLOSED UNITS.
8-SEE DRIVING TORQUE CURVE ON PAGE 4.
9-✓ NO PAINT
10-⊙ CONCENTRIC TO SHAFT WITHIN .005 T.I.R.
11-⊥ PERPENDICULAR TO SHAFT WITHIN .005 T.I.R.
12-LEADS 12 INCHES LONG.
13-BLACK FINISH

TOLERANCE
.XX ± .03
.XXX ± .005

FIGURE 1 | CB

SQUARE BRUSH STANDARD.

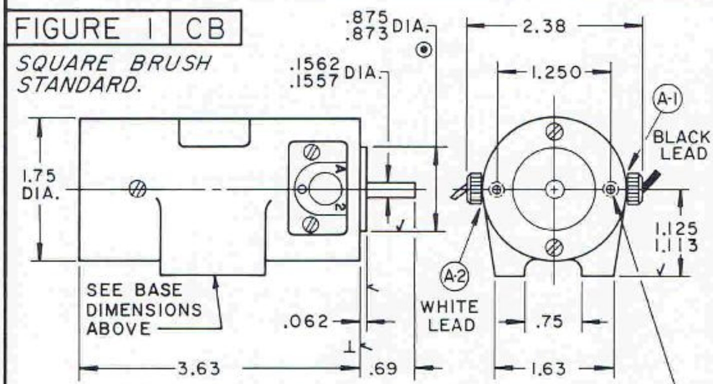


FIGURE 2 | CB

FINGER BRUSH STANDARD.

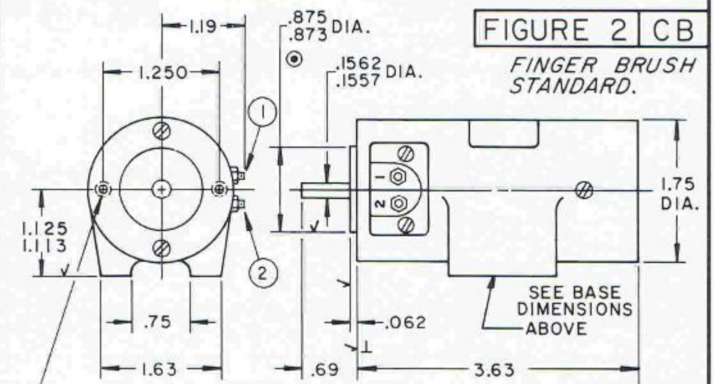
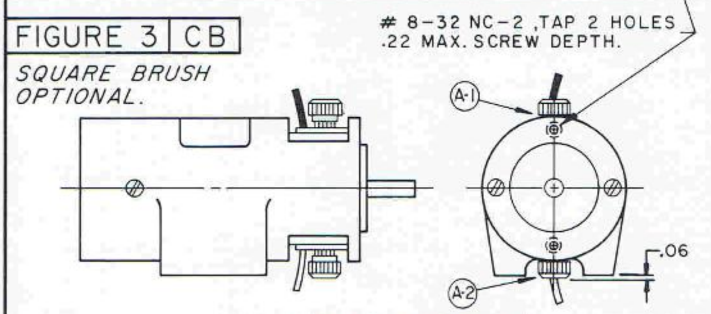


FIGURE 3 | CB

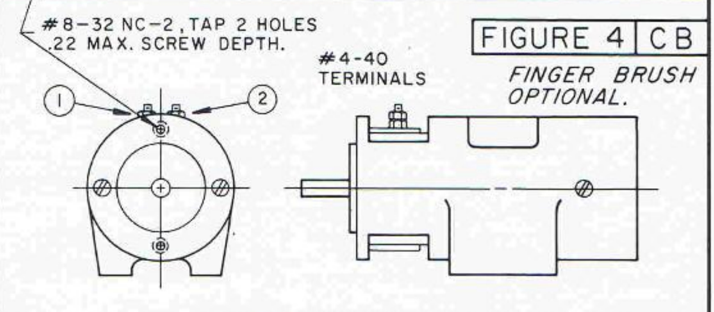
SQUARE BRUSH OPTIONAL.



(ALL DIMENSIONS SAME AS FIG. 1)

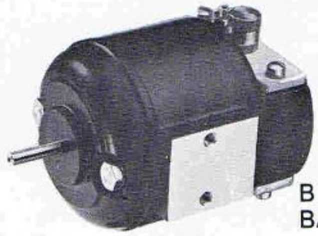
FIGURE 4 | CB

FINGER BRUSH OPTIONAL.



(ALL DIMENSIONS SAME AS FIG. 2)

DC PM TACHOMETER GENERATORS



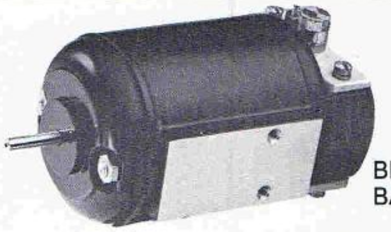
B
BASE

F
FACE

R
RING

B-F-R FRAMES

TYPE NO.	*VOLTS PER 1000 RPM	ARMATURE RESIS. OHMS ± 15%	CONT. MAX. AMPS	COMMUTATOR MATERIAL	MAX. RIPPLE %	TYPE OF BRUSH	MAX. SPEED RPM
348	1	0.8	.85		7		10000
159	1.65	1.6	.60		7		10000
363	4.2	17.3	.30		4	+	3000
646	4.5	20	.25		4		10000
501	7.5	55	.10		4		10000
582	9	56	.10	†	4		10000
107	11	104	.10		4		10000
472	16	228	.05	†	4	+	3000
81	16.7	240	.05		4		10000
442	20	286	.05	†	4		10000
500	20	286	.05	†	4	+	3000
400	29.2	450	.04	†	4	+	3000
1044	38	450	.04		4	+	3000
1182	38	450	.04	†	4		6000
950	47	640	.02		4		5000
1256	47	640	.02		4	+	5000



BL
BASE

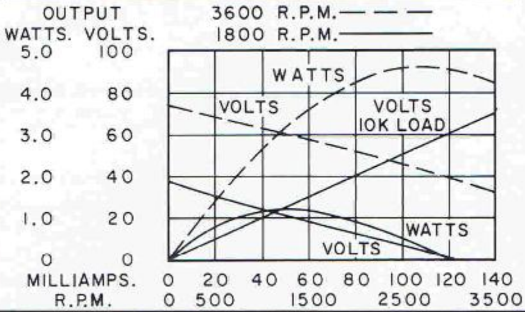
RL
RING

BL-FL-RL FRAMES

TYPE NO.	*VOLTS PER 1000 RPM	ARMATURE RESIS. OHMS ± 15%	CONT. MAX. AMPS	COMMUTATOR MATERIAL	MAX. RIPPLE %	TYPE OF BRUSH	MAX. SPEED RPM
236	0.8	0.22	2		7		10000
362	1.6	0.9	1		7		10000
182	2.9	1.9	.80		7		10000
186	4.4	3.6	.50		4		10000
462	12	55	.15		4		10000
183	21	80	.10		4		10000
139	24.5	136	.08		4		10000
533	24.5	136	.08	†	4	+	3000
95	28.5	138	.08		4		10000
742	30	158	.08		4		10000
364	30	280	.05	†	2	+	3000
465	45	385	.05	†	4		7500
506	45	385	.05		4	+	3000
633	45	385	.05		3		7500
570	48	474	.04		4		7000
769	60	380	.04		4	+	3000
1036	75	580	.04	†	4		4000
771	75	580	.04		4	+	3000
772	100	930	.04		4		3000

1—CONNECTION DIAGRAM: PAGE 16, NUMBER 1.
2—SYMBOL † INDICATES UNIT WITH A SILVER COMMUTATOR, ALL OTHER ARE COPPER.
3—SYMBOL + INDICATES UNIT WITH FINGER TYPE BRUSHES, ALL OTHER ARE SQUARE.

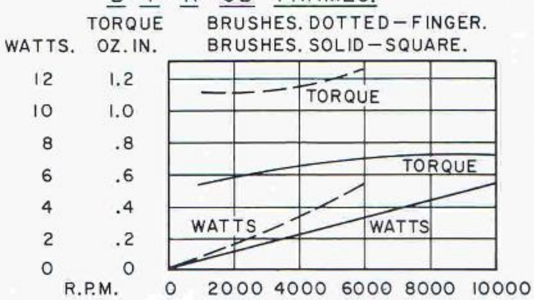
LINEARITY & REGULATION CURVE B-500



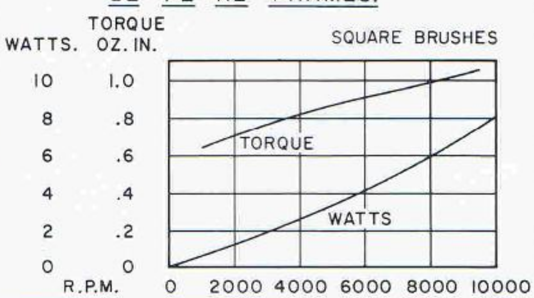
DRIVING TORQUE & WATTS VS. R.P.M.

DRIVING WATTS AND TORQUE INCLUDES ALL LOSSES (ie) FRICTION WINDAGE & IRON LOSS. TO GET ACTUAL LOAD TORQUE & WATTS FOR VARIOUS LOAD CONDITIONS, ADD ACTUAL LOAD TO BE USED PLUS I^2R OF ARMATURE.

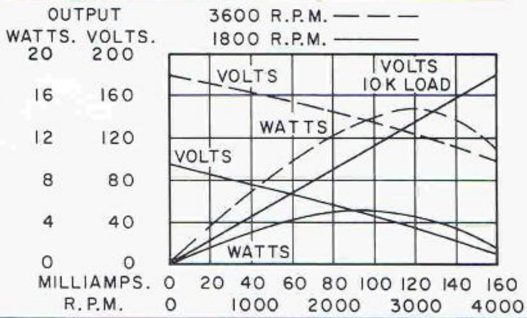
"B"-"F"-"R"-"CB" FRAMES.



"BL"-"FL"-"RL" FRAMES.



LINEARITY & REGULATION CURVE BL-465



FRAME DIMENSIONS

FIGURE 1 | B–BL

BASE MOUNTING.

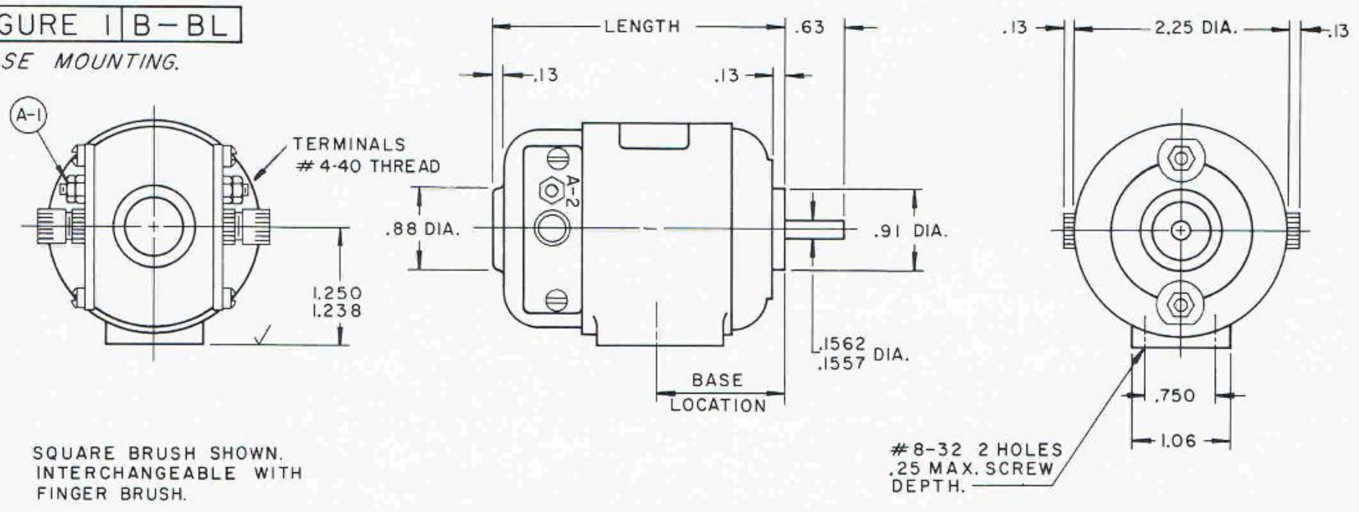


FIGURE 2 | F–FL

FACE MOUNTING WITH PILOT.

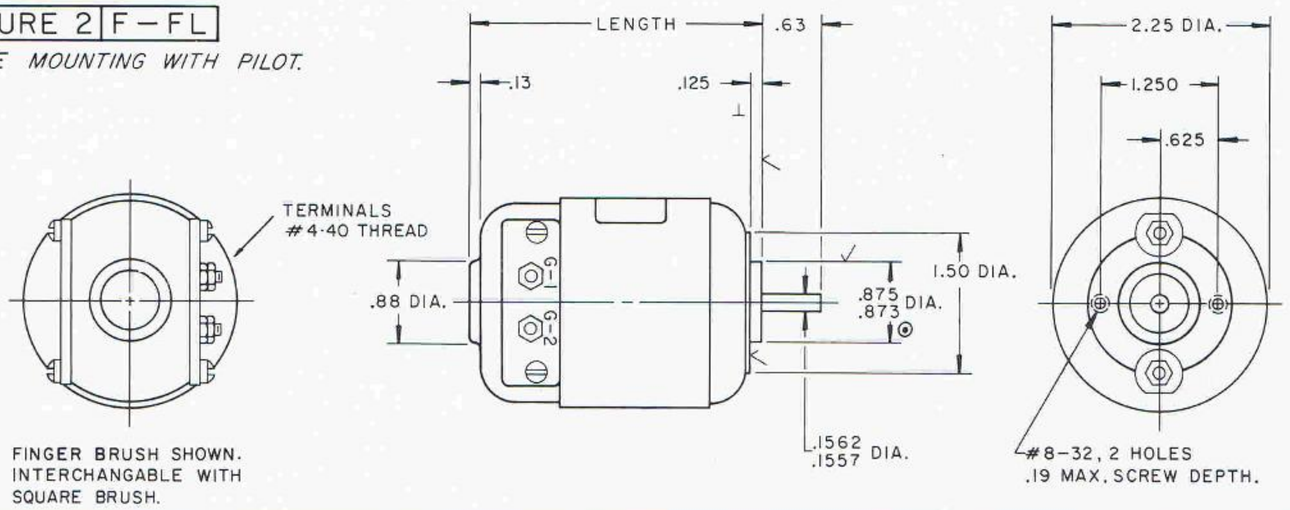
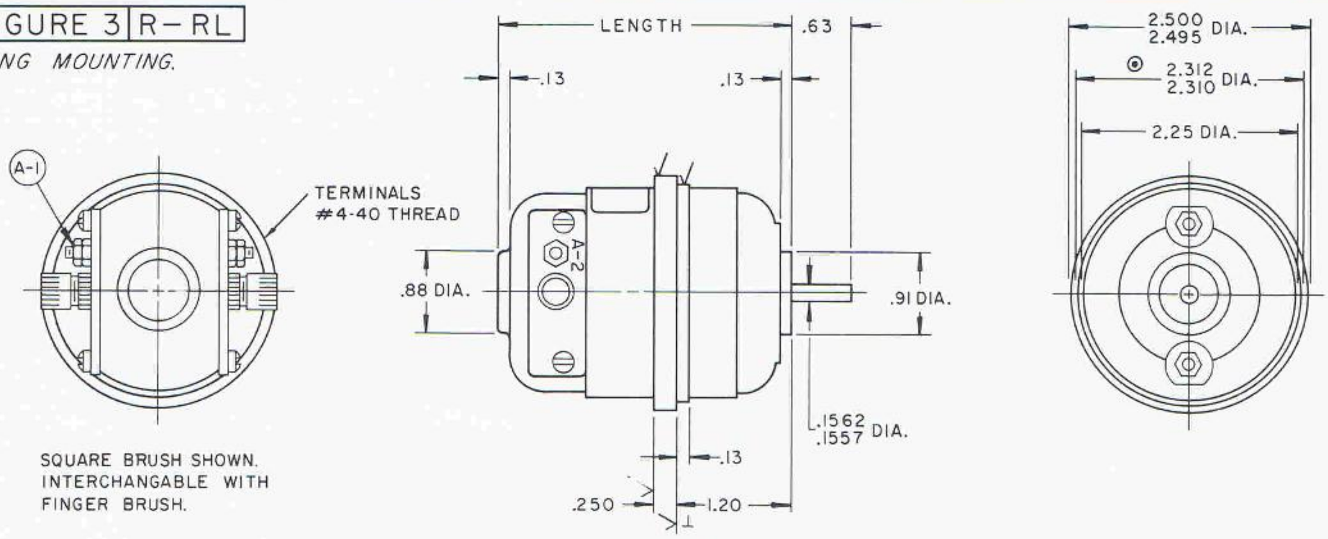


FIGURE 3 | R–RL

RING MOUNTING.



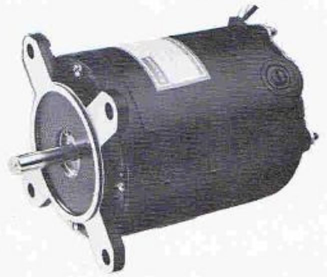
FRAME	LENGTH	BASE LOCATION
B – F – R	3.13	1.19
BL – FL – RL	4.00	2.06

TOLERANCE
.XX ± .03
.XXX ± .005

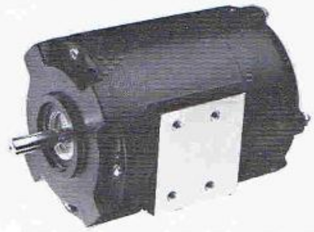
NOTES.
1–ALUMINUM FRAME.
2–STEEL SHAFT.
3–BALL BEARING UNITS.
4–BLACK FINISH.
5–SHAFT RUNOUT .001 T.I.R.
6–✓ NO PAINT.
7–◎ CONCENTRIC TO SHAFT WITHIN .005 T.I.R.
8–⊥ PERPENDICULAR TO SHAFT WITHIN .005 T.I.R.

5

DC PM TACHOMETER GENERATORS



J
FLANGE

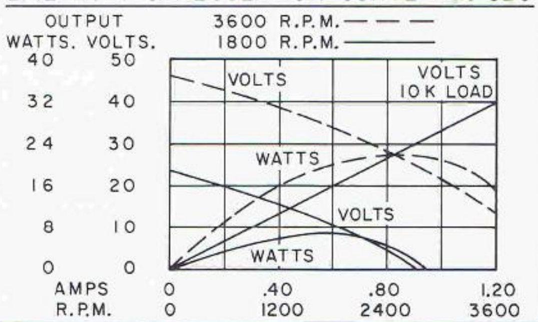


B
BASE

ASC FRAMES

TYPE NO.	*VOLTS PER 1000 RPM	ARMATURE RESISTANCE OHMS ± 15%	CONT. MAX. AMPS	MAX. RIPPLE %	MAX. SPEED RPM
282	.66	3.8	3.5	4	10000
605	5.9	22	.5	4	10000
635	5.9	9.2	.85	4	10000
520	11	67	.25	4	10000
2702	50	72	.25	4	3000
588	87	1300	.05	4	4000
560	120	2750	.025	4	3000

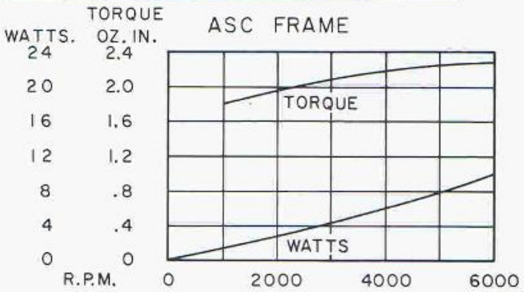
LINEARITY & REGULATION CURVE ASC-520



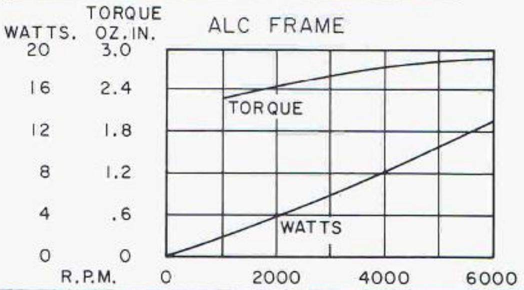
DRIVING TORQUE & WATTS VS. R.P.M.

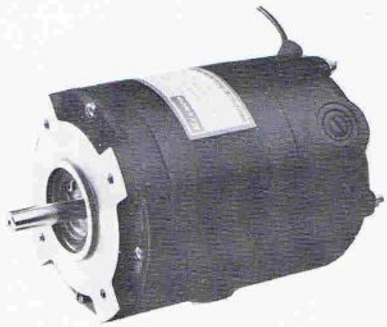
DRIVING WATTS AND TORQUE INCLUDES ALL LOSSES (ie) FRICTION WINDAGE & IRON LOSS. TO GET ACTUAL LOAD TORQUE & WATTS FOR VARIOUS LOAD CONDITIONS, ADD ACTUAL LOAD TO BE USED PLUS I^2R OF ARMATURE.

DRIVING TORQUE & WATTS VS. R.P.M.



DRIVING TORQUE & WATTS VS. R.P.M.





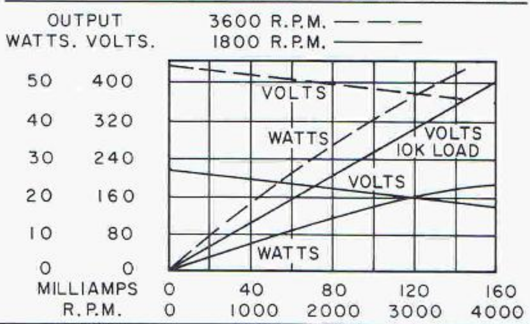
F
FACE/PILOT

M
FACE

ALC FRAMES

TYPE NO.	*VOLTS PER 1000 RPM	ARMATURE RESISTANCE OHMS ± 15%	CONT. MAX. AMPS	MAX. RIPPLE %	MAX. SPEED RPM
1523	21.5	25	.32	4	6000
726	50	95	.16	4	6000
634	75	425	.07	4	4000
639	100	375	.085	4	3600
575	170	3150	.025	4	2000
638	170	1350	.040	4	2000

LINEARITY & REGULATION CURVE ALC-639



NOTES

1 – * VOLTAGE OUTPUT PER 1000 R.P.M. WITH 10000 OHM LOAD.
2 – CONNECTION DIAGRAM SEE PAGE 16 NUMBER 1

FRAME DIMENSIONS

FIGURE 1 ASCJ-ALCJ

FLANGE MOUNTING.

FRAME	LENGTH
ASCJ	4.61
ALCJ	5.11

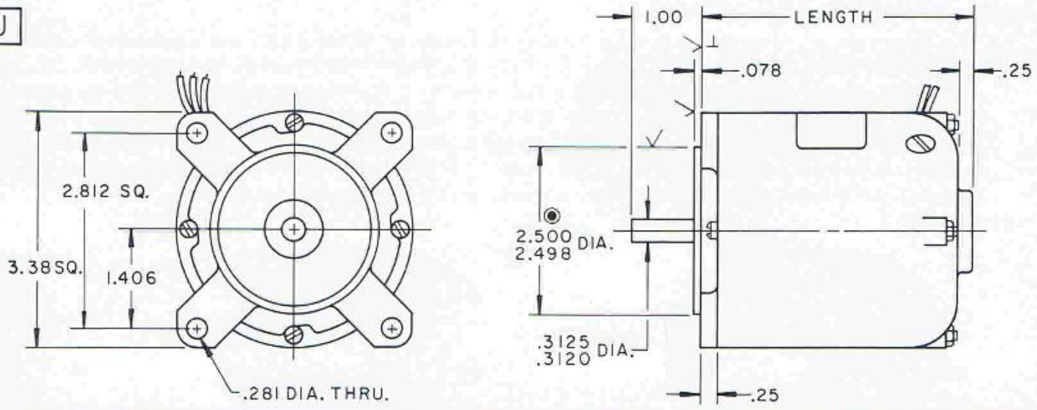


FIGURE 2 ASCB-ALCB

BASE MOUNTING.

FRAME	LENGTH
ASCB	4.61
ALCB	5.11

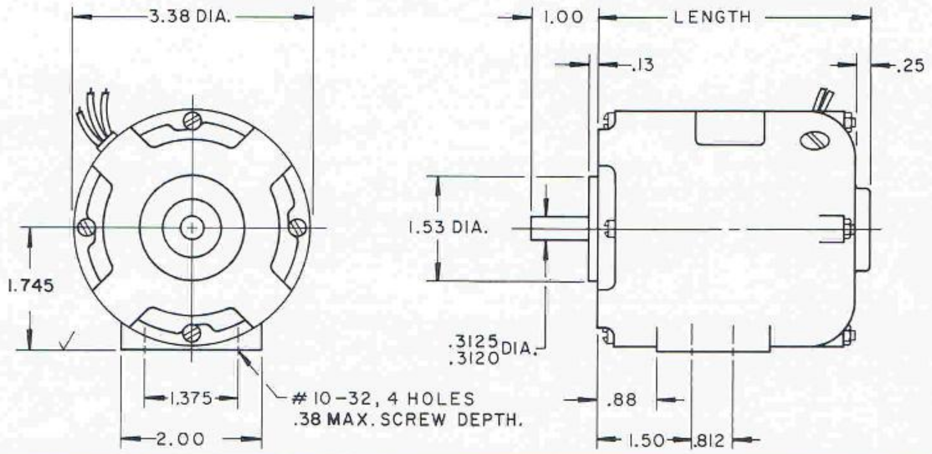


FIGURE 3 ASCF-ALCF

FACE MOUNTING, WITH PILOT.

FRAME	LENGTH
ASCF	4.61
ALCF	5.11

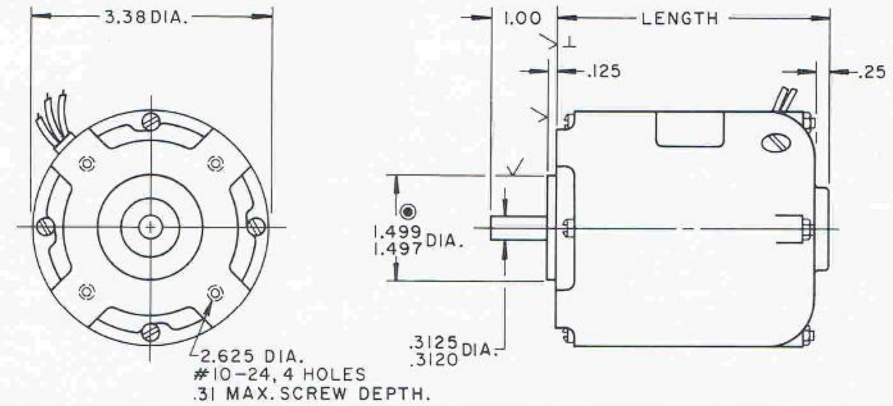
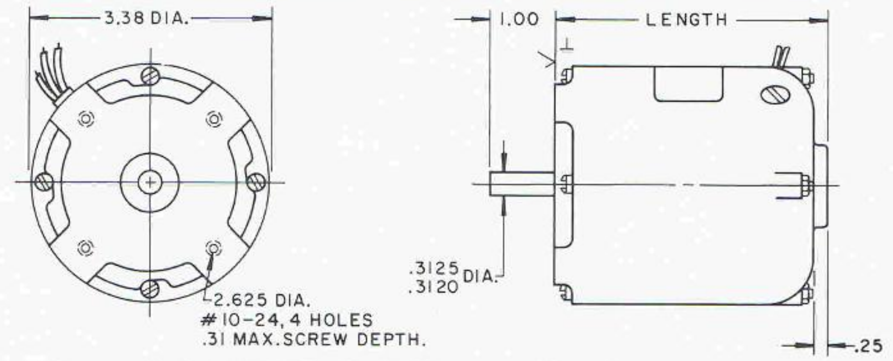


FIGURE 4 ASCM-ALCM

FACE MOUNTING, NO PILOT.

FRAME	LENGTH
ASCM	4.61
ALCM	5.11

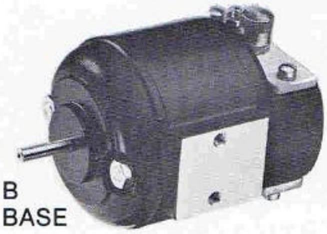


NOTES.
1-ALUMINUM FRAME.
2-STEEL SHAFT.
3-BALL BEARING UNITS.
4-LEADS 12" LONG.
5-BLACK FINISH.
6-SHAFT RUNOUT .001 T.I.R.
7- ✓ NO PAINT.
8- ◉ CONCENTRIC TO SHAFT WITHIN .005 T.I.R.
9- ⊥ PERPENDICULAR TO SHAFT WITHIN .005 T.I.R.

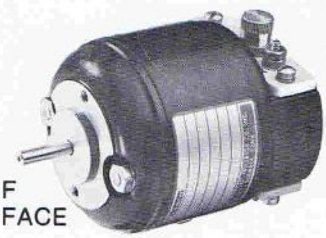
TOLERANCE
.XX ± .03
.XXX ± .005

DC WOUND FIELD GENERATORS

"ELINCO" wound field generators are D.C. shunt wound generators. They can be used as D.C. generators either for constant voltage or where it is desired to vary the output depending on field excitation. They can be wound as split field units where it is desirable to change the armature polarity and amplitude depending on differential current in the two fields. They can be used as tachometers where higher outputs are required and linearity requirements are not too critical, since variation in field resistance due to heating will introduce linearity errors. Units can be compensated for field variations due to heating if required. An infinite number of voltage outputs and field windings can be made.



B
BASE



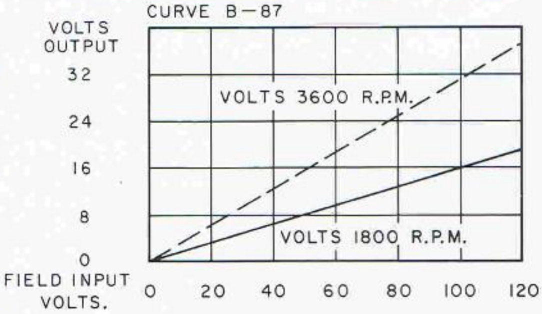
F
FACE

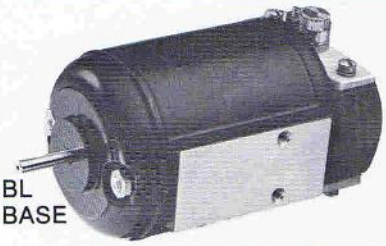
R
RING

B-F-R FRAMES

TYPE NO.	NOMINAL FIELD VOLTS	ARM. V./1000 RPM AT 10K LOAD	ARM. MAX. LOAD MA	MAX. RPM	FIELD RESIS. OHMS	ARM. RESIS. OHMS	FRAME DIMENSIONS SEE PAGE
99	100	2.5	50	15000	5140	8.8	5
694	28	4	50	10000	216	11.1	5
87	100	6.6	20	15000	5140	115	5
459	24	19.7	30	10000	74	154	5
466	120	19.7	30	10000	1270	154	5
448	80	21.4	25	10000	1270	286	5
360	28	22	20	10000	192	286	5

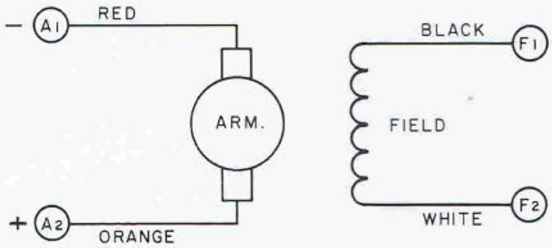
VOLTAGE OUTPUT VS. FIELD VOLTS.





BL
BASE

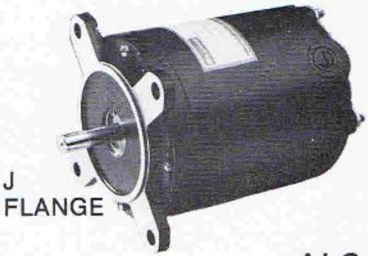
RL
RING



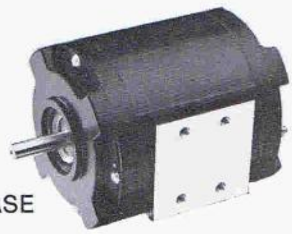
BL-FL-RL FRAMES

TYPE NO.	NOMINAL FIELD VOLTS	ARM. V./1000 RPM AT 10K LOAD	ARM. MAX. LOAD MA	MAX. RPM	FIELD RESIS. OHMS	ARM. RESIS. OHMS	FRAME DIMENSIONS SEE PAGE
528	20	6	50	15000	127	14.1	5

NOTES.
1. B-F-R-BL-FL-RL FRAMES:
   SEE PAGE 5 FOR FRAME DIMENSIONS.
   TERMINALS MARKED PER ABOVE CONNECTION DIAGRAM WILL BE PROVIDED.
2. ALC FRAMES: SEE PAGE 7
   FOR FRAME DIMENSIONS.
   LEADS COLOR CODED PER ABOVE CONNECTION DIAGRAM WILL BE PROVIDED.
3. SEE DRIVING TORQUE CURVES ON PAGE 4 AND 6.



J
FLANGE

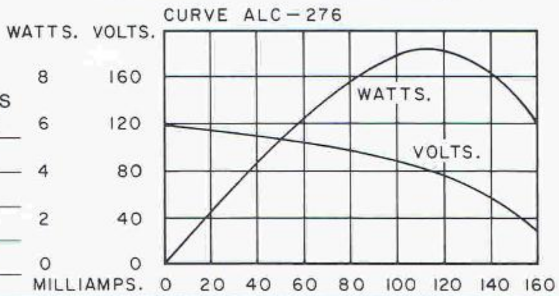


B
BASE

ALC FRAMES

TYPE NO.	NOMINAL FIELD VOLTS	ARM. V./1000 RPM AT 10K LOAD	ARM. MAX. LOAD MA	MAX. RPM	FIELD RESIS. OHMS	ARM. RESIS. OHMS	FRAME DIMENSIONS SEE PAGE
692	100	3.4	50	10000	1460	7.4	7
276	115	58.5	50	3000	835	190	7
738	125	140	28	2000	3450	780	7
1277	5	59.2	35	4000	6.5	125	7

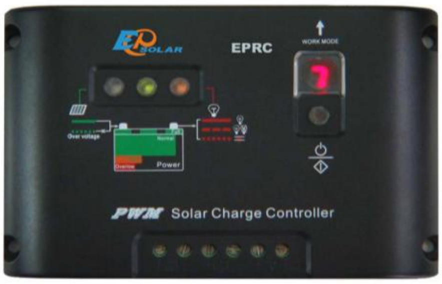
LOAD REGULATION 2000 R.P.M.



INSTRUCTION MANUAL

----------For solar charge controller,

----------EPRC series



RATINGS (12V or 12/24V auto work)

EPRC-5, 12V or 12/24V auto-work, 5Amp
EPRC-10 12V or 12/24V auto-work, 10Amp
NOTES: For use with solar panels only

TECHNICAL INFORMATION

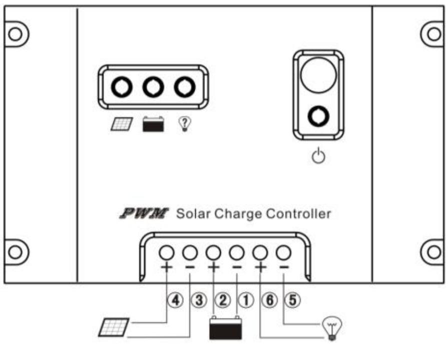
	12Volt	24Volt
Rated solar input	**5/10A**	**5/10A**
Rated load	**5/10A**	**5/10A**
25% Current overload	**1 min.**	**1 min.**
Load disconnect	**11.1V**	**22.2V**
Load reconnect	**12.6V**	**25.20V**
Equalization voltage(10 minutes)	**14.6v**	**29.2v**
Boost voltage(10 minutes)	**14.4v**	**28.8v**
Float voltage	**13.6v**	**27.2v**
Temp Comp.(mV/℃)	**-30mV**	**-60mV**

Temperature: -35℃ to +55℃

QUICK START INSTRUCTIONS

This section provides a brief overview of how to get started using the controller. However, please review the entire manual to ensure best performance and years of trouble-free service.

1. Mount the controller to a vertical surface. Allow space above and below the controller for air flow.
2. Make sure the PV and load currents will not exceed the ratings of the controller being installed.
3. It is recommended that the connections be made in order from 1 to 6. (see the following picture)



- Use with 12V or 24V batteries only
- Use with 12V or 24V systems only

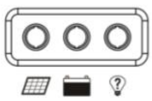
4. Connect the **BATTERY** first. Use care that bare wires do not touch the metal case of the controller.
5. Connect the **SOLAR**(PV array) next. The green LED indicator will light if sunlight is present.
6. Connect the **LIGHT** last. If the red LED indicator lights, the battery capacity is low and should be charged before completing the system installation
7. Press the **BUTTON** as **6.** or **7.** to verify the system connecting.

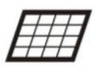
LIGHTING CONTROL OPTIONS

8. Press the power switch for 5 seconds, and select the desired LIGHTING CONTROL option. The LED is on, which confirmed you have selected the right one.
9. The controller requires 3 minutes of continuous transition values before it starts to work. These constraints avoid false transitions due to lightning or dark storm clouds.
10. 3 minutes off before the controller start to work.
11. A brief description follows below:

Number 0:	Dusk-to-Dawn, light is on all night
Number 1:	Light is turn on after sundown for 1 hour
Number 2:	Light is turn on after sundown for 2 hours
Number 3:	Light is turn on after sundown for 3 hours
Number 4:	Light is turn on after sundown for 4 hours
Number 5:	Light is turn on after sundown for 5 hours
Number 6:	Light is turn on after sundown for 6 hours
Number 7:	Light is turn on after sundown for 7 hours
Number 0.:	Light is turn on after sundown for 8 hours
Number 1.:	Light is turn on after sundown for 9 hours
Number 2.:	Light is turn on after sundown for 10 hours
Number 3.:	Light is turn on after sundown for 11 hours
Number 4.:	Light is turn on after sundown for 12 hours
Number 5.:	Light is turn on after sundown for 13 hours
Number 6.:	Lights remain turned off, ON/OFF mode
Number 7.:	Test mode, lights on after it detects no light, lights off after it detects light.

LED INDICATOR





Green ON when solar is charging battery
Green blink when the system over voltage

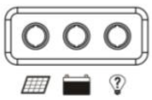
Green ON when battery level in the right range
Green slowly flashing when battery level full
Yellow ON when battery level low
Red ON when loads cut off

Red ON when the output is on.
Red slowly flashing when its over load
(the load amps is 1.25 times of rated current for 60 seconds, or the load amps is 1.5 times of rated current for 5 seconds)
Red blink when the load is short-circuit.

Please note:

the output will cut off once there is over load or short circuit. Disconnect all the equipment and reconnect, and press the button, the controller will resume to work after 10 seconds, or wait for it to work the next day.

TROUBLESHOOTING



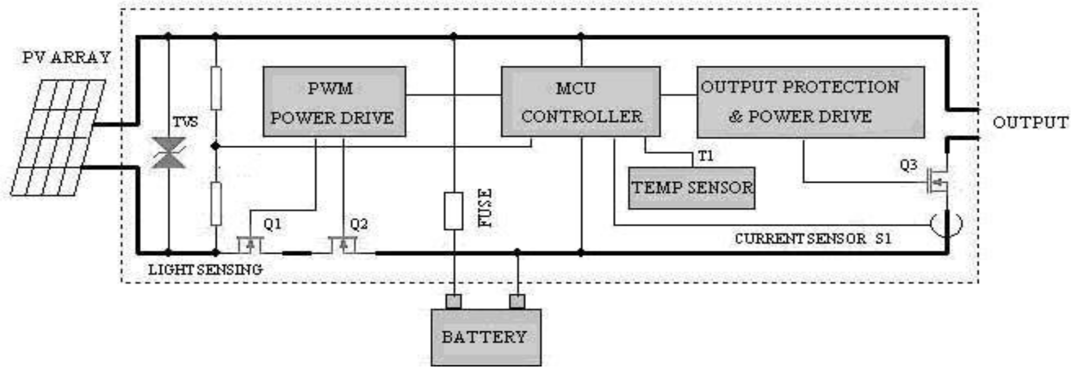
1. Charging LED indicator is off when it is daytime
   a. The green Charging LED should be on if its day time.
   b. Check that the proper battery type has been selected.
   c. Check that all wire connections in the system are correct and tight. Check the polarity(+ and -) of the connections
   d. Measure the PV array open-circuit voltage and confirm it is within normal limits. If the voltage is low or zero, check the connections at the PV array itself. Disconnect the PV from the controller when working on the PV array.
   e. Measure the PV voltage and the battery voltage at the controller terminals. If the voltage at the terminals is the same(within a few tenths of volts) the PV array is charging the battery. If the PV voltage is close to the open circuit voltage of the panels and the battery voltage is low, the controller is not charging the batteries and may be damaged.
2. Charging LED indicator is blinking
   a. First check the operating conditions to confirm that the voltage is higher than specifications. Consider the temperature compensation of the controller's PWM setpoint. For example, at 0℃ the controller will regulate at about 15.0 volts
   b. Check that all wire connections in the system are correct and tight.
3. Load LED indicator is blinking, or flashing or on red(load not operating properly)
   a. Check that the load is turned on. Check that no system fuses are defective.
   b. Check connections to the load, and other controller and battery connections. Make sure voltage drops in the system wires are not too high.
   c. If the LED indicator is blinking and no output, check if the load is short-circuit. Disconnect the load, and press the switch button, the controller will return to work after 10 seconds.
   d. If the LED indicator is flashing and no output, check if the load is over the rated power. Reduce the load, and press the switch button, the controller will return to work after 10 seconds.

INSPECTION AND MAINTENANCE

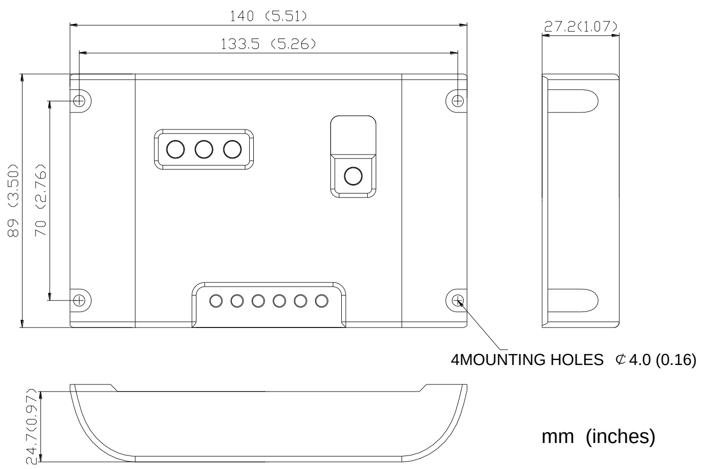
The following inspections and maintenance tasks are recommended at least once per year for best controller performance

1. Confirm that the correct battery type has been selected.
2. Confirm that the current levels of the solar array and load do not exceed the controller ratings.
3. Tighten all the terminals. Inspect for loose, broken, or burnt wire connections. Be certain no loose strands of wire are touching other terminals
4. Press the TEST button(number: 6. or 7.) to verify the lights are working
5. Check that the controller is securely mounted in a clean environment. Inspect for dirt, insects and corrosion.
6. Check the air flow around the controller is not blocked.
7. Protect from sun and rain. Confirm that water is not collecting under the cover
8. Check that the controller functions and LED indicators are correct for the system conditions at that time.
9. Make sure the PV array is clean and clear of debris and snow. Confirm the array is oriented correctly for the installation location.

SYSTEM MAIN CIRCUIT DIAGRAM



MECHANICAL



XLSEMI

XL6009

400KHz 60V 4A Switching Current Boost / Buck-Boost / Inverting DC/DC Converter

Features

- Wide 5V to 32V Input Voltage Range
- Positive or Negative Output Voltage Programming with a Single Feedback Pin
- Current Mode Control Provides Excellent Transient Response
- 1.25V reference adjustable version
- Fixed 400KHz Switching Frequency
- Maximum 4A Switching Current
- SW PIN Built in Over Voltage Protection
- Excellent line and load regulation
- EN PIN TTL shutdown capability
- Internal Optimize Power MOSFET
- High efficiency up to 94%
- Built in Frequency Compensation
- Built in Soft-Start Function
- Built in Thermal Shutdown Function
- Built in Current Limit Function
- Available in TO263-5L package

Applications

- EPC / Notebook Car Adapter
- Automotive and Industrial Boost / Buck-Boost / Inverting Converters
- Portable Electronic Equipment

General Description

The XL6009 regulator is a wide input range, current mode, DC/DC converter which is capable of generating either positive or negative output voltages. It can be configured as either a boost, flyback, SEPIC or inverting converter. The XL6009 built in N-channel power MOSFET and fixed frequency oscillator, current-mode architecture results in stable operation over a wide range of supply and output voltages.

The XL6009 regulator is special design for portable electronic equipment applications.

Figure1. Package Type of XL6009

Pin Configurations

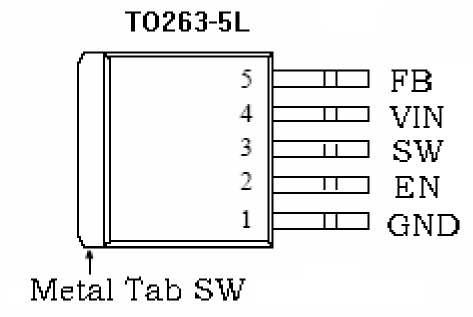


Figure2. Pin Configuration of XL6009 (Top View)

Table 1 Pin Description

Pin Number	Pin Name	Description
1	GND	Ground Pin.
2	EN	Enable Pin. Drive EN pin low to turn off the device, drive it high to turn it on. Floating is default high.
3	SW	Power Switch Output Pin (SW).
4	VIN	Supply Voltage Input Pin. XL6009 operates from a 5V to 32V DC voltage. Bypass Vin to GND with a suitably large capacitor to eliminate noise on the input.
5	FB	Feedback Pin (FB). Through an external resistor divider network, FB senses the output voltage and regulates it. The feedback threshold voltage is 1.25V.

Function Block

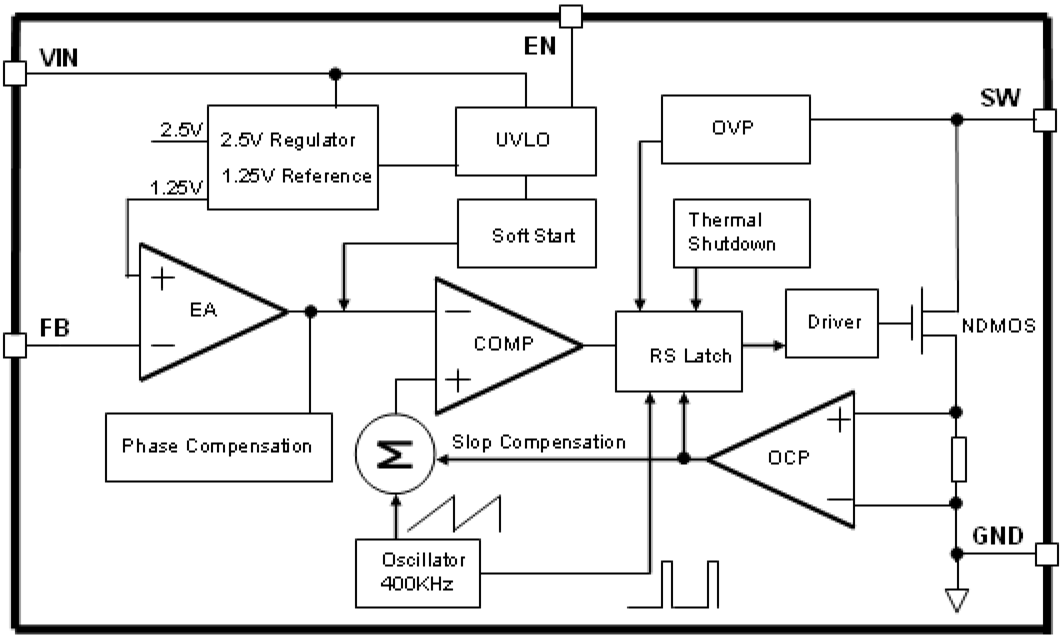


Figure3. Function Block Diagram of XL6009

Typical Application Circuit

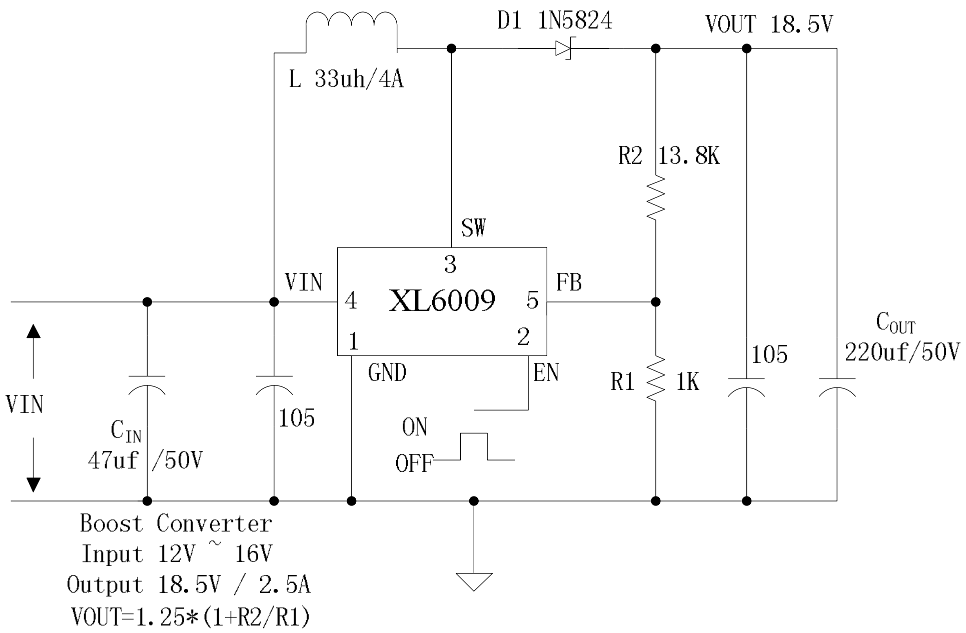


Figure4. XL6009 Typical Application Circuit (Boost Converter)

Ordering Information

Package	Temperature Range	Part Number	Marking ID	Packing Type
		Lead Free	Lead Free	
		XL6009E1	XL6009E1	Tube
		XL6009TRE1	XL6009E1	Tape & Reel

XLSEMI Pb-free products, as designated with "E1" suffix in the par number, are RoHS compliant.

Absolute Maximum Ratings（Note1）

Parameter	Symbol	Value	Unit
Input Voltage	Vin	-0.3 to 36	V
Feedback Pin Voltage	V_{FB}	-0.3 to Vin	V
EN Pin Voltage	V_{EN}	-0.3 to Vin	V
Output Switch Pin Voltage	V_{Output}	-0.3 to 60	V
Power Dissipation	P_D	Internally limited	mW
Thermal Resistance (TO263-5L) (Junction to Ambient, No Heatsink, Free Air)	R_{JA}	30	ºC/W
Operating Junction Temperature	T_J	-40 to 125	ºC
Storage Temperature	T_{STG}	-65 to 150	ºC
Lead Temperature (Soldering, 10 sec)	T_{LEAD}	260	ºC
ESD (HBM)		>2000	V

Note1: Stresses greater than those listed under Maximum Ratings may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operation is not implied. Exposure to absolute maximum rating conditions for extended periods may affect reliability.

XL6009 Electrical Characteristics

T_a = 25℃;unless otherwise specified.

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Unit
System parameters test circuit figure4						
VFB	Feedback Voltage	Vin = 12V to 16V, Vout=18V Iload=0.1A to 2A	1.213	1.25	1.287	V
Efficiency	ŋ	Vin=12V ,Vout=18.5V Iout=2A	-	92	-	%

Electrical Characteristics (DC Parameters)

Vin = 12V, GND=0V, Vin & GND parallel connect a 220uf/50V capacitor; Iout=0.5A, T_a = 25℃; the others floating unless otherwise specified.

Parameters	Symbol	Test Condition	Min.	Typ.	Max.	Unit
Input operation voltage	Vin		5		32	V
Shutdown Supply Current	I_{STBY}	V_{EN}=0V		70	100	uA
Quiescent Supply Current	I_q	V_{EN} =2V, V_{FB} =Vin		2.5	5	mA
Oscillator Frequency	Fosc		320	400	480	Khz
Switch Current Limit	I_L	V_{FB} =0		4		A
Output Power NMOS	Rdson	Vin=12V, I_{SW}=4A		110	120	mohm
EN Pin Threshold	V_{EN}	High (Regulator ON) Low (Regulator OFF)		1.4 0.8		V
EN Pin Input Leakage Current	I_H	V_{EN} =2V (ON)		3	10	uA
	I_L	V_{EN} =0V (OFF)		3	10	uA
Max. Duty Cycle	D_{MAX}	V_{FB}=0V		90		%

Schottky Diode Selection Table

Current	Surface Mount	Through Hole	VR (The same as system maximum input voltage)				
			20V	30V	40V	50V	60V
1A		√	1N5817	1N5818	1N5819		
3A		√	1N5820	1N5821	1N5822		
		√	MBR320	MBR330	MBR340	MBR350	MBR360
	√		SK32	SK33	SK34	SK35	SK36
	√			30WQ03	30WQ04	30WQ05	
		√		31DQ03	31DQ04	31DQ05	
		√	SR302	SR303	SR304	SR305	SR306
5A		√	1N5823	1N5824	1N5825		
		√	SR502	SR503	SR504	SR505	SR506
		√	SB520	SB530	SB540	SB550	SB560
	√			50WQ03	50WQ04	50WQ05	

Typical System Application for EPC/Notebook Car Adapter – Boost (Output 18.5V/2.5A)

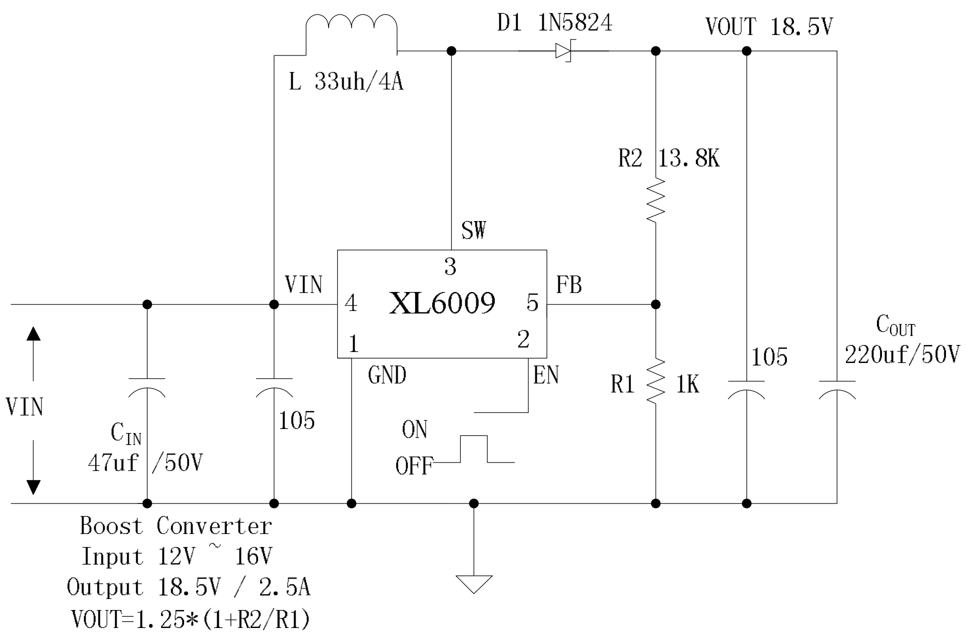


Figure5. XL6009 Typical System Application (Boost Converter)

Typical System Application for Portable Notebook Car Adapter
– SEPIC Buck-Boost Topology (Input 10V~30V, Output 12V/2A)

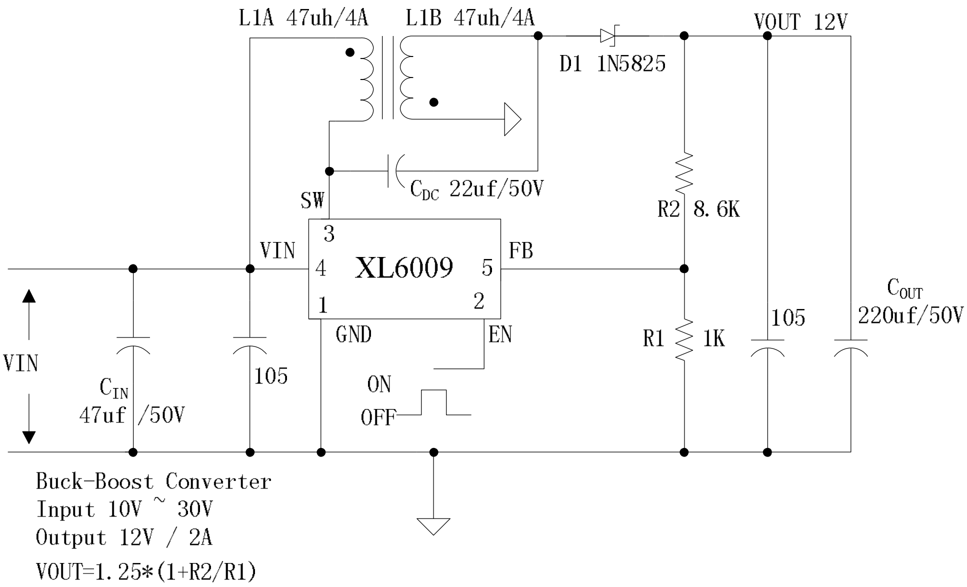


Figure6. XL6009 Typical System Application (SEPIC Buck-Boost Converter)

Typical System Application for Inverting Converter
– SEPIC Inverting Topology (Input 10V~30V, Output + -12V/1A)

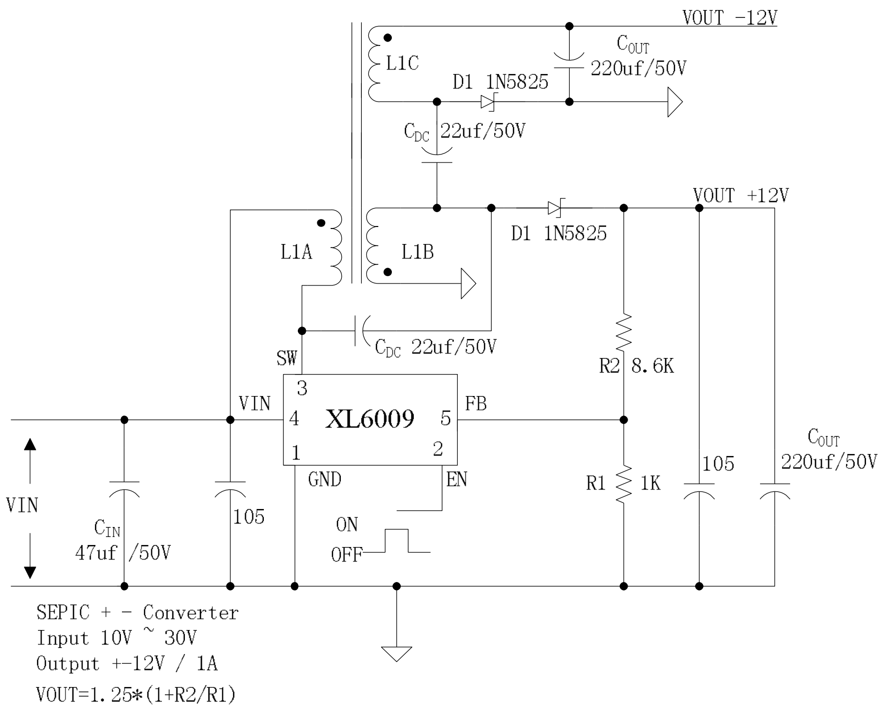
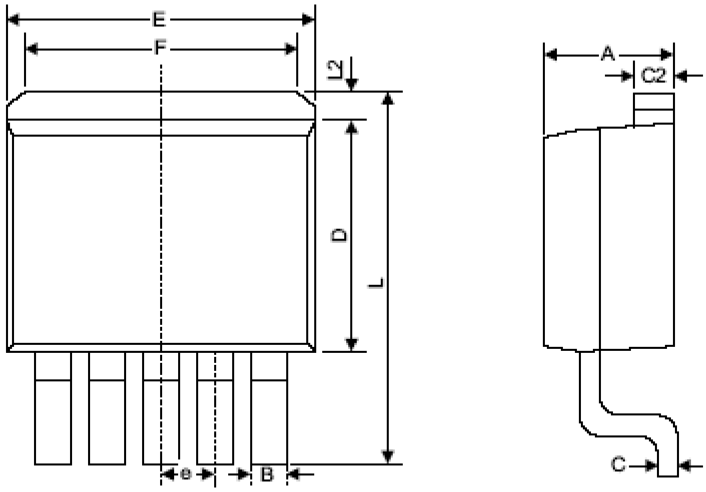
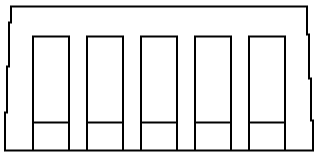


Figure7. XL6009 Typical System Application (SEPIC Inverting Converter)

Package Information

TO263-5L





Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	4.440	4.650	0.175	0.183
B	0.710	0.970	0.028	0.038
C	0.360	0.640	0.014	0.025
C2	1.255	1.285	0.049	0.051
D	8.390	8.890	0.330	0.350
E	9.960	10.360	0.392	0.408
e	1.550	1.850	0.061	0.073
F	6.360	7.360	0.250	0.290
L	13.950	14.750	0.549	0.581
L2	1.120	1.420	0.044	0.056

Sealed Lead-Acid Battery
General Purpose

537-7305(12V12Ah)

Specification

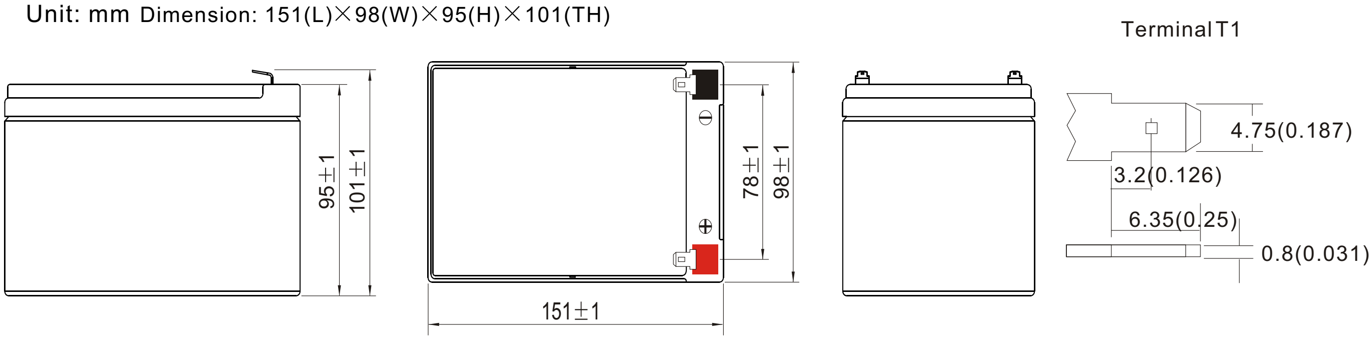
Cells Per Unit	6
Voltage Per Unit	12
Capacity	12.0Ah@20hr-rate to 1.80V per cell @25°C
Weight	Approx 3.50 kg
Max. Discharge Current	180 A(5 sec)
Internal Resistance	Approx 14mΩ
Operating Temp.Range	Discharge : -15~50°C (5~122°F) Charge : 0~40°C (32~104°F) Storage : -15~40°C (5~104°F)
Nominal Operating Temp. Range	25±3°C (77±5°F)
Float charging Voltage	13.5 to 13.8 VDC/unit Average at 25°C
Recommended Maximum Charging Current Limit	3.6A
Equalization and Cycle Service	14.4 to 15.0 VDC/unit Average at 25°C
Self Discharge	The batteries can be stored for more than 6 months at 25°C. Self-discharge ratio less than 3% per month at 25°C. Please charge batteries before using.
Terminal	T1
Container Material	A.B.S. (UL94-HB) , Flammability resistance of UL94-V0 can be available upon request.

Applications

- *All purpose*
- *Uninterruptable Power Supply (UPS)*
- *Electric Power System (EPS)*
- *Emergency backup power supply*
- *Emergency light*
- *Railway signal*
- *Aircraft signal*
- *Alarm and security system*
- *Electronic apparatus and equipment*
- *Communication power supply*
- *DC power supply*
- *Auto control system*

Dimensions

Unit: mm Dimension: 151(L)×98(W)×95(H)×101(TH)



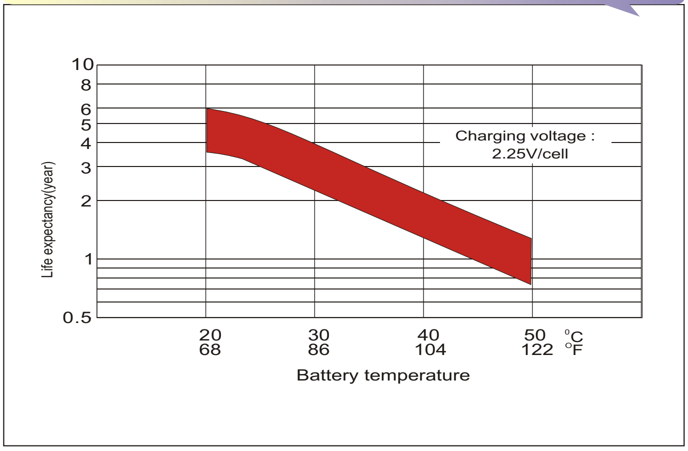
Constant Current Discharge Characteristics : A (25°C) — Amps

F.V/Time	5min	10min	15min	20min	30min	45min	1h	2h	3h	4h	5h	6h	8h	10h	20h
1.85V/cell	22.9	17.5	14.5	12.6	9.72	7.16	6.03	3.57	2.79	2.27	1.85	1.61	1.30	1.08	0.594
1.80V/cell	30.7	22.4	17.6	14.9	11.5	8.33	6.76	3.90	3.00	2.42	1.99	1.72	1.37	1.12	0.600
1.75V/cell	34.6	24.6	19.2	16.0	11.9	8.64	7.07	4.04	3.06	2.48	2.04	1.77	1.40	1.15	0.606
1.70V/cell	38.1	26.9	20.5	16.8	12.4	8.99	7.29	4.14	3.15	2.54	2.09	1.81	1.42	1.17	0.617
1.65V/cell	42.0	29.0	21.8	17.8	13.1	9.21	7.46	4.20	3.28	2.63	2.15	1.85	1.44	1.19	0.625
1.60V/cell	46.3	31.5	23.3	19.0	13.8	9.60	7.54	4.38	3.38	2.71	2.22	1.89	1.45	1.21	0.629

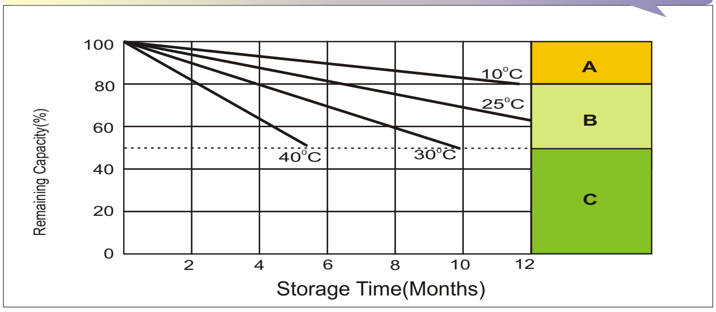
Constant Power Discharge Characteristics : W (25°C) — Watts

F.V/Time	5min	10min	15min	20min	30min	45min	1h	2h	3h	4h	5h	6h	8h	10h	20h
1.85V/cell	41.8	32.4	27.1	23.7	18.5	13.8	11.6	6.93	5.44	4.44	3.63	3.16	2.56	2.14	1.18
1.80V/cell	55.5	40.9	32.3	27.6	21.5	15.9	13.0	7.51	5.82	4.71	3.88	3.37	2.71	2.21	1.19
1.75V/cell	61.2	44.3	34.9	29.4	22.2	16.3	13.5	7.76	5.91	4.80	3.97	3.46	2.75	2.26	1.20
1.70V/cell	65.6	47.1	36.7	30.7	22.9	16.9	13.9	7.94	6.06	4.92	4.06	3.52	2.78	2.31	1.22
1.65V/cell	71.3	50.4	38.7	32.3	24.0	17.2	14.1	8.01	6.29	5.07	4.16	3.59	2.82	2.35	1.23
1.60V/cell	76.8	53.5	40.8	34.1	25.2	17.8	14.2	8.31	6.45	5.21	4.28	3.65	2.84	2.37	1.24

Effect of Temperature on Long Term Float Life



Self Discharge Characteristics

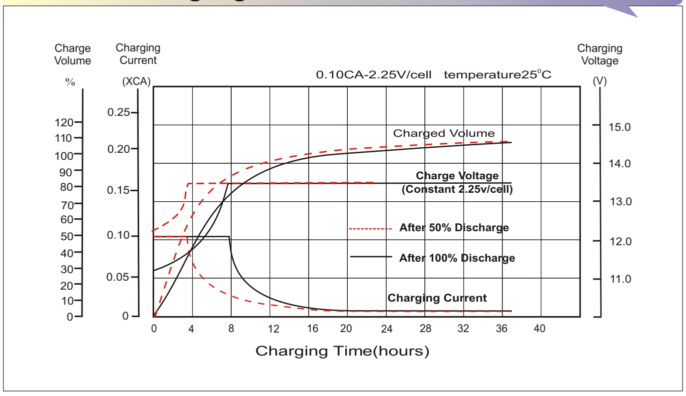


A No supplementary charge required
(Carry out supplementary charge before use if 100% capacity is required.)

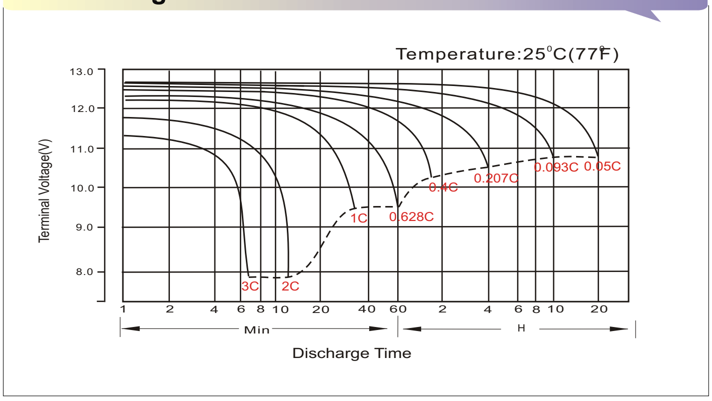
B Supplementary charge required before use.Optional charging way as below:
1.Charged for above 3 days at limted current 0.25CA and constant volatge 2.25V/cell.
2.Charged for above 20hours at limted current 0.25CA and constant volatge 2.45V/cell.
3.Charged for 8~10hours at limted current 0.05CA .

C Avoid this storage period unless regular Top charge.
Supplementary charge may often fail to recover the full capacity

Float Charging Characteristics



Discharge Characteristics



Available Capacity Subject to Temperature

Battery Type		-20℃	-10℃	0℃	5℃	10℃	20℃	25℃	30℃	40℃	45℃
AGM Battery	6V&12V	46%	66%	76%	83%	90%	98%	100%	103%	107%	109%

Discharge Current VS. Discharge Voltage

Final Discharge Voltage V/cell	1.80V	1.75V	1.60V
Discharge Current (A)	（A）≤0.2C	0.2C＜（A）＜1.0C	（A）≥1.0C

Charge the batteries at least once every six months, if they are stored at 25°C.

Charging Method:

Constant Voltage	-0.2Cx2h+2.4~2.45V/Cellx24h,Max. Current 0.3CA
Constant Current	0.1C until the voltage reaching 14.4V,then 0.1Cx4h

Pb

Maintenance & Cautions

Float Service:
◆It is recommended to check battery/Float voltage each month.
Equalisation charge:
◆Equalisation charging is recommended once every 3 to 6 months using.
◆Discharge 100% rated capacity.
◆Charge 2.35v/cell constant voltage, maximum 0.3CA 24hrs.
Cyclic Service:
◆Temperature compensation for varying temperatures:
-Charge voltage -3mV/Cell/degC from 25degC norm.
◆The service life of your battery will be affected by:
-The number of discharge cycles, depth of discharge, ambient
temperature and charging voltage.

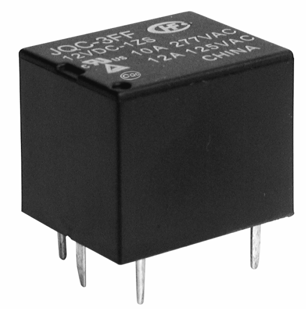
Issue date: Oct. 2014

JQC-3FF SUBMINIATURE HIGH POWER RELAY

File No.:R50034671

File No.:E133481

File No.:CQC02001001953



Features

* Extremely low cost
* SPST-NO & SPDT configuration
* Subminiature, standard PCB layout
* Sealed IP67 and Flux proof types available

CONTACT DATA

Contact Arrangement	1A	1C
Initial Contact Resistance Max.	100mΩ (at 1A 6VDC)	
Contact Material	Silver Alloy	
Contact Rating (Res. Load)	10A 277VAC	7A 250VDC 10A 277VAC
Max. switching voltage	277VAC/30VDC	
Max. switching current	15A	10A
Max. switching power	2770VA 210W	
Mechanical life		1 x 10^7OPS
Electrical life		1 x 10^5OPS

CHARACTERISTICS

Initial Insulation Resistance		100MΩ ,500VDC
Dielectric Strength	Between coil and contacts	1500VAC, 1min
	Between open contacts	750VAC, 1min
Operate time (at nomi. Volt.)		Max. 10ms
Release time (at nomi. Volt.)		Max. 5ms
Temperature rise (at nomi. Volt.)		Max. 60˚C
Shock Resistance	Functional	98 m/s^2(10g)
	Destructive	980 m/s^2(100g)
Vibration Resistance		1.5mm, 10 to 55Hz
Humidity		35% to 85%RH
Ambient temperature		-40˚C to +85˚C
Termination		PCB
Unit weight		Approx. 10g
Construction		Sealed IP67 & Flux proof

COIL

Coil power	0.36W*48VDC : 0.51W*

COIL DATA

Nominal Voltage VDC	Pick-up Voltage VDC	Drop-out Voltage VDC	Max. allowable Voltage VDC(at 25˚C)	Coil Resistance Ω
5	3.80	0.5	6.5	70 ± 10%
6	4.50	0.6	7.8	100 ± 10%
9	6.80	0.9	11.7	225 ± 10%
12	9.00	1.2	15.6	400 ± 10%
18	13.5	1.8	23.4	900 ± 10%
24	18.0	2.4	31.2	1600 ± 10%
48	36.0	4.8	62.4	4500 ± 10%

SAFETY APPROVAL RATINGS

UL	1 Form C	10A 277 VAC 10A 120VAC 1/2 HP 125/250VAC
	1 Form A	10A 277VAC TV-5 120VAC 15A 125VAC 120VAC 125VAC 1/2hp,125VAC
TÜV	1 Form C	8A 250VAC 12A 125VAC cos phi=1 5A 250VAC cos phi=1
	1 Form A	10A 277VAC 12A 125VAC cos phi=1 5A 250VAC cos phi=1

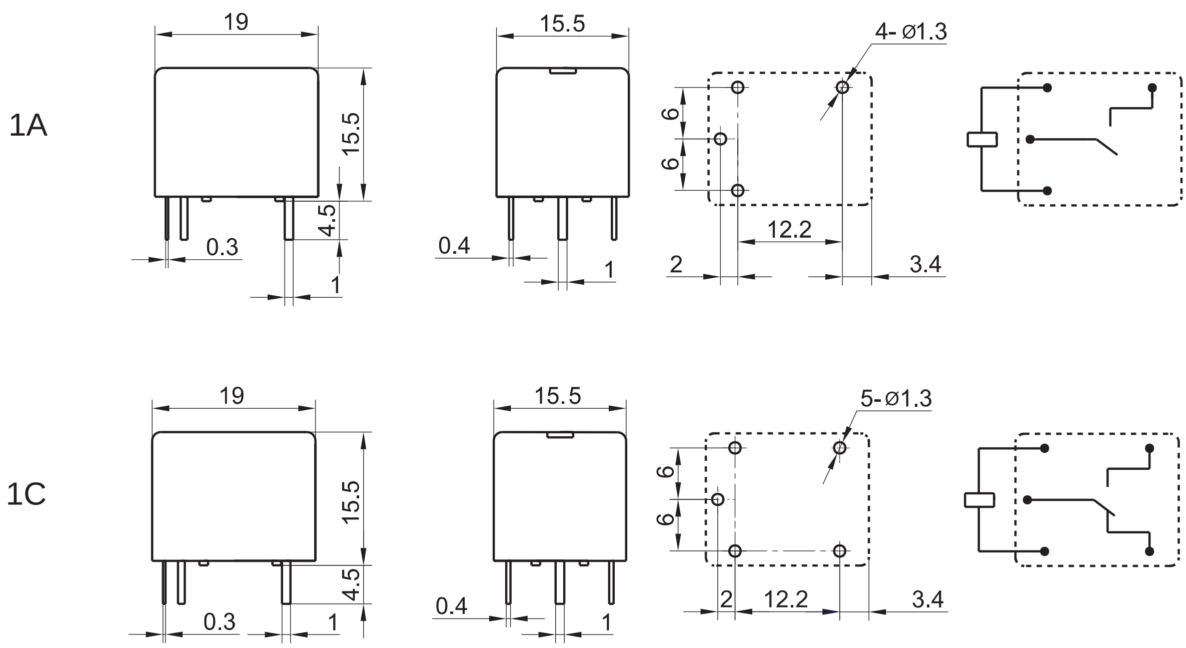
ORDERING INFORMATION

JQC-3FF / 012 1H S T F

Type	JQC-3FF
Coil voltage	5, 6, 9, 12, 18, 24, 48VDC
Contact arrangement	**1H**:1 Form A (SPST-NO) **1Z**:1 Form C (SPDT)
Structure	**S**: Sealed IP67 **Nil**: Flux proof
Contact Material	**T**: $AgSnO_2$ **Nil**: AgCdo
Insulation System	**F**: Class F 155˚C **Nil**: Class B 130˚C

OUTLINE DIMENSIONS, WIRING DIAGRAM AND PC BOARD LAYOUT

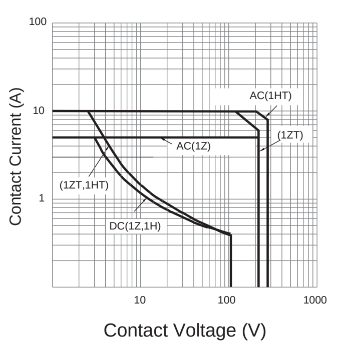
Outline Dimensions PCB layout Wiring Diagram



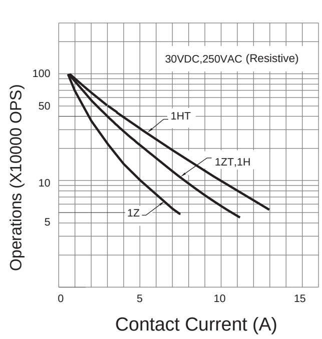
Bottom view Bottom view

CHARACTERISTICS CURVE

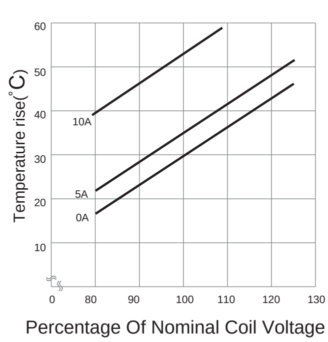
MAXIMUM SWITCHING POWER



LIFE CURVE



COIL TEMPERATURE RISE



LM555 Timer

1 Features

- Direct Replacement for SE555/NE555
- Timing from Microseconds through Hours
- Operates in Both Astable and Monostable Modes
- Adjustable Duty Cycle
- Output Can Source or Sink 200 mA
- Output and Supply TTL Compatible
- Temperature Stability Better than 0.005% per °C
- Normally On and Normally Off Output
- Available in 8-pin VSSOP Package

2 Applications

- Precision Timing
- Pulse Generation
- Sequential Timing
- Time Delay Generation
- Pulse Width Modulation
- Pulse Position Modulation
- Linear Ramp Generator

3 Description

The LM555 is a highly stable device for generating accurate time delays or oscillation. Additional terminals are provided for triggering or resetting if desired. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For a stable operation as an oscillator, the free running frequency and duty cycle are accurately controlled with two external resistors and one capacitor. The circuit may be triggered and reset on falling waveforms, and the output circuit can source or sink up to 200 mA or drive TTL circuits.

Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LM555	SOIC (8)	4.90 mm × 3.91 mm
	PDIP (8)	9.81 mm × 6.35 mm
	VSSOP (8)	3.00 mm × 3.00 mm

(1) For all available packages, see the orderable addendum at the end of the datasheet.

Schematic Diagram

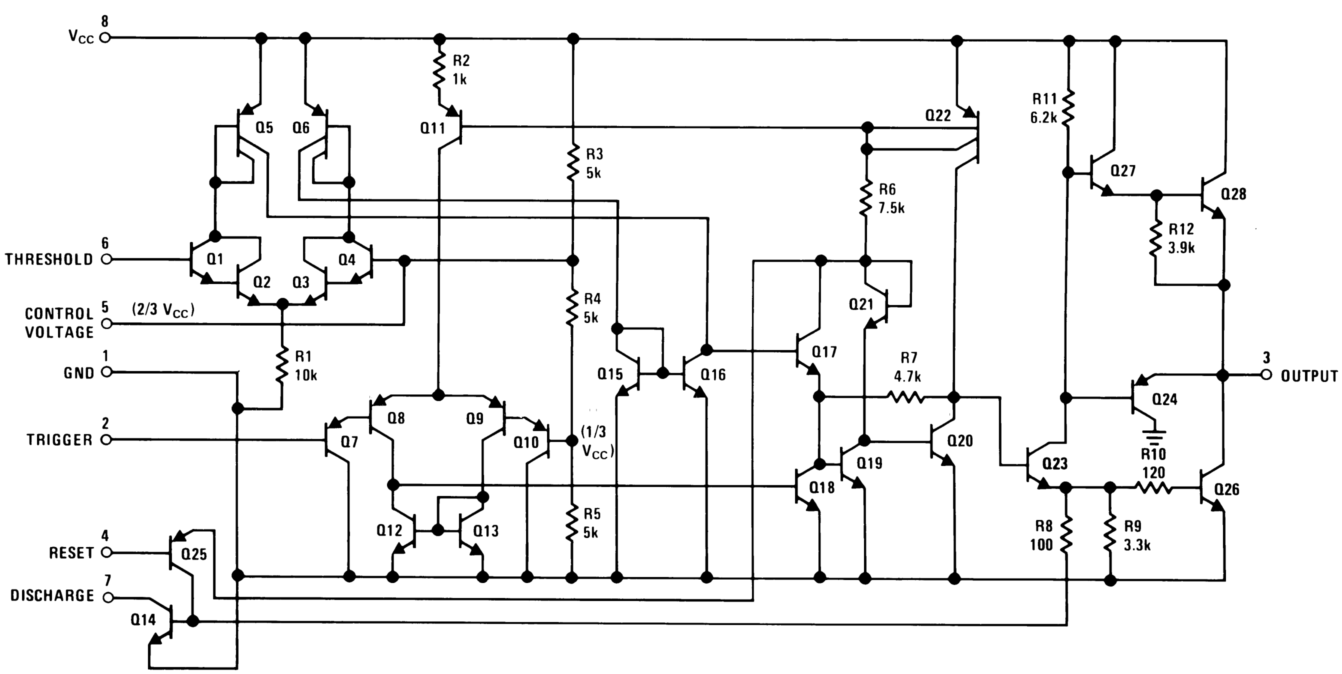


Table of Contents

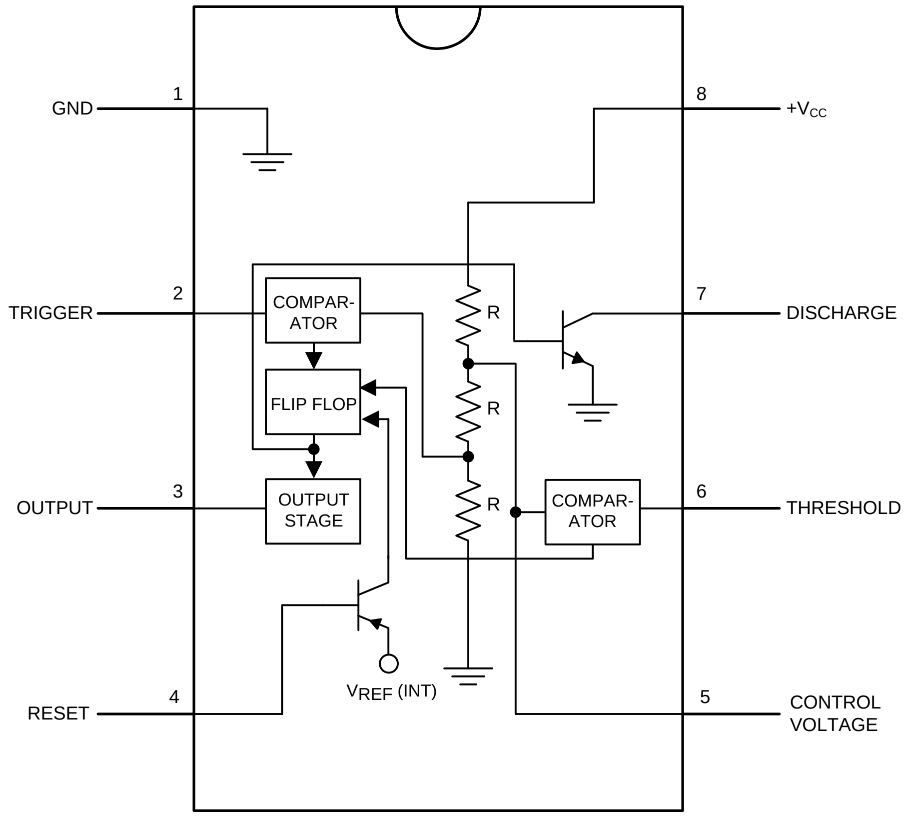
4 Revision History

Changes from Revision C (March 2013) to Revision D	Page
• Added *Pin Configuration and Functions* section, *ESD Ratings* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section	1

Changes from Revision B (March 2013) to Revision C	Page
• Changed layout of National Data Sheet to TI format	13

5 Pin Configuration and Functions

D, P, and DGK Packages
8-Pin PDIP, SOIC, and VSSOP
Top View



Pin Functions

PIN		I/O	DESCRIPTION
NO.	NAME		
5	Control Voltage	I	Controls the threshold and trigger levels. It determines the pulse width of the output waveform. An external voltage applied to this pin can also be used to modulate the output waveform
7	Discharge	I	Open collector output which discharges a capacitor between intervals (in phase with output). It toggles the output from high to low when voltage reaches 2/3 of the supply voltage
1	GND	O	Ground reference voltage
3	Output	O	Output driven waveform
4	Reset	I	Negative pulse applied to this pin to disable or reset the timer. When not used for reset purposes, it should be connected to VCC to avoid false triggering
6	Threshold	I	Compares the voltage applied to the terminal with a reference voltage of 2/3 Vcc. The amplitude of voltage applied to this terminal is responsible for the set state of the flip-flop
2	Trigger	I	Responsible for transition of the flip-flop from set to reset. The output of the timer depends on the amplitude of the external trigger pulse applied to this pin
8	V^+	I	Supply voltage with respect to GND

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)(2)

			MIN	MAX	UNIT
Power Dissipation(3)		LM555CM, LM555CN(4)		1180	mW
		LM555CMM		613	mW
Soldering Information	PDIP Package	Soldering (10 Seconds)		260	°C
	Small Outline Packages (SOIC and VSSOP)	Vapor Phase (60 Seconds)		215	°C
		Infrared (15 Seconds)		220	°C
Storage temperature, T_{stg}			–65	150	°C

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
(2) If Military/Aerospace specified devices are required, please contact the TI Sales Office/Distributors for availability and specifications.
(3) For operating at elevated temperatures the device must be derated above 25°C based on a 150°C maximum junction temperature and a thermal resistance of 106°C/W (PDIP), 170°C/W (S0IC-8), and 204°C/W (VSSOP) junction to ambient.
(4) Refer to RETS555X drawing of military LM555H and LM555J versions for specifications.

6.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001(1)	±500(2)	V

(1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
(2) The ESD information listed is for the SOIC package.

6.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

	MIN	MAX	UNIT
Supply Voltage		18	V
Temperature, T_A	0	70	°C
Operating junction temperature, T_J		70	°C

6.4 Thermal Information

THERMAL METRIC(1)		LM555			UNIT
		PDIP	SOIC	VSSOP	
		8 PINS			
$R_{\theta JA}$	Junction-to-ambient thermal resistance	106	170	204	°C/W

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.

6.5 Electrical Characteristics

(T_A = 25°C, V_{CC} = 5 V to 15 V, unless otherwise specified)(1)(2)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Supply Voltage		4.5		16	V
Supply Current	V_{CC} = 5 V, R_L = ∞		3	6	mA
	V_{CC} = 15 V, R_L = ∞ (Low State) (3)		10	15	
Timing Error, Monostable					
Initial Accuracy			1 %		
Drift with Temperature	R_A = 1 k to 100 kΩ,		50		ppm/°C
	C = 0.1 µF, (4)				
Accuracy over Temperature			1.5 %		
Drift with Supply			0.1 %		V
Timing Error, Astable					
Initial Accuracy			2.25		
Drift with Temperature	R_A, R_B =1 k to 100 kΩ,		150		ppm/°C
	C = 0.1 µF, (4)				
Accuracy over Temperature			3.0%		
Drift with Supply			0.30 %		/V
Threshold Voltage			0.667		x V_{CC}
Trigger Voltage	V_{CC} = 15 V		5		V
	V_{CC} = 5 V		1.67		V
Trigger Current			0.5	0.9	µA
Reset Voltage		0.4	0.5	1	V
Reset Current			0.1	0.4	mA
Threshold Current	(5)		0.1	0.25	µA
Control Voltage Level	V_{CC} = 15 V	9	10	11	V
	V_{CC} = 5 V	2.6	3.33	4	
Pin 7 Leakage Output High			1	100	nA
Pin 7 Sat (6)					
Output Low	V_{CC} = 15 V, I_7 = 15 mA		180		mV
Output Low	V_{CC} = 4.5 V, I_7 = 4.5 mA		80	200	mV
Output Voltage Drop (Low)	V_{CC} = 15 V				
	I_{SINK} = 10 mA		0.1	0.25	V
	I_{SINK} = 50 mA		0.4	0.75	V
	I_{SINK} = 100 mA		2	2.5	V
	I_{SINK} = 200 mA		2.5		V
	V_{CC} = 5 V				
	I_{SINK} = 8 mA				V
	I_{SINK} = 5 mA		0.25	0.35	V

(1) All voltages are measured with respect to the ground pin, unless otherwise specified.
(2) *Absolute Maximum Ratings* indicate limits beyond which damage to the device may occur. *Recommended Operating Conditions* indicate conditions for which the device is functional, but do not ensure specific performance limits. *Electrical Characteristics* state DC and AC electrical specifications under particular test conditions which ensures specific performance limits. This assumes that the device is within the *Recommended Operating Conditions*. Specifications are not ensured for parameters where no limit is given, however, the typical value is a good indication of device performance.
(3) Supply current when output high typically 1 mA less at V_{CC} = 5 V.
(4) Tested at V_{CC} = 5 V and V_{CC} = 15 V.
(5) This will determine the maximum value of R_A + R_B for 15 V operation. The maximum total (R_A + R_B) is 20 MΩ.
(6) No protection against excessive pin 7 current is necessary providing the package dissipation rating will not be exceeded.

Electrical Characteristics (continued)

(T_A = 25°C, V_{CC} = 5 V to 15 V, unless otherwise specified)(1)(2)

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
Output Voltage Drop (High)	I_{SOURCE} = 200 mA, V_{CC} = 15 V		12.5		V
	I_{SOURCE} = 100 mA, V_{CC} = 15 V	12.75	13.3		V
	V_{CC} = 5 V	2.75	3.3		V
Rise Time of Output			100		ns
Fall Time of Output			100		ns

6.6 Typical Characteristics

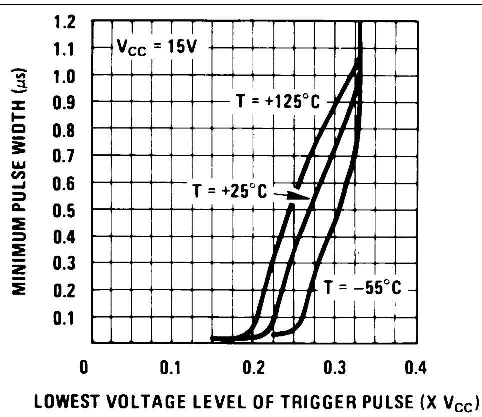


Figure 1. Minimum Pulse Width Required For Triggering

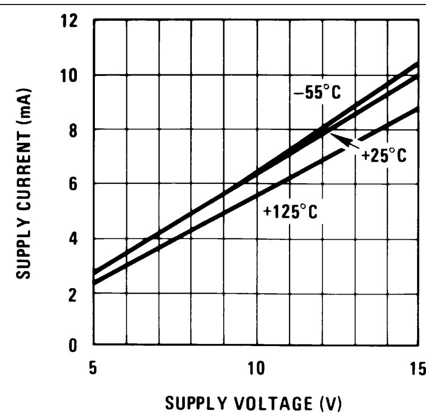


Figure 2. Supply Current vs. Supply Voltage

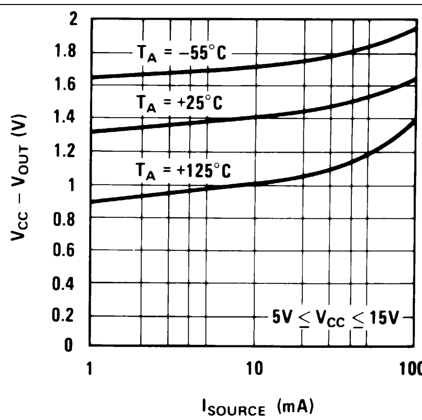


Figure 3. High Output Voltage vs. Output Source Current

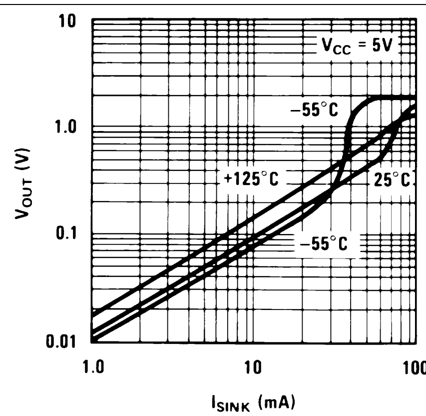


Figure 4. Low Output Voltage vs. Output Sink Current

Typical Characteristics (continued)

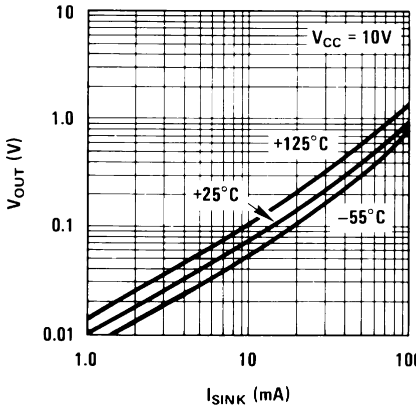


Figure 5. Low Output Voltage vs. Output Sink Current

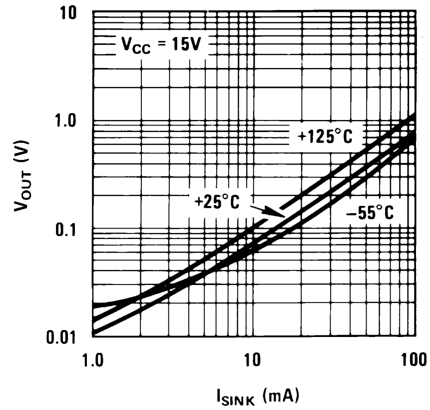


Figure 6. Low Output Voltage vs. Output Sink Current

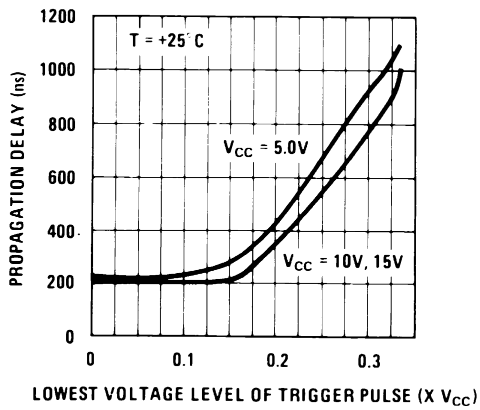


Figure 7. Output Propagation Delay vs. Voltage Level of Trigger Pulse

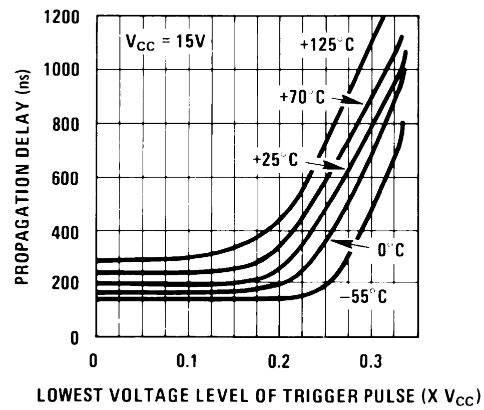


Figure 8. Output Propagation Delay vs. Voltage Level of Trigger Pulse

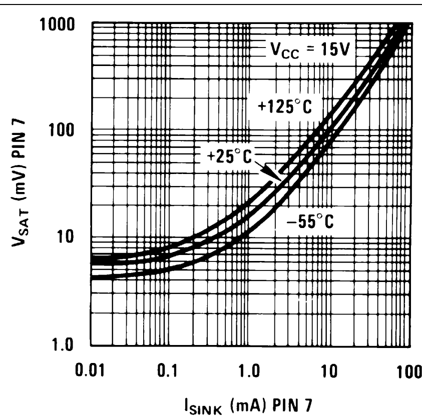


Figure 9. Discharge Transistor (Pin 7) Voltage vs. Sink Current

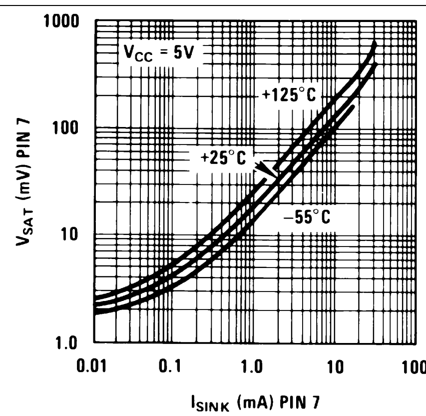


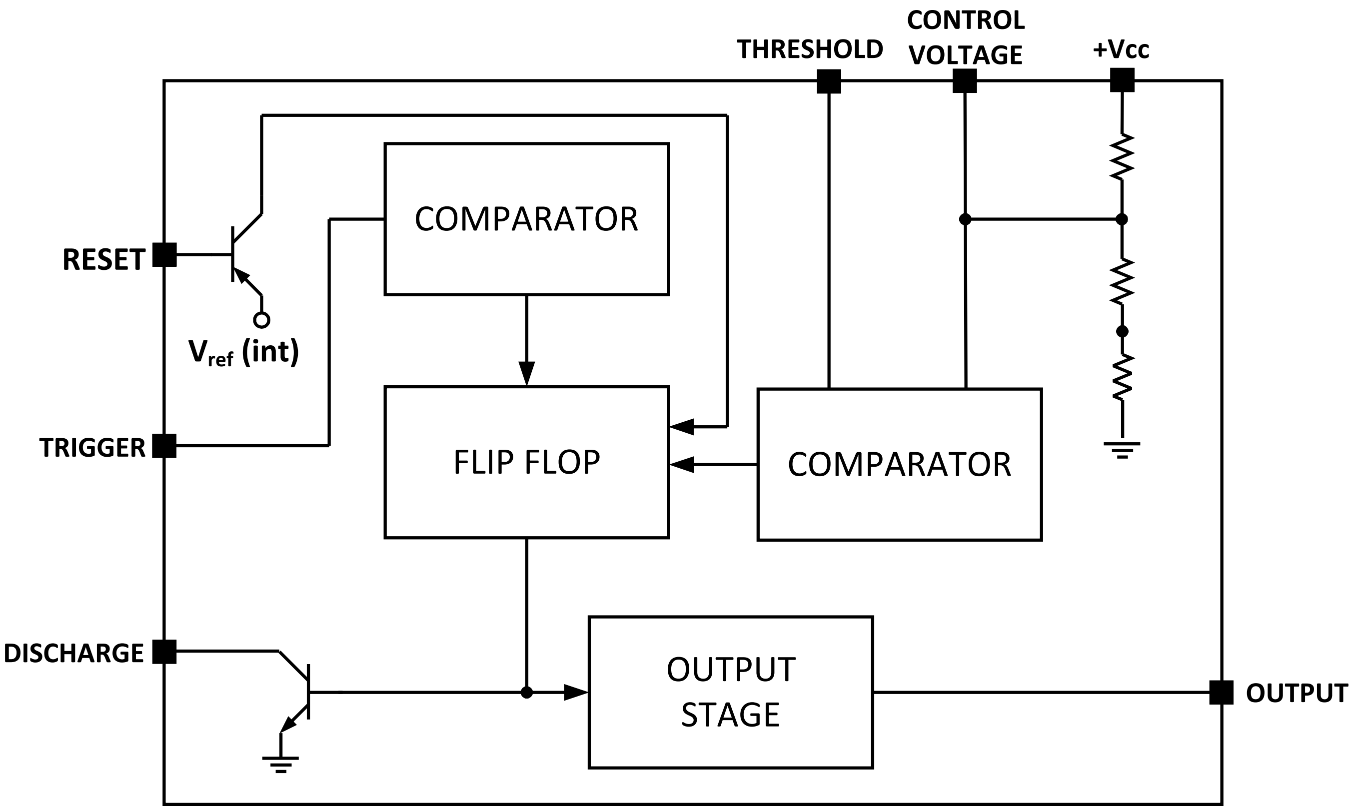
Figure 10. Discharge Transistor (Pin 7) Voltage vs. Sink Current

7 Detailed Description

7.1 Overview

The LM555 is a highly stable device for generating accurate time delays or oscillation. Additional terminals are provided for triggering or resetting if desired. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For astable operation as an oscillator, the free running frequency and duty cycle are accurately controlled with two external resistors and one capacitor. The circuit may be triggered and reset on falling waveforms, and the output circuit can source or sink up to 200mA or driver TTL circuits. The LM555 are available in 8-pin PDIP, SOIC, and VSSOP packages and is a direct replacement for SE555/NE555.

7.2 Functional Block Diagram



7.3 Feature Description

7.3.1 Direct Replacement for SE555/NE555

The LM555 timer is a direct replacement for SE555 and NE555. It is pin-to-pin compatible so that no schematic or layout changes are necessary. The LM555 come in an 8-pin PDIP, SOIC, and VSSOP package.

7.3.2 Timing From Microseconds Through Hours

The LM555 has the ability to have timing parameters from the microseconds range to hours. The time delay of the system can be determined by the time constant of the R and C value used for either the monostable or astable configuration. A nomograph is available for easy determination of R and C values for various time delays.

7.3.3 Operates in Both Astable and Monostable Mode

The LM555 can operate in both astable and monostable mode depending on the application requirements.

- Monostable mode: The LM555 timer acts as a “one-shot” pulse generator. The pulse beings when the LM555 timer receives a signal at the trigger input that falls below a 1/3 of the voltage supply. The width of the output pulse is determined by the time constant of an RC network. The output pulse ends when the voltage on the

Feature Description (continued)

capacitor equals 2/3 of the supply voltage. The output pulse width can be extended or shortened depending on the application by adjusting the R and C values.

- Astable (free-running) mode: The LM555 timer can operate as an oscillator and puts out a continuous stream of rectangular pulses having a specified frequency. The frequency of the pulse stream depends on the values of R_A, R_B, and C.

7.4 Device Functional Modes

7.4.1 Monostable Operation

In this mode of operation, the timer functions as a one-shot (Figure 11). The external capacitor is initially held discharged by a transistor inside the timer. Upon application of a negative trigger pulse of less than 1/3 V_{CC} to pin 2, the flip-flop is set which both releases the short circuit across the capacitor and drives the output high.

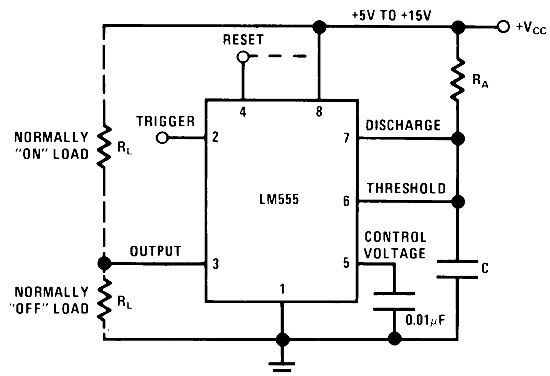
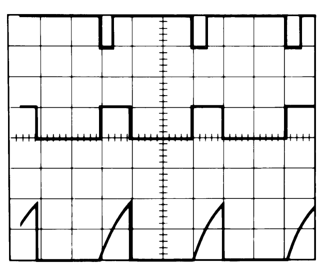


Figure 11. Monostable

The voltage across the capacitor then increases exponentially for a period of t = 1.1 R_A C, at the end of which time the voltage equals 2/3 V_{CC}. The comparator then resets the flip-flop which in turn discharges the capacitor and drives the output to its low state. Figure 12 shows the waveforms generated in this mode of operation. Since the charge and the threshold level of the comparator are both directly proportional to supply voltage, the timing interval is independent of supply.



V_{CC} = 5 V	Top Trace: Input 5V/Div.
TIME = 0.1 ms/DIV.	Middle Trace: Output 5V/Div.
R_A = 9.1 kΩ	Bottom Trace: Capacitor Voltage 2V/Div.
C = 0.01 µF	

Figure 12. Monostable Waveforms

During the timing cycle when the output is high, the further application of a trigger pulse will not effect the circuit so long as the trigger input is returned high at least 10 µs before the end of the timing interval. However the circuit can be reset during this time by the application of a negative pulse to the reset terminal (pin 4). The output will then remain in the low state until a trigger pulse is again applied.

When the reset function is not in use, TI recommends connecting the Reset pin to V_{CC} to avoid any possibility of false triggering.

Device Functional Modes (continued)

Figure 13 is a nomograph for easy determination of R, C values for various time delays.

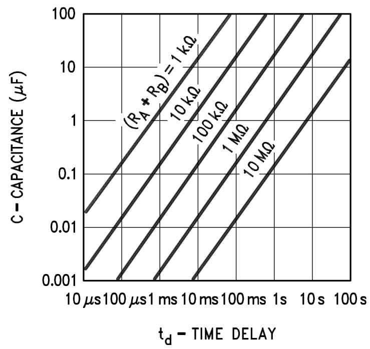


Figure 13. Time Delay

7.4.2 Astable Operation

If the circuit is connected as shown in Figure 14 (pins 2 and 6 connected) it will trigger itself and free run as a multivibrator. The external capacitor charges through R_A + R_B and discharges through R_B. Thus the duty cycle may be precisely set by the ratio of these two resistors.

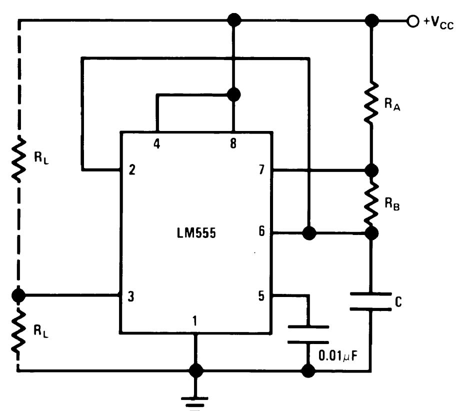
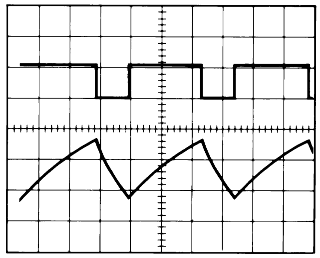


Figure 14. Astable

In this mode of operation, the capacitor charges and discharges between 1/3 V_{CC} and 2/3 V_{CC}. As in the triggered mode, the charge and discharge times, and therefore the frequency are independent of the supply voltage.

Figure 15 shows the waveforms generated in this mode of operation.

Device Functional Modes (continued)



V_{CC} = 5 V
TIME = 20µs/DIV.
R_A = 3.9 kΩ
R_B = 3 kΩ
C = 0.01 µF

Top Trace: Output 5V/Div.
Bottom Trace: Capacitor Voltage 1V/Div.

Figure 15. Astable Waveforms

The charge time (output high) is given by:

$$t_1 = 0.693\ (R_A + R_B)\ C \tag{1}$$

And the discharge time (output low) by:

$$t_2 = 0.693\ (R_B)\ C \tag{2}$$

Thus the total period is:

$$T = t_1 + t_2 = 0.693\ (R_A + 2R_B)\ C \tag{3}$$

The frequency of oscillation is:

$$f = \frac{1}{T} = \frac{1.44}{(R_A + 2\,R_B)\,C} \tag{4}$$

Figure 16 may be used for quick determination of these RC values.

The duty cycle is:

$$D = \frac{R_B}{R_A + 2R_B} \tag{5}$$

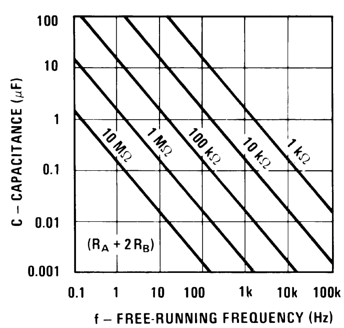


Figure 16. Free Running Frequency

8 Application and Implementation

NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

8.1 Application Information

The LM555 timer can be used a various configurations, but the most commonly used configuration is in monostable mode. A typical application for the LM555 timer in monostable mode is to turn on an LED for a specific time duration. A pushbutton is used as the trigger to output a high pulse when trigger pin is pulsed low. This simple application can be modified to fit any application requirement.

8.2 Typical Application

Figure 17 shows the schematic of the LM555 that flashes an LED in monostable mode.

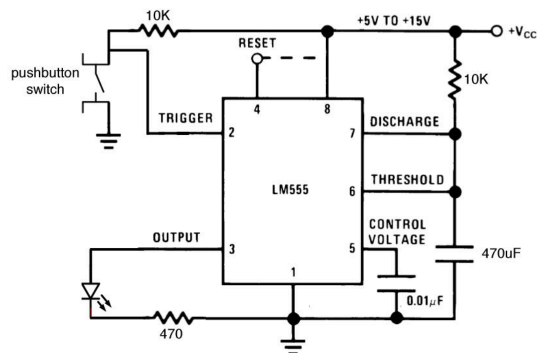


Figure 17. Schematic of Monostable Mode to Flash an LED

8.2.1 Design Requirements

The main design requirement for this application requires calculating the duration of time for which the output stays high. The duration of time is dependent on the R and C values (as shown in Figure 17) and can be calculated by:

$$t = 1.1 \times R \times C \text{ seconds} \quad (6)$$

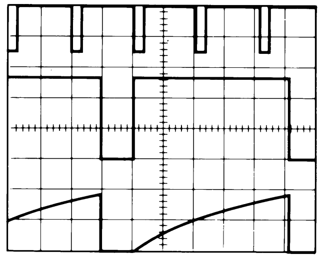
8.2.2 Detailed Design Procedure

To allow the LED to flash on for a noticeable amount of time, a 5 second time delay was chosen for this application. By using Equation 6, RC equals 4.545. If R is selected as 100 kΩ, C = 45.4 µF. The values of R = 100 kΩ and C = 47 µF was selected based on standard values of resistors and capacitors. A momentary push button switch connected to ground is connected to the trigger input with a 10-K current limiting resistor pullup to the supply voltage. When the push button is pressed, the trigger pin goes to GND. An LED is connected to the output pin with a current limiting resistor in series from the output of the LM555 to GND. The reset pin is not used and was connected to the supply voltage.

8.2.2.1 Frequency Divider

The monostable circuit of Figure 11 can be used as a frequency divider by adjusting the length of the timing cycle. Figure 18 shows the waveforms generated in a divide by three circuit.

Typical Application (continued)



V_{CC} = 5 V Top Trace: Input 4 V/Div.
TIME = 20 μs/DIV. Middle Trace: Output 2V/Div.
R_A = 9.1 kΩ Bottom Trace: Capa citor 2V/Div.
C = 0.01 μF

Figure 18. Frequency Divider

8.2.2.2 Additional Information

Lower comparator storage time can be as long as 10 μs when pin 2 is driven fully to ground for triggering. This limits the monostable pulse width to 10 μs minimum.

Delay time reset to output is 0.47 μs typical. Minimum reset pulse width must be 0.3 μs, typical.

Pin 7 current switches within 30 ns of the output (pin 3) voltage.

8.2.3 Application Curves

The data shown below was collected with the circuit used in the typical applications section. The LM555 was configured in the monostable mode with a time delay of 5.17 s. The waveforms correspond to:

- Top Waveform (Yellow) – Capacitor voltage
- Middle Waveform (Green) – Trigger
- Bottom Waveform (Purple) – Output

As the trigger pin pulses low, the capacitor voltage starts charging and the output goes high. The output goes low as soon as the capacitor voltage reaches 2/3 of the supply voltage, which is the time delay set by the R and C value. For this example, the time delay is 5.17 s.

Typical Application (continued)

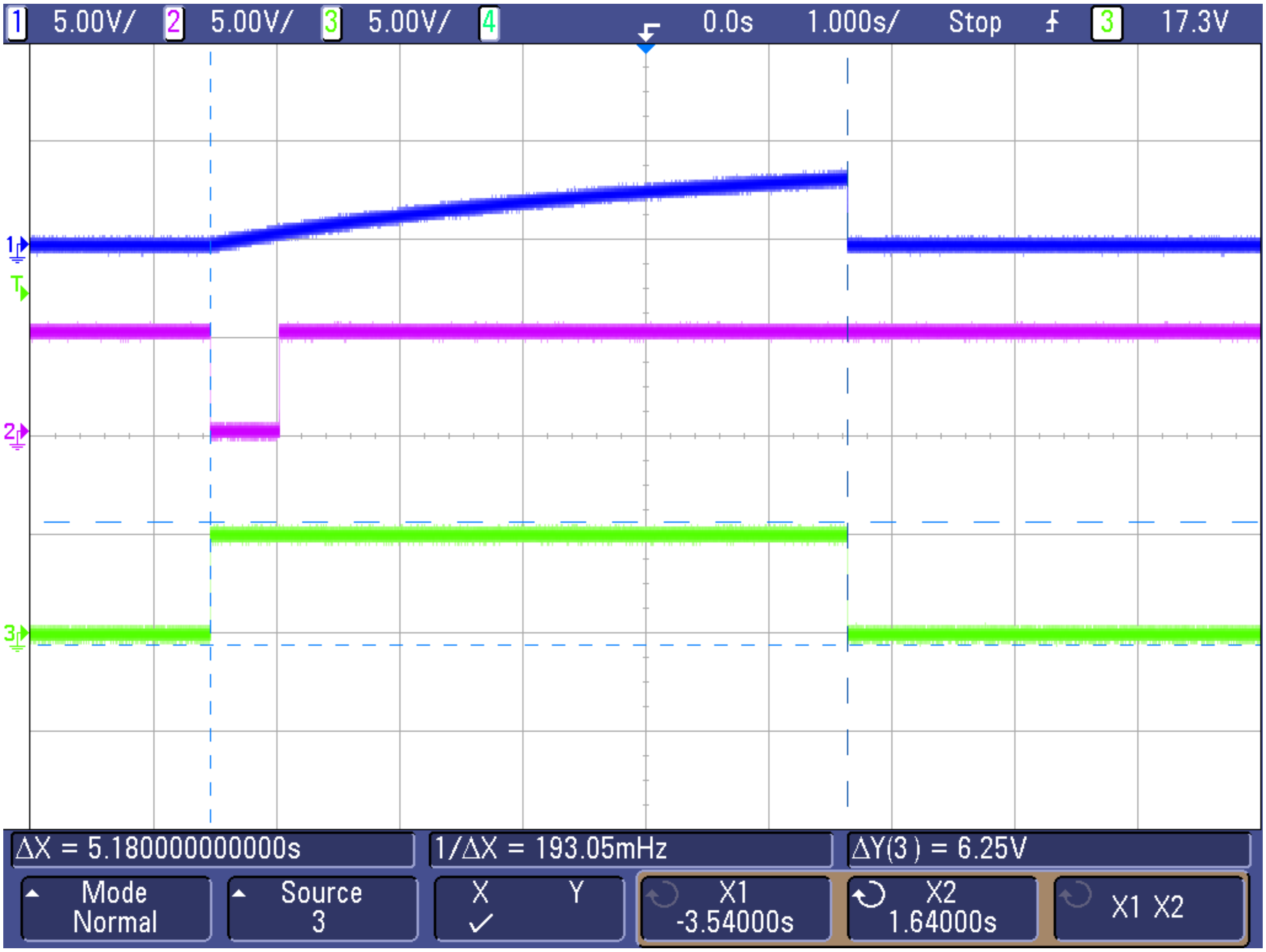


Figure 19. Trigger, Capacitor Voltage, and Output Waveforms in Monostable Mode

9 Power Supply Recommendations

The LM555 requires a voltage supply within 4.5 V to 16 V. Adequate power supply bypassing is necessary to protect associated circuitry. The minimum recommended capacitor value is 0.1 μF in parallel with a 1-μF electrolytic capacitor. Place the bypass capacitors as close as possible to the LM555 and minimize the trace length.

10 Layout

10.1 Layout Guidelines

Standard PCB rules apply to routing the LM555. The 0.1-μF capacitor in parallel with a 1-μF electrolytic capacitor should be as close as possible to the LM555. The capacitor used for the time delay should also be placed as close to the discharge pin. A ground plane on the bottom layer can be used to provide better noise immunity and signal integrity.

Figure 20 is the basic layout for various applications.

- C1 – based on time delay calculations
- C2 – 0.01-μF bypass capacitor for control voltage pin
- C3 – 0.1-μF bypass ceramic capacitor
- C4 – 1-μF electrolytic bypass capacitor
- R1 – based on time delay calculations
- U1 – LMC555

10.2 Layout Example

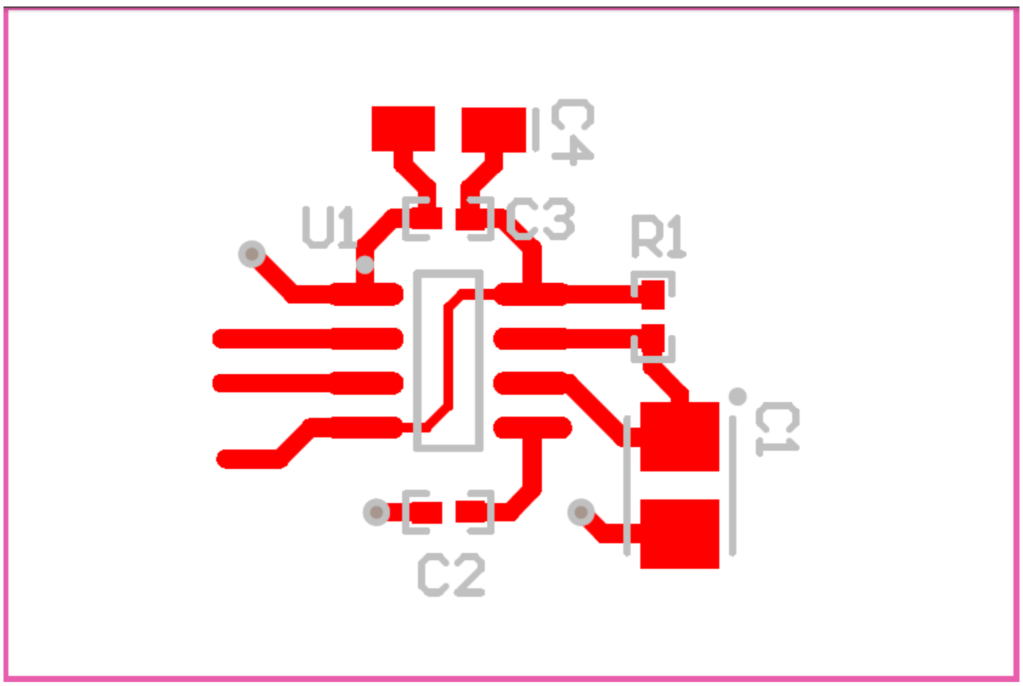


Figure 20. Layout Example

11 Device and Documentation Support

11.1 Trademarks

All trademarks are the property of their respective owners.

11.2 Electrostatic Discharge Caution

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

11.3 Glossary

SLYZ022 — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

12 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
LM555CM	NRND	SOIC	D	8	95	TBD	Call TI	Call TI	0 to 70	LM 555CM	
LM555CM/NOPB	ACTIVE	SOIC	D	8	95	Green (RoHS & no Sb/Br)	SN	Level-1-260C-UNLIM	0 to 70	LM 555CM	Samples
LM555CMM	NRND	VSSOP	DGK	8	1000	TBD	Call TI	Call TI	0 to 70	Z55	
LM555CMM/NOPB	ACTIVE	VSSOP	DGK	8	1000	Green (RoHS & no Sb/Br)	SN	Level-1-260C-UNLIM	0 to 70	Z55	Samples
LM555CMMX/NOPB	ACTIVE	VSSOP	DGK	8	3500	Green (RoHS & no Sb/Br)	SN	Level-1-260C-UNLIM	0 to 70	Z55	Samples
LM555CMX	NRND	SOIC	D	8	2500	TBD	Call TI	Call TI	0 to 70	LM 555CM	
LM555CMX/NOPB	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	SN	Level-1-260C-UNLIM	0 to 70	LM 555CM	Samples
LM555CN/NOPB	ACTIVE	PDIP	P	8	40	Green (RoHS & no Sb/Br)	Call TI | SN	Level-1-NA-UNLIM	0 to 70	LM 555CN	Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

[5] Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

[6] Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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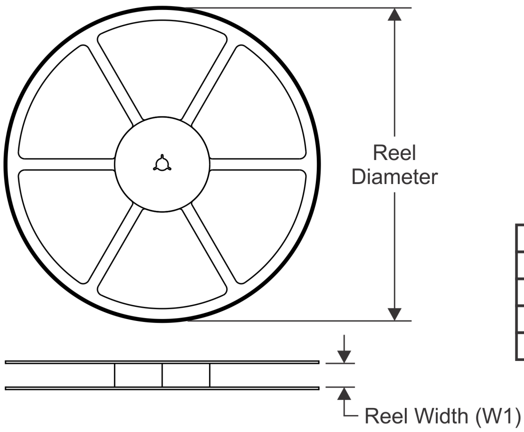
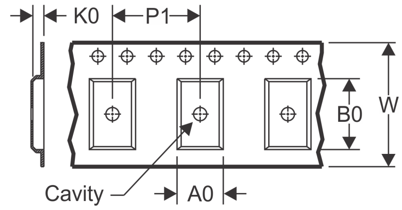
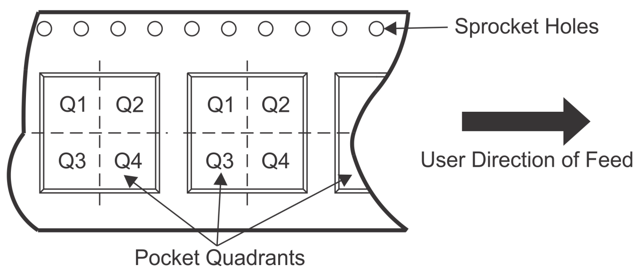
TAPE AND REEL INFORMATION





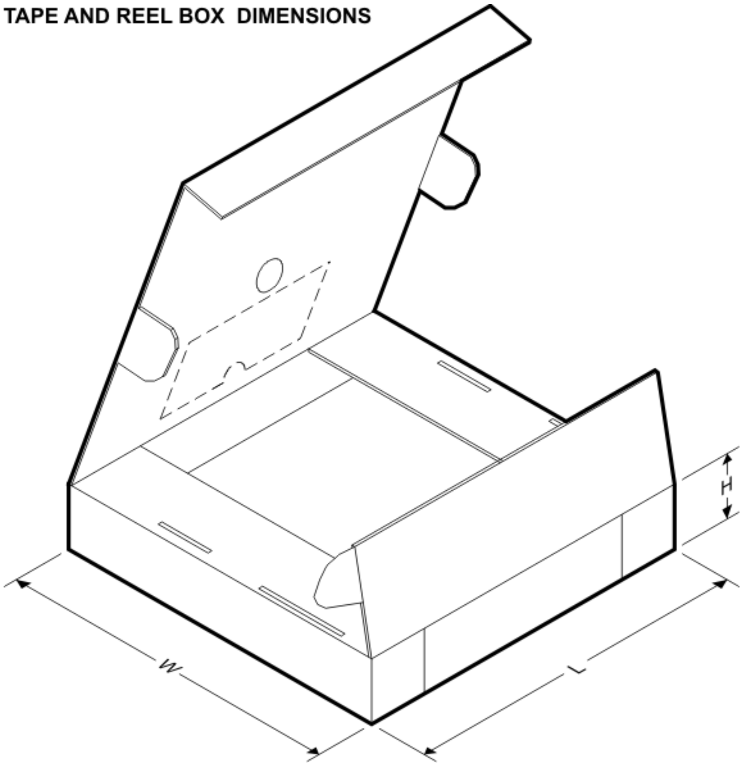
A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers



*All dimensions are nominal

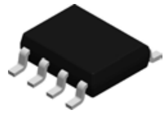
Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
LM555CMM	VSSOP	DGK	8	1000	178.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM555CMM/NOPB	VSSOP	DGK	8	1000	178.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM555CMMX/NOPB	VSSOP	DGK	8	3500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
LM555CMX	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1
LM555CMX/NOPB	SOIC	D	8	2500	330.0	12.4	6.5	5.4	2.0	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
LM555CMM	VSSOP	DGK	8	1000	210.0	185.0	35.0
LM555CMM/NOPB	VSSOP	DGK	8	1000	210.0	185.0	35.0
LM555CMMX/NOPB	VSSOP	DGK	8	3500	367.0	367.0	35.0
LM555CMX	SOIC	D	8	2500	367.0	367.0	35.0
LM555CMX/NOPB	SOIC	D	8	2500	367.0	367.0	35.0

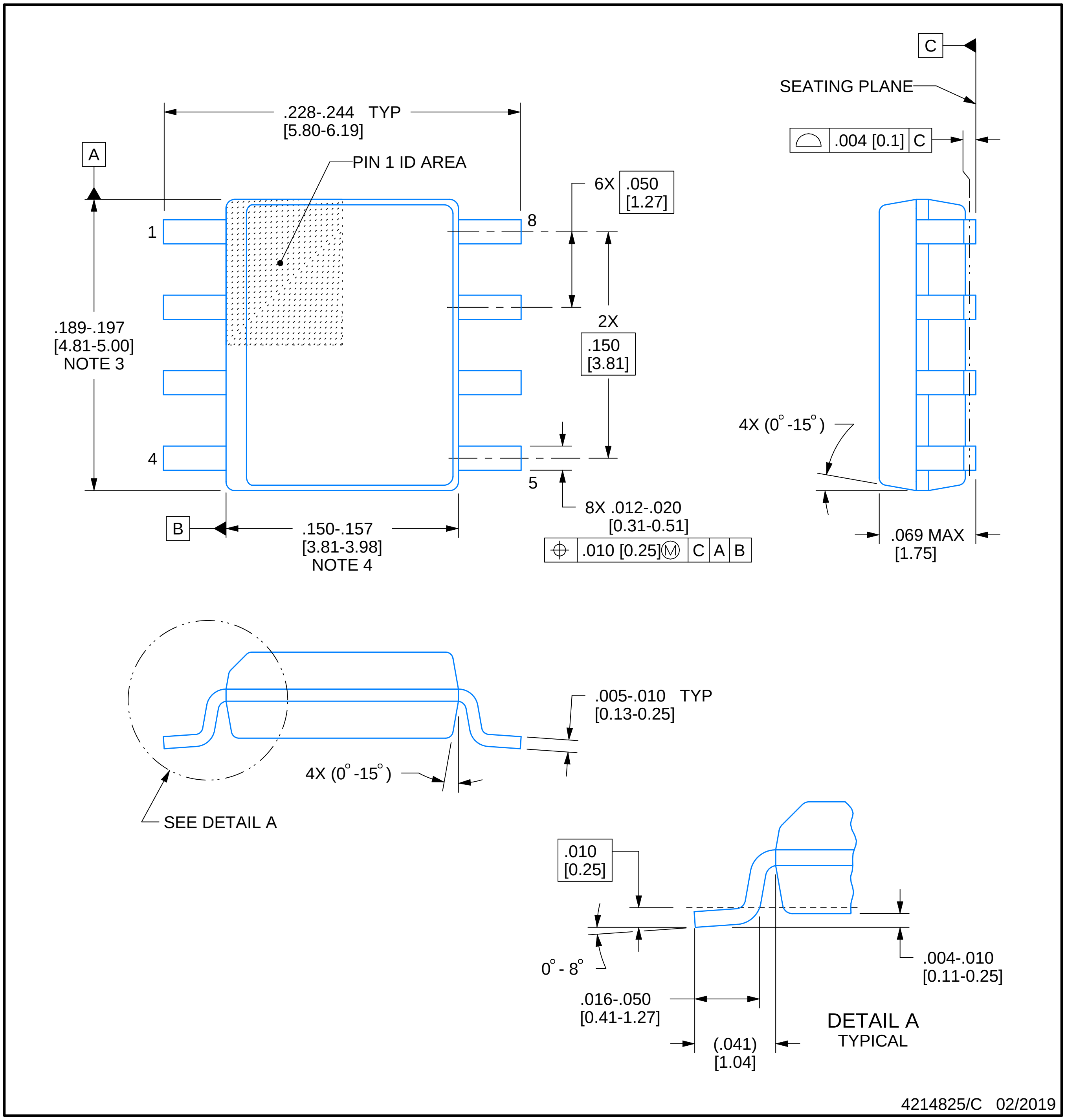


PACKAGE OUTLINE

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



NOTES:

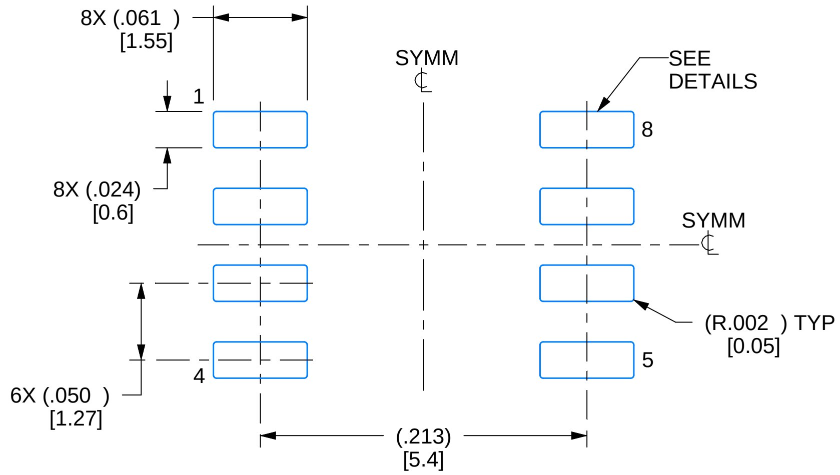
1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed .006 [0.15] per side.
4. This dimension does not include interlead flash.
5. Reference JEDEC registration MS-012, variation AA.

EXAMPLE BOARD LAYOUT

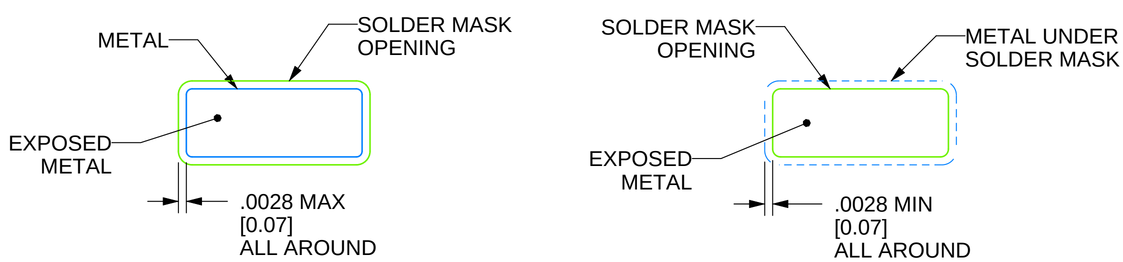
D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:8X



NON SOLDER MASK DEFINED

SOLDER MASK DEFINED

SOLDER MASK DETAILS

4214825/C 02/2019

NOTES: (continued)

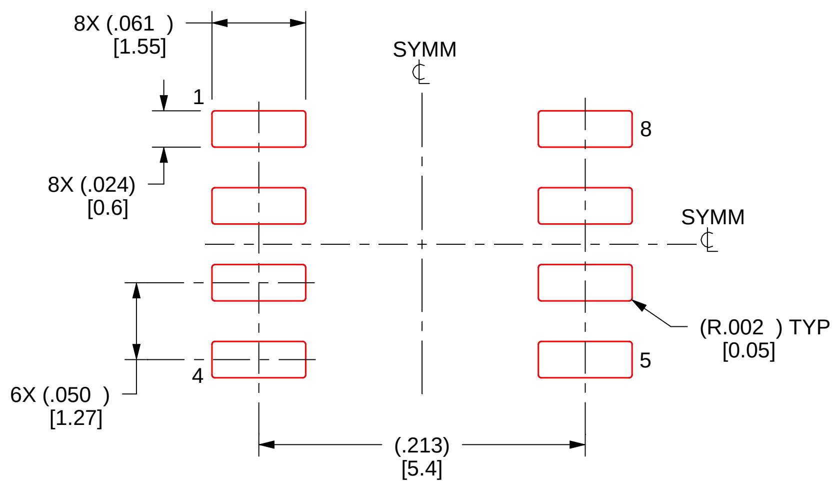
6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



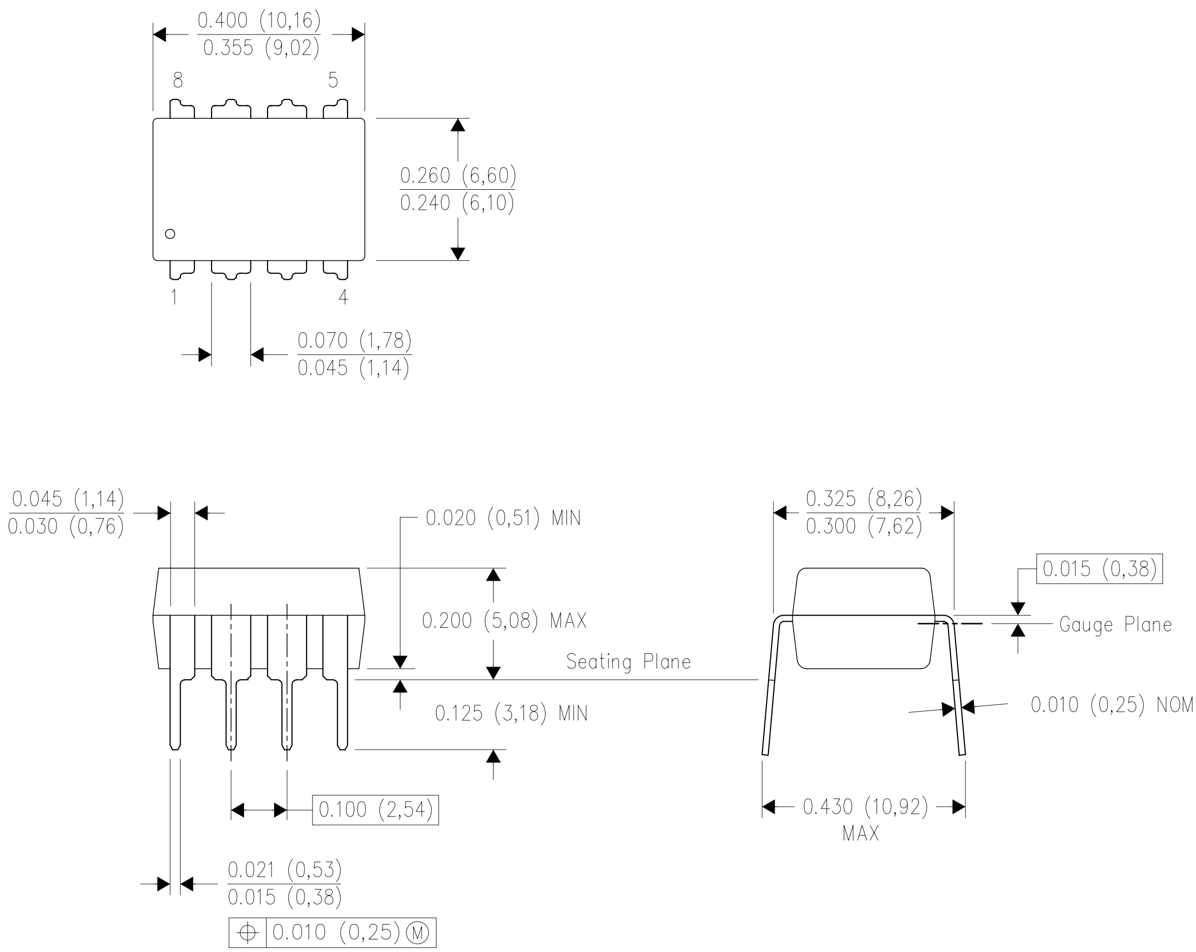
SOLDER PASTE EXAMPLE
BASED ON .005 INCH [0.125 MM] THICK STENCIL
SCALE:8X

4214825/C 02/2019

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

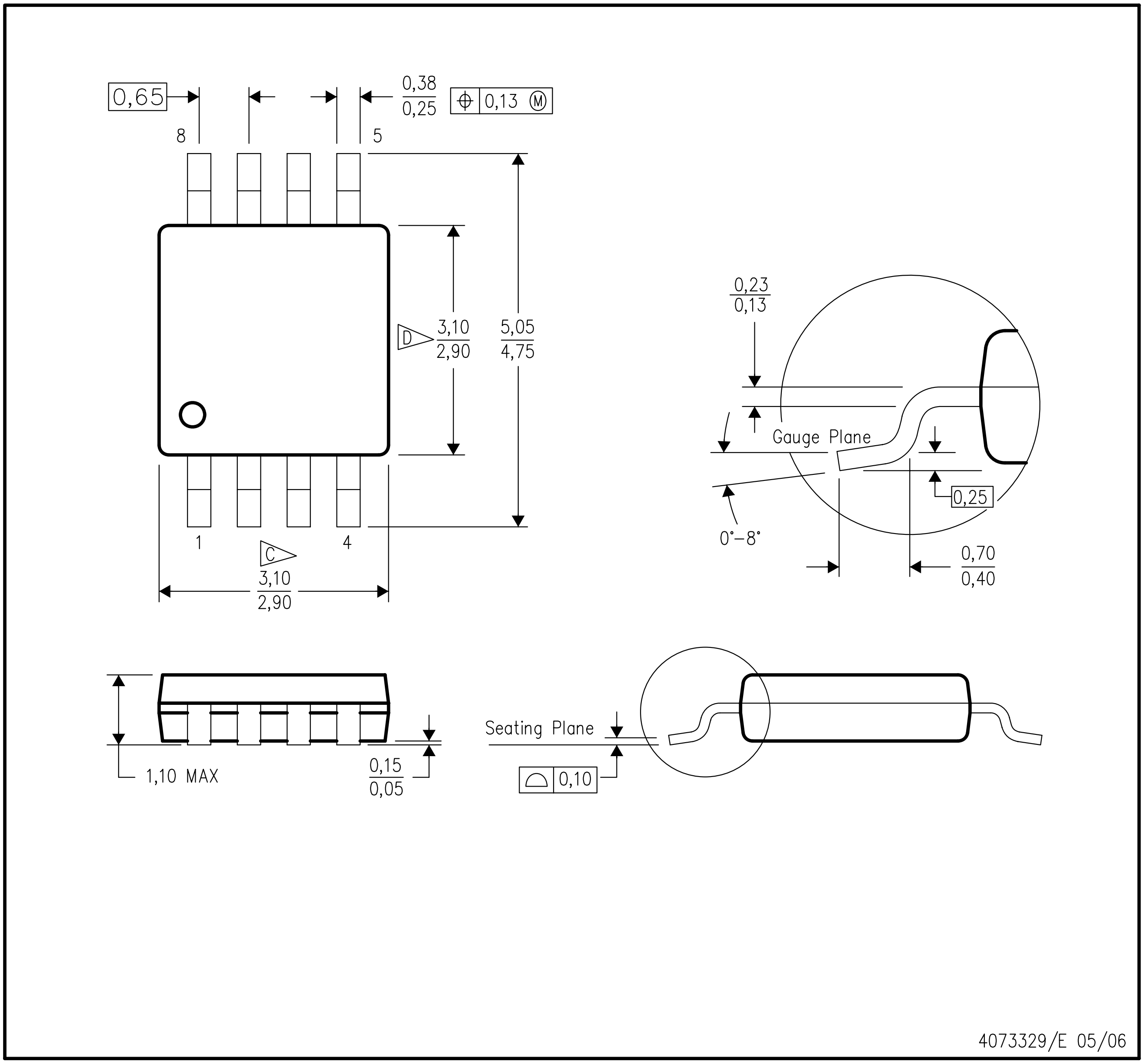
P (R–PDIP–T8) PLASTIC DUAL–IN–LINE PACKAGE



4040082/E 04/2010

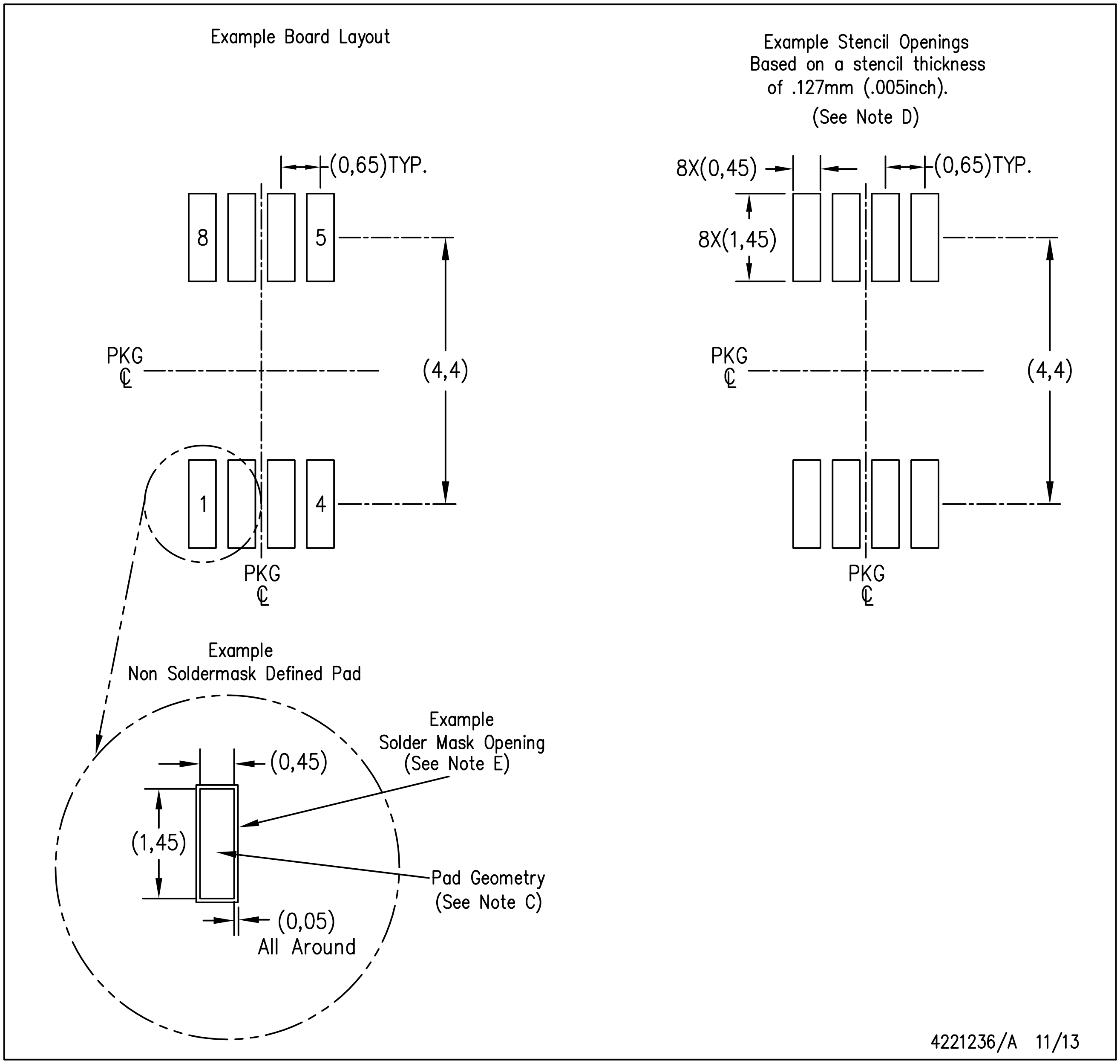
NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS–001 variation BA.

DGK (S–PDSO–G8) PLASTIC SMALL–OUTLINE PACKAGE



NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 per end.
- D. Body width does not include interlead flash. Interlead flash shall not exceed 0.50 per side.
- E. Falls within JEDEC MO–187 variation AA, except interlead flash.

DGK (S-PDSO-G8) PLASTIC SMALL OUTLINE PACKAGE



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC-7351 is recommended for alternate designs.
D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

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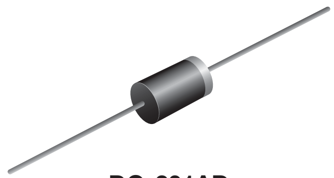
Schottky Barrier Plastic Rectifier



DO-201AD

PRIMARY CHARACTERISTICS	
$I_{F(AV)}$	3.0 A
V_{RRM}	20 V, 30 V, 40 V
I_{FSM}	80 A
V_F	0.475 V, 0.500 V, 0.525 V
T_J max.	125 °C
Package	DO-201AD
Diode variations	Single

FEATURES

- Guardring for overvoltage protection
- Very small conduction losses
- Extremely fast switching
- Low forward voltage drop
- High forward surge capability
- High frequency operation
- Solder dip 275 °C max. 10 s, per JESD 22-B106
- Material categorization: For definitions of compliance please see www.vishay.com/doc?99912

RoHS COMPLIANT

TYPICAL APPLICATIONS

For use in low voltage high frequency inverters, freewheeling, DC/DC converters, and polarity protection applications.

MECHANICAL DATA

Case: DO-201AD
Molding compound meets UL 94 V-0 flammability rating
Base P/N-E3 - RoHS-compliant, commercial grade

Terminals: Matte tin plated leads, solderable per J-STD-002 and JESD 22-B102
E3 suffix meets JESD 201 class 1A whisker test

Polarity: Color band denotes the cathode end

MAXIMUM RATINGS (T_A = 25 °C unless otherwise noted)

PARAMETER	SYMBOL	1N5820	1N5821	1N5822	UNIT
Maximum repetitive peak reverse voltage	V_{RRM}	20	30	40	V
Maximum RMS voltage	V_{RMS}	14	21	28	V
Maximum DC blocking voltage	V_{DC}	20	30	40	V
Non-repetitive peak reverse voltage	V_{RSM}	24	36	48	V
Maximum average forward rectified current at 0.375" (9.5 mm) lead length at T_L = 95 °C	$I_{F(AV)}$		3.0		A
Peak forward surge current, 8.3 ms single half sine-wave superimposed on rated load	I_{FSM}		80		A
Operating junction and storage temperature range	T_J, T_{STG}		- 65 to + 125		°C

ELECTRICAL CHARACTERISTICS (T_A = 25 °C unless otherwise noted)

PARAMETER	TEST CONDITIONS	SYMBOL	1N5820	1N5821	1N5822	UNIT
Maximum instantaneous forward voltage	3.0	V_F [(1)]	0.475	0.500	0.525	V
Maximum instantaneous forward voltage	9.4	V_F [(1)]	0.850	0.900	0.950	V
Maximum average reverse current at rated DC blocking voltage	T_A = 25 °C	I_R [(1)]		2.0		mA
	T_A = 100 °C			20		

Note

(1) Pulse test: 300 μs pulse width, 1 % duty cycle

THERMAL CHARACTERISTICS (T_A = 25 °C unless otherwise noted)					
PARAMETER	SYMBOL	1N5820	1N5821	1N5822	UNIT
Typical thermal resistance	$R_{\theta JA}$ (1)	40			°C/W
	$R_{\theta JL}$ (1)	10			

Note

(1) Thermal resistance from junction to lead vertical PCB mounted, 0.500" (12.7 mm) lead length with 2.5" x 2.5" (63.5 mm x 63.5 mm) copper pad

ORDERING INFORMATION (Example)				
PREFERRED P/N	UNIT WEIGHT (g)	PREFERRED PACKAGE CODE	BASE QUANTITY	DELIVERY MODE
1N5820-E3/54	1.08	54	1400	13" diameter paper tape and reel
1N5820-E3/73	1.08	73	1000	Ammo pack packaging

RATINGS AND CHARACTERISTICS CURVES

(T_A = 25 °C unless otherwise noted)

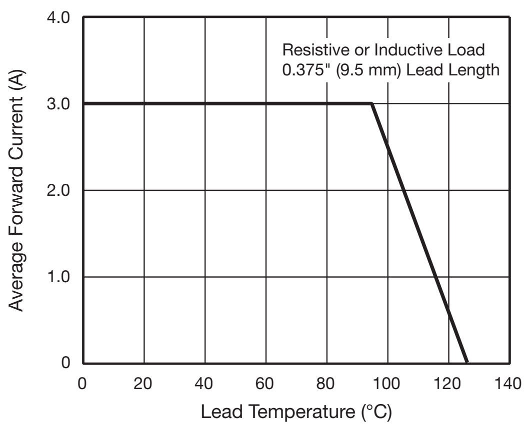


Fig. 1 - Forward Current Derating Curve

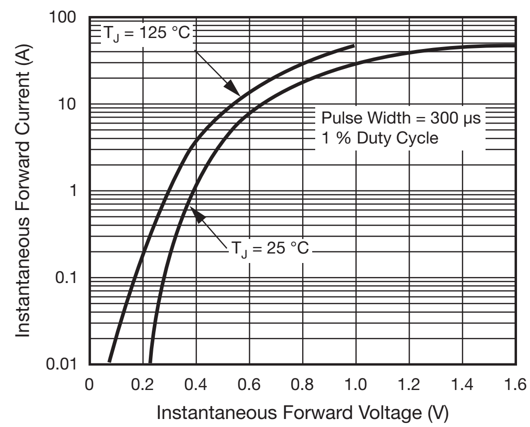


Fig. 3 - Typical Instantaneous Forward Characteristics

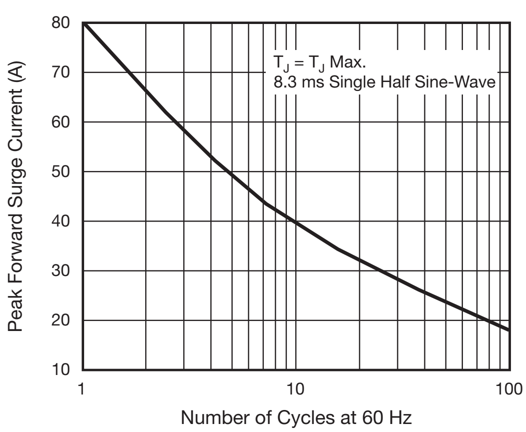


Fig. 2 - Maximum Non-Repetitive Peak Forward Surge Current

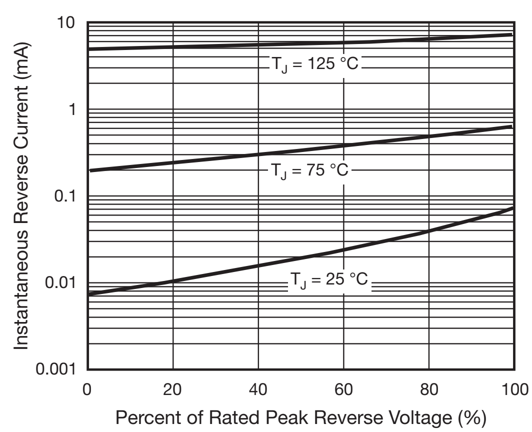


Fig. 4 - Typical Reverse Characteristics

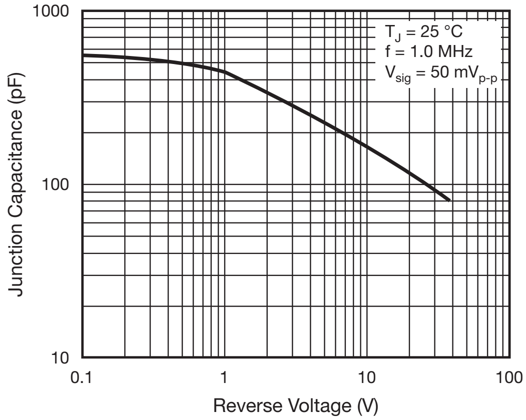


Fig. 5 - Typical Junction Capacitance

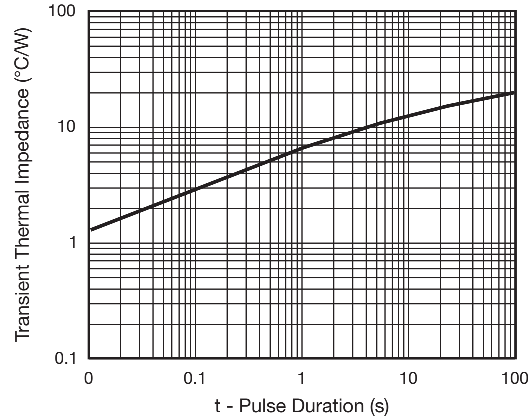
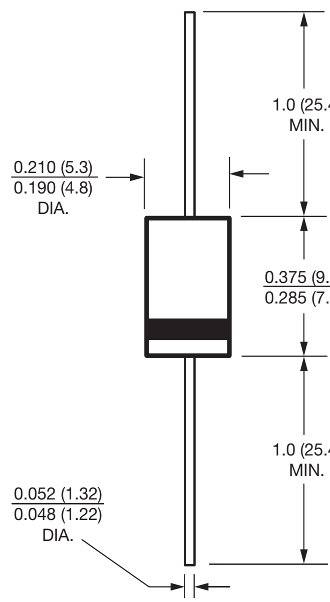


Fig. 6 - Typical Transient Thermal Impedance

PACKAGE OUTLINE DIMENSIONS in inches (millimeters)

DO-201AD



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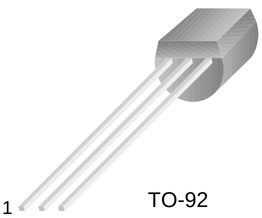
FAIRCHILD
SEMICONDUCTOR®

BC546/547/548/549/550

Switching and Applications

- High Voltage: BC546, V_{CEO}=65V
- Low Noise: BC549, BC550
- Complement to BC556 ... BC560



1 TO-92

1. Collector 2. Base 3. Emitter

NPN Epitaxial Silicon Transistor

Absolute Maximum Ratings T_a=25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CBO}	Collector-Base Voltage : BC546 : BC547/550 : BC548/549	80 50 30	V V V
V_{CEO}	Collector-Emitter Voltage : BC546 : BC547/550 : BC548/549	65 45 30	V V V
V_{EBO}	Emitter-Base Voltage : BC546/547 : BC548/549/550	6 5	V V
I_C	Collector Current (DC)	100	mA
P_C	Collector Power Dissipation	500	mW
T_J	Junction Temperature	150	°C
T_{STG}	Storage Temperature	-65 ~ 150	°C

Electrical Characteristics T_a=25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Typ.	Max.	Units
I_{CBO}	Collector Cut-off Current	V_{CB}=30V, I_E=0			15	nA
h_{FE}	DC Current Gain	V_{CE}=5V, I_C=2mA	110		800	
V_{CE} (sat)	Collector-Emitter Saturation Voltage	I_C=10mA, I_B=0.5mA I_C=100mA, I_B=5mA		90 200	250 600	mV mV
V_{BE} (sat)	Base-Emitter Saturation Voltage	I_C=10mA, I_B=0.5mA I_C=100mA, I_B=5mA		700 900		mV mV
V_{BE} (on)	Base-Emitter On Voltage	V_{CE}=5V, I_C=2mA V_{CE}=5V, I_C=10mA	580	660	700 720	mV mV
f_T	Current Gain Bandwidth Product	V_{CE}=5V, I_C=10mA, f=100MHz		300		MHz
C_{ob}	Output Capacitance	V_{CB}=10V, I_E=0, f=1MHz		3.5	6	pF
C_{ib}	Input Capacitance	V_{EB}=0.5V, I_C=0, f=1MHz		9		pF
NF	Noise Figure : BC546/547/548 : BC549/550 : BC549 : BC550	V_{CE}=5V, I_C=200μA f=1KHz, R_G=2KΩ V_{CE}=5V, I_C=200μA R_G=2KΩ, f=30~15000MHz		2 1.2 1.4 1.4	10 4 4 3	dB dB dB dB

h_{FE} Classification

Classification	A	B	C
h_{FE}	110 ~ 220	200 ~ 450	420 ~ 800

Typical Characteristics

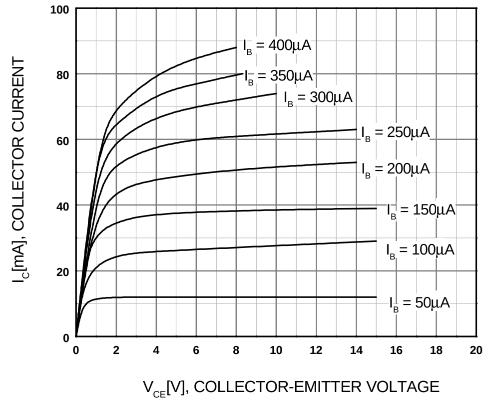


Figure 1. Static Characteristic

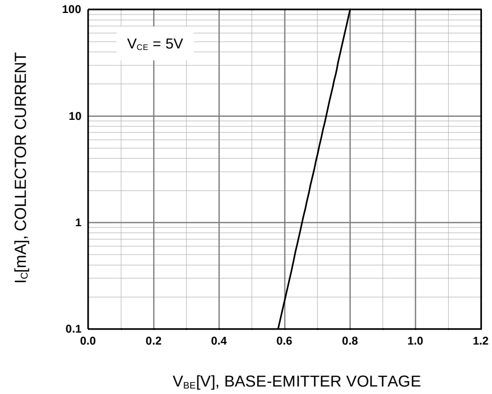


Figure 2. Transfer Characteristic

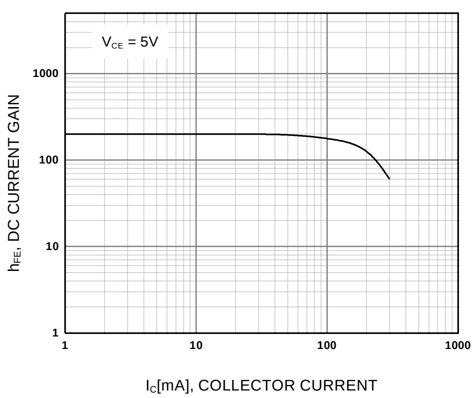


Figure 3. DC current Gain

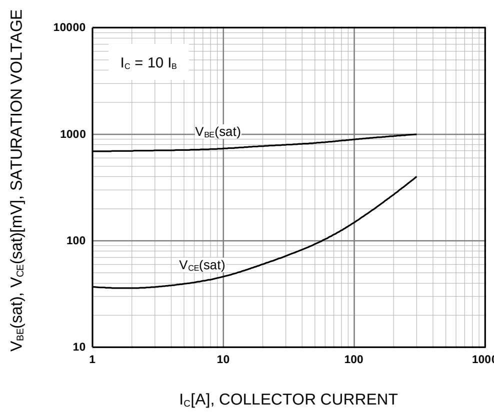


Figure 4. Base-Emitter Saturation Voltage Collector-Emitter Saturation Voltage

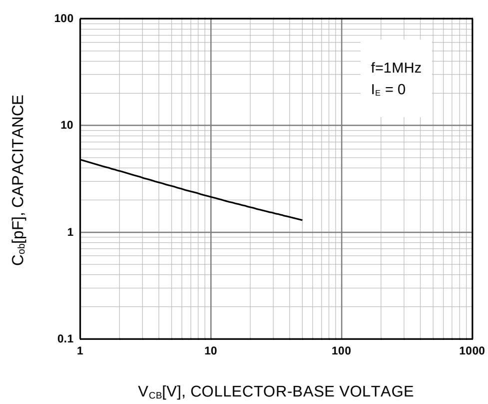


Figure 5. Output Capacitance

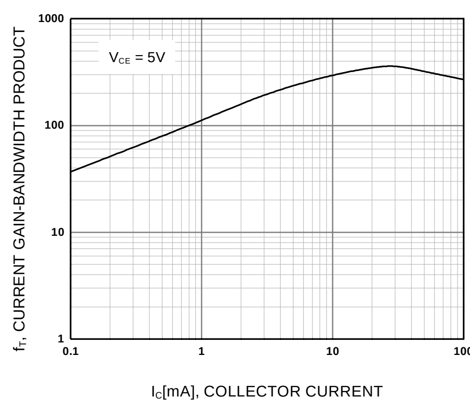
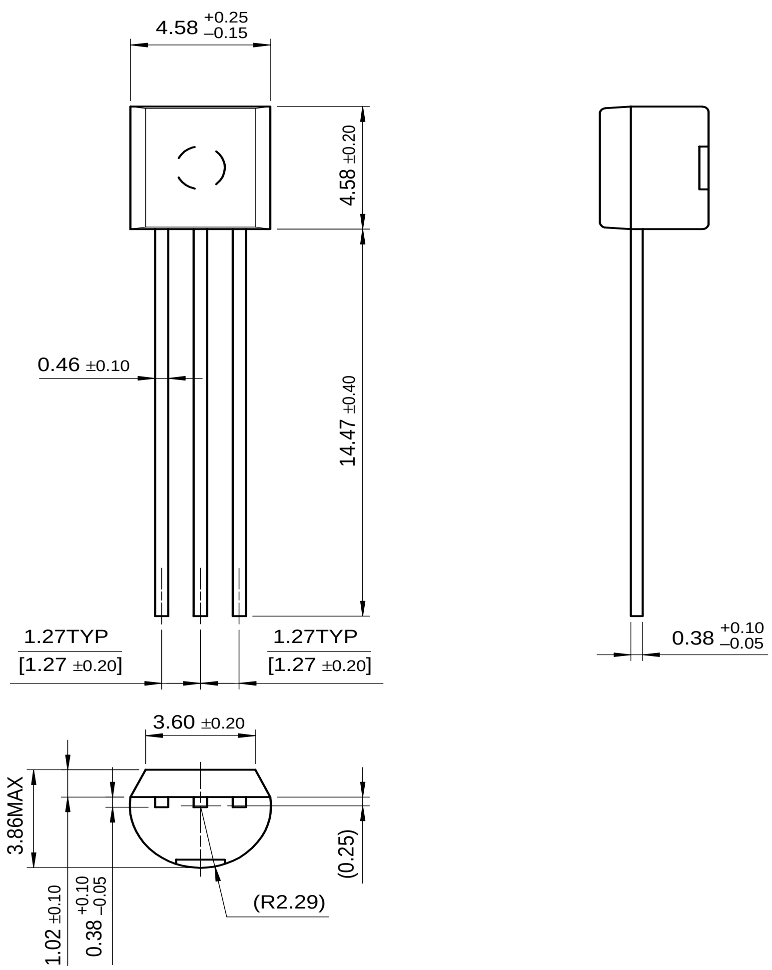


Figure 6. Current Gain Bandwidth Product

Package Dimensions

TO-92



Dimensions in Millimeters

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ActiveArray™	FACT Quiet series™	ISOPLANAR™	POP™	Stealth™
Bottomless™	FAST®	LittleFET™	Power247™	SuperSOT™-3
CoolFET™	FASTr™	MicroFET™	PowerTrench®	SuperSOT™-6
CROSSVOLT™	FRFET™	MicroPak™	QFET™	SuperSOT™-8
DOME™	GlobalOptoisolator™	MICROWIRE™	QS™	SyncFET™
EcoSPARK™	GTO™	MSX™	QT Optoelectronics™	TinyLogic™
E^2CMOS™	HiSeC™	MSXPro™	Quiet Series™	TruTranslation™
EnSigna™	I^2C™	OCX™	RapidConfigure™	UHC™
Across the board. Around the world.™		OCXPro™	RapidConnect™	UltraFET®
The Power Franchise™		OPTOLOGIC®	SILENT SWITCHER®	VCX™
Programmable Active Droop™		OPTOPLANAR™	SMART START™	

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PRODUCT STATUS DEFINITIONS

Definition of Terms

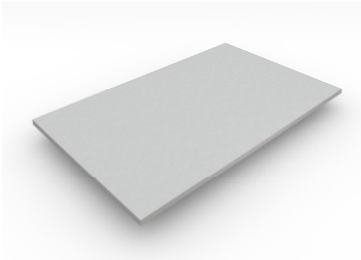
Datasheet Identification	Product Status	Definition
Advance Information	Formative or In Design	This datasheet contains the design specifications for product development. Specifications may change in any manner without notice.
Preliminary	First Production	This datasheet contains preliminary data, and supplementary data will be published at a later date. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
No Identification Needed	Full Production	This datasheet contains final specifications. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
Obsolete	Not In Production	This datasheet contains specifications on a product that has been discontinued by Fairchild semiconductor. The datasheet is printed for reference information only.

 Rev. I1

Verotec
Sto Group

Technical data sheet

VeroBoard® Acoustic F



Characteristics

Application

Interior
Versatile, acoustically effective, lightweight and easy-to-install board for cladding or as a carrier board for a wide range of surface applications
For acoustically effective ceilings, grid false ceilings, wall coverings, partition and screening walls

Properties

Properties	Advantages
Acoustically effective → High sound absorption capability	Reduction in the noise level Reduction in reverberation time Improvement in the ability to concentrate Improvement in speech intelligibility
Low weight	Low system weight Simple handling during installation
Mechanical resistance	System security
Very low humidity and thermal expansion	Use in swimming baths
Easy to handle and install	Simple handling during installation No special tools necessary

Material description

The VeroBoard® Acoustic F is manufactured from a material, consisting of approx. 96 % expanded glass granulate and bonded with an organic binding agent. A carrier layer made of fleece is applied to both of the outer sides.

Format

Board thicknesses: 15, 19, 25 mm
Standard format: 1200 x 800 mm; 2400 x 1200 mm
Special formats on request

Appearance

VeroBoard® Acoustic F
Front and back side with white fleece

Technical data

Criterion	Standard/Test specifications	Value/unit
Apparent density		350 kg/m³
Reaction to fire	DIN EN 13501-1	B-s1,d0
Thermal conductivity	TIAP-655 in line with EN 12667	0.08 W/(m*K)
Sound absorption factor		0.60 - 0.80*

The characteristic values stated are average values or approx. values. Due to the raw materials used in our products, the stated values can vary slightly in the same delivery batch without adversely affecting the suitability of the product.

All values relate to the VeroBoard as a raw board without any surface application.

*depending on the area of application/surface

Delivery

Transport	Protect from humidity and damage during transport. Product is sensitive to shocks.
Conditions	Ex works Verotec GmbH, Lauingen, Germany
Packaging	pieces / pallet or pallets / trailer
Customs Tariff Number	70169070

Storage / disposal

Storage conditions

Store in dry conditions and protect against sun

Disposal

When disposing of waste, take the local and statutory regulations into consideration.

When deposited in landfill sites, the material does not release any water-soluble substances, which could cause contamination of the ground water. The material also does not decompose into harmful products over time.

Waste code AVV 17 09 04 Mixed building waste in accordance with the German Technical Guidelines on Waste and the catalogue of the Federal Consortium on Waste (LAGA)

The disposal of clean packaging waste can be carried out via Zentek GmbH & Co. KG, contract number TVP-VdL-1311383.

Expert report / approval

Test certificate P-SAC02/III-052

Special information	
	The VeroBoard® Acoustic F must never be exposed to permanent damp penetration or waterlogging.
	The information or data in this technical data sheet serves to ensure the product's intended use, or its suitability for use, and is based on our findings and experience. Nevertheless, users are responsible for establishing the suitability of the product for its intended use.
	Applications, which are not specifically mentioned in this Technical Data Sheet, are only permitted after prior consultation with Verotec.
Human health	
	Contains no toxic substances. There is no hazard or impairment to health based on the current state of knowledge (ISO 14025 und EN 15804).

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When this Technical Data Sheet is published, all previous applicable Technical Data Sheets no longer have any validity.

Revision no. 05/04.17

Product name: VeroBoard® Acoustic F

Validity from: 13 April 2017