Department of Electrical Engineering
RCC INSTITUTE OF INFORMATION TECHNOLOGY

Voltage Regulation in Isolated Power System Using MATLAB

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 of Declaration

To whom it may concern

This is to certify that the project work entitled **Voltage Regulation in Isolated Power System Using MATLAB (Simulation Based)** is the bona fide work carried out by **SAYAK MAJUMDER (11701616035), MANISHANKHA SARKAR (11701616051), SHOVAN DEY (11701617030)**, the students 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 2016-20, in partial fulfillment of the requirements for the degree of Bachelor of Technology in Electrical Engineering.

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ACKNOWLEDGEMENT

We are immensely pleased to express our gratitude to **Dr. SHILPI BHATTACHARYA** in the Department of Electrical Engineering under whose supervision we have done our project work on **'Voltage Regulation in Isolated Power System Using MATLAB**. We express our sincere thanks and deepest sense of gratitude to our guide for her constant support, unparalleled guidance and limitless encouragement.

We would also like to convey our gratitude to all the faculty members and staffs of the Department of Electrical Engineering, RCCIIT for their wholehearted cooperation to make this work turn into reality.

Thanks to the fellow members of our group for sincerely co-operating in this work-

SAYAK MAJUMDER (11701616035),

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To
The Head of the Department,
Department of Electrical Engineering,
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Respected Sir,

In accordance with the requirements of the degree of Bachelor of Technology in Electrical Engineering from RCC Institute of Information Technology under MAKAUT, we present the following project report entitled '**Voltage Regulation in Isolated Power System Using MATLAB (Simulation Based)'.** This work was performed under the valuable guidance of Dr. Shilpi Bhattacharya, Associate Professor, Dept. of Electrical Engineering.

We declare that the project report 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.

Yours sincerely,

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TABLE OF CONTENTS

Abbreviations & Acronyms

DVFC - Decoupled Voltage and Frequency Controller

IAG - Isolated Asynchronous Generator

SEIG - Self Excited Induction Generator

STATCOM - STAtic synchronous Compensator

IGBT - Insulated Gate Bipolar Transistor

CC- VSC - Current Controlled Voltage Sourced Converter

PSB - Power System Blockset

FACTS - Flexible AC Transmission System

GTO - Gate Turn-off Thyristors

VAR - Volt-Ampere Reactive

SCR - Silicon Controlled Rectifier

SVC - Static VAR Compensator

PWM - Pulse-Width Modulation

PI - Proportional Integral

ELC - Electronic Load Controller

ABSTRACT

This project deals with a decoupled voltage and frequency controller (DVFC) for an isolated asynchronous generator (IAG), also known as the self-excited induction generator (SEIG), used in constant power applications such as pico-hydro uncontrolled turbine driven IAG for feeding three-phase four-wire loads. The proposed controller is used to control the voltage and frequency at the generator terminal independently. The proposed decoupled controller is a combination of a Static synchronous Compensator (STATCOM) for regulating the voltage. The STATCOM is realized using a 4-leg Insulated Gate Bipolar Transistor (IGBT)-based current controlled voltage-sourced converter (CC-VSC) and a self-supporting dc bus. The proposed generating system is modeled and simulated in MATLAB along with Simulink and power system blockset (PSB) toolboxes. The simulated results are presented to demonstrate the capability of an isolated generating system for feeding three-phase four-wire loads with the neutral current compensation.

INTRODUCTION: In isolated generating systems for harnessing renewable energy from available nonconventional energy sources, such as small hydro, wind and bio-mass, an asynchronous machine, driven by these prime movers and operated as an isolated asynchronous generator (IAG) with its excitation requirement being met by a capacitor bank connected across its terminals, has become the compatible option since last two decades because of its low cost, small size, light weight, brushless construction, and self-short-circuit protection. However, the poor voltage and frequency regulation is a major bottleneck in its commercialization.

In constant power applications, there are harmonics into the asynchronous machine. These harmonics in voltage and current increase the power losses, create unequal heating and cause torque pulsation on the shaft of the generator and derate the machine. In some other schemes for regulating the voltage and frequency along with harmonic elimination and load balancing a voltage-sourced converter (VSC) along with chopper and auxiliary load have been proposed, but due to continuous flow of auxiliary power through the VSC it increases the rating of the controller. However, in variable power application like biogas, gasoline, and diesel engines driven asynchronous generator where speed is almost constant, a reactive power compensator like STATCOM serves the purpose of voltage regulation.

OBJECTIVE: To make a solution for voltage fluctuation. By using this method, the industry machinery will run in healthy condition and will be protected from under-voltage and under-frequency conditions.

SOFTWARE USED and the controlling unit:

In this project we are using MATLAB Simulation as the software tool, where the components are mainly the STATCOM in controlling unit.

STATCOM:

- **Definition: STATCOM** or **Static Synchronous Compensator** is a shunt device, which uses force-commutated power electronics (i.e. GTO, IGBT) to control power flow and improve transient stability on electrical power networks. It is also a member of the so-called Flexible AC Transmission System (FACTS) devices. The STATCOM basically performs the same function as the Static VAR Compensator but with some advantages.

- **Application:** STATCOMs are typically applied in long distance transmission systems, power substations and heavy industries where voltage stability is the primary concern.

In addition, static synchronous compensators are installed in select points in the power system to perform the following:

- Voltage fluctuation and flicker mitigation
- Unsymmetrical load balancing
- Power factor correction
- Active harmonics cancellation
- Improve transient stability of the power system

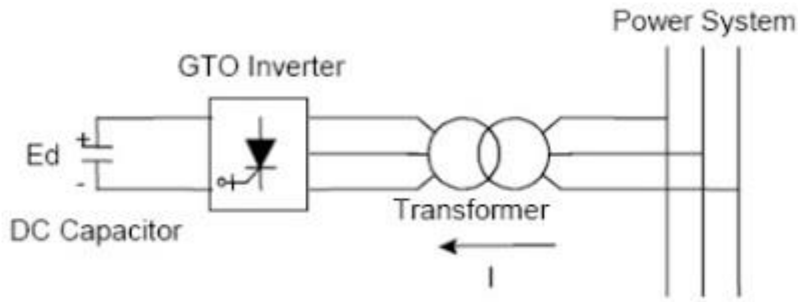
- **Types:** There are two types of STATCOM- a) Voltage-sourced, b) Current-sourced.

•In VSC, the SCRs are parallelly connected where these are connected in series for Current source converter.

The voltage-source converter transforms the DC input voltage to an AC output voltage. Two of the most common VSC types are described below.

1. Square-wave Inverters using Gate Turn-Off Thyristors

Generally, four three-level inverters are utilized to make a 48-step voltage waveform. Subsequently, it controls reactive power flow by changing the DC capacitor input voltage, simply because the fundamental component of the converter output voltage is proportional to the DC voltage.



GTO-based STATCOM Simple Diagram

In addition, special interconnection transformers are employed to neutralize harmonics contained in the square waves produced by individual inverters.

2. PWM Inverters using Insulated Gate Bipolar Transistors (IGBT)

It uses Pulse-Width Modulation (PWM) technique to create a sinusoidal waveform from a DC voltage source with a typical chopping frequency of a few kHz. In contrast to the GTO-based type, the IGBT-based VSC utilizes a fixed DC voltage and varies its output

AC voltage by changing the modulation index of the PWM modulator.

Moreover, harmonic voltages are mitigated by installing shunt filters at the AC side of the VSC.

Modes of Operation

The STATCOM can be operated in two different modes:

A. Voltage Regulation:

The static synchronous compensator regulates voltage at its connection point by controlling the amount of reactive power that is absorbed from or injected into the power system through a voltage-source converter.

In steady-state operation, the voltage V_2 generated by the VSC through the DC capacitor is in phase with the system voltage V_1 ($\delta=0$), so that only reactive power (Q) is flowing (P=0).

1. When system voltage is high, the STATCOM will absorb reactive power (inductive behavior)
2. When system voltage is low, the STATCOM will generate and inject reactive power into the system (capacitive).

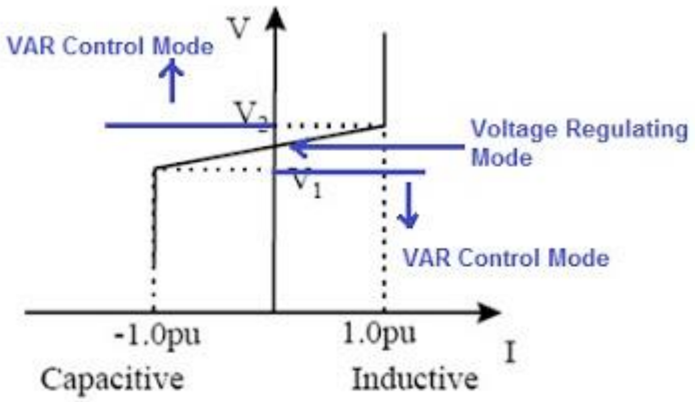
Subsequently, the amount of reactive power flow is given by the equation:

$Q = [V_1(V_1-V_2)] / X$

B. VAR Control:

In this mode, the STATCOM reactive power output is kept constant independent of other system parameter.

The figure below well explains the above two modes of operation of STATCOM-



The figure above is the Voltage Current Characteristics of STATCOM. As can be seen, voltage regulation capability of STATCOM is from V1 (in lower side) to V2 in upper side of power system. If the voltage of power system goes below V1 or above V2, STATCOM acts in VAR Control mode. Here V1 and V2 are just taken for example, it should not be confused with the V1 (used for output voltage of STATCOM) and V2 (Voltage of power system) used in the discussion above.

STATCOM vs SVC:

Points	**Static VAR Compensator(SVC)**	**STATCOM**
Components	A SVC is comprised of Thyristor-controlled Reactors(TCR),Thristor-switched	STATCOM consists of VSC, DC Capacitor, Inductive reactance (X_L).

	Capacitors(TC), Fixed Capacitors(FC)	
Harmonics	It will reduce the harmonics in the system.	STATCOM reduces harmonic efficiently than SVC.
Power transfer	SVC increases the power transfer capacity.	STATCOM is more efficient than SVC.
Reactive power	SVC can change reactive power.	The main working principle of STATCOM is to change the reactive power in the system efficiently and within a range of small duration.

SYSTEM CONFIGURATION AND CONTROL SCHEME:

The DVFC (STATCOM consisting of a 4-legged, IGBT-based VSC) and consumer loads. A star-connected three-phase capacitor bank is used for the generator excitation and the value of the excitation capacitor is selected to generate the rated voltage at no load. The asynchronous generator generates constant power, the STATCOM is used to regulate the voltage.

The output of the VSC is connected to the generator terminals through the ac filtering inductors. The dc bus capacitor is used to filter voltage ripples and is self supporting. The control scheme of the STATCOM to regulate the terminal voltage of the generator is based on the generation of reference source currents, which have two components, in-phase and quadrature, with the ac voltage. The in-phase unit templates (u_a, u_b and u_c) are three-phase sinusoidal functions, computed by dividing the ac voltages v_a , v_b and v_c by their amplitude V_t. Another set of quadrature unit templates (w_a, w_b and w_c) are sinusoidal functions obtained from in-phase templates (u_a, u_b and u_c).

To regulate the ac terminal voltage V_t, it is sensed and compared with the reference voltage. The voltage error is processed in the proportional integral (PI) controller. The output of the PI controller (I^*_{smq}) for an ac voltage control loop decides the amplitude of reactive current to be generated by the STATCOM. Multiplication of quadrature unit templates (w_a, w_b and w_c) with the output of of the PI-based ac voltage controller yields the quadrature component of the reference source currents (i^*_{saq}, i^*_{sbq}, and i^*_{scq}). To provide self-supporting dc bus of the STATCOM, its dc bus voltage is sensed and compared with the dc reference voltage. The error voltage is processed in another PI controller. The output of the PI controller (I^*_{smd}) decides the amplitude of active current. Multiplication of in-phase unit templates (u_a, u_b and u_c) with output of the PI controller (I^*_{smd}) yields the in-phase component of the reference source currents (i^*_{sad}, i^*_{sbd} and i^*_{scd}). The instantaneous sum of quadrature and in-phase components provides the reference source currents i^*_{sa}, , and), which are compared with the sensed line currents (i_{sa}, i_{sb} and i_{sc}). These current error signals are amplified and compared with the hysteresis controller to generate the gating signals for IGBTs of the VSC. Fourth leg of the STATCOM is used to compensate the source neutral cur- rent (i_{sn}) that is maintained at zero reference value (i^*_{sn}) through switching of the IGBTs of this leg.

CONTROL ALGORITHM:

Basic equations of the control scheme of the proposed decoupled controller (DVFC) for an asynchronous generator are developed in this section. The control scheme is divided into two sections. Section III describes the equations of controlling the "STATCOM".

Control Algorithm for the STATCOM

Different components of the STATCOM used in asynchronous generator-system are modeled as follows. Three line voltages at the generator terminals (v_{ab}, v_{bc} and v_{ca}) are considered sinusoidal, and hence their amplitude is computed as-

$$V_t=\sqrt{(2/3)} * (v_{ab}^2 + v_{bc}^2+v_{ca}^2) \quad . \quad . \quad . \ 1)$$

The unit template in phase with v_{ab}, v_{bc} and v_{ca} are derived as-

$$u_a = v_{ab}/V_t;\ u_b = v_{bc}/V_t;\ u_c= v_{ca}/V_t \quad . \quad . \quad . \ 2)$$

The unit template in quadrature with v_{ab} , v_{bc} and v_{ca} may be derived using a quadrature transformation of the in-phase unit template u_a , u_b and u_c as-

$$w_a= -u_b/\sqrt{3} + u_c/\sqrt{3} \quad . \quad . \quad . \ 3)$$

$$w_b= \sqrt{3}u_a/2+ (u_b-u_c)/2\sqrt{3} \quad . \quad . \quad . \ 4)$$

$$w_c= -\sqrt{3}u_a/2+ (u_b-u_c)/2\sqrt{3} \quad . \quad . \quad . \ 5)$$

- ***Quadrature Component of Reference Source Currents:*** The ac voltage error $V_{er(n)}$ at the n^{th} sampling instant is-

$$V_{er(n)}= V_{tref(n)}- V_{t(n)} \quad . \quad . \quad . \ 6)$$

Where $V_{tref(n)}$ is the amplitude of the sensed three-phase ac voltage at the generator terminals at n^{th} instant.

The output of the PI controller ($I^*_{smq(n)}$) for maintaining the ac terminal voltage constant at the n^{th} sampling instant is expressed as-

$$I^*_{smq(n)}= I^*_{smq(n-1)} + K_{pa}\{V_{er(n)} - V_{er(n-1)}\} + K_{ia}V_{er(n)} \quad . \quad . \quad . \ 7)$$

Where K_{pa} and K_{ia} are the proportional and integral gain constants of the PI controller, $V_{er(n)}$ and $V_{er(n-1)}$ are the voltage errors at n^{th} and $(n-1)^{th}$ instants. $I^*_{smq(n-1)}$ is the amplitude of quadrature component of the reference source current at $(n-1)^{th}$ instant.

The quadrature components of reference source currents are computed as-

$I^*_{saq} = I^*_{smq}w_a$; $I^*_{sbq} = I^*_{smq}w_b$; $I^*_{scq} = I^*_{smq}w_c$ . . . 8)

- ***In-Phase Component of Reference Source Currents:*** The error in dc bus voltage of the STATCOM ($V_{dcer(n)}$) at the n^{th} sampling instant is-

$V_{dcer(n)} = V_{dcref(n)} - V_{dc(n)}$ . . . 9)

Where $V_{dcref(n)}$ is the reference DC voltage and $V_{dc(n)}$ is the sensed DC link voltage of the STATCOM.

The output of PI controller of the STATCOM at the n^{th} sampling instant is-

$I^*_{smd(n)} = I^*_{smd(n-1)} + K_{pd} \{V_{dcer(n)} - V_{dcer(n-1)}\} + K_{id}V_{dcer(n)}$ . . . 10)

Where $I^*_{smd(n)}$ is considered as the amplitude of the active source current, K_{pd} & K_{id} are the proportional and integral gain constants of DC bus PI voltage controller.

The in-phase components of reference source currents are computed as-

$i^*_{sad} = I^*_{smd}u_a$; $i^*_{sbd} = I^*_{smd}u_b$; $i^*_{scd} = I^*_{smd}u_c$ . . . 11)

- ***Reference Source Currents:*** Total reference source currents are a sum of in-phase and quadrature components of the reference source currents, as follows:

$i^*_{sa} = i^*_{saq} + i^*_{sad}$ . . .12)

$i^*_{sb} = i^*_{sbq} + i^*_{sbd}$ . . .13)

$i^*_{sc} = i^*_{scq} + i^*_{scd}$ . . .14)

- ***Neutral Current Compensation:*** The fourth leg of the VSC of the STATCOM is used to compensate the source neutral current and is controlled at the reference value (i*sn). The source neutral current (isn) which is sum of source phase currents is compared with its reference value (i*sn).

$i^*_{sn} = 0$; $i_{sn} = i_{sa} + i_{sb} + i_{sc}$; $i_{snerr} = i^*_{sn} - i_{sn}$ . . . 15)

The current error signal (i_{snerr}) is amplified and compared using a hysteresis current controller for generating the PWM signal for switching of the fourth leg of the VSC. For making source neutral current (i_{sn}) “zero”, the compensating current (i_{cn}) should be equal and opposite in direction of sum of load currents.

- ***PWM Current Controller:*** The reference currents (i^*_{sa} , i^*_{sb} and i^*_{sc}) are compared with the sensed source currents (i_{sa}, i_{sb} and i_{sc}). The ON/OFF switching patterns of the gate drive signals to the IGBTs are generated from the PWM current controller. The current errors are computed as-

$i_{saerr} = i^*_{sa} - i_{sa}$ . . . 16)

$i_{sberr} = i^*_{sb} - i_{sb}$ . . . 17)

$i_{scerr} = i^*_{sc} - i_{sc}$ . . . 18)

These current error signals are amplified and then compared in the PWM hysteresis controller for switching of the IGBT of the VSC of the STATCOM.

Control System Panel:

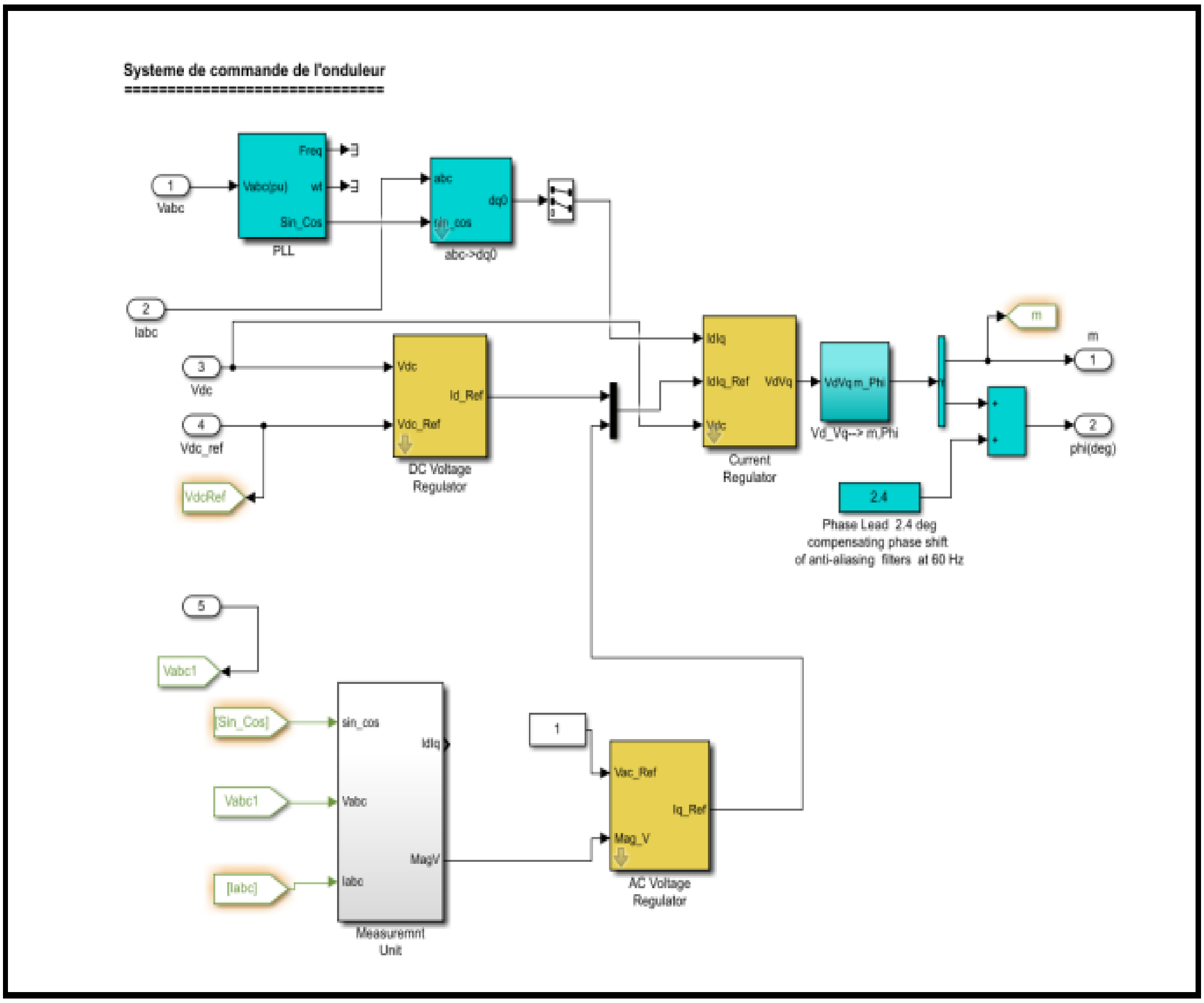


Fig: 1

MATLAB SIMULATION DIAGRAM OF LINEAR LOAD CIRCUIT:

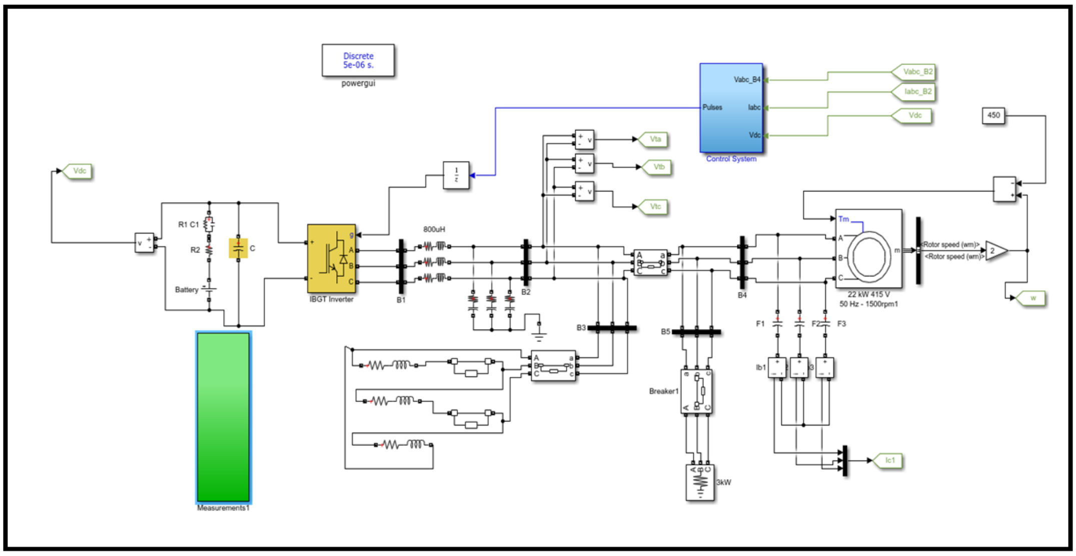


Fig.1: MATLAB Simulation diagram of Linear Load Circuit

SCHEMATIC DIAGRAM OF LINEAR LOAD OUTPUT:

Fig.2: OUTPUT of Linear Load Circuit

MATLAB SIMULATION DIAGRAM OF NON-LINEAR LOAD CIRCUIT:

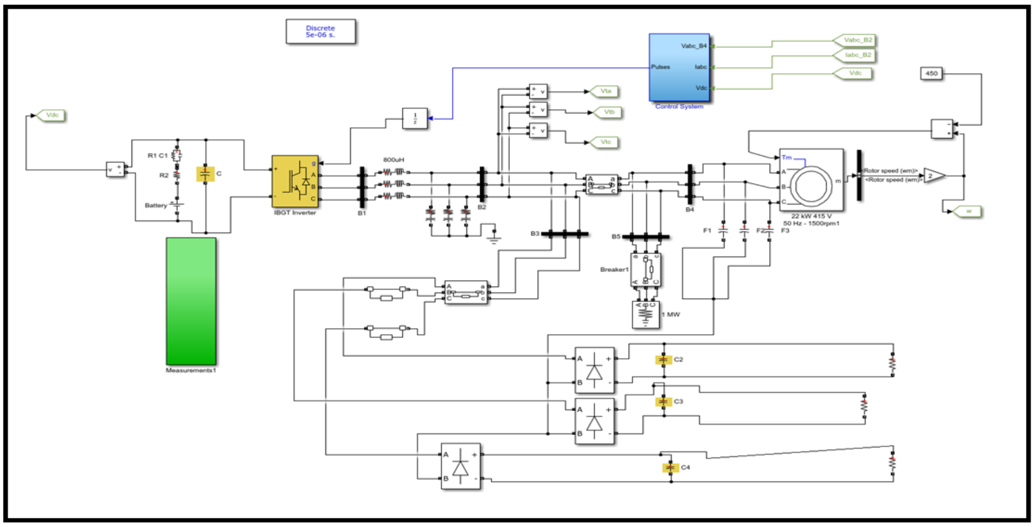


Fig.3: MATLAB Simulation diagram of Non-Linear Load Circuit

SCHEMATIC DIAGRAM OF NON-LINEAR LOAD OUTPUT:

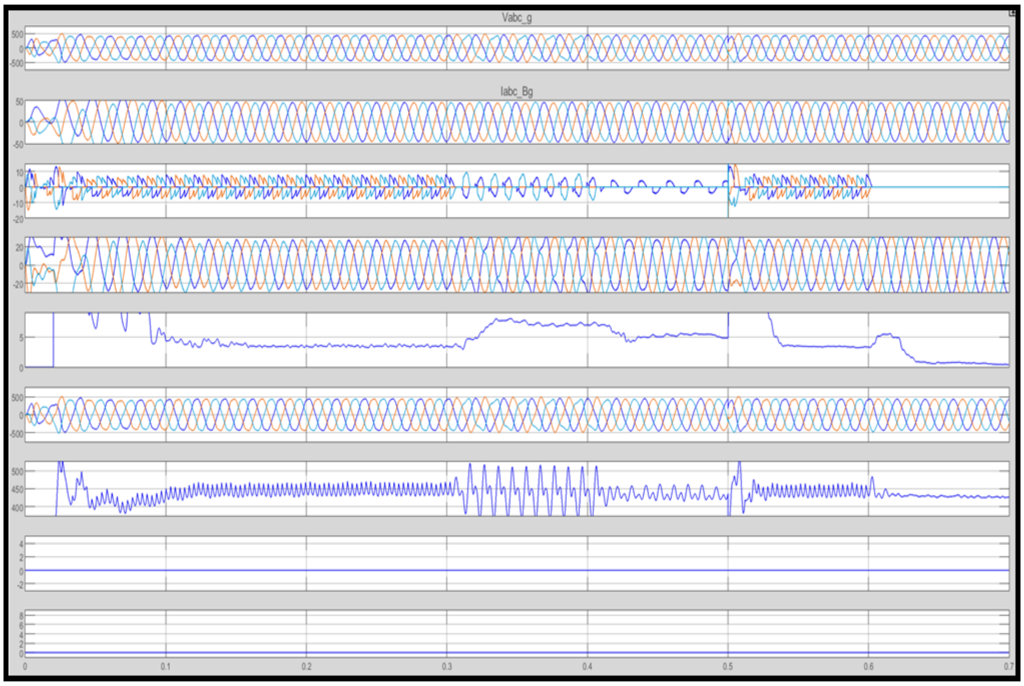


Fig.4: OUTPUT of Non-Linear Load Circuit

FUTURE SCOPES:

We didn’t use ELC in this project. We can use it as a future scope to control the constant power. Consumers who are located at city centres and a few remote places receive electric power conveniently from conventional power plants like thermal or hydroelectric generating stations. But this is not the case with consumers located in hilly and a few remote areas, where economic and logistic constraints come into effect and it is not possible to install a receiving substation to receive and distribute electric power, leave alone the maintenance of electrical equipment’s in these remote areas. In such situations Micro Hydro Systems (MHS) can be installed to deliver power, provided water resources with potential energy are available. Like any conventional generating stations even Micro Hydro Systems require controlling, monitoring and distributing circuits for power flow from the generating stations to the load.

Conventional hydro electric generators use speed governor and also excitation controller to regulate the speed, frequency and voltage generated and fed to the user loads. Since the cost of speed governor is high with associated problems in hydraulic systems. Micro Hydro Systems do not use speed governors. However, the speed is governed indirectly by maintaining constant load on the generator and hence the turbine by using electronic circuits. Thus, by using ELECTRONIC LOAD CONTROLLER (ELC) the load on the generator is maintained constant for a given water input. An ELC is a solid-state electronic device designed to regulate output power of the generator used in the micro-hydropower system. Maintaining a near-constant load on the turbine, the generator generates a stable voltage and frequency for a given constant water input. ELCs react so fast to load changes that speed changes are not even noticeable unless a very large load is applied.

METHODOLOGY:

ELC triggers the thyristor switches so that the power which is not drawn by the consumers is diverted to the dummy load. The parallel path of thyristor and dummy load is an open switch when rated power is being drawn by the consumers. When the consumer draws less than the rated power, there is a difference in the current, this current is sensed by the CT, and a signal is fed to the error amplifier of ELC and correspondingly a triggering signal is generated which is fed to the gate of thyristors. Thus, the thyristors start conducting when rated power is not drawn by the consumers and diverts the power to dummy load. The main principle is that current is the parameter which is being sensed and depending on the sensed signal corresponding triggering signals are produced.

Other than the above-mentioned scope we can also control the frequency as following steps-

1. We all know frequency is very much connected with voltage as following-

$$w= 2*\pi*f$$

$$q = \omega t$$

$$e= E_{max} \sin \theta$$

where, ω = Angular velocity, θ = Angle from reference, e= Induced emf.

2. If frequency gets decreased then voltage will get decreased to which will result in efficiency of machinery.

3.Therefore, we can use the Electronic Load Controller (ELC) to mitigate the frequency fluctuations.

CONCLUSION: The performance of proposed DVFC for an isolated asynchronous generator has demonstrated the satisfactory operation for feeding all type of consumer loads including three-phase four-wire loads. The IAG-DVFC system is able to feed balanced/unbalanced linear and non-linear loads with minimal harmonic distortion compared to all previously reported controllers and because of variable reactive power compensation it does not require large value of excitation capacitor such as used in a previously proposed controller. It is also concluded that the proposed controller has been found suitable for the voltage and frequency control along with load balancing, neutral current compensation and harmonic elimination.

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