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PI Based Series and Shunt Voltage Controller for Isolated Asynchronous Generators

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***Abstract*— This paper deal with comparative analysis of PI(proportional-integral) based STATCOM (Static Compensator) and DVR (dynamic voltage restorer) for power control of a prime mover operated at a constant speed isolated asynchronous generators (IAG) powering three-phase linear and non-linear load. Biomass, Biogas, gas-turbine, Diesel engine like SEIG stands for self-excited induction generator powered by prime mover operating at a constant speed used for isolated control generation has an issue with the voltage regulation. The DVR is a parallel voltage controller, which the system by adding voltage in series constant source and voltage at load. Other side STATCOM is a shunt voltage controller, which inject current into the system for maintain constant source voltage. The DVR and STATCOM controllers are modelled utilising a self-supporting DC bus and a voltage source converter (VSC) that utilises an IGBT (Insulated Gate Bipolar Junction Transistor) as its foundational component. The SEIG-based 7.5Kw, 415V, 50Hz producing system has Simulink, the toolbox for the power system block set (PSB), as well as DVR and STATCOM modelling and simulation are done in MATLAB.**

Keywords- Artificial Neural Network (ANN), Distributed power Generation, DVR (Dynamic Voltage Restore), Isolated Asynchronous Generator, STATCOM (static compensator).

I. INTRODUCTION

The induction generator, also known as an isolated asynchronous generator or SEIG (self-exited induction generator), operates via a separate self-excitation capacitance. IAG is the good option for distributed power generation with their reasonably priced; reduce construction that is low-maintenance, tough, and brushless. Distributed power generation refers to the scattered production of electricity at the load centre where the produced power is sent immediately to the load. Distributed generating is a useful choice, especially in rural areas where the utility system is unable to deliver the electricity. The IAG's incapability to regulate voltage at the terminals under various load circumstances is one of its main flaws. Thus, Poor voltage regulation in an underutilization of the unit is the result of using an asynchronous generating system that is equipped with capacitor self-excitation. Reactive power derived from an outside source must be supplied for the machine if it is to function at the level of capacity for which it was designed and maintain a terminal voltage that varies in response to the load. [1]

Although the frequency of biomass and diesel and gas engine prime movers is constant, the voltage control issue arises when the load changes. The reactive power compensator acts like a Voltage control is accomplished using STATCOM (static compensator) and DVR (dynamic voltage restorer). The STATCOM is shunt voltage controller, which inject current into a method for ensuring continuous supply voltage. DVR is series voltage controller, which inject voltage into mechanism to keep the source and load voltage constant. Here, we make an effort to investigate power generation using IAGs powered by constant-speed biomass, diesel, and gas turbine prime movers in conjunction with linear and nonlinear demand.

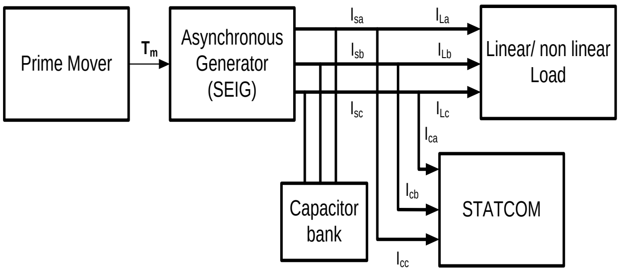


Figure 1 A diagram of the SEIG-STATCOM system in schematic form

The STATCOM is an energy storage capacitor-equipped current control (CCVSC) voltage source converter an IGBT-based dc bus. STATCOM is a shunt voltage controller because it connects in shunt at the system's PCC (point of common connection). A schematic Figure 1 presents an illustration of a capacitor-supported STATCOM equipped with SEIG.

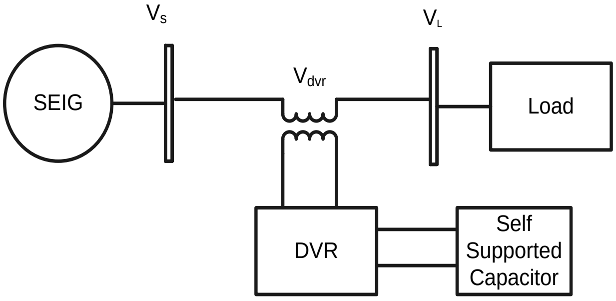


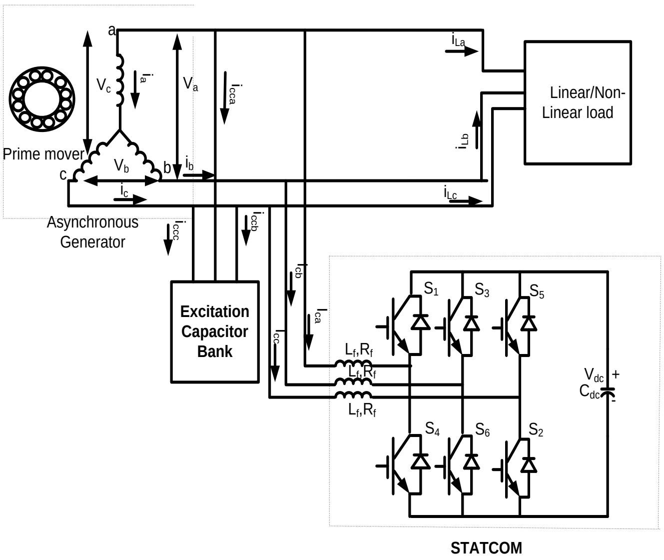
Figure 2: SEIG-DVR schematic diagram The DVR is a power electronics device that uses a voltage source converter, sometimes referred to as a VSC. A Between the source and the load, a series connection is made up of a transformer, VSC, and capacitor. SEIG Schematic Figure supporting DVR with capacitors Fig. 2 illustrates. With DVR may enhance the power quality of the load terminal voltage may be improved if the load side voltage is brought back to a balanced sinusoidal voltage and the appropriate amplitude is reached.

In [5,] series compensation is examined as a means of enhancing the self-exiting induction generator's performance. Presented in [6] is PSCAD/EMTDC's modelling and analysis of unique power systems. For unbalanced and distorted loads, [7] describes how to design a a dynamic voltage restorer (DVR) assisted by capacitors. It is described in [8] how to control a DVR that is supported by capacitors using Adaline [9]. Looked at a perspective on the control in terms of voltage for generators that are self-excited by induction used in commercial applications. According to what is described in [10], the performance of the three-phase self-exited induction generator under transient conditions is rectified in series. For the purpose of controlling load voltage [11] contrasts the effectiveness of shunt and series compensators in distribution systems. based on VSC. Using a squirrel-cage induction generator as a control method, [12] explains how to increase wind farm stability.

More often, voltage sags and swells occur, resulting in serious issues and financial losses. Harmonics, flickers, imbalanced electricity, etc. These voltage and current harmonics exacerbate power losses, result in uneven heating, and pulse the torque on the generator shaft. Thus, we investigate the efficient and cost-effective operation of a self-exiting induction generator when it is coupled to a suitable series voltage controller, three-phase linear loads, and nonlinear loads. employed in conjunction with a three-leg current control voltage source converter, the STATCOM (shunt voltage controller) and DVR (series voltage controller) provide the necessary reactive power and manage the system voltage. STATCOM and DVR propose a hysteresis controller approach to regulate the system's voltage. In MATLAB, the whole system is represented utilising Simulink in conjunction with a toolset called PSB (power system block set). The findings of the simulation demonstrate that an asynchronous generator can support a three-phase load when it is fitted with a voltage controller.

II. THE SYSTEM'S CONFIGURATION AND CONTROL SCHEME

a primary mover with constant speed, such as a diesel or biogas engine) and a voltage controller make up this system. Under shifting load conditions, STATCOM/DVR satisfies the increased requirement for reactive power. The STATCOM/DVR serves as both a reactive power source and sink to maintain the terminal voltage constant. The suggested system is shown schematically in Fig. 3 together with the SEIG, STATCOM, and consumer load. STATCOM is a three-legged CCVSC (current control voltage source converter), filter inductor and dc bus capacitance. Fig.4 Display the set-up of the SEIG system, including the excitation capacitor, 3-leg CCVSC series voltage controller, consumer load, a transformer, and a capacitor with an IGBT converter (DVR). A synchronous speed test is conducted to establish the saturation characteristics of the generator, which is an asynchronous unit rated at 7.5 kW, 415V, 50Hz. The rated voltage is produced with no load using an excitation capacitor bank coupled in a delta configuration of 5 KVARAlong with reducing voltage dips, the VSC is often employed to solve additional problems with power quality, such as flicker and harmonics.



1) Fig. 3: SEIG-STATCOM schematic diagram

2) 1) The STATCOM control method includes the unit in phase voltage templets. Sensod source voltages (Va,Vb,Vc) create (Ua, Ub, and Uc) as well as quadrature voltage templates (Wa, Wb, and Wc). A controller using PI transmits the error signal by comparing the sensing device's dc bus voltage to the dc bus voltage of the device serving as the reference. *and provides* I_{smd}*. The unit in phase voltage vecters are multiplied by I_{smd}* to generate part of the reference currents $(I^*_{sad}, I^*_{sbd}, I^*_{scd})$ that are in phase. The quadrature voltage is multiplied to create the quadrature components of reference source currents $(I^*_{saq}, I^*_{sbq}, and\ I^*_{scq})$. templets with I^*_{smq}. I^*_{smq} is generate through another PI controller in which voltage at the terminals' amplitude (V_t) as well as reference terminal voltage (V_{tref}) are input signalsThe reference source current ($I^*_{sa}, I^*_{sb}, and\ I^*_{sc}$)'s in phase and quadrature components are added to create reference source currents. In order to create gate pulses for the system's IGBTs, the currents from the reference source are compared to the values of the sensoed source currents $(I_{sa}, I_{sb}, and\ I_{sc})$. *CCVSC after passing through the hysteresis controller. Figure 5 depicts the STATCOM control architecture.*

3) Control scheme of DVR: Unit voltage templates for three phases (U_{sad}, U_{sbd}, U_{scd}) are obtained from supply currents that are in phase (i_{sa}, i_{sb}, i_{sc}). To modify the DVR's dc bus voltage, an example of what a PI controller looks like placed over the observed voltage (V_{dc}) references, as well (V_{dc}*) voltages on the dc bus. The amplitude is determined by the result of the PI controller's calculations (V_{cd}*). The (V_{cd}*) creates in-phase by multiplying by unit voltage templates one of the injection voltages' components ($V_{Cad^*}, V_{Cbd^*}, V_{Ccd^*}$). Another to keep a PI controller is used in order to keep the voltage at the load terminal constant. The detected load voltage's amplitude (V_{Lp}) plus a reference point (V_{Lp}*) voltage at the load terminal passes through controller based on PI. The result of the PI controller's calculations V_{cq}* is voltage vectors in the quadrature unit multiplied (U_{saq}, U_{sbq}, U_{scq}) to create the voltages of the injections' quadrature component ($V_{Caq}*, V_{Cbq}*, V_{Ccq}*$) with the DVR. The in phase component's algebraic sum ($V_{Cad}*, V_{Cbd}*, V_{Ccd}*$), the portion of the equation that deals with quadrature ($V_{Caq*}, V_{Cbq*}, V_{Ccq*}$) generate the reference signals ($V_{La}*, V_{Lb}*, V_{Lc}*$). The reference is utilised over the hysteresis controller ($V_{La}*, V_{Lb}*, V_{Lc}*$) and measured the voltages at the sources (V_{La}, V_{Lb}, V_{Lc}) for the VSC's IGBTs (insulated gate bipolar transistors) to provide gating signals. Control scheme of STATCOM shown in fig. 6.

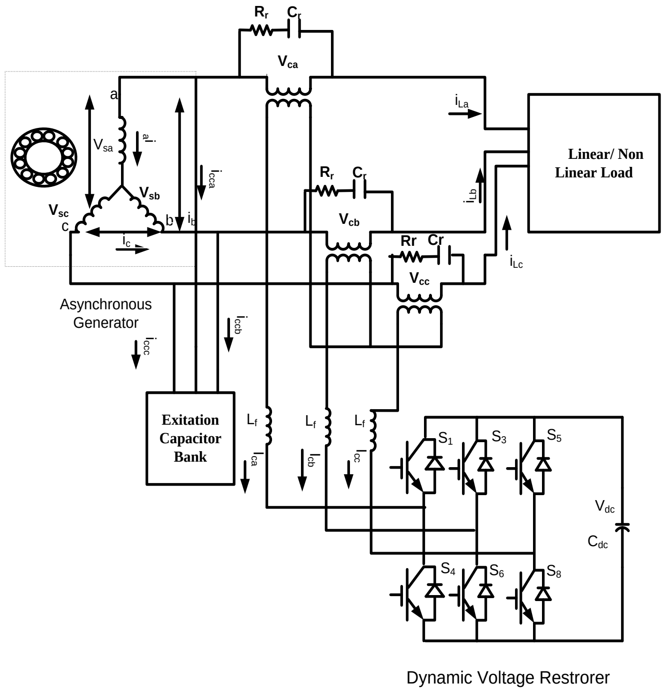


Figure 4. Schematic diagram of proposed system configuration

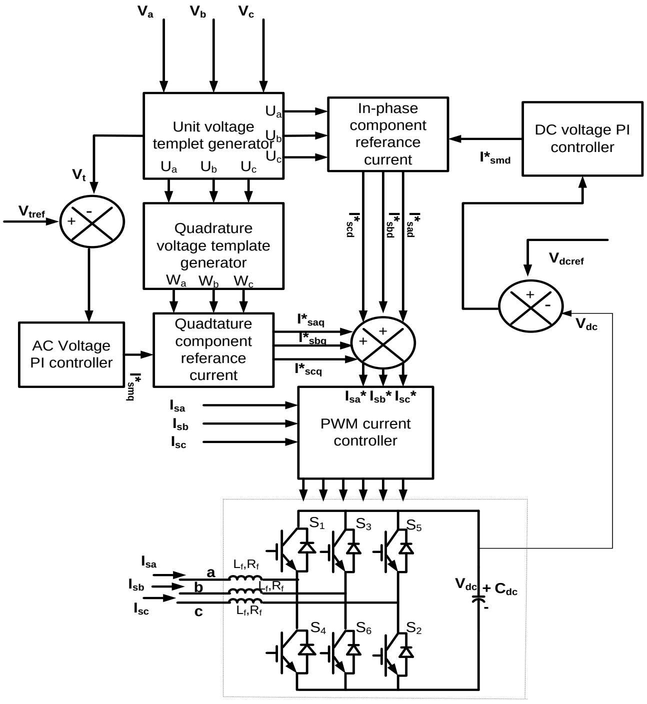


Fig.5 Control scheme of STATCOM

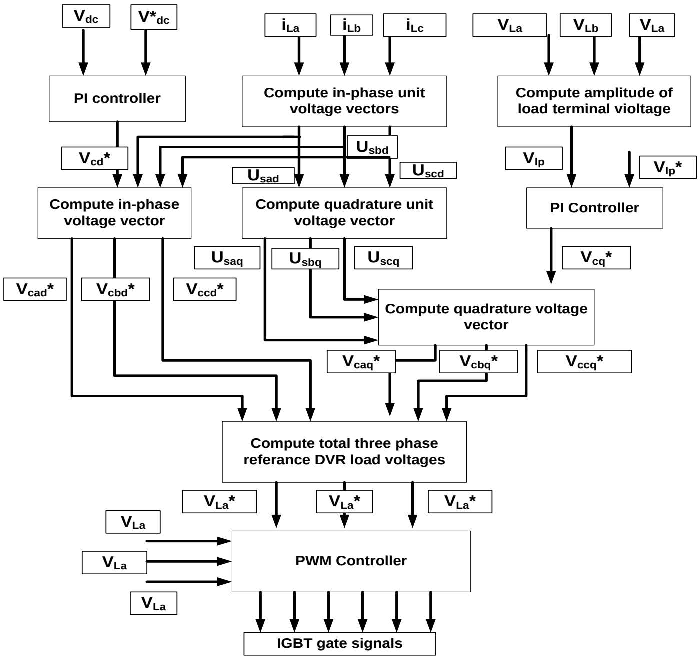


Figure 6. Control scheme of the DVR

III MODELING OF IAG WITH DVR AND STATCOM

4) The following describes the modelling about the control approach used by the SEIG-STATCOM system for the feeding of three phase load.

By dividing the ac voltages, three-phase sinusoidal functions, which serve as the unit templates, may be generated, are created V_a, V_b and V_c by the size of them V_t. The voltages on the line at the SEIG terminals in real time ($V_a, V_b\ and\ V_c$) are calculated based on their amplitude and are thought to be nearly sinusoidal:

$$V_t = \{(1/2)\ (V_a^2 + V_b^2 + V_c^2)\}^{1/2} \qquad (1)$$

Unit templates include:

$$U_a = V_a/V_t{:}\quad U_b = V_b/V_t{:}\quad U_c = V_c/V_t \qquad (2)$$

With respect to the associated unit vectors $U_a,\ U_b\ and\ U_c$ the quadrature set of unit vectors with a phase shift of 90° leading is approximated as,

$$W_a = (-U_b)/\sqrt{3}\ +\ (U_c)/\sqrt{3} \qquad (3)$$

$$W_b = \ \left(\sqrt{3}\ U_a\right)/\sqrt{2} + (U_b - U_c)/2\sqrt{3} \qquad (4)$$

$$W_c = \ -\left(\sqrt{3}\ U_a\right)/\sqrt{2} +\ (U_b - U_c)/2\sqrt{3} \qquad (5)$$

A. *Estimation of a source's in-phase component current*

The STATCOM $V_{dcer}\ (u)$ Inaccuracy of the voltage on the DC bus at the u^{th} The definition of the sampling moment is as follows:

$$V_{dcer} = V_{dc(u)}^* - V_{dc(u)} \qquad (6)$$

Where $V_{dc(n)}$ is the measured The STATCOM's direct current link voltage and $V_{dc(n)}^*$ is the voltage referenced in the DC system. The voltage on the STATCOM's DC bus comes in at maintained by the output of the PI controller at the point when the n^{th}sampling moment, and it is shown in the following way:

$$I_{smd(u)}^* = I_{smd(u-1)}^* + K_{pp}\left\{V_{dcer(u)} - V_{dcer(u-1)}\right\} + K_{ip}V_{dcer(u)} \qquad (7)$$

In equation (7) K_{pp} and K_{ip} proportional integral (PI) controller's integral and proportional gain constants, and $V_{cd(u-1)^*}$ is the magnitude of the in-phase voltage of the reference load component at the point where the $(u-1)^{th}$ instant. The estimated The following is a list of the instantaneous values of the active component currents coming from the reference source:

$$I_{sad}^* = I_{smd}^*U_a;\ \ I_{sbd}^* = I_{smd}^*U_b;\ \ I_{scd}^* = I_{smd}^*U_c \qquad (8)$$

B. *Estimation of Source current's quadrature component*

At the SEIG terminal, The alternating current measurement of voltage is performed, after which a contrast with the reference voltage is made $\left(V_{treff}\right)$. The PI controller handles the correction of the voltage inaccuracy. The current that is reactive to the alternating current voltage control loop is controlled by the PI controller's output (I_{smq}^*).

$$I_{smq(u)}^* = I_{smq(u-)}^* + K_{pq}\left\{V_{error(u)} - V_{error(u-)}\right\} + K_{iq}V_{error(u)} \qquad (9)$$

K_{pq} and K_{iq} are the gains and constants for the PI controller may be found in equation 9. It is anticipated that the reactive component of the instantaneous quadrature will be:

$$I_{saq}^* = I_{smq}^*W_a;\ \ I_{sbq}^* = I_{smq}^*W_b;\ \ I_{scq}^* = I_{smq}^*W_c \qquad (10)$$

C. *Estimation of the refractive source current*

The total amount pertaining to both the active and the reactive components that make up the total reference source current is the reference source current, which is the reference source current.:

$$i_{sa}^* = i_{saq}^* + i_{sap}^*;\ \ i_{sb}^* = i_{sbq}^* + i_{sbp}^*;\ \ i_{sc}^* = i_{scq}^* + i_{scp}^* \qquad (11)$$

Comparisons are made between the felt source currents $\left(i_{ga}^*, i_{gb}^*\ and\ i_{gc}^*\right)$ and the reference source currents $(i_{sa}^*, i_{sb}^*\ and\ i_{sc}^*)$. Current mistakes are calculated as follows:

$$i_{saerror} = i_{sa}^* - i_{sa};\quad i_{sberror} = i_{sb}^* - i_{sb};\quad i_{scerror} = i_{sc}^*\ \ i_{sc} \qquad (12)$$

These error signals are then applied to the gate drive (IGBT) signals' ON/OFF switching patterns, which create pulses using the hysteresis current controller.

2) The following describes the modelling of the SEIG-DVR system's control strategy for supplying a load with three phases.

As a result, the amplitude of the calculation for the three phase load currents of the SEIG feeding load is as follows:

$$i_{Lmag} = [2/3\ (i_{La}^2 +\ i_{Lb}^2 +\ i_{Lc}^2)]^{1/2} \qquad (13)$$

Individual load currents are divided by their amplitude to get the voltage vectors for the in phase units.

$$U_{sad}\ =\ i_{La}/i_{Lmag}\ ;\ U_{sbd}\ =\ i_{Lb}/i_{Lmag}\ ;\ U_{scd}\ = i_{Lc}/i_{Lmag} \qquad (14)$$

A quadrature transformation of it is possible to get the quadrature unit voltage templates by making use of the in-phase unit vector.

$$U_{saq} = -U_{sbd}/\sqrt{3} + U_{scd}/\sqrt{3} \qquad (15)$$

$$U_{sbq} = \sqrt{3}U_{sad}/2 + (U_{sbd} - U_{scd})/2\sqrt{3} \qquad (16)$$

$$U_{scd} = \sqrt{3}U_{sad}/2 + (U_{sbd} - U_{scd}/2\sqrt{3} \qquad (17)$$

A. Component of voltage vectors with quadrature

The following equation is what is used to determine a measure of the voltage present at the load terminals:

$$V_{Lp} = [2/3\,(V_{La}^2 + V_{Lb}^2 + V_{Lc}^2)]^{1/2} \qquad (18)$$

This load terminal voltage's amplitude, V_{Lp} , is contrasted with the example that it serves as value, V_{Lp}^* and produces an error signal. The following is the Ac load terminal error $V_{er(n)}$at the n^{th}sampling instant:

$$V_{er(n)} = V_{L(n)p}^* - V_{Lp(n)} \qquad (19)$$

For keeping during the nth sample moment, the AC load terminal voltage remained unchanged, the PI controller's output, denoted by $V_{cq(n)}^*$, is stated as follows:

$$V_{cq(n)}^* = V_{cq(n-1)}^* + K_{pa}\{V_{er(n)} - V_{er(n-1)}\} + K_{ia}V_{er(n)} \qquad (20)$$

Where $V_{cp(n-1)}^*$ corresponds to the amplitude about the voltage of the reference load quadrature component at $(n-1)^{th}$ instant and K_{pa} and K_{ia} correspond, respectively, to the proportional gain constant and proportional integral (PI) controller's integral gain constant; also known as the integral gain. For the purpose of computing, the following equation should be utilized reference load voltage's quadrature component:

$$V_{caq}^* = V_{cq}^*U_{saq};\quad V_{cbq}^* = V_{cq}^*U_{sbq};\quad V_{ccq}^* = V_{cq}^*U_{scq} \qquad (21)$$

B. Component of voltage vectors' in-phase

The DVR $V_{dcer}(n)$ Discrepancy in the measurement of the voltage that was obtained from the DC bus at the n^{th} the moment of sampling is:

$$V_{dcer(n)} = V_{dc(n)}^* - V_{dc(n)} \qquad (22)$$

Where $V_{dc(n)}$ is the measured voltage across the DC connection of the DVR and $V_{dc(n)}^*$ is the reference Direct current voltage. The following is given as the output of the PI controller, which ensures that the DC bus voltage of the DVR is maintained at the level of n^{th} sampling from at the moment.

$$V_{cd(n)}^* = V_{cd(n-1)}^* + K_{pd}\{V_{dcer(n)} - V_{dcer(n-1)}\} + K_{id}V_{dcer(n)} \qquad (23)$$

Where $V_{cd(n-1)^*}$, where K_{pd} and K_{id} is the amplitude of the component that occurs in phase with the reference load voltage at, proportional and integral gain constants of the proportional integral (PI) controller are denoted by and respectively, respectively, the $(n-1)^{th}$ in an instant. The following equation is used to calculate the components of the reference load voltage that are in phase are as follows:

$$V_{cad^*} = V_{cd^*}U_{sad};\ V_{cbd^*} = V_{cd^*}U_{sbd};\ V_{ccd^*} = V_{cd^*}U_{scd} \ (24)$$

C. Voltages of Reference Loads

The following are the results of multiplying the load voltages' components that are in-phase and quadrature in order to get the three-phase reference load voltages in their entirety:

$$V_{La^*} = V_{Cad^*} + V_{Caq^*} \qquad (25)$$

$$V_{Lb^*} = V_{Cbd^*} + V_{Cbq^*} \qquad (26)$$

$$V_{Lc^*} = V_{Ccd^*} + V_{Ccq^*} \qquad (27)$$

These reference load voltage signals are compared to the measured load voltages $(V_{La}, V_{Lb}, and\ V_{Lc})$, and they produce error signals. These error signals then travel by means of a hysteresis controller so that gating pulses may be generated for the purpose of switching the IGBTs of the voltage source converter.

3) Modeling of VSC (Voltage Source Converter)

The STATCOM/DVR is modelled as the following and is a current-controlled VSI. Its dc voltage's derivative is represented by:

$$pv_{dc} = (i_{ca}\,SA + i_{cb}SB + i_{cc}SC)/C_{dc} \qquad (28)$$

In this case, SA, SB, and SC refer to the and p = d/dt switches that control switches are used for the VSI Bridge on/off settings S_1-S_6.

The ac line with three phase PWM modulation voltages $e_a, e_b, and\ e_c$, which are denoted as the dc buster voltage at the output of the inverter are as follows:

$$e_a = v_{dc}(SA - SB), e_b = v_{dc}(SB - SC), e_c = v_{dc}(SC - SA) \qquad (29)$$

The output of the VSI of the SAF's volt-current equations are:

$$v_a = R_f i_{ca} + L_f p i_{ca} + e_a - R_f i_{cb} - L_f p i_{cb} \qquad \textit{(30)}$$

$$v_b = R_f i_{cb} + L_f p i_{cb} + e_a - R_f i_{cc} - L_f p i_{cc} \qquad (31)$$

$$i_{ca} + i_{cb} + i_{cc} = 0 \qquad (32)$$

The value of i_{cc} obtained from (10), which is then replaced into (9), yields the following results:

$$v_b = R_f i_{cb} + L_f p i_{cb} + e_a + r_f i_{ca} + L_f p i_{ca} + R_f i_{cb} + L_f p i_{cb} \qquad (33)$$

By rearranging (20) and (23), these result in

$$L_f p i_{ca} - L_f p i_{cb} = v_a - e_a - R_f i_{ca} + R_f i_{cb} \qquad (34)$$

$$L_f p i_{ca} + 2L_f p i_{cb} = v_b - e_b - R_f i_{ca} - 2R_f i_{cb} \qquad (35)$$

Hence, the SAF Solving for current derivatives results in (12) and (13) as:

$$p i_{ca} = \{(v_b - e_b) + 2(v_a - e_a) - 3R_f i_{ca}/(3L_f) \qquad (36)$$

$$p i_{cb} = \{(v_b - e_b) + (v_a - e_a) - 3R_f i_{ca}/(3L_f) \qquad (37)$$

4). Transformer modelling

Transformer magnetic flux ϕ produced by the SAF currents induces voltages $V_{ca1}, V_{cb1}, and\ V_{cc1}$ across the SAF side.

$$V_{ca1} = 1.414\, f \phi_{ca} N \qquad (38)$$

N is the quantity of turns across the transformer's SAF side, and f represents the SAF voltages and currents frequency. V_{ca}, V_{cb}, and V_{cc} are the voltages that the transformer pumped into the system?

$$(V_{ca}/V_{ca1}) = (V_{cb}/V_{cb1}) = (V_{cc}/V_{cc1}) = (N_1/N_2) \qquad (39)$$

Transformer rotations across the system side are represented by the number N_2.

5) Asynchronous generator modelling

By supplying torque via a prime mover with a constant speed, the self-excitation capacitance of the asynchronous machine functions as an IAG. The Simulink package contains the stationary reference frame model of the d-q axis asynchronous machine with saturation characteristic. By doing test of asynchronous speed on the device, saturation characteristics are discovered. An asynchronous machine's Equations for the following is a list of elements that make up the flux state-space model along the d-q axis:

$$p\phi_{ds} = v_{ds} - R_s i_{ds} \qquad (40)$$

$$p\phi_{qs} = v_{qs} - R_s i_{qs} \qquad (41)$$

$$p\phi_{dr} = v_{dr} - R_r i_{dr} - w_r \phi_{qr} \qquad (42)$$

$$p\phi_{qr} = v_{qr} - R_r i_{qr} + w_r \phi_{dr} \qquad (43)$$

IAG's developed torque is provided via

$$T_e = (3/4)\, p\, (\phi_{ds} i_{qs} - \phi_{qs} i_{ds}) \qquad (44)$$

The squirrel-cage rotor's voltages are

$$v_{dr} = v_{qr} = 0 \qquad (45)$$

The following currents may be used to represent these d-q axis flux linkages:

$$\phi_{ds} = L_s i_{ds} + L_m i_{dr}, \quad \phi_{qs} = L_s i_{qs} + L_m i_{qr} \qquad (46)$$

$$\phi_{dr} = L_s i_{dr} + L_m i_{ds}, \quad \phi_{qr} = L_s i_{dr} + L_m i_{qs} \qquad (47)$$

$$L_s = L_{ls} + L_m, \quad L_r = L_{lr} + L_m \qquad (48)$$

In the d and q axes, the s, r, l, and m subscripts stand for the stator, rotor, leakage, and magnetising amounts and so on.
The test of synchronous speed on the asynchronous machine yields the magnetising inductance L_m, which is given as a polynomial as follows:

$$L_m = a + bI_m + cI_m^2 + dI_m^2 \qquad (49)$$

where a, b, c, and d are fixed values. IAG's magnetising current is calculated as:

$$I_m = \{(i_{ds} + i_{dr})^2 + (i_{qs} + i_{qr})^2\}^{1/2}/\sqrt{2} \qquad (50)$$

The following is the primary mover torque speed characteristic:

$$T_{sh} = K_1 - K_{2\omega r} \qquad (51)$$

Where r is the rotor speed and K_1 and K_2 are constants listed inside the Appendix. The IAG stator voltages (v_s), followed by a capacitance for excitation (C_e) current through (i_e), are as follows:

$$C_e p[v_s] = [i_e] \qquad (52)$$

6) The consumer loads' modelling

Utilising readily accessible resistive and reactive elements, 7.5 kW linear loads with a power factor of 1 and 7.5 kW at 0.8pf are modelled. Utilising a a resistive element in this model, A three-phase diode rectifier is used in order to perform a simulation of the nonlinear demand. $V_{La}, V_{Lb}, and\ V_{Lc}$ are the three dc load voltages that are created when the load voltages for the three phases are as follows rectified to generate the dc load voltage. The I_d represents the current flowing through the dc load, while the R_L denotes the resistive load.

$$I_d = v_d/R_L \qquad (53)$$

IV STRUCTURE OF STATCOM/DVR

1) STATCOM Design: The evaluation of the STATCOM Design may be found in the IGBT, the voltage that is present across the capacitor for the DC link, the capacitance of the capacitor for the DC link, and the inductance of the capacitor for the DC link filtering coil.
In the case of a 0.8 pf trailing an induction generator required 140–160% of the reactive power when it was connected to a reactive load that it was producing to feed the reactive power. Consequently, STATCOM's VAR rating is around 15 KVAR for a 7.5 kW SEIG generator.

The power that once seemed to be (P_{appr}) is:

$$P_{appr} = [(P_{active})^2 + (P_{reactive})^2]^{1/2} = [(7.5)^2 + (15)^2]^{1/2} = 16.77 \quad KVA$$

As of right now, the rating of the VSC of STATCOM is:

$$P_{appr} = \sqrt{3}V_L I_c,\ I_c = (16.77^*/\sqrt{3}\,415^* = 23.3\,A$$

Iaver = 0.9*Ic*23.3 = 20.97 is the average current. For the hysteresis controller to operate well, Because of this, the voltage of it is necessary for the DC bus to have a voltage that is higher than the line's peak voltage.

$$V_{dc} = 2\sqrt{2}(V_L/\sqrt{3}m_a^* = 677\,V$$

The voltage of the DC connection is currently fixed at 700 V
Inductance of the filter:

$$L_{fan} = L_{fbn} = L_{fcn} = (\sqrt{3}^* m_{a^*} V_{DC})/(12^* \partial F_{s^*} I_{Lripple(p-p)}$$

$$I_{lripple(p-p)} = 0.05^*\ 23.3^* \surd 2 = 1.65\,A$$

$$L_{fan} = L_{fbn} = L_{fcn} = \sqrt{3}^* 1^* 700/(12^* 1.8^* 10^* 10^{3*} 1.65) = 3.4\,mH$$

Calculating the value of the DC connection capacitor goes as follows:

$$V_{DC-ripple} = (1/C) \int i_c\,dt = (I_{aver})/(2 * w * C_{DC}),\ C_{DC} = 4000\,\mu F$$

Calculation for the rating of IGBT of STATCOM:
Through STATCOM, a maximum rms current rating of 23.3 A is permitted. The switching devices' largest current at any one time is

$$I_{SD} = 1.25\,(I_{cripple(p-p)} + I_{cpeak}) = 1.25(0.05 * \surd 2 * 23.3 + \surd 2 * 23.3) = 43.4\,A$$

where $I_{cripple(p-p)}$ denotes the ripple current's peak to peak. Peak line current is represented by I_{cpeak}, while the safety margin used in design is represented by 1.25.

The switching device's voltage rating is determined according to the most powerful voltage present in the DC connection, which is 750 V. The following is the proposed voltage rating for use with switching devices $V_{SD} = 1.25^*\ 750 = 937.5\,V$, taking a 125% margin into account.

2) Creating a DVR: The voltage rating, current rating, and Rating in KVA of the DVR's voltage source converter are all included in design of the digital video recorder. This is the injection rating of the transformer, voltage on the capacitance of the dc bus as well as the dc bus itself, inductance of the ac interface, and so on are all factors to be considered. The ripple filter when linear and nonlinear loads are present in the system.
The highest voltage that may be injected under a linear load scenario determines the maximum allowable voltage of the video signal conditioner of the DVR. The following formula is used to compute the maximum drop in the voltage at the source terminal if a voltage swings up to 25% of the phase voltage: The voltage that is injected is 179.7 V (V_c), which is calculated as follows:

$$V_c = \surd(V_s^2 - V_L^2) = \surd(239.6^2 - 179.7^2) = 158.4\,V$$

The load from the three phase rectifier may be found in the event that a nonlinear load is present. This is the voltage that is present on the dc bus utilised to design the voltage of the DVR. The only component of the load voltage that the DVR will inject is the harmonic component and eliminates harmonics from the source current. Consequently, the following is the crucial component:

$$V_{LL} = (\surd 6/\pi)\,V_d = 0.779 * V_d$$

V_d is 532.7 V where V_{LL} refers to the line voltage which is 415 volts. Taking the difference between these two values gives us the voltage rating of the DVR between the voltage at the source terminal and the voltage at the load. The following formula may be used in the calculation of the voltage of the DVR:

$$V_{C(rms)}^2 = \frac{1}{\pi}[\{2\int_0^{\pi/3} (415\surd 2 \sin\theta - 0)\} + \{\int_0^{2\pi/3} (415\surd 2 \sin\theta - 532.7)\}]d\theta$$

$V_{C(rms)} = 145.56\,V$ VSC's rating of voltage in a load that is nonlinear is. The ideal given that there is a mix of a linear and nonlinear load, the value of the voltage rating of the VSC is thus determined to be V_c = 158.4 V.

The linked load on the aforementioned system establishes the rating that is currently assigned to VSC. The currents are estimated as follows for a 7.5kW load with 0.8 pf loads and unity power factor:

$$\sqrt{3}\, V_s I_s \ = \ 7500/pf$$

Where Is and Vs, respectively, stand for both voltage and current on the line. The current VSC rating assuming V_s is constant at 415 V and unity pf is $I_s = 10.43A,$ whereas the current VSC rating for 0.8 pf is $I_s = 13.343A.$
When used to nonlinear loads, the component of the main load current is what establishes the VSC's maximum allowable current rating. The following equation is used to calculate the rating of the VSC at this time for a source current of unity pf, a resistive load of 7.5kW, and the voltage at the load, V_L, equals 415 V:

$$I_s \ = \ P/(\sqrt{3} V_L) \ = \ 13.043A$$

The R_L is calculated by using the dc load's equivalent resistance as a reference point :

$$P_{dc} \ = \ (V_d^2/R_L)$$

For $P_{dc} \ = \ 7.5kW$ and $V_d = \ 532.7\ V$, the $R_L = \ 37.84\ \Omega$

The formula for calculating the KVA rating of the DVR's VSC is:

$$kVA \ = \ 3V_c I_s/1000 \ = \ (3 * 158.4 * 13.043)/1000 \ = \ 6.198kVA$$

The characteristics of the injection transformer and VSC's kVA ratings are same.

$$kVA \ = \ 3\, V_c I_s/1000 \ = \ (3 * 158.4 * 13.043)/1000 \ = \ 6.198\ kVA$$

Consequently, A rating of 158/158 can be seen on the injection transformer, which has a kVA rating of 6.198.

The VSC side voltage of the injection transformer voltage determines the dc capacitor voltage $V_{C(s)}$ = 158 V

$$V_{dc} > \ 2\sqrt{2}\, V_{C(s)} \ = \ 446.8\, V$$

Hence V_{dc} = 450 V is selected for DVR.

Depending on the amount of momentary energy that's required during a shift in load situation, the capacitance of the dc bus is chosen. Consider the capacitor's energy reserve as being equal to the load's energy need for a portion of the power cycle.

$$(1/2)\ C_{dc}(V_{dc}^2 - V_{dc1}^2) \ = \ 3\, Vph * Iph \ * \ t$$

Whereas the required voltage for the dc bus is denoted by Vdc, the voltage denoted by Vdc1 is drop that allows for transients, and t is the duration for which assistance is needed. Taking into account the following values: t = 400 s, Vdc = 450 V, Vdc1 = 450 - 2% of 450 = 441 V, and Cdc is the dc bus capacitance.
1/2 * Cdc (4502 - 4412) = 3*239.6*13.043*0.40 ms

C_{dc} = 0.935 mF, hence for DVR, a 1000F, 450V dc bus is used.
The switching frequency determines how a ripple filter is designed. The series inductor offers a high impedance channel for switching ripple, while the capacitor offers a low impedance path. At a frequency equal to 5 kilohertz, which is half of the switching frequency, the reactance that is given by the capacitor and the inductor may be estimated as follows:

$$X_{Cr} = \ 1/\ (2 * \pi * f_r * C_r) \ = \ 1/\ (2 * 3.14 * 5000 * C_r)$$
$$X_{Lr} \ = \ 2 * \pi * f_r * L_r \ = \ 2 * 3.14 * 5000 * L_r$$

For $X_{Cr} \ = \ 3\Omega, C_r = \ 10.61\mu F\ and\ for\ X_{Lr} = \ 100\Omega, L_r = \ 3.18\ mH$

Calculation for the DVR's IGBT rating:
13.043 A is the maximum rms current rating using DVR. The switching devices can handle a maximum current of $ISD \ = \ 1.25\ (I_{cripple(p-)} \ + \ I_{cpeak}) \ = \ 1.25\ (0.05 * 2 * 13.043 \ + \ 2 * 13.043) \ = \ 24.2\ A.$
where $I_{cripple(p-p)}$ denotes the ripple current's peak to peak. Peak line current is represented by I_{cpeak} , while the safety margin used in design is represented by 1.25.
The maximum DC-link voltage, which is 450 V, determines the switching device's voltage rating. Switching devices should have a voltage rating of VSD = 1.25 * 450 = 562.5 V, taking a 125% margin into account. Design criteria for STATCOTM and DVR shows in Table-I

TABLE-I

	IAG- STATCOM	IAG-DVR
Rating of IAG	7.5kW	7.5kW
Source Voltage	415V	415V
Rating in KVA for the VSC	16.77 KVA	6.198KVA
Current Rating of VSC	23.3A	13.043A
DC Bus Voltage	700V	450V
DC Bus Capacitance	4000µF	1000µF
Filters	3.48mH	3.18mH,10.6µF
Current Rating of IGBT	43.4A	24.2A
Voltage Rating of IGBT	937.5V	562.5V
Rating of Transformer	-	6.198KVA, 158V/158V

V RESULT AND DISCUSSION

Figures 7 and 8 show the waveforms of the generated sours the terminal, the voltage (Vs), the current (Is), and the excitation current (Ic) voltage (Vt), compensating current (Icc) and load current (IL), Voltage across a DC connection, measured in (Vdc), and mechanical speed, measured in (Wm) for a STATCOM-based voltage regulator connected with SEIG is responsible for supplying consistent speed to three-phase linear and nonlinear loads application. The 7.5-kilowatt, 415-volt, 4-pole SEIG generator with STATCOM was utilised, and the appendix has detailed parameters. Figure 9 illustrates the operation of three phases of the SEIG-STATCOM with three phase loads ranging from 4.5 to 7.5 kW at 1.1 seconds. Both the load current and generator current rise in lockstep. Both the source voltage, as well as the voltage of the DC link are stable.

Waveforms of the generated sours voltage (Vs) and current (Is), DVR load, as well as the voltage after correction, which is denoted by V_c and V_L. and current (IL), direct current link voltage (Vdc), and mechanical speed (Wm), in addition to the functionality of a DVR-based voltage regulator connected with a SEIG feeding three phase linear and non-linear loads at constant speed application are shown in figs. 10 and 11, respectively. It was decided to make use of the 7.5 kW, 415V, 4 poles SEIG with DVR, and the appendix has detailed parameters. Figure 12 illustrates the operation of a three-phase SEIG with three-phase loads ranging from 4.5 to 7.5 kW at 1.1 seconds. Both the load current and generator current rise in lockstep. For a few cycles, the load voltage is steady with a little transient. Even when there is an inductive load, the voltage at the source drops but the voltage at the load does not change.. The voltage of the DC connection also doesn't change.

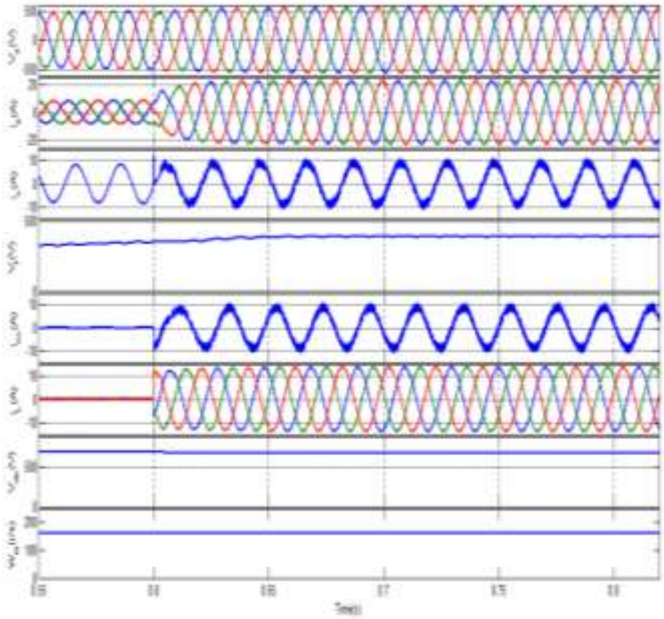


Figure 7 Performance of SEIG-STATCOM under Linear Loads

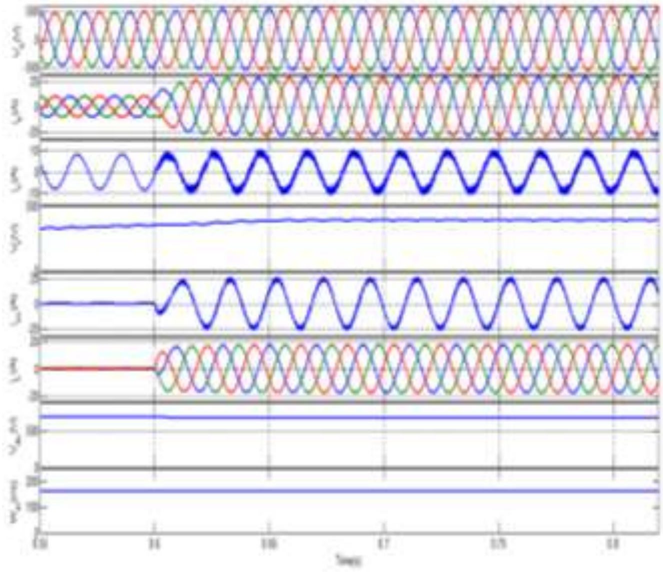


Figure 9 Performance of SEIG-STATCOM under Varying Load Condition

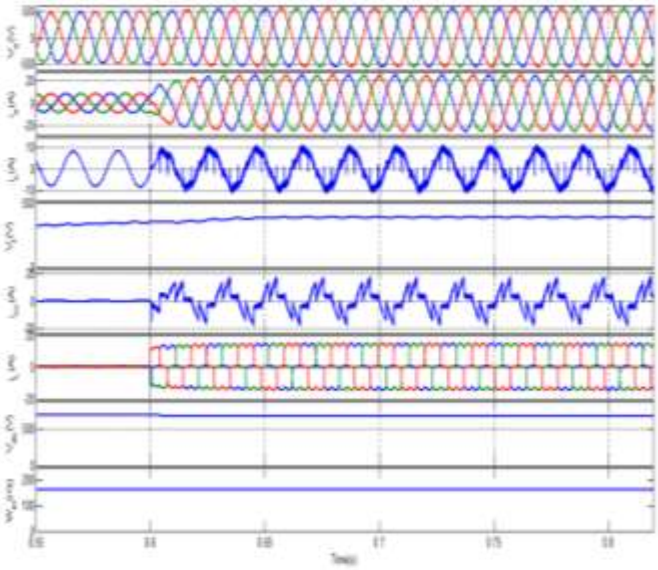


Figure 8 Performance of SEIG-STATCOM under Nonlinear Loads

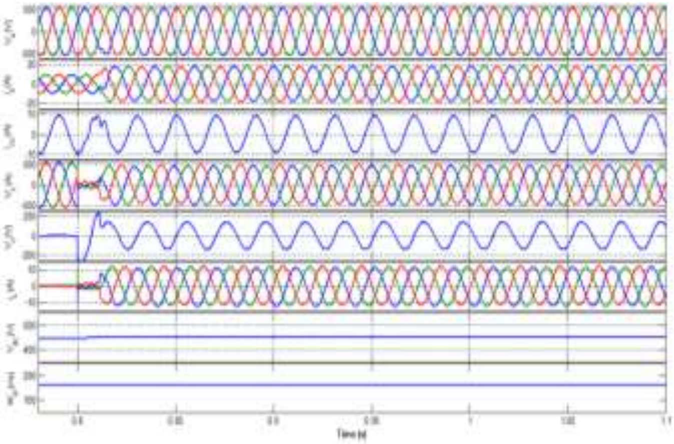


Figure 10 Performance of SEIG-DVR under Linear Loads

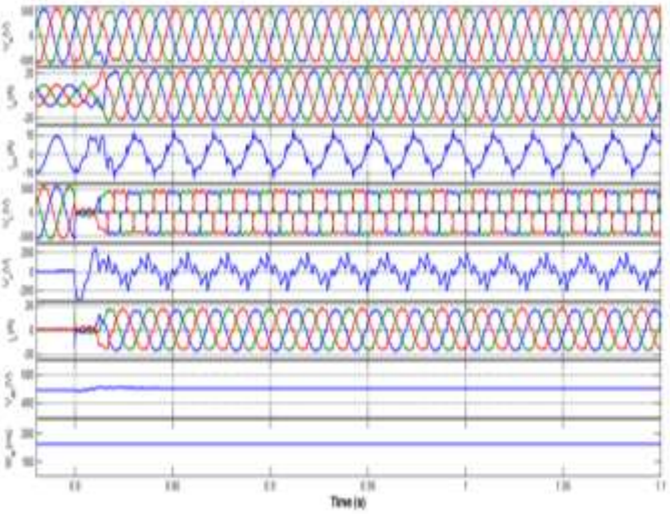


Figure 11 Performance of SEIG-DVR under Non-Linear Loads

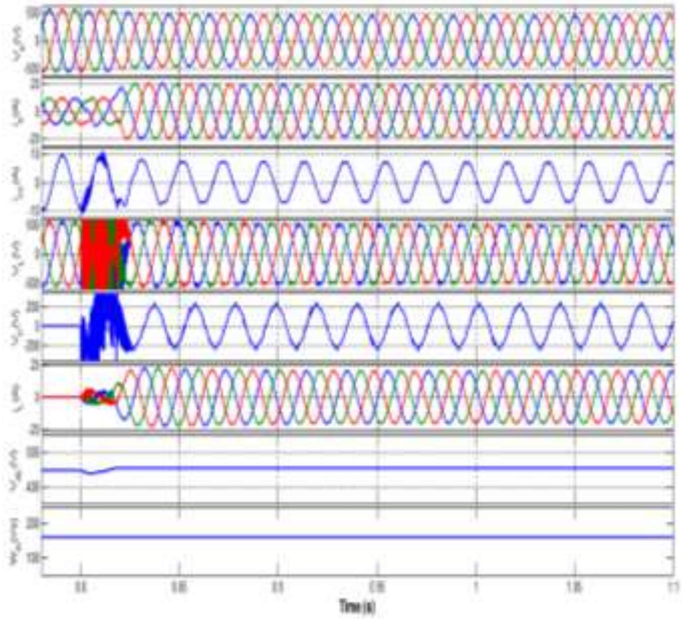


Figure 12 Performance of SEIG-DVR under Varying Loads Condition

VI CONCLUSION

It has been shown that the SEIG-STATCOM and SEIG-DVR systems are capable of three-phase feed nonlinear and variable linear loads in applications requiring constant speed. STATCOM and DVR are used to illustrate a 7.5 kW, 415 V, 50 Hz, Y-connected SEIG that supplies variable three-phase resistive loads with an output power range of 4.5 kW to 7.5 kW, as well as a 7.5 kW, 0.8 pf inductive load. Simulated results using MATLAB have shown very good performance. The proposed DVR and STATCOM controller is appropriate for effective voltage management even when the system is operating at full capacity.

VII. APPENDIX

A. The following is a list of the specifications for an asynchronous machine with 4 poles, 7.5 kW of power, 415 volts, and 50 hertz.

$$L_m = 0.134H\ (I_m < 3.16)$$

$$R_s = 1\Omega, R_r = 0.77\Omega, Xl_r = Xl_s = 1.5\Omega, J = 0.1384kg - m2$$

$$L_m = 0.068H\ (I_m > 12.72)$$

$$L_m = 9e - 5I_m2 - 0.0087I_m + 0.1643(3.16 < I_m < 12.72)$$

B. The parameters of the controller

L_f = 2mH, R_f = 4Ω, C_f = 10uF and C_{dc} = 1000uF.

$K_{pa} = 10, K_{ia} = 8.$

$K_{pd} = 0.0048, K_{id} = 0.018.$

There are there are three distinct single-phase transformers, each of which has a rating of 3kVA and a voltage range of 300V/300V; 400 volts is the value of the DC link voltage.

C. Consumer Loads

A load with a resistive component 1.5kW and 2.5kW load at each phase

D. Prime Movers Characteristics

$K_2 = 100,$

$K_1 = 16100,$

$T_{sh.} = K_1 - K_2\omega_m$

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