

## A Voltage Regulator for Parallel Operated Isolated Synchronous Generators Using Statcom

Sravanthi Gudipati, Srikanth D, B.Deepthi

Assistant Professor Electrical & Electronics Engineering Department Vignan Institute of Technology & Science Deshmukhi, Nalgonda

Assistant Professor Electrical & Electronics Engineering Department Vignan Institute of Technology & Science Deshmukhi, Nalgonda

Assistant Professor Electrical & Electronics Engineering Department Vignan's Institute of Management & Technology for Women, Ghatkesar

### Abstract

Reactive power (vars) is required to maintain the voltage to deliver active power through transmission lines. Generator and other loads require reactive power to convert the flow of electrons into useful work. When there is not enough reactive power, the voltage sags down and it is not possible to push the power demanded by loads through the lines. Thus reactive power is injected using the compensating device STATCOM. The Paper deals on static synchronous compensator (STATCOM) which is connected to the parallel operated isolated synchronous generators to drive a 3-phase load. These generators are driven by constant prime mover like diesel engine, bio-mass, gasoline, steam turbine etc. Three single phase IGBT based Voltage source converter (VSC) along with 3-single phase transformers and self supported D.C bus is used as a voltage controller. The project deals with controlling a STATCOM using non-linear techniques that involves hysteresis current control and Park's transformation. The voltage controller of parallel operated generators for feeding 3-phase loads driven by constant speed prime mover like Hydraulic turbine governor model helps in satisfactory operation under varying loads and in load balancing. If the line current is less than the expected, the compensating current generated by STATCOM is taken by loads.

**Keywords-** STATCOM, Synchronous generator, VSC, load balancing.

### I. INTRODUCTION

It has been recognized that the steady-state transmittable power can be increased and the voltage profile along the line controlled by appropriate reactive shunt compensation. The purpose of this reactive compensation is to change the natural electrical characteristics of the transmission line to make it more compatible with the prevailing load demand. Thus, shunt connected, fixed or mechanically switched reactors are applied to minimize line overvoltage under light load conditions and shunt connected and fixed or mechanically switched capacitors are applied to maintain voltage levels under heavy load conditions. The project deals on FACTS controllers, how the FACTS controllers can be used to control power flow in ac transmission line. The rapid depletion and increased cost of conventional fuels have given a thrust in the research on developing synchronous generators as an alternative power sources. Synchronous generators usually operate together (or in parallel), forming a large power system supplying electrical energy to the loads or consumers. Here we deal about nonlinear techniques used to control STATCOM operation. It

involves hysteresis current control technique and parks transformation. The hysteresis control scheme provides excellent dynamic performance because it acts quickly and an inherent peak current limiting capability is also provided. Park's transformation is commonly used, in three-phase electric machine models, to eliminate time-varying inductances by referring the stator and rotor quantities to a fixed or rotating reference frame. On an overall cost point of view, the voltage-sourced converters seem to be preferred, and will be the basis for presentations of most converter-based FACTS Controllers. For the voltage-sourced converter, its ac output voltage is controlled such that it is just right for the required reactive current flow for any ac bus voltage de capacitor voltage is automatically adjusted as required to serve as a voltage source for the converter. STATCOM can be designed to also act as an active filter to absorb system harmonics.

### II. BASIC DIAGRAM OF STATCOM

Recently the Voltage Source Inverter (VSI) based Static VAR compensators have been used for reactive power control. These compensators are known as Advanced Static VAR Compensator

(ASVC) or Static Synchronous Compensator (STATCOM)

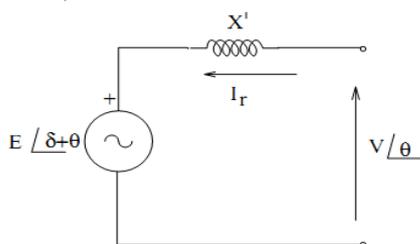


Fig.1: Synchronous compensator

A STATCOM is comparable to a Synchronous Condenser (or Compensator) which can supply variable reactive power and regulate the voltage of the bus where it is connected. The equivalent circuit of a Synchronous Condenser (SC) is shown in Fig 1 which shows a variable AC voltage source (E) whose magnitude is controlled by adjusting the field current. Neglecting losses, the phase angle ( $\delta$ ) difference between the generated voltage (E) and the bus voltage (V) can be assumed to be zero. By varying the magnitude of E, the reactive current supplied by SC can be varied. When  $E = V$ , the reactive current output is zero. When  $E > V$ , the SC acts as a capacitor whereas when  $E < V$ , the SC acts as an inductor. When  $\delta = 0$ , the reactive current drawn ( $I_r$ ) is given by

$$I_r = \frac{V - E}{X'} \quad (1)$$

The steady state control characteristics of a STATCOM are shown in Fig 2. The losses in the STATCOM are neglected and  $I_{STATCOM}$  is assumed to be purely reactive. As in the case of a SVC, the negative current indicates capacitive operation while positive current indicates inductive operation. The limits on the capacitive and inductive currents are symmetric (+ or -  $I_{max}$ ). The positive slope BC is provided for the V-I characteristic to

- (i) Prevents the STATCOM hitting the limits.
- (ii) Allows parallel operation of two or more units.

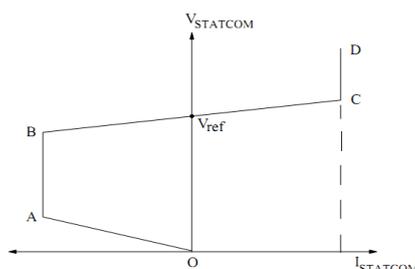


Fig .2: V-I characteristics of STATCOM

### III. CONTROL STRATEGIES

#### 3.1. HYSTERESIS CURRENT CONTROL

The hysteresis control is used for rapid switching of each switch according to the continuous measurement of the difference between the STATCOM supply current and reference sinusoidal current. The basic principle of current hysteresis control technique is that the switching signals are derived from the comparison of the current error signal with a fixed width hysteresis band width simple, extreme robustness, good stability, fast dynamic, this current control technique exhibits some unsatisfactory features. Hysteresis control the phase output current is fed back to compared with the reference current. In this approach a sine reference current wave is compared to the actual phase current wave. As the current exceeds a prescribed hysteresis band, the upper switch in the half-bridge is turned off and the lower switch is turned on. The total reference currents ( $i^*a$ ,  $i^*b$  and  $i^*c$ ) are compared with the sensed source currents ( $i_a$ ,  $i_b$  and  $i_c$ ) which is some of source currents of both isolated synchronous generators. The error signal thus obtained is used to generate the ON/OFF switching patterns of the gate drive signals to the STATCOM by PWM hysteresis controller. The current errors are computed as:-

$$I_{aerr} = I_a - I_a^* \quad (2)$$

$$I_{berr} = I_b - I_b^* \quad (3)$$

$$I_{cerr} = I_c - I_c^* \quad (4)$$

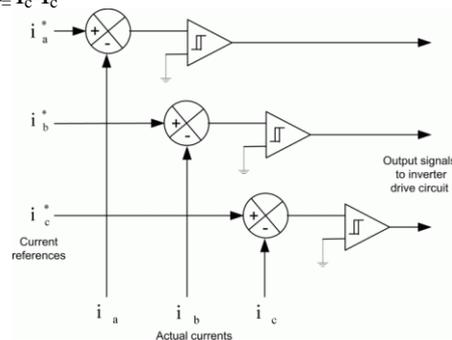


Fig.3: Hysteresis Current controller

#### 3.2. PARK'S TRANSFORMATION

Park's transformation is commonly used, in three-phase electric machine models, to eliminate time-varying inductances by referring the stator and rotor quantities to a fixed or rotating reference frame. In the case of a synchronous machine, the stator quantities are referred to the rotor.

$$\frac{d\varphi}{dt} = -[R][L]^{-1}\varphi - \theta \quad (5)$$

$$I = [L]^{-1} \varphi \quad (6)$$

Where

$$[L] = \begin{bmatrix} L_{ss} & L_{sr} \\ L_{rs} & L_{rr} \end{bmatrix} \quad (7)$$

$L_{ss}$ =self-inductance,  $L_{sr}$ =mutual inductance

$$R = \begin{bmatrix} R_s & 0 \\ 0 & R_r \end{bmatrix} \tag{8}$$

For abc to dq0 transformation:-

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = [C_p] \begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} \tag{9}$$

$V_a, V_b, V_c$  = Voltages with reference to stator

$V_d, V_q, V_0$  = Voltages with reference to rotor

Where

$$[C_p] = \begin{bmatrix} K_d \cos \theta & K_q \sin \theta & K_0 \\ K_d \cos(\theta - 240) & K_q \sin(\theta - 240) & K_0 \\ K_d \cos(\theta + 240) & K_q \sin(\theta + 240) & K_0 \end{bmatrix} \tag{10}$$

Where  $K_d=1.0, K_q=-1.0, K_0=1$

For dq0 to abc transformation:-

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = [C_p]^{-1} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{11}$$

$$[C_p]^{-1} = \begin{bmatrix} K_1 \cos \theta & K_1 \cos(\theta - 240) & K_1 \cos(\theta + 240) \\ K_2 \sin \theta & K_2 \sin(\theta - 240) & K_2 \sin(\theta + 240) \\ K_3 & K_3 & K_3 \end{bmatrix} \tag{12}$$

Where  $k_1 = (2/3 k_d), k_2 = (2/3 k_q), k_3 = (1/3k_0)$

Voltage equations for abc to dq0 transformation:-

$$V_a = V_d \sin(\omega t) + V_q \cos(\omega t) + V_0 \tag{13}$$

$$V_b = V_d \sin(\omega t - 2\pi/3) + V_q \cos(\omega t - 2\pi/3) + V_0 \tag{14}$$

$$V_c = V_d \sin(\omega t + 2\pi/3) + V_q \cos(\omega t + 2\pi/3) + V_0 \tag{15}$$

Voltage equations for dq0 to abc transformation:-

$$V_d = V_a \sin(\omega t) + V_b \sin(\omega t - 2\pi/3) + V_c \sin(\omega t + 2\pi/3) \tag{16}$$

$$V_q = V_a \cos(\omega t) + V_b \cos(\omega t - 2\pi/3) + V_c \cos(\omega t + 2\pi/3) \tag{17}$$

$$V_0 = 1/3(V_a + V_b + V_c) \tag{18}$$

Where  $\omega$  = rotation speed (rad/s) of the rotating frame.

The abc to dq0 Transformation block computes the direct axis, quadratic axis, and zero sequence quantities in a two-axis rotating reference frame for a three-phase sinusoidal signal. The transformation is the same for the case of a three-phase current we simply replace the  $V_a, V_b, V_c, V_d, V_q,$  and  $V_0$  variables with the  $I_a, I_b, I_c, I_d, I_q,$  and  $I_0$  variables. This transformation is commonly used in three-phase electric machine models, where it is known as a Park's transformation. It allows us to

eliminate time-varying inductances by referring the stator and rotor quantities.

#### IV. BLOCK DIAGRAM OF THE SYSTEM

Block diagram consists of Synchronous generator system driving load with shunt compensation using STATCOM. dq0 and inverse dq0 transformation block produces referenced source currents which are compared with sensed source currents in comparator. The comparator gives error signal obtained to the pulse generator block which generates gate pulses using hysteresis control technique. This gate signals triggers the STATCOM in order to generate compensating current. This compensating current induces into line with help of shunt connected three single phase transformers. The resultant current flows through lines to drive loads. Implementation of nonlinear control of STATCOM using MATLAB consists of following subsystems.

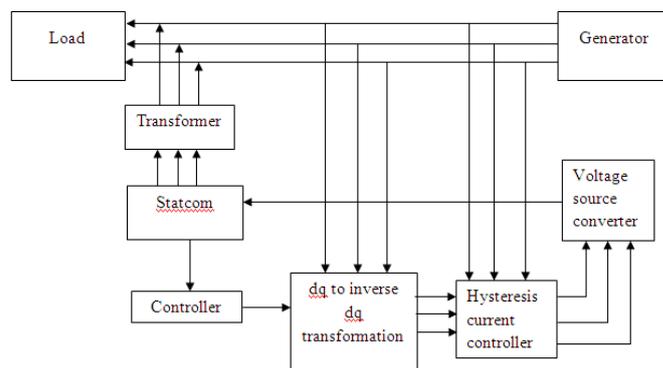


Fig.4: Block diagram of system

#### 4.1. GENERATING SYSTEM

Generation circuit employs mainly consists of two generating units. Each unit consists of a synchronous machines attached to steam turbine and governor. The turbine and governor is connected in order to supply positive mechanical power to make synchronous machine acts as generator. The Steam Turbine and Governor block implements a complete compound steam prime mover, including a speed governing system, a four-stage steam turbine, and a shaft with up to four masses. The speed governing system consists of a proportional regulator, a speed relay, and a servomotor controlling the gate opening. The mechanical power  $P_m$  is developed using the turbine shaft model where as field voltage  $V_f$  is generated by excitation blocks. This  $P_m, V_f$  acts as inputs to the synchronous machine. By receiving inputs from steam turbine and governor system synchronous machine generates power feeding lines a, b, c. The same process takes place in generating unit two also. Thus two generating units operate in parallel generate power that fed loads through transmission lines. The generating system is shown in below figure

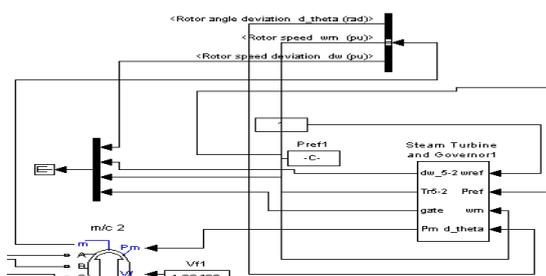


Fig.5: Generating system

4.2 TRANSFORMATION SYSTEM

This involves abc-dq0 and dq0-abc transformations using parks transformation formulae. In general all systems are nonlinear. It is not possible to change nonlinear parameters. We can change system parameters linear mode .So we are converting non linear to linear i.e. three phase to two phase). Here three phase is converted to two phase in order to modify parameters and by using filters unwanted ripples are eliminated. The transformation system is shown in fig 6

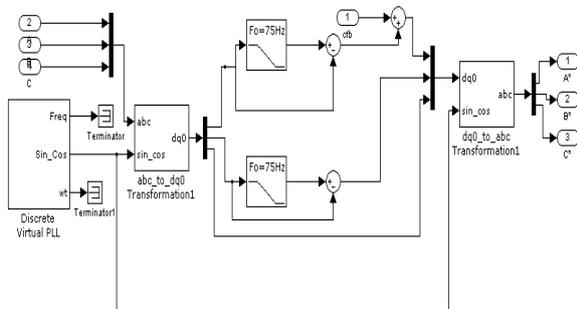


Fig .6: Transformation system

4.3 HYSTERESIS SYSTEM

The obtained error signal from transformation system and the reference signals that are resulted from the voltage source inverter are processed here using the comparators flip flops and unit delay blocks resulting a switching pulses. Thus generated pulses are applied to gate terminal of STATCOM. The Hysteresis system is shown in fig 7

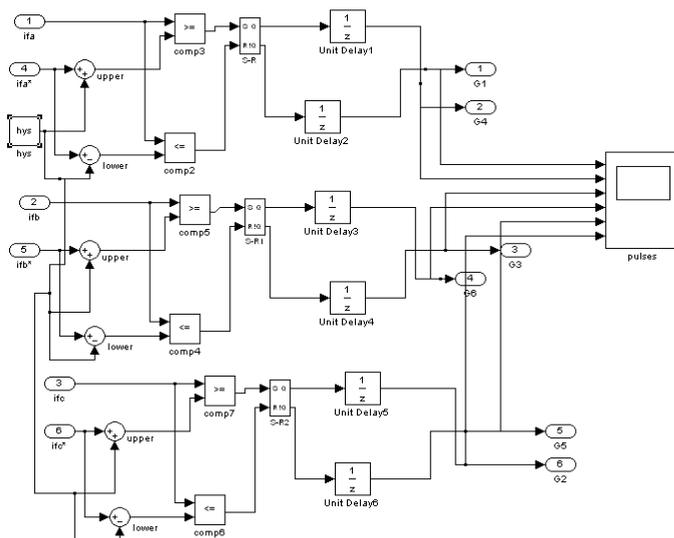


Fig.7: Hysteresis current controller

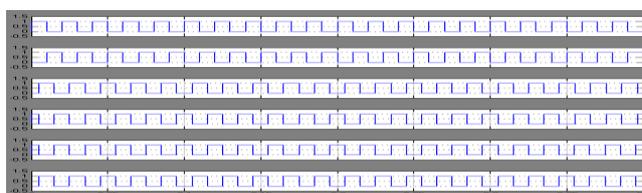


Fig.8: Gate pulses generated by the hysteresis controller

4.4 STATCOM SYSTEM

STATCOM is main device using in this project. It takes, supply from dc source, and gate pulses generated by hysteresis control block. If line current is less than the compensating current generated by STATCOM is used by the loads. Feedback is connected to the PI controller in order to regulate the error between the capacitor voltage and its reference.

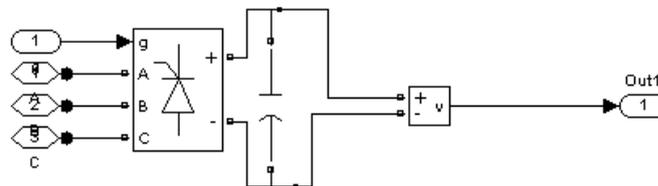


Fig.9: STATCOM system

4.5 MAIN CIRCUIT LAYOUT

The main circuit diagram is formed by connecting all the above discussed sub systems such as generation subsystem, STATCOM sub system, Hysteresis current block, load connected in proper manner as shown below fig 10.

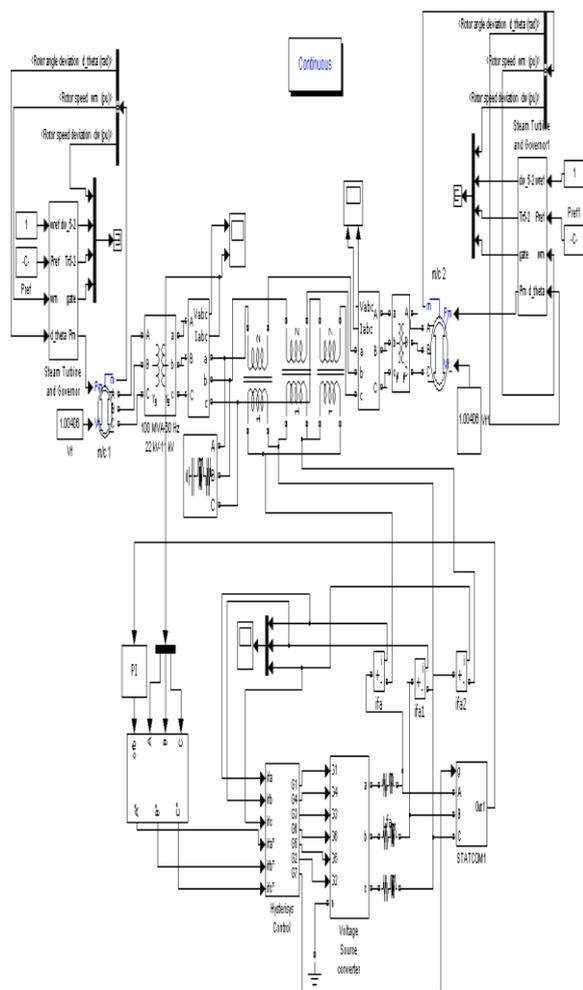


Fig.10: Main Simulink diagram

### V. WORKING

The generation sub system consisting of two parallel operated synchronous generators acts as an alternating current source. The current generated by this generating subsystem is used to drive loads. Line current is directly going to transformation subsystem where three phase power is converted into two phase power with the help of Park transformation to eliminate time-varying inductances by referring the stator and rotor quantities to a fixed or rotating reference frame and then again it is converted to three phase power. The currents obtained from this block are called as reference source currents. Thus error signals obtained after comparing these reference source currents with compared with sensed source currents is fed to hysteresis current control block. The gate pulses required to trigger thyristors in STATCOM are generated from hysteresis current control block and its inverse pulse signal by Boolean data type conversion. This gate signals trigger thyristors in voltage source converter correspondingly. The dc source is connected on dc

terminal side of STATCOM and ac terminals to lines with the help of single phase transformers. When thyristors are fired in proper sequence STATCOM generates compensating current which induces into transmission lines through shunt connected single phase transformers. Feedback is connected to the PI controller in order to regulate the error between the capacitor voltage and its reference.

### VI. SIMULATION RESULTS AND ANALYSIS

The simulation using the MATLAB/SIMULINK software environment and Sim Power Systems. The voltage and current wave forms in (p.u) of parallel operated generators are shown in the below figures.

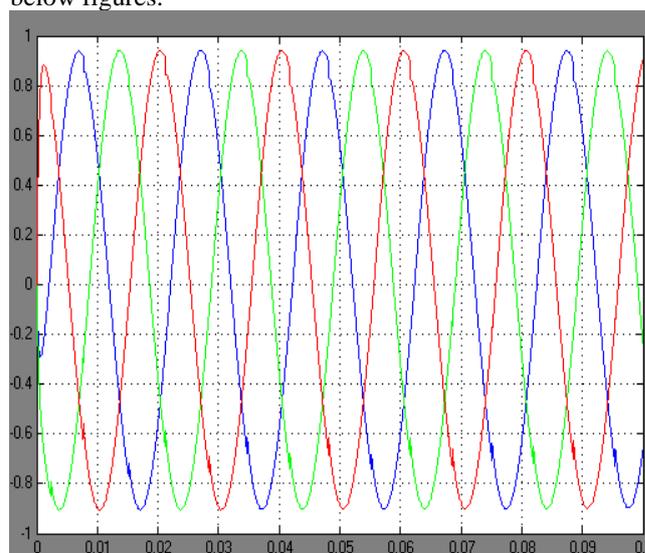


Fig 11 Voltage vs time wave form at generation

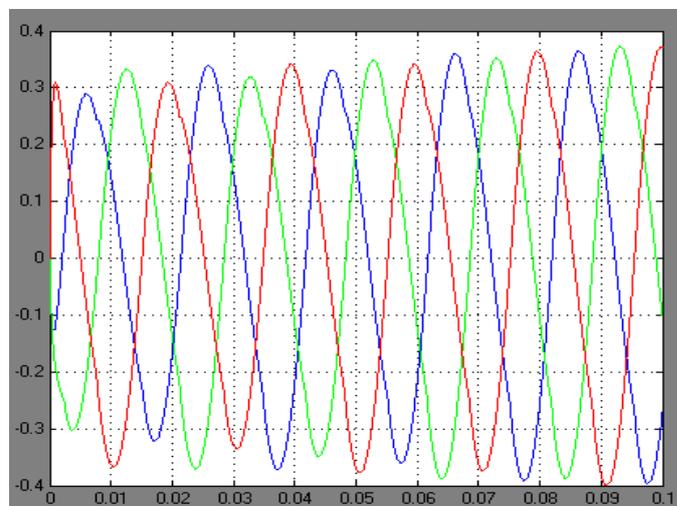


Fig 12 Current vs time wave form at generation

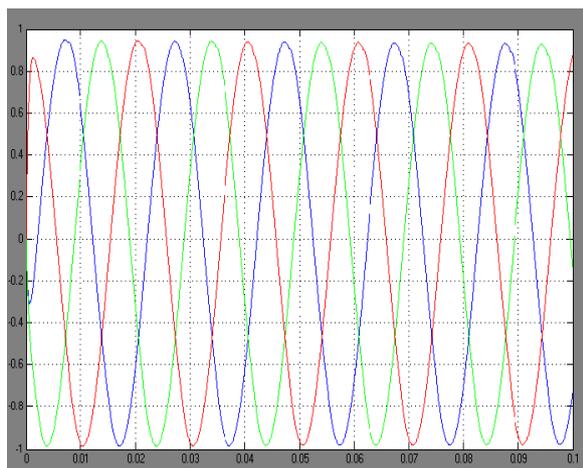


Fig 13 Voltage vs time wave form at Load

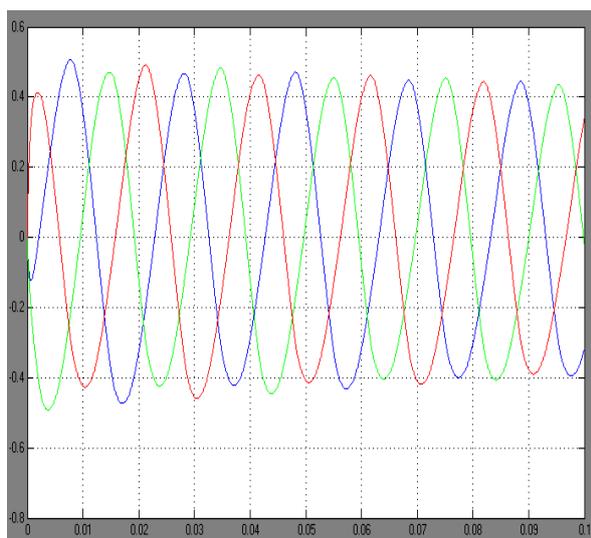


Fig 14 Current vs time wave form at Load

### VII. COMPARISON OF THE PERFORMANCE OF THE SYSTEM BY THE USAGE OF COMPENSATING DEVICE

The working of the system is faster with a shunt compensating device rather than without a shunt compensating device.

WITH STATCOM

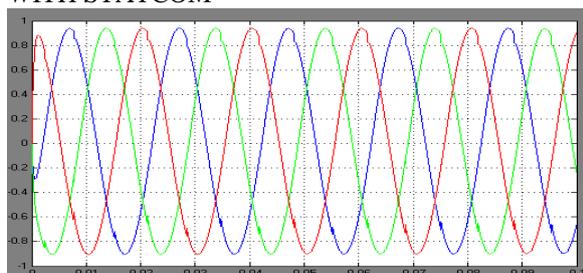


Fig.15: Voltage vs time wave form without STATCOM

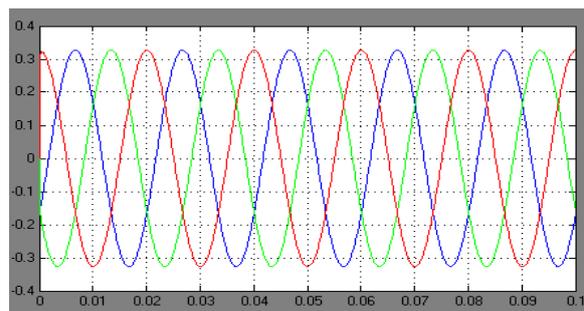


Fig.16: Current vs. time wave form without STATCOM

### VIII. ANALYSIS OF RESULTS

The performance of proposed voltage controller for isolated synchronous generators while feeding a 3 phase RLC load is satisfactory. If we compare fig 11 and 13 it is observed that the voltage distortions that are present in fig 11 are being removed by the STATCOM and is presented at load in fig 13. The compensating current generated by STATCOM is used to drive loads if the line current is sufficient enough. If we compare fig 12 with 14 it is evident that the compensating current generated by statcom is taken by load.

The operation of circuit resulted different values of voltage and current without the STATCOM and with STATCOM the results are Without STATCOM: - Voltage 0.88 p.u Current 0.32 p.u With STATCOM: - Voltage 0.94p.u Current 0.54 p.u

### IX. CONCLUSION

The proposed voltage controller of parallel operated synchronous generators for feeding 3-phase load driven by constant speed prime mover like hydraulic turbine governor model has resulted in quite satisfactory operation under varying loads. The proposed controller also helps in load balancing. If line current is less than expected, the compensating current generated by STATCOM is taken by loads.

### REFERENCES

- [1] Bhaskar, M.A.; Dash, S.S.; Subramani, C.; kumar, M.J.; Harish,D.; Shalini, R."Non Linear Control of STATCOM," Recent Trends inInformation,Telecommunoc -ion and Computing (ITC), 2010 International Conferenceon,vol., no., pp.190-195, 12-13 March 2010.
- [2] Bhim Sing, S.S.Murthy and Sushma Gupta "Analysis and Design of STATCOM based regulator for self excited induction Generator"IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 19, NO. 4, DECEMBER 2004.

- [3] O.Ojo, O.Omozusi and Adison A.jimoh  
“The operation of an inverter assisted single phase induction generator” IEEE.Trans. on Industrial Electronics, Vol.47, no.3. pp 632-640, June2000.
- [4] Chandan Chakraborty, S.N. Bhadra. MuneakiIshidaand A.K Chattopadhyay. “Performance of parallel operated self excited induction generators with the variation of machine parameters.” in proc. Of IEEE Conference on Power Electronic and Drive Systems. July 1999, pp. 86-91.
- [5] S.N Mahato, M.P.Sharma and S.P Singh, “Transient performance of a single phase self regulated induction generator using a three-phase machine” Electric power Systems and Research digital object identifier doi;10.1016/j.epsr.2006.07.009.
- [6] Bhim Singh, Kamal-AI-Haddad and Ambrish Chandra.“A review of active filters for power quality improvement,” IEEE Trans. On Industrial Electronics, vol.46, no.5, pp 960-970, oct. 1999.
- [7] S. Tara Kalyani and G. Tulasiram Das. “Simulation of D-Q control system for a unified power flow controller”, ARPN Journal of Engineering and Applied Sciences, VOL. 2, NO. 6, DECEMBER 2007.
- [8] N. G. Hingorani and L. Gyugyi. 2000. “Understanding FACTS, Concepts, and Technology of Flexible AC Transmission Systems”. Piscataway, NJ: IEEE Press.
- [9] M.S.EI-Moursi, A.M.Sharaf, “Novel reactive power controllers for the STATCOM and SSSC”, Electric Power System Research 76, 228-241, August 2005.
- [10] Anshuman Shukla, Arindam Ghosh and Avinash Joshi, “Hysteresis Current Control Operation of Flying Capacitor Multilevel Inverter and Its Application in Shunt Compensation of Distribution Systems”, IEEE Transaction on Power Delivery, Vol.22, No. 1, January 2007.
- [11] K.R.Padiyar,”FACTS controllers in power transmission and distribution”, 2007.
- [12] “Pulse Width Modulation Techniques for Voltage-Fed Inverters” ECE 8830 – Electric Drives, Topic 7, Spring 2004.