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Voltage Regulation of Self-Excited Induction Generator Using Static Synchronous Compensator

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ABSTRACT: Reactive current introduces power quality problems like voltage sags, swell, and poor load power factor, these problems result in unexpected behaviour of sensitive equipment. A STATCOM provides effective compensation to linear /nonlinear loads by injecting appropriate reactive power at PCC. So STATCOM is implemented using indirect control scheme. The SEIG has major drawback of poor voltage regulation due to the difference between the reactive power demanded by load and excitation capacitor. This work describes the simulation of reactive power control of SEIG using STATCOM. Simulation results show that statcom is regulating voltage very well in case of inductive load put on/off.

KEYWORDS: PCC (point of common coupling) STATCOM (static synchronous compensator), SEIG (self-excited induction generator),

I. INTRODUCTION

The fast rate of fossil fuel depletion is drawing attention to explore the alternative energy sources, e.g. small hydropower, wind and tidal power. An isolated electric supply using a self-excited induction generator (SEIG) is an economical option for such small-capacity applications as lighting and small motor loads in remote locations, since the generated voltage depends upon the speed, excitation capacitance, and power factor of load. A suitable control scheme is required which may change capacitance automatically. In early days synchronous condenser and mechanically switched capacitor and inductors have been used for reactive power compensation, with the advent of TSC and TCR drawbacks of mechanical switches were eliminated but large size inductor and capacitor were still a problem. Recently the Voltage Source Inverter (VSI) based Static VAR compensators have been recognized as solution are known as Advanced Static VAR Compensator (ASVC) or Static Synchronous Compensator (STATCOM). Fig.1 consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power. The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

1. Voltage regulation and compensation of reactive power
2. Correction of power factor
3. Elimination of current harmonics.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter. When the shunt injected current I_q is kept in quadrature with E_t , the desired voltage correction can be achieved without injecting any active power into the system.

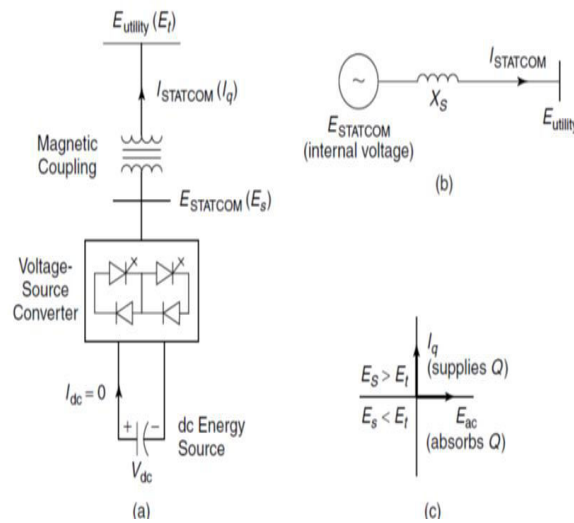


Fig.1.The STATCOM principle diagram: (a) power circuit; (b) equivalent circuit (c) power exchange

The contribution of the STATCOM to the load bus voltage equals the injected current times the impedance seen from the device, which is the source impedance in parallel with the load impedance. The ability of the STATCOM to compensate the voltage dip is limited by this available parallel impedance. In addition, the device should be installed as close to the sensitive load as possible to maximize the compensating capability.

II. DESCRIPTION OF THE SYSTEM

Shows the test system used to carry out the STATCOM simulation. It's main components are SEIG, load, inverter, dc capacitor, inductor and controller as shown in fig.2

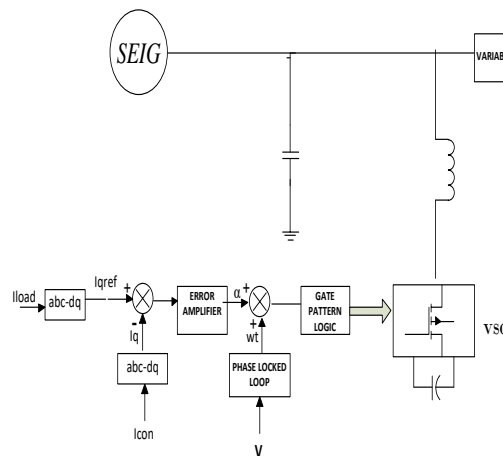


Fig 2 Single line diagram of the test system for D-STATCOM

SEIG (self-excited induction generator)

An externally driven induction machine operates as a self-excited induction generator (SEIG), with its excitation requirements being met by a capacitor bank connected across its terminals.

Inverter with capacitor

Inverters are used to convert DC signal to AC signal. In this work a 3-phase inverter has been developed. The DC source in the system is the DC capacitor, which is located in parallel with the D-STATCOM. The capacitor charges when the current in the system is higher than in the D-STATCOM and discharges when the current is lower. For the inverter, the most important part is the sequence of operation of the MOSFETs. The MOSFETs signals are referred to the Sinusoidal Pulse Width Modulation (SPWM) that will generate the pulses for the firing of the MOSFETs.

Capacitor size

capacitor size is calculated from difference in load current before and after inductive load switching. A suitable range of DC capacitor is needed to store the energy to mitigate the voltage sag The DC capacitor, C_{DC} is used to inject reactive power to the D-STATCOM when the voltage is in sag condition. The following

$$\frac{1}{2} C_{dc} [V_{cmax}^2 - V_{dc}^2] = 1/2 V_{sm} \cdot (I_2 - I_1) \cdot T$$

But for three phase system

$$C_{dc} = 3 \times \frac{V_{sm} \cdot (I_2 - I_1) \cdot T}{[V_{cmax}^2 - V_{dc}^2]}$$

Where

- V_{sm}=peak phase voltage
- (I₂-I₁)=load current difference before and after switching
- V_{dc}=Voltage across capacitor(per-phase)
- V_{dc}= $\frac{3\sqrt{3}V_s}{\pi}$ if delay angle $\alpha=0$
- V_{cmax}=upper limit of voltage generally two times V_{dc}

By using above relations C_{dc} is calculated 45µF for the simulation which is taken 50 µF.

Controller

Purpose of control scheme is to maintain constant voltage magnitude at the generator bus under system disturbances. In PLL three phase distorted supply voltages are accurately judged which generates Sine and Cosine which are used for abc to dq conversions. Control system measures the load current I_{load}, converter current I_{con}, voltage at generator bus V_{abc}. The controller input is an error signal generated from I_{qref} and I_q which are obtained using abc to dq transformation of I_{load} and I_{con} respectively. This error is processed through a controller (as shown in fig3.) resulting the angle α , which is added to ωt (derived from PLL) and resulting signal is given to PWM generator. The modulating signals V_{aref}, V_{bref}, V_{cref} are compared against triangular carrier signals to generate switching pattern for Mosfet switches.

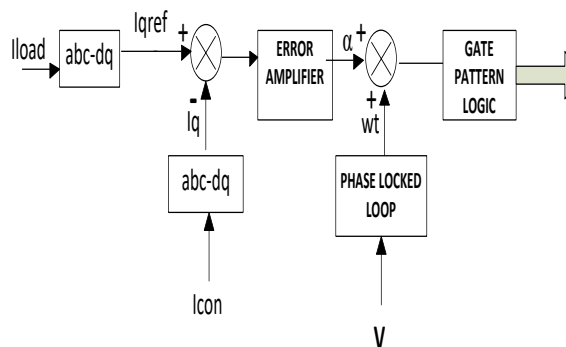


Fig. 3 indirect control scheme for pulse generation

$$V_{aref} = m \cdot \sin(\omega t + \alpha)$$

$$V_{bref} = m \cdot \sin(\omega t + \alpha - 2\pi/3)$$

$$V_{cref} = m \cdot \sin(\omega t + \alpha + 2\pi/3)$$

In this technique, if the reference signal is more than carrier one then switch will be on, else off. Pulse widths could be changed to control the output voltage. Although pulse widths could be different to each other, we can select the pulse width in such way that desired harmonics come out. As the reference signal in this way is a sinusoidal form, this Technique is called SPWM.

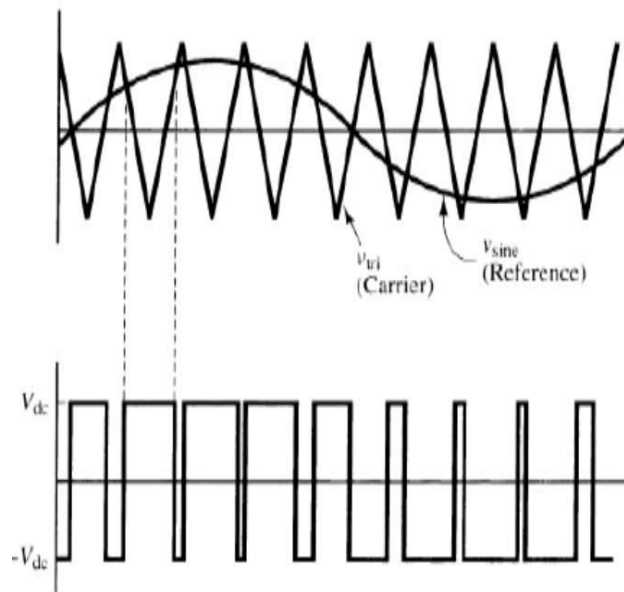


Fig.4 sinusoidal pulse width modulation

$$m = \frac{V_{sine}}{V_{tri}}$$

$$V_{out} = m V_{dc} \sin(\omega t + \alpha)$$

The modulation index m is kept constant at 0.99 in order to obtain maximum fundamental voltage at VSC output. peak amplitude of triangular signal is kept +/-1. The switching frequency is set at 10.8kHz

III.SIMULINK MODEL OF D-STATCOM TEST SYSTEM

Fig.5 shows the test system implemented in MATLAB simulink. The test system comprises a 7.5kw, 400V, 50Hz induction generator, with excitation capacitor 40microfarad, voltage source inverter with dc bus capacitor 50 microfarad (STATCOM) is shown in fig. 5. The excitation capacitors are connected at the terminals of SEIG, which have a fixed value to result rated terminal voltage. The SEIG generate constant voltage 240 volt(line to ground) if delta connected load(4kw,0.9pf) is kept constant. A two-level D-STATCOM is connected in shunt via coupling inductor of 1e-03H to provide instantaneous voltage support /reactive power compensation at the load point. A 50 μF capacitor on the dc side provides the D-STATCOM energy storage capabilities. To show the effectiveness of this controller in providing continuous voltage regulation, simulations were carried out with and without D-STATCOM connected to the system. In this study, the model of power system, D-STATCOM and controller are developed in MATLAB/Simulink environment and shown in Figure 5

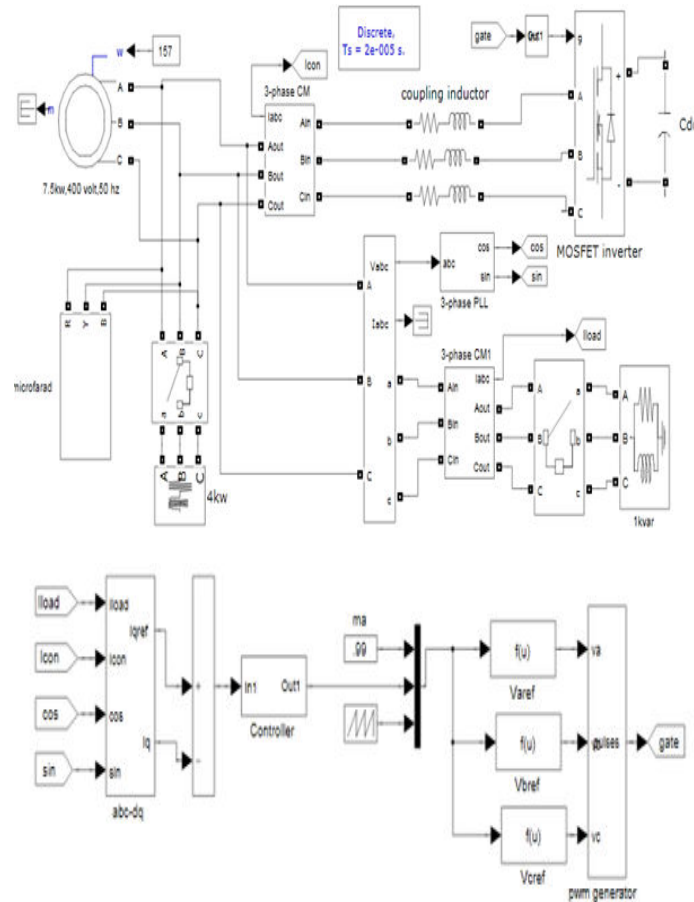


Fig.5 Matlab simulation of SEIG with STATCOM

IV. RESULTS AND DISCUSSION

The SEIG generate constant voltage 240volt(line to ground) if load(4kw,0.9pf) is kept constant .At t=1sec inductive load of 1kvar ,0.0099 pf is switched on terminal voltage of SEIG falls regularly because reactive power demanded by inductive load can not be supplied by induction generator,to meet reactive power requirement STATCOM is turned on at t=1.5 sec which restores generator bus voltage to 240 volt .if inductive load is switched off at t=2 sec voltage is still maintained to 240 volt (transient at t=2 sec) as shown in fig 6., during t=1.5to2 sec converter current(STATCOM) rises from zero to 2 amp to supply reactive current and falls to zero after t=2 sec because inductive load is switched off, as shown in fig. 6 which is actually compensating the lagging current required by the load. But if there would be no STATCOM turning on of inductive load may have resulted a low voltage 180 volt(line to ground) as shown in fig. 9.similar can be seen from capacitor voltage shown in fig.8 which drops at t= 1sec when inductive load is turned on and rises at t=1.5 sec to 700 volt when statcom is turned on which restores generator bus voltage to 240 volt.

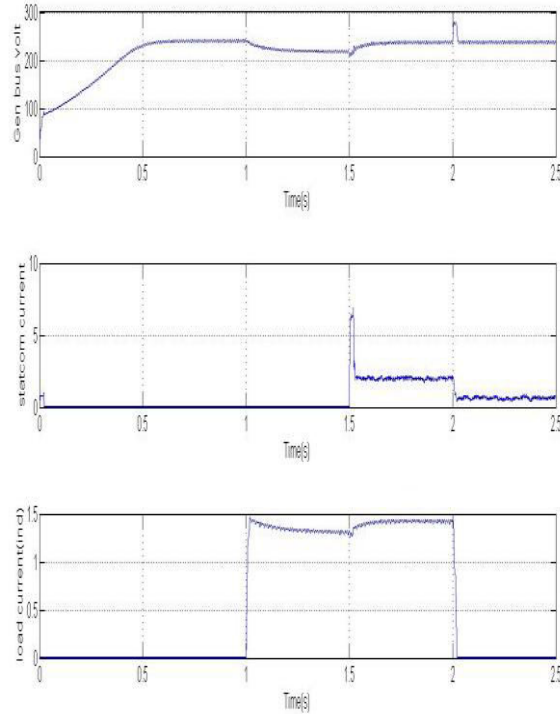


Fig. 6. SEIG with statcom (At t=1sec inductive load 1kvar is turned on , at t=1.5 sec STATCOM is turned on and at t=2 sec inductive load turned off).

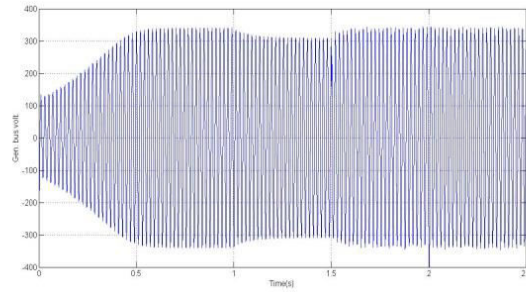


Fig. 7 Generator bus voltage with statcom (At t=1sec inductive load 1kvar is turned on , at t=1.5 sec STATCOM is turned on and at t=2 sec inductive load turned off).

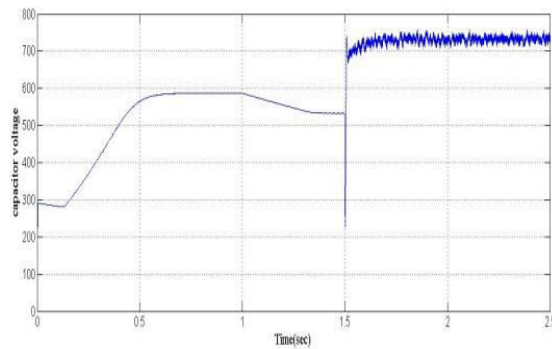


Fig 8. Capacitor voltage

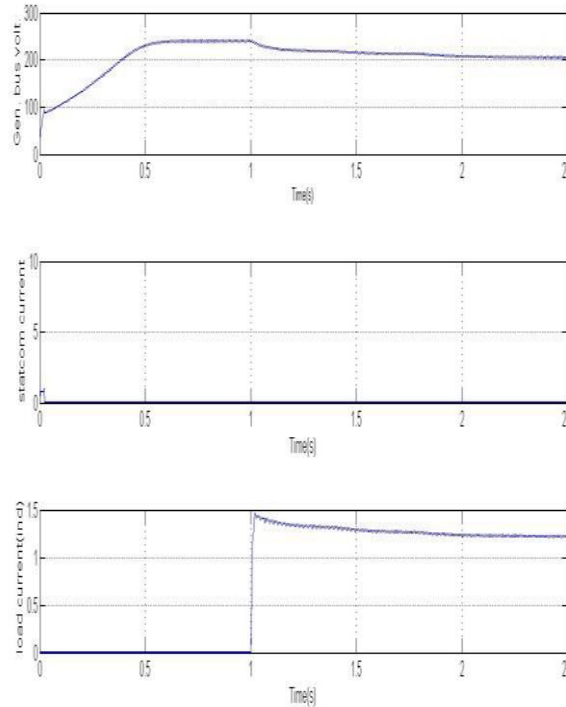


Fig.9 SEIG without statcom(At t=1sec inductive load 1kvar is turned on and not turned off).

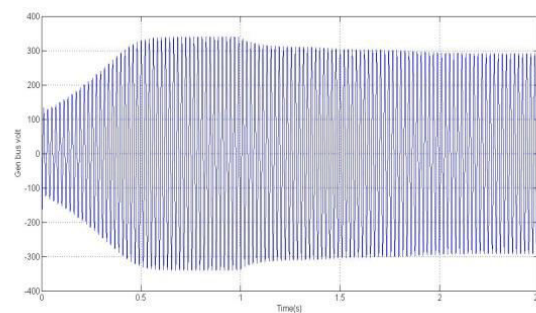


Fig.10 terminal voltage waveform of SEIG without statcom(At t=1sec inductive load 1kvar is turned on and not turned off).

V. CONCLUSIONS

A simulation model of the 6-pulse D-STATCOM has been designed using the MAT LAB software. The control strategy for the D-STATCOM is reactive power control. Single gain controller is used to control the flow of reactive power to and from the DC capacitor. Phase Lock Loop components are used in the control to generate the Cosine and sine. PWM switching control is used to switch on and off the MOSFETs. From the simulation results, the designed DSTATCOM compensates reactive power demand of SEIG caused by inductive load switching. The difference of step drop load current during sag is the amount of reactive current needed to be compensated. Lastly, the D-STATCOM is a promising device and will be a prominent feature in power systems in mitigating power quality related problems in the near future.

Appendix

Induction Generator (10 hp, 2 poles, 400 volt, 50 hz)

Stator resistance $r_s = 0.7384$



Rotor resistance $r_r = 0.7402$

Stator leakage reactance $x_s = 0.003045$

Rotor leakage reactance $x_r = 0.003045$

Mutual inductance $l_m = 0.1241$

Excitation capacitance $c = 40 \times 10^{-6} \text{ f}$

Prime Mover Characteristics

Speed = 157 rad/sec

STATCOM

Series line resistance $R_s = 10$

Series line reactance $X_s = 1 \times 10^{-3}$

Dc link capacitance $C_{dc} = 500 \times 10^{-6}$

Controller Parameters

$A = 0.0011$, sampling time, $T_s = 2 \times 10^{-5} \text{ sec}$

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