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Reactive Power Compensation of Hybrid System Having Induction Motor Load

Sreedevi P.R[1], Aparna Thampi[2], Pawan Sharma [3]

M.Tech Student, SAINTGITS College of Engineering, Kottayam, Kerala, India[1]

Assistant Professor, SAINTGITS College of Engineering, Kottayam, Kerala, India[2]

ABSTRACT*:* This paper presents the reactive power compensation of an isolated wind-diesel hybrid power system. The wind energy conversion system is using a permanent magnet induction generator (PMIG) and synchronous generator (SG) is used with the diesel engine set. The PMIG requires less reactive power compared to an induction generator for its operation and this demand is continuously changing by the variation of load and wind power. Most of the loads are inductive in nature and to capture the dynamic performance of a system, dynamic load modelling is done. The load considered in this case is an induction motor. The synchronous generator used by the diesel generating system partially supplies the reactive power needed by the system. The mismatch between generation and consumption of reactive power causes voltage fluctuations at generator terminals which reduces the stability and quality of the supply. To manage the mismatch a variable source of reactive power such as STATCOM is used. Reactive power flow balance equations are used for the mathematical modelling of the system. The MATLAB/SIMULINK environment is used for simulation.

KEYWORDS*:* Permanent-magnet induction generator (PMIG), Induction Generator(IG),Synchronous Generator (SG), Induction Motor(IM), Static synchronous compensator (STATCOM)

I. INTRODUCTION

Hybrid systems can be considered as the combination of different energy sources. Wind-diesel systems combine power from diesel generators and wind turbines. They are intended to overcome the problems due to the intermittent nature of power supply

from wind and at the same time increasing the use of renewable energy which is eco friendly. The non-conventional energy source such as wind have induction generator to generate electricity but induction generators require reactive power for its operation and this demand is continuously changing by the variation of load and wind power. The performance of an IG is poor in terms of voltage regulation this decreases both the power factor and efficiency of the IG. The power factor, voltage regulation, and efficiency can be improved by the use of PMIG [2]. The modelling of PMIG is given in [2] and is considered in this paper. Most of the loads are inductive in nature and they also require reactive power for their proper operation. Load modelling is important for power system dynamic analysis since power system variations affect the load and load variations affects the power system[3]. A load model is a mathematical representation of real and reactive power changes to power system voltage and frequency changes[4]. The synchronous generator used in hybrid system for generating power through diesel system is supplying reactive power to the system partially. The mismatch between generation and consumption of reactive power causes voltage fluctuations at generator terminal which reduces the stability and quality of the supply explained in [5,6]. Therefore, a source of reactive power is required to fulfil this demand. The variable reactive power needed by the system is provided by a static synchronous compensator (STATCOM)[2]. MATLAB/SIMULINK environment is used for the simulation and the reactive power flow balance equations are used for mathematical modelling of the system.

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II. MATHEMATICAL MODELLING OF HYBRID POWER SYSTEM

The configuration of wind- diesel hybrid power system feeding an induction motor is shown in Fig.1. The wind turbine converts the kinetic energy to mechanical energy and the generator then converts the mechanical energy to electrical energy. Diesel engine coupled to SG acts as a prime mover. The real power demand of the system is met by PMIG, SG and the reactive power demand of the system is met by both SG and STATCOM.

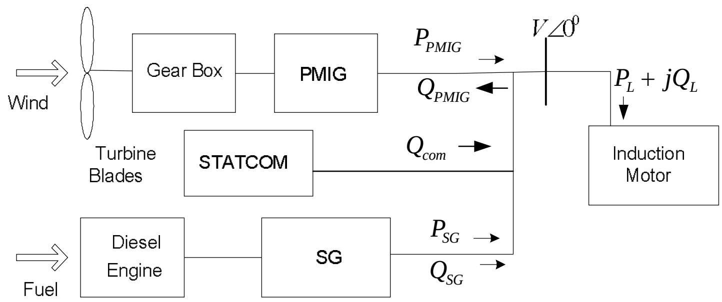

Fig. 1 Layout of the Isolated Wind-Diesel System

The reactive power balance equation of the system is[2]

$$Q_{SG} + Q_{COM} = Q_{PMIG} + Q_L \quad (1)$$

Due to load reactive power disturbance, the system voltage may change which results in an incremental change in reactive power of other components.The net reactive power surplus, $\Delta Q_{SG} + \Delta Q_{COM} - \Delta Q_{PMIG} - \Delta Q_L$ will change the system bus voltage which will govern by the following transfer function equation [2]

$$\Delta V(S) = K_V \frac{1}{1+sTv} [\Delta Q_{SG}(S) + \Delta Q_{COM}(S) - \Delta Q_{PMIG}(S) - \Delta Q_L(S)] \quad (2)$$

An IEEE type-I excitation system is used to provide excitation control to the SG. It partially reduces the terminal voltage variation but it is found to be insufficient for proper voltage control [1] and is shown in Fig. 2

The state transfer equations are [1]

$$\Delta E_{fd}(s) = \frac{1}{K_E + sT_E} \Delta V_a(s) \quad (3)$$

$$\Delta V_a(s) = \frac{K_A}{1+sT_A}[\Delta V(s) - \frac{K_F}{T_F}\Delta E_{fd}(s) + \Delta V_f(s)] \quad (4)$$

$$\Delta V_f(s) = \frac{K_F}{T_F}\frac{1}{1+sT_F}\Delta E_{fd}(s) \quad (5)$$

The small change in voltage behind transient reactance is as follows

$$\Delta E'_q(s) = \frac{1}{1+sT_G}[K_1 \Delta E_{fd}(s) + K_2 \Delta V(s)] \quad (6)$$

Where

$$K_1 = \frac{X'_d}{X_d} \quad (7)$$

$$K_2 = \frac{[(X_d - X'_d)\cos\delta]}{X_d} \quad (8)$$

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$$T_G = \frac{X'_d T'_{do}}{X_d} \tag{9}$$

Under transient condition the reactive power output of SG, Q_{SG} is given by [1]

$$Q_{SG} = \frac{[E'_q V \cos\delta - V^2]}{X'_d} \tag{10}$$

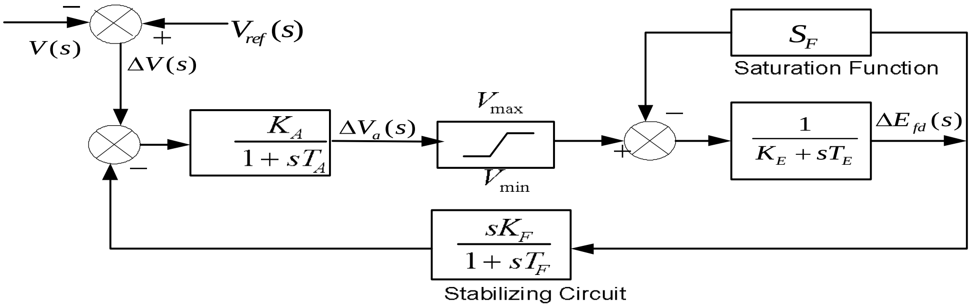

Fig. 2 IEEE type-I excitation control system. *SF* = Saturation function (neglected) [1]

For small perturbation, above equation can be written as[1]

$$\Delta Q_{SG} = \frac{V\cos\delta}{X'_d} \times \Delta E'_q + \frac{[E'\cos\delta - 2V]}{X'_d} \times \Delta V \tag{11}$$

$$\Delta Q_{SG}(s) = K_3\, \Delta E'_q(s) + K_4 \Delta V(s) \tag{12}$$

Where

$$K_3 = \frac{V\cos\delta}{X'_d} \tag{13}$$

$$K_4 = \frac{[E'\cos\delta - 2V]}{X'_d} \tag{14}$$

For variable input wind power, variable speed/slip operation the term R_Y is not constant. The change in reactive power absorbed, in terms of generator terminal voltage, slip, and generator parameters for change in input wind power can be written as[2]

$$\Delta Q_{PMIG}(s) = K_6 \Delta P_{IW}(s) + K_7 \Delta V(s) \tag{15}$$

Where

$$K_6 = -\frac{2X_{eq}R_Y V^2}{(R_Y^2 + X_{eq}^2)\{2R_Y(P_{IW} - P_{coreloss}) + V^2\}} \tag{16}$$

$$K_7 = -\left[K_{c1} + \frac{V^2}{X_C}\left\{-\frac{3aV^2 + 2bV + c}{3X_C^3} + \frac{2}{V}\right\}\right] \tag{17}$$

$$K_{c1} = \frac{2X_{eq}V}{R_Y^2 + X_{eq}^2}\left[1 + \frac{2R_P R_Y V^2}{(R_Y^2 + X_{eq}^2)\{2R_Y(P_{IW} - P_{coreloss}) + V^2\}}\right] \tag{18}$$

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The reactive power injection to the system bus by the STATCOM has the form[2]

$$Q_{com} = kV_{dc}^2 B - kV_{dc} VB \cos\alpha \quad (19)$$

The flow of reactive power depends upon the variables V and α, and therefore, for small perturbation, the reactive power change of STATCOM can be written by taking the partial derivative of Q_{com} with respect to α and V.

$$\Delta Q_{com}(s) = K_8 \Delta\alpha(s) + K_9 \Delta V(s) \quad (20)$$

Where

$$K_8 = kV_{dc} VB \sin\alpha \quad (21)$$

$$K_9 = -\ kV_{dc} B \cos\alpha \quad (22)$$

An induction motor's reactive power equation can be written in terms of steady state voltage, reactance, slip and rotor resistance [4]

$$Q = \frac{V_{qso}^2 s_m^2 X}{r_r^2} \quad (23)$$

For small perturbations the above equation can be written as ,

$$Q_{e0} + \Delta Q_e = \frac{V_{qso}^2 (S_{l0} + \Delta s_l)^2 X}{r_r^2} \quad (24)$$

Transfer function of reactive power change by changing the supply voltage is,

$$\frac{\Delta Q_e}{\Delta V_{qs}} = \frac{X}{r_r^2} 2V_{qso} S_{l0}^2 \frac{S + \frac{B}{2H} - \frac{V_{qso}^2}{2Hr_r\omega_b}}{S + \frac{B}{2H} + \frac{V_{qso}^2}{2Hr_r\omega_b}} \quad (25)$$

Table I Values of Constants/Parameters of Hybrid System

System Parameters	Values(p.u.)
SG	
Reactive power	0.2
Voltage of internal armature	1.1136
Internal armature electromotive force	0.9603
δ (degree)	21.05
PMIG	
Real power	0.6
Slip	-4

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Stator reactance	0.19
Stator resistance	0.56
STATCOM	
Main time constant	10 - 50
Transport lag	0.2 - 0.3
Average dead time of zero crossings	1.67
IM	
Machine Inertia	0.5
Stator reactance	0.0322
Rotor reactance	0.074

Wind is a natural phenomena occurring in the nature due to the temperature and pressure variations in the atmosphere created by the heating effect of sun rays. The heating effect is different at different times of a day and hence the wind energy is also varying. In this paper random step function is used to represent the variable nature of wind.

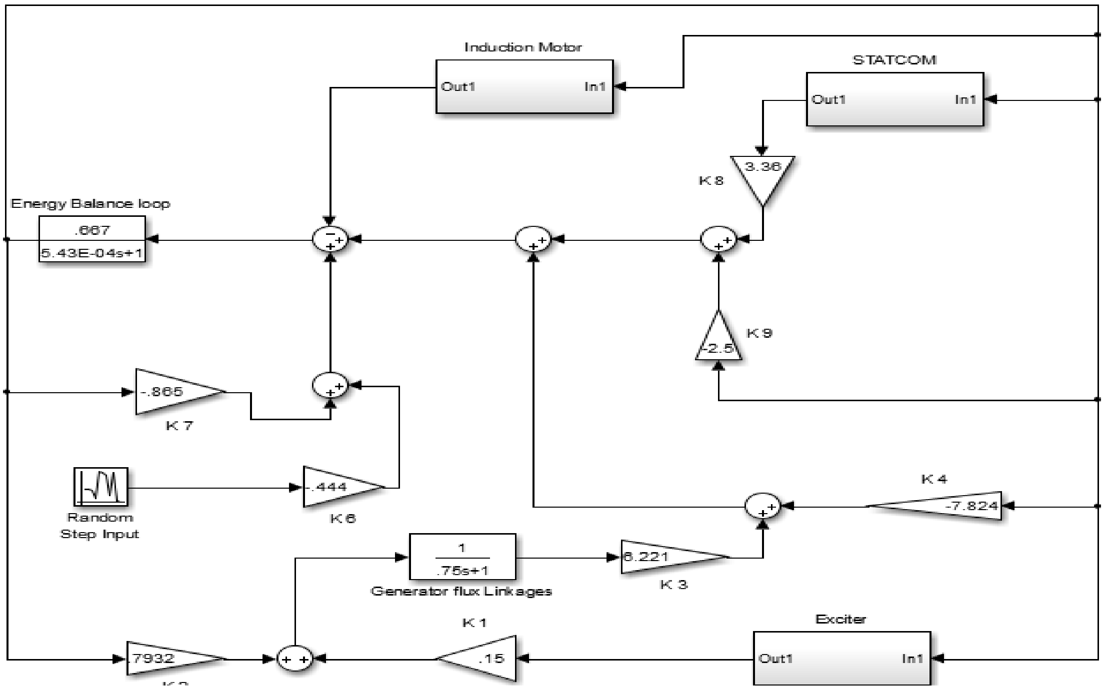

Fig.4. Transfer function block diagram of the wind-diesel hybrid power system

Fig. 5 shows the dynamic response of the system for random step changes in input wind power.

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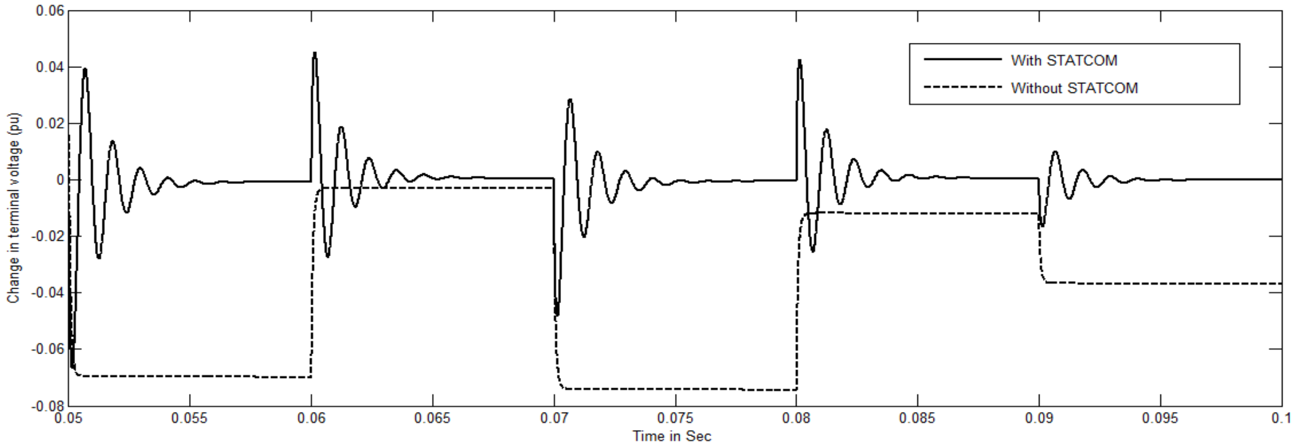

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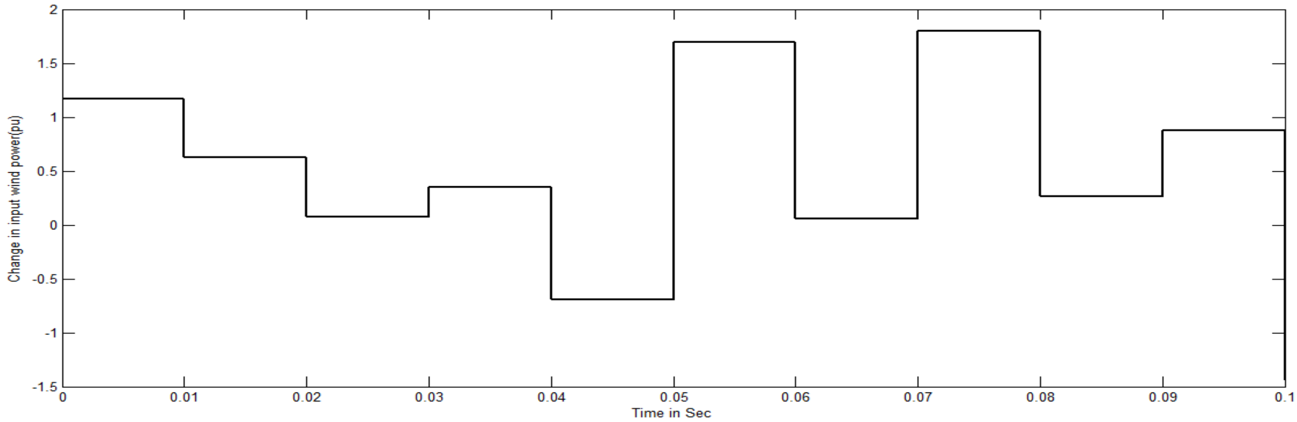

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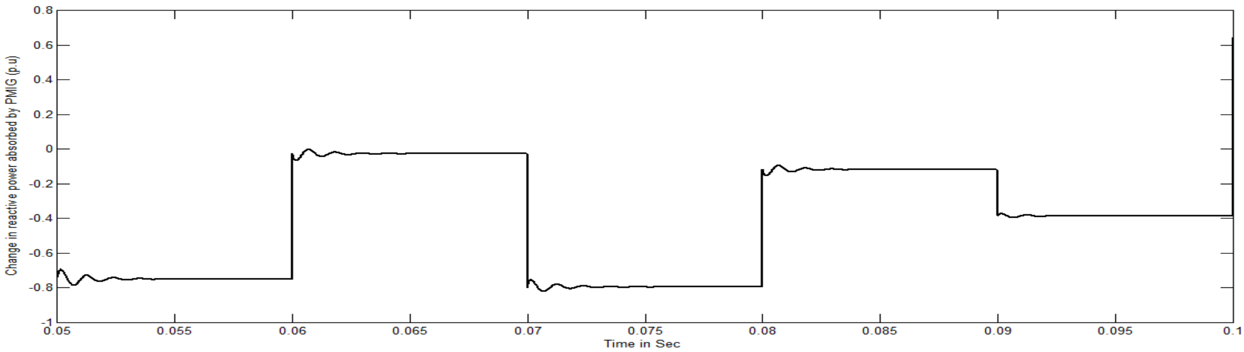

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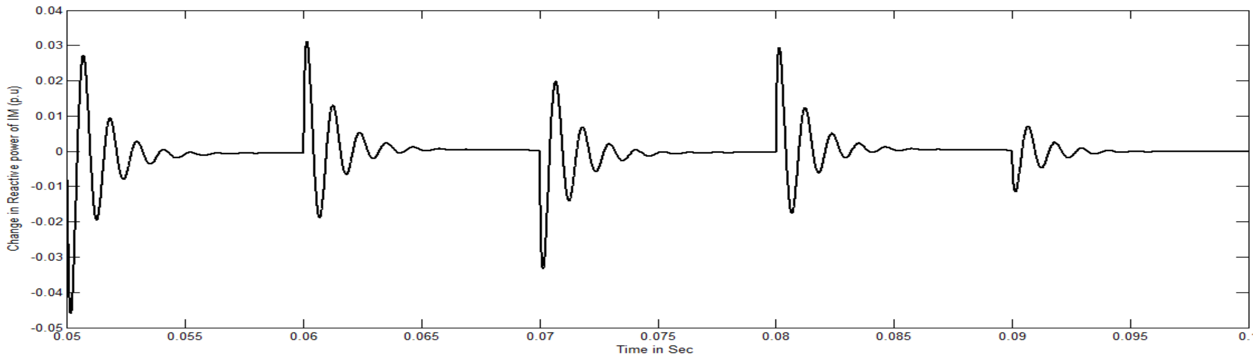

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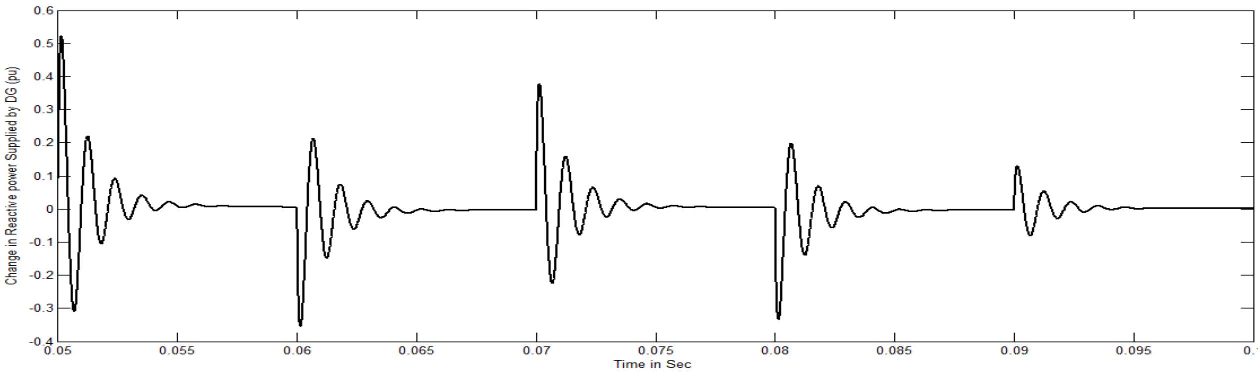

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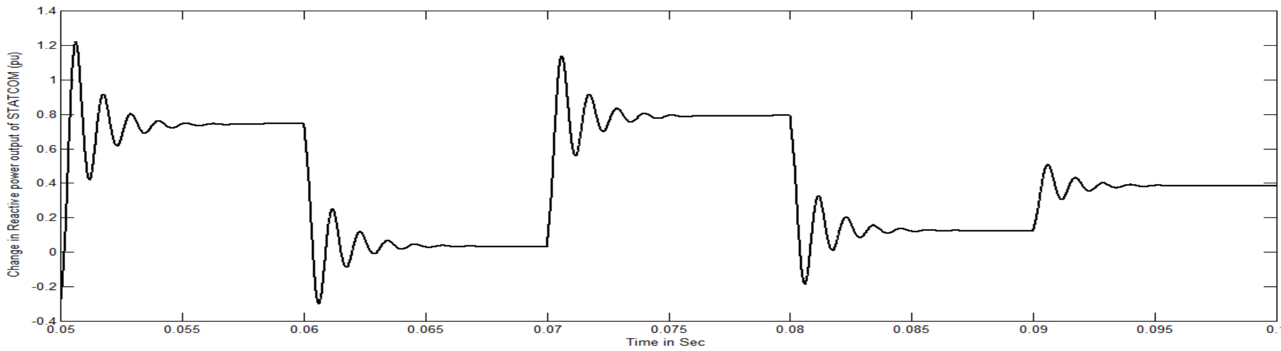

(f)

Fig.5 Transient response of the wind-diesel systems feeding an induction motor with random step changes in input wind power

III. CONCLUSION

Reactive power compensation of an isolated wind–diesel hybrid power system feeding an induction motor has been investigated when STATCOM is used for reactive power support. Wind energy is continuously varying; this idea is implemented by using random step change as input wind power. The WECSs are interconnected to diesel system to enhance the reliability of the supply. The mathematical model of the system based on reactive power flow balance equations is developed. It has been observed that the terminal voltage variation is higher when STATCOM is not used and STATCOM effectively stabilizes the oscillations, caused by disturbances in load reactive power and in input wind power. The change in input wind power causes change in slip, therefore increase in input wind power increases the reactive power absorption by PMIG which results in more deviations in ΔQ_{PMIG} and hence results more deviations in terminal voltage. During the transient condition reactive power requirement of the entire system is met by both

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STATCOM and SG. Reactive power requirement of the system during the steady state condition is met by STATCOM alone.

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