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Hybrid Wind-Diesel Power Systems Stabilization Using STATCOM and Genetic Algorithm Optimization Technique

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Abstract: Application of FACTS controller called static synchronous compensator STATCOM to improve the performance of power grid with hybrid wind-diesel system is investigated. The essential feature of the STATCOM is that it has the ability to absorb or inject fastly reactive power with power grid. Therefore, the voltage regulation of the power grid with STATCOM FACTS device is achieved. Moreover, restoring the stability of the power system having hybrid wind-diesel system after occurring severe disturbance, such as faults or suddenly step up wind speed is obtained with STATCOM controller. One of the most common controlling devices in the industry is the Proportional-Integral (PI) controller tuned by Genetic Algorithm (GA) is introduced. Genetic algorithm is employed to find the optimal values for PI controller parameters in a very short time. These methods are tested in MATLAB and their results are obtained. The dynamic model of the power system having hybrid wind-diesel system controlled by proposed STATCOM is developed. To validate the potential of the STATCOM FACTS controller, the studied power system is simulated and subjected to different severe disturbances. The results prove the effectiveness of the proposed STATCOM controller in terms of fast damping of the power system oscillations and restoring the power system stability.

Key words: Hybrid wind diesel power system, STATCOM, PI controller, genetic algorithm, Egypt

INTRODUCTION

Global warming is one of the most serious environmental problems facing the world community today. It is typified by increasing the average temperature of Earth's surface and extremes of weather both hot and cold. Therefore, implementing a smart and renewable energies, such as wind power, photo voltaic, etc., are expected to deeply reduce heat-trapping emissions. Moreover, wind power is expected to be economically attractive when the wind speed of the proposed site is considerable for electrical generation and where electric energy is not easily available from the grid (Ackermann, 2005). This situation is usually found on islands and/or in remote localities. However, wind power is intermittent due to worst case weather conditions, such as an extended period of overcast skies or when there is no wind for several weeks. As a result, wind power generation is variable and unpredictable. The hybrid wind power with diesel generation has been suggested by Hunter and Elliot (1994) and Nacfaire (1989) to handle the problem above. A hybrid wind diesel system is very reliable because the diesel acts, as a cushion to take care of variation in wind speed and would always maintain an average power equal to the set point. However in addition to the unsteady nature of wind, another serious problem faced by the isolated power generation is the frequent change in load demands. This may cause large and severe oscillation of power. The fluctuation of output power of such renewable sources may cause a serious problem of frequency and voltage fluctuation of the grid, especially in the case of isolated microgrid which is the a small power supply network consisting of some renewable sources and loads. In the worst case, the system may lose stability if the system frequency can not be maintained in the acceptable range.

Control schemes to enhance stability in a hybrid wind diesel power system have been proposed by much researchers in the previous research. The Programmed Pitch Controller (PPC) in the wind side can be expected to be a cost-effective device for reducing frequency deviation (Bhatti *et al*., 1997; Das *et al*., 1999). Nevertheless, under the sudden change of load demands and random wind power input, the pitch controller of the wind side and the governor of the diesel side may no longer be able to effectively control the system frequency

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Corresponding Author: M.K. Saad, Department of Electrical Engineering, Faculty of Engineering of Shoubra, University of Benha, Benha, Egypt due to theirs slow response. FACTS devices can be a solution to these problems (Hingorani and Gyugyi, 2000). They are able to provide rapid active and reactive power compensations to power systems and therefore can be used to provide voltage support and power flow control, increase transient stability and improve power oscillation damping. Suitably located FACTS devices allow more efficient utilization of existing transmission networks. Among the FACTS family, the shunt FACTS devices such as the STATCOM has been widely used to provide smooth and rapid steady state and transient voltage control at points in the network. In this study, a STATCOM is added to the power network to provide dynamic voltage control for the hybrid wind diesel system, dynamic power flow control for the transmission lines, relieve transmission congestion and improve power oscillation damping.

Traditional optimization methods, such as mixed integer linear and non linear programming have been investigated to address this issue, however difficulties arise due to multiple local minima and overwhelming computational effort. In order to overcome these problems, evolutionary computation techniques have been employed to solve the optimal parameters of FACTS devices. Different algorithms, such as Particle Swarm Optimization (PSO) (Park *et al*., 2005; Nanvala and Awari, 2011), tabu search (Mori and Goto, 2000) and evolutionary programming (Ongsakul and Jirapong, 2005) have been tested for finding the optimal parameters, as well as the types of devices and their sizes with promising results. Genetic Algorithms (GA) is an evolutionary computation technique that has been applied to other power engineering problems, giving better results than classical techniques and with less computational effort (Cai *et al*., 2004; Gerbex *et al*., 2001). In this study, the gains of the controllers with STATCOM have been optimized by genetic algorithm, it is used to determine the optimal parameters of the PI controller in STATCOM, such as PI controller in AC voltage regulator, DC voltage regulator. Simulation results show that the STATCOM devices significantly improve the performance of the hybrid wind diesel system and the power network during transient disturbances.

HYBRID WIND DIESEL SYSTEM

A wind-diesel hybrid system is one of autonomous electricity generating system using wind turbine (s) and diesel generator (s) to obtain a maximum contribution by the intermittent wind resource to the total power produced while providing continuous high quality electric power (AWEA, 1991). Figure 1 presents a schematic diagram of a generalized wind-diesel system with STATCOM.

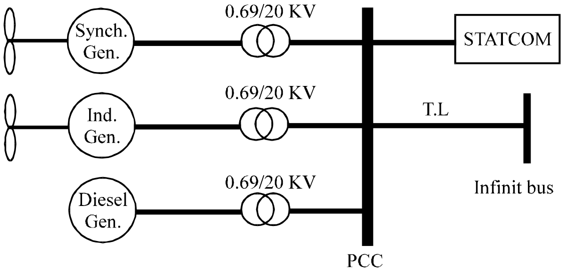

Fig. 1: Hybrid wind-diesel system STATCOM

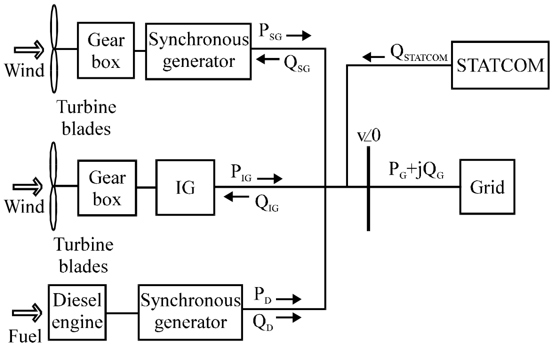

Fig. 2: Hybrid wind-diesel systems STATCOM

The model represents the wind turbine and 3 types of generators (3 phase synchronous generator, squirrel-cage induction generator and synchronous generator diesel). All generators are connected in parallel at the Point of Common Coupling (PCC) and connected to STATCOM and the utility grid through transmission line. The model is created in MATLAB software that enables the dynamic and static simulations of electromagnetic and electromechanical systems.

MATHEMATICAL MODEL OF THE SYSTEM

The hybrid wind-diesel power system in general comprises induction generator, synchronous generator, diesel generator, grid and reactive power compensator (STATCOM) and a control mechanism. A single line diagram of the system is shown in Fig. 2.

The active power fed to the grid is fulfilled by the synchronous generator and the induction generator. The reactive power required for the operation of induction generator and grid is provided by synchronous generator and STATCOM. The equations representing the power system shown in Fig. 2 is given by:

$$P_{SG} + P_{IG} + P_D = P_G \quad (1)$$

$$Q_{SG} + Q_{COM} = Q_{IG} + Q_G \quad (2)$$

STATCOM MODEL

Shunt compensators are primarily used for bus voltage regulation to providing or absorbing reactive power, they are effective for damping electromechanical oscillations (Heier, 1998; Uzunovic, 2001). Different kinds of shunt compensators are currently being used in power systems of which the most popular ones are Static Var Compensator SVC and STATCOM (MathWorks Inc., 2003). In this research, only the STATCOM which has a more complicated topology than a SVC is studied. The resulting STATCOM can inject or absorb reactive power to or from the bus to which it is connected and thus, regulate bus voltage magnitudes (Math Works Inc., 2003). The main advantage of a STATCOM over a SVC is its reduced size which results from the elimination of AC capacitor banks and reactors, moreover a STATCOM response is about 10 times faster than that of a SVC due to its turn-on and turn-off capabilities (Math Works Inc., 2003). The complex power supplied by the STATCOM to the AC power system is given by the following equations (Chen and Hsu, 2007):

$$P_s = \frac{|V_1||V_m|}{X_s}\sin\alpha \qquad (3)$$

$$Q_s = -\frac{|V_m|^2}{X_s} + \frac{|V_1||V_m|}{X_s}\cos\alpha \qquad (4)$$

Where:

V_m and V_1 = The voltages at the PCC and STATCOM output voltage

α = The STATCOM output voltage angle

Figure 3 illustrate a single-line diagram of the STATCOM and a simplified block diagram of its control system. The control system of STATCOM consists of a Phase-Locked Loop (PLL) which synchronizes on the positive-sequence component of the 3 phase primary voltage V_1. The output of the PLL (angle $\theta = \alpha t$) is used to compute the direct-axis and quadrature-axis components of the AC 3 phase voltage and currents (labeled as V_d, V_q or I_d, I_q on the diagram).

Measurement systems measuring the d and q components of AC positive-sequence voltage and currents to be controlled, as well as the DC voltage Vdc. An outer regulation loop consisting of an AC voltage regulator and a DC voltage regulator. The output of the AC voltage regulator is the reference current I_{qref} for the current regulator (I_q = Current in quadrature with voltage which controls reactive power flow). The output of the DC voltage regulator is the reference current I_{dref} for the current regulator (I_d = Current in phase with voltage which controls active power flow). Figure 4 and 5 have shown the AC voltage regulator and the DC voltage regulator, respectively.

An inner current regulation loop consisting of a current regulator. The current regulator controls the magnitude and phase of the voltage generated by the PWM converter (V_{2d}, V_{2q}) from the I_{dref} and I_{qref} reference currents produced, respectively by the DC voltage

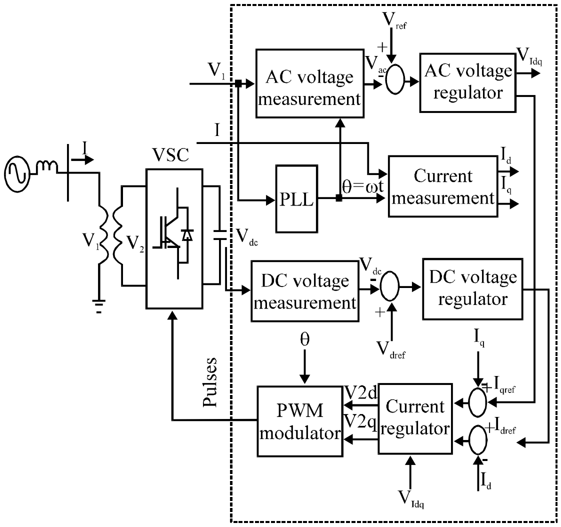

Fig. 3: STATCOM and control system

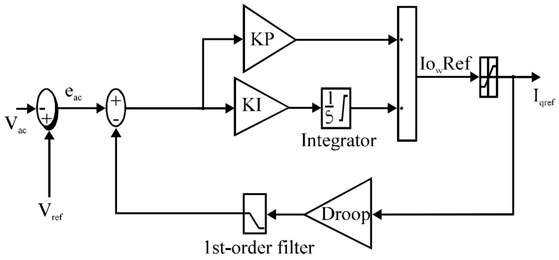

Fig. 4: AC voltage regulator

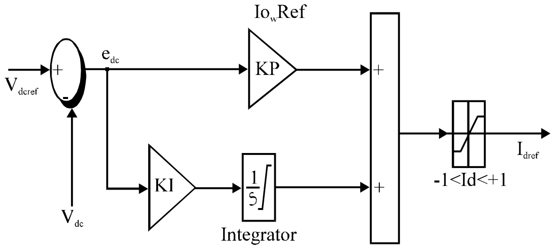

Fig. 5: DC voltage regulator

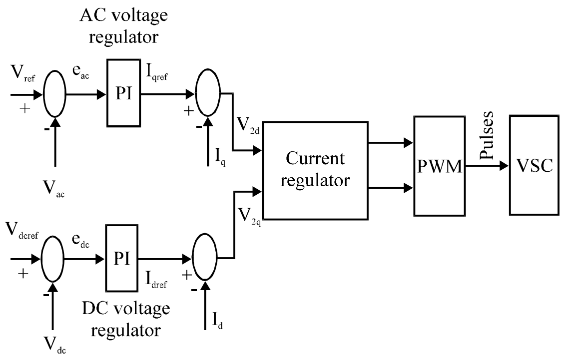

Fig. 6: PI controller in STATCOM

regulator and the AC voltage regulator (in voltage control mode). The current regulator is assisted by a feed forward type regulator which predicts the V_2 voltage output (V_{2d}, V_{2q}) from the V_1 measurement (V_{1d}, V_{1q}) and the transformer leakage reactance.

The PI controller in STATCOM on hybrid wind-diesel system consists of two PI, firstly in AC voltage regulator, secondly in DC voltage regulator. Error in PI controller is given as:

$$e = e_{ac} + e_{dc} \tag{5}$$

$$e_{ac} = V_{ref} - V_{ac} \tag{6}$$

$$e_{dc} = V_{ref} - V_{dv} \tag{7}$$

Figure 6 shows the schematic PI controller in STATCOM with hybrid wind-diesel system. This study is intended for presenting the Genetic Algorithm technique (GA) for tuning the PI controller in STATCOM.

GA ON HYBRID WIND DIESEL SYSTEM

Genetic Algorithm (GA) is a random search and optimisation method inspired by Darwin's reproduction and survival of the fittest individual (Davis, 1991). This algorithm looks for the fittest individual from a set of candidate solutions called population. The population is exposed to crossover, mutation and selection operators to find the fittest individual. The fitness function assesses the quality of each individual in evaluation process. The selection operator ensures the fittest individuals for the next generation. The crossover and mutation operators are used for variety of populations. Figure 7 represents the flowchart of the genetic algorithm.

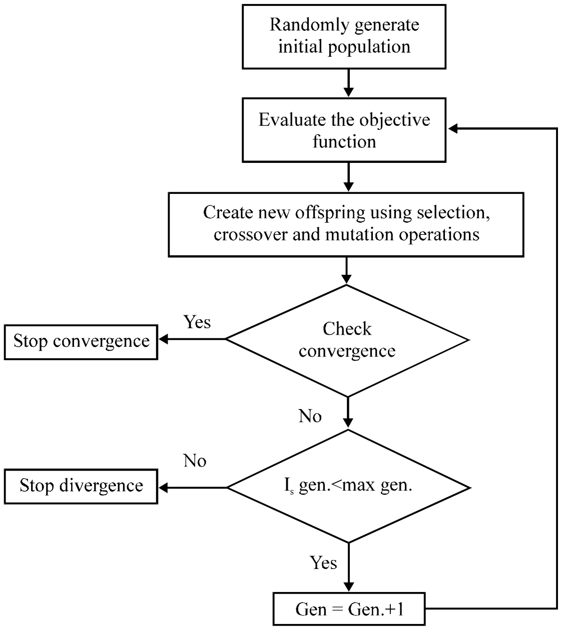

Fig. 7: The flow chart of the genetic algorithm

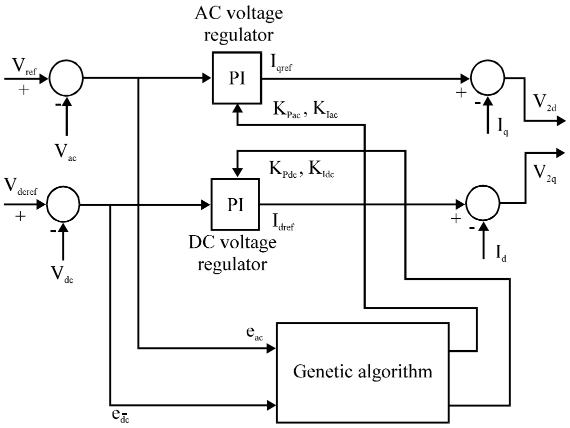

Fig. 8: Hybrid wind-diesel system with STATCOM and GA

The performance indices used were integral of absolute magnitude of the error (IAE). IAE gets the absolute value of the error to remove negative error components. IAE is good for simulation studies.

$$I_{IAE} = \int_0^T |e(t)| dt \tag{8}$$

$$e(t) = e_{ac} + e_{dc} \tag{9}$$

In this study, this error criteria will be minimized by applying an existing tuning algorithm through the application of a genetic algorithm, as will presently be elucidated for a comprehensive and introduction to GA (Davis, 1991). The genetic algorithm works on a coding of the parameters of the PI controller in AC voltage regulator (K_{Pac}, K_{Iac}) and DC voltage regulator (K_{Pdc}, K_{Idc}) in STATCOM to be optimized rather than the parameters themselves. Figure 8 represents single line diagram of hybrid wind diesel system with STATCOM and GA. The upper and lower of the parameters of PI controller in STATCOM of (K_{Pac}, K_{iac}, K_{Pdc}, K_{Idc}) from 0-2000.

SIMULATION RESULTS

The gains K_P, K_I of the PI controllers in AC voltage regulation and DC voltage regulation of STATCOM have been optimized using Genetic Algorithm (GA). The optimum values obtained for the hybrid wind diesel system are shown in Table 1.

Table 1: The parameters of PI controller in STATCOM

Items	Parameters	Values
PI AC voltage regulator	K_{Pac}	0.8510
	K_{iac}	0.7350
PI DC voltage regulator	K_{Pdc}	0.0001
	K_{Idc}	0.0200

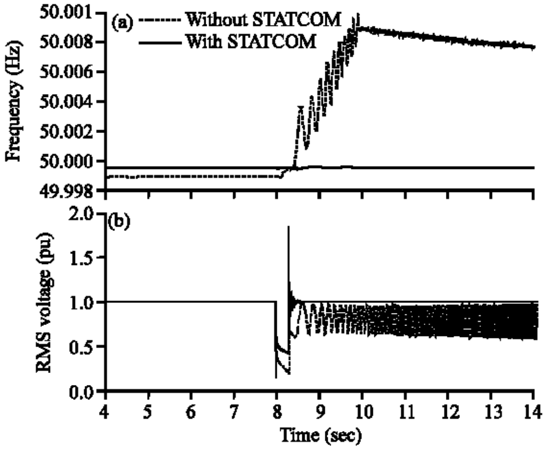

Fig. 9: Frequency and RMS voltage

In this study, of the dynamic performance of the overall system at three lines to ground fault is done. Analysis of the hybrid wind diesel system and the effect of fault on all generators will be discussed also.

Three lines to ground fault where phase A-C are shorted with the ground for 300 m sec before the fault was cleared. Three lines to ground fault occur on transmission lines during the constant wind speed at 13 m sec^{-1}. The following figures show hybrid wind diesel system without and with STATCOM at pre and after three lines to ground fault. Figure 9 illustrates the grid frequency and the RMS voltage at the Point of Common Coupling (PCC).

From Fig. 9a, show the frequency of the system at fault at time 8 sec without STATCOM, then the system is oscillated and is unstable but with STATCOM the frequency is constant and the system is stable. From Fig. 9b, show the RMS voltage of the system at PCC when occur 3 phase fault at time 8 sec then the voltage is oscillation and the system is unstable without STATCOM but with STATCOM the RMS voltage is effect during fault and STATCOM operates in inductive mode operation to regulate the terminal voltage bus voltage to 1 pu, then the system is stable.

Figure 10-12 illustrates the rotor speed, stator current, active and reactive power of the synchronous generator, induction generator and diesel generator, respectively. From Fig. 10a, show the rotor speed of synchronous generator that start at 1 pu and when occur fault at time 8 sec without STATCOM then the rotor speed increase to reach the system is unstable but with STATCOM the rotor speed is oscillate and return to 1 pu, then the system is stable. From Fig. 10b show the stator current of synchronous generator without STATCOM at occur faults at time 8 sec will very oscillation but with STATCOM the stator current is return to steady state after 2 sec. From Fig. 10c, d show the active and reactive power of synchronous generator will oscillation when

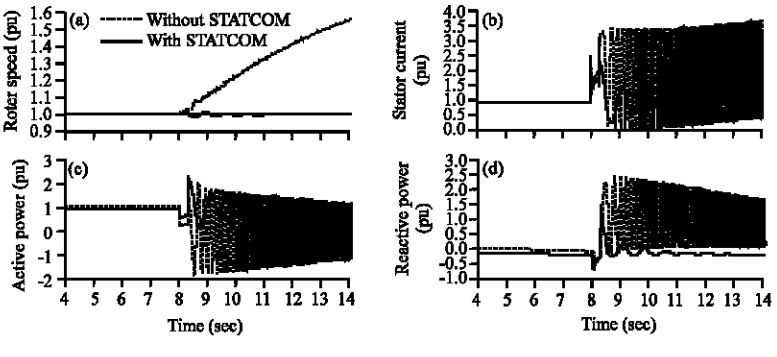

Fig. 10: Rotor speed, stator current, active and reactive power of synchronous generator

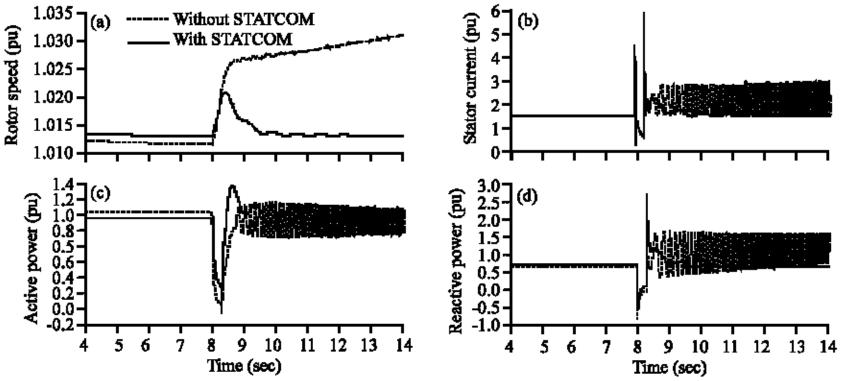

Fig. 11: Rotor speed, stator current, active and reactive power of induction generator

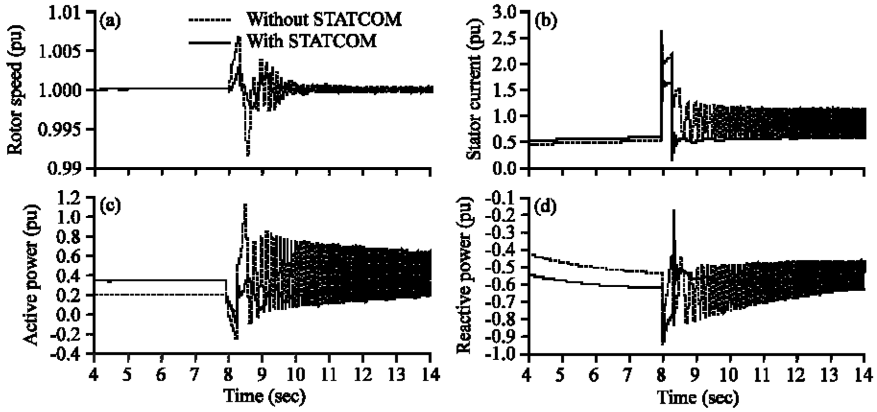

Fig. 12: Rotor speed and stator current, active and reactive power of diesel generator

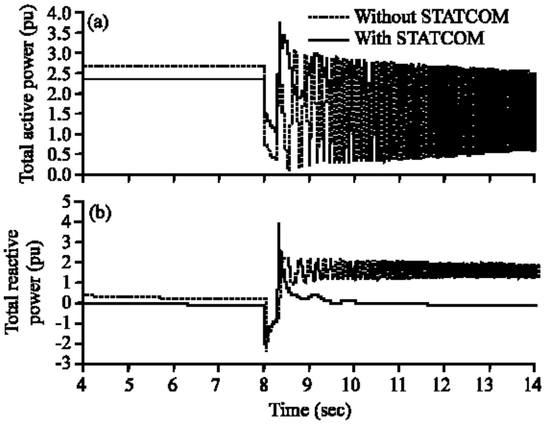

Fig. 13: Total active and reactive power at PCC

occur fault without STATCOM but with STATCOM the system is return to steady state after fault by 2 sec.

Figure 11a, show the rotor speed of induction generator when occur faults at time 8 sec without STATCOM, then the rotor speed increase to reach the system is unstable but with STATCOM the rotor speed is increase and return to 1 pu then the system is stable. Figure 11b, show the stator current of induction generator without STATCOM at occur faults at time 8 sec will very oscillation but with STATCOM the stator current is return to steady state after 2 sec from 8 sec. Figure 11c-d, show the active and reactive power of induction generator will oscillation when occur faults without STATCOM but with STATCOM the system is return to steady state after fault by 2 sec.

Figure 12a, show the rotor speed of diesel generator when occur faults at time 8 sec without STATCOM, then the rotor speed oscillate but with STATCOM the rotor speed is oscillate and return to steady state after 2 sec then the system is stable. Figure 12b, show the stator current of diesel generator without STATCOM at occur faults at time 8 sec will very oscillation but with STATCOM the stator current is return to steady state after 2 sec from the time of fault. Figure 12c, d show the active and reactive power of diesel generator will oscillation when occur faults without STATCOM but with STATCOM the system is return to steady state after fault by 2 sec.

Figure 13, show the total active and reactive power at PCC when occur faults at time 8 sec without and with STATCOM.

Figure 13a shows the total active power of the hybrid wind diesel system without STATCOM will start at 2.6 pu and the system is stable until occur faults at time 8 sec then the system is oscillation and unstable but with STATCOM the system is return to steady state after faults by 4 sec at 2.4 pu. Then system is stable. Also, Fig. 13b illustrates the total reactive power of the hybrid wind diesel system without STATCOM, the system is stable until occur faults at time 8 sec then the system is oscillation and unstable but with STATCOM the system is return to steady state after faults by 2 sec. Then system is stable.

CONCLUSION

Control scheme of hybrid wind diesel power generation has been proposed in this work. STATCOM controllers were designed based on genetic algorithm in an hybrid wind diesel power system. The performance and stability conditions of technique have been applied, as the objective function in the optimization problem. The GA has been used to tune the control parameters of controllers.

The controlled reactive power has been investigated by using STATCOM. The system has been simulated by taking typical data and the gains of the controller have been optimized. Comparing between the hybrid wind diesel system connected with STATCOM and without STATCOM, it has been observed that peak deviations in the system voltage are less in case of STATCOM than that of without STATCOM. From figures mentioned earliar the hybrid wind diesel system without STATCOM will oscillation and the system is unstable but with STATCOM the system is stable. It has been shown that STATCOM is a better choice for damping transient oscillations due to disturbances in the hybrid wind diesel system.

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