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STATCOM for Improved Dynamic Performance of Wind Farms in Power Grid

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Abstract—Application of FACTS controller called Static Synchronous Compensator STATCOM to improve the performance of power grid with Wind Farms is investigated .The essential feature of the STATCOM is that it has the ability to absorb or inject fastly the 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 wind farm after occurring severe disturbance such as faults or wind farm mechanical power variation is obtained with STATCOM controller . The dynamic model of the power system having wind farm controlled by proposed STATCOM is developed . To Validate the powerful 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 the power system oscillations and restoring the power system stability .

Index Terms-- **STATCOM, Wind Generation , Transient Stability**

I. INTRODUCTION

NOWADAYS wind as a significant proportion of non-pollutant energy generation, is widely used. If a large wind farm, which electrically is far away from its connection point to power system, is not fed by adequate reactive power, it present major instability problem. Various methods to analyze and improve wind farm stability have been performed [1-4]. The stability of wind driven self excited induction generator SEIG s is analyzed [2]. A breaking resistor to absorb active power during fault to enhance the system stability is developed [5]. Flexible AC transmission system FACTS devices such as Static Synchronous Compensator STATCOM to improve the stability in wind farm is studied [6].

As a consequence, it will become necessary to require wind farms to maintain continuous operation during grid disturbances and thereby support the network voltage and frequency. In addition, in the area of a deregulated electricity industry, the policy of open access to transmission systems, which helped create competitive electricity markets, led to a huge increase in energy transactions over the grid and possible congestion in transmission systems. The expansion of power transfer capability of transmission systems has been a major problem over the past two decades. Under these conditions, the modern power system has had to confront some major operating problems, such as voltage regulation, power flow control, transient stability, and damping of power oscillations, etc. FACTS devices can be a solution to these problems [7]. 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. This issue is even more critical in the case of microgirds, since certain FACTS controllers, particularly STATCOMs, are being considered as a possible solution for some of the voltage and angle stability problems inherent to these power grids. Consequently, typical STATCOM models are validated here using system identification techniques to extract the relevant electromechanical mode information from time-domain signals [13-15]. System identification techniques are used to readily and directly compare fairly distinct STATCOM models, thus avoiding matrix based eigenvalue studies of complex system models and/or modeling approximations.

In this paper, a STATCOM is added to the power network to provide dynamic voltage control for the wind farm, dynamic power flow control for the transmission lines, relieve transmission congestion and improve power oscillation damping. Simulation results show that the STATCOM devices significantly improve the performance of the wind farm and the power network during transient disturbances.

II. WIND FARM AND ELECTRIC GENERATOR MODEL

In dynamic simulations, the electricity-producing wind turbine is treated as a complex electromechanical system consisting of the induction generator, the drive train system and the rotating wind turbine. Its modular diagram is given in Fig. 1.

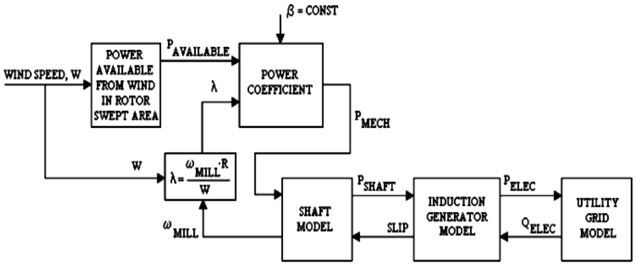


Fig. 1 Modular model of a grid-connected, stall-controlled wind turbine equipped with an induction generator

The wind turbine model is developed based on the steady-state power characteristics of the turbine. The stiffness of the drive train is infinite and the friction factor and the inertia of the generator coupled to the turbine [8]. The mechanical power captured by wind turbine based on its power utilization coefficient C_P for a given wind velocity V_W and can be represented by:

$$P_t = \frac{1}{2}\rho A C_P V_W^3 \tag{1}$$

Where P_t is the turbine power, ρ is the air density, A is the swept turbine area, C_P is the coefficient of performance and V_w is the wind speed. The coefficient of performance C_P is nonlinear function of magnitudes: the pitch angle β of rotor blades and tip speed ratio λ, which is the quotient between the tangential speed of the rotor blade tips and the undisturbed wind speed velocity [9]. A general equation used to model $C_P(\lambda, \beta)$, based on the modeling turbine characteristics is given by [10]:

$$C_P(\lambda,\beta) = C_1\left[\frac{C_2}{\lambda_i} - C_3\beta - C_4\right]e^{\frac{C_3}{\lambda_i}} + C_6\lambda \tag{2}$$

Where: the coefficient C_1 to C_6 are constants: C_1=0.5176, C_2=116, C_3=0.4, C_4=5, C_5=21, and C_6=0.0068 in this works a constant pitch angle β is used and value is assigned as zero, the based speed is selected at 9m/sec.

Wind turbines use squirrel cage induction generators are shown in Fig. 2. The stator winding is connected directly to the grid and the rotor driven by the wind turbine. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by the stator winding. The pitch angle is controlled in order to limit the generator output power to its nominal value for high wind speeds. In order to generate power the induction speed must be slightly above the synchronous speed but the speed variation is typically so small that the WTIG is considered to be affixed-speed wind generator.

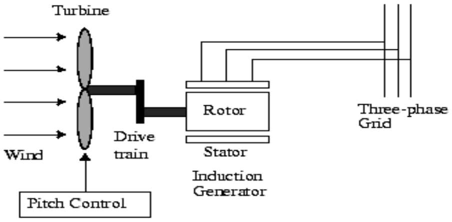


Fig. 2 Wind turbine and induction generator

III. STATCOM MODEL

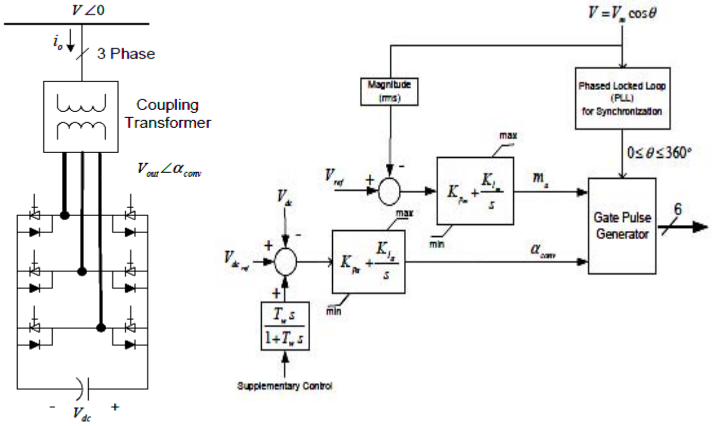
Shunt compensators are primarily used for bus voltage regulation y means of providing or absorbing reactive power; they are effective for damping electromechanical oscillations [10, 11]. Different kinds of shunt compensators are currently being used in power systems, of which the most popular ones are Static Var Compensator SVC and STATCOM [16]. In this work, only the STATCOM, which has a more complicated topology than a SVC, is studied. The STATCOM is a FACTS controller based on voltage sourced converter VSC technology. A VSC generates a synchronous voltage of fundamental frequency and controllable magnitude and phase angle. If a VSC is shunt-connected to a system via a coupling transformer as shown in Fig. 3(a), 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 [16]. 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. The active and reactive power exchange between the VSC and the system in Fig. 3 are a function of the converter output voltage denoted as V_{out}, i.e.

.

$$P = \frac{V_{out}V}{X}\sin\alpha_{conv} \tag{3}$$

$$Q = \frac{V_{out}^2 - V_{out}V\cos\alpha_{conv}}{X} \tag{4}$$

Where α_{conv} is the angle between the ac system voltage V and V_{out}, and X denotes the reactance of the coupling transformer.



(a) Basic structure (b) Control block diagram with PWM control

Fig. 3 STATCOM basic structure, and control block diagram

Two control strategies may be used for a STATCOM, namely, phase control and PWM control. With phase control, the dc bus voltage V_{dc} is regulated by changing α_{conv}, i.e. charging and discharging the dc capacitor, which ultimately controls V_{out}, as this voltage is proportional to V_{dc}. On the other hand, with PWM control, both the angle and the magnitude of the converter output voltage are regulated as shown in Fig. 3(b). Although low frequency harmonics can be reduced using PWM control, the high switching losses due to the high switching frequencies are the main constraints for its application in transmission systems.

For the case where the output voltage of the STATCOM is balanced and harmonic free, a TS model that does not include converter switching phenomena has been proposed and developed in, for example, [9, 12]. This model, which is an improved model of other similar STACOM TS models widely utilized in TS studies, is based on the power balance between the controllers ac power P and dc power P_{dc} under balanced operation at fundamental frequency, since TS models are based on the assumption of balanced three-phase voltages at fundamental frequency, i.e.

$$P = P_{dc} + P_{loss} \tag{5}$$

$$3a\frac{V_{out}V}{X}\sin\alpha_{conv} = V_{dc}I_{dc} + P_{loss}$$

Where a stands for the transformer ratio, I_{dc} is the current in the dc capacitor, and P_{loss} represents the converter losses. This leads to a STATCOM TS model depicted in Fig. 4, in which the magnitude of the capacitor voltage is determined by the following differential equation derived from (6) [9]:

$$\frac{dV_{dc}}{dt} = \frac{3akV}{CX}\sin\alpha_{conv} - \frac{V_{dc}}{R_c C} \qquad (6)$$

Where the resistance R_c represents the converter losses, which can be significant, depending on the number of switches and the switching frequency. In Fig. 4, the coefficient k is proportional to the modulation index m_a, which for a two level inverter is $k = m_a/2\sqrt{2}$. It has been shown, by means of time-domain simulations that this TS model response is reasonably close to that obtained from a detailed STATCOM model for transients relatively afar from the controller [9].

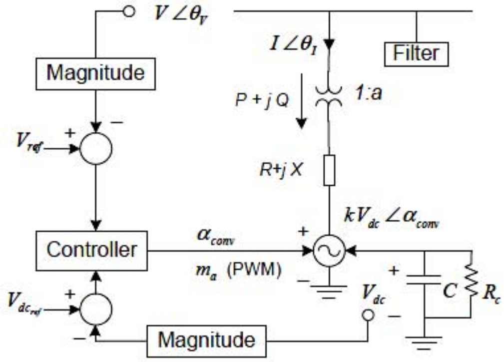


Fig. 4 STATCOM transient stability model and its control

IV. STUDIED SYSTEM AND RESULTS

A wind farm consisting of six 1.5-MW wind turbines is connected to a 25-kV distribution system exports power to a 120-kV grid through a 25-km 25-kV feeder as shown in Fig.5a.

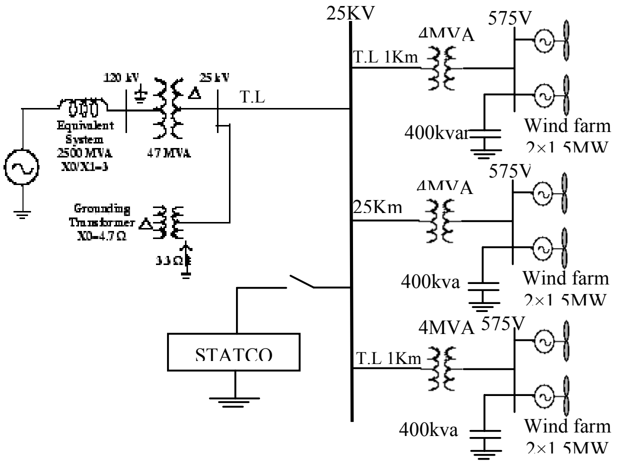


Fig. 5a Studied model

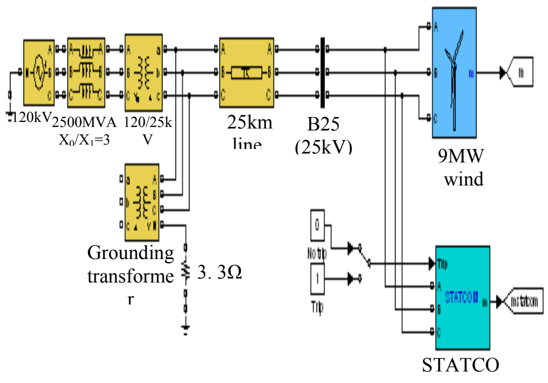
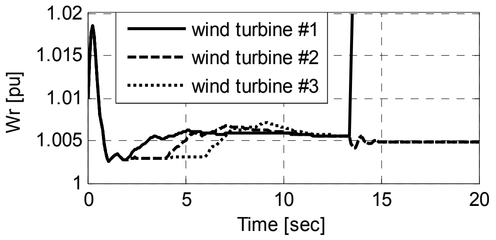


Fig.5b System Equipped by STATCOM using Simulink matlab [16]

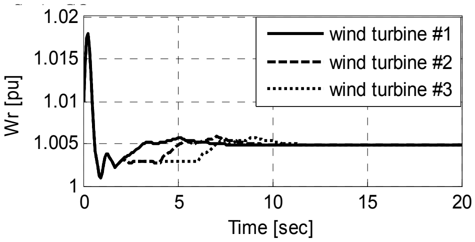
The studied power system is simulated using Simulink Matlab software package as shown in fig 5b. This paper discussed the effect of speed variables on wind turbines, effect of phase-phase to ground fault on wind turbine #2, and three phase-fault on wind turbine #2 on the system studied to depicts the following: Three wind turbine rotor speed, active, reactive power, and voltage on 25kV bus with and without STATCOM.

A. *Effect of Speed Variables on Wind Turbines*

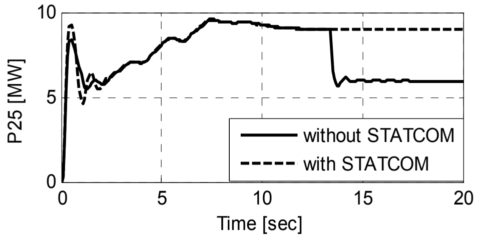
When the wind speed changes for each turbine as following: initially, wind speed is set at 8 m/s, then starting at t=2s for "Wind turbine #1", is rammed to 11 m/s in 3 sec. The same gust of wind is applied to Turbine #2 and Turbine #3, respectively with 2 sec and 4 sec delays. It can be observed from Fig. 6, the impact change in wind speed for each turbine has a low voltage condition results in an overload of the IG of "Wind Turbine #1", and it is tripped at t=13.43sec by the AC over current protection. After wind turbines #2, and #3 continue to generate 3MW with absorbs 1.47Mvar, and turbine speed for wind turbine #1 is highly increased shown in Fig. 6(a). Because of the lack of reactive power support, the voltage at bus 25kV now drops to 0.91pu as shown in Fig. 6(e). While, with STATCOM the output active power for each pair of turbine 3MW, absorbed reactive power for each pair of turbine is reach 1.47Mvar, turbine speed for each pair of turbine is reach to 1.0047pu as shown in Fig. 6, with respect bus 25kV. Voltage reach to 0.984pu in Fig. 6(e), active power reach to 8.951MW, and absorbed reactive power is 2.08Mvar.



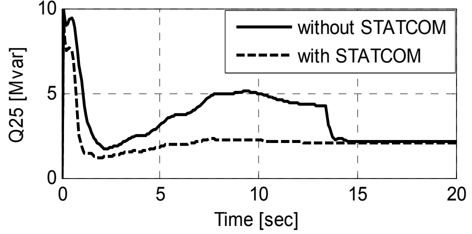
(a) Three wind turbine rotor speed without



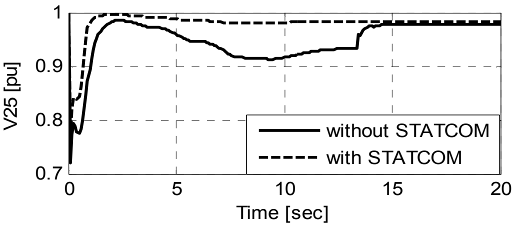
(b) Three wind turbine rotor speed with



(c) Active power on bus 25kV



(d) Reactive power on bus 25kV

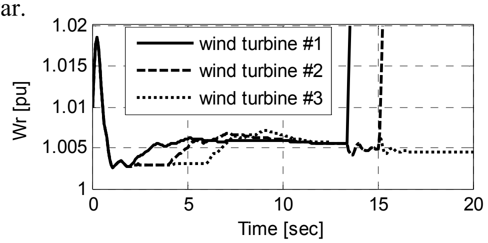


(e) Voltage on bus 25kV

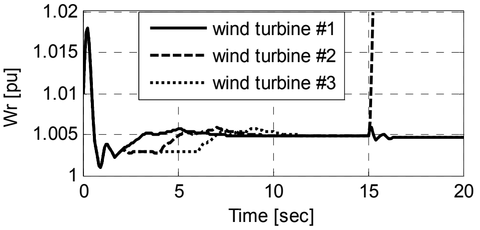
Fig. 6. Effects of rotor speed variations on three wind

B. Effect of Phase-Phase to Ground Fault on Wind Turbine #2

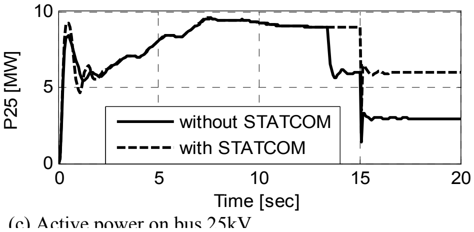
Fig. 7 shows the impact of change in wind speed and, the studied system has subjected to phase-phase to ground fault occurred at wind turbine #2 only and cleared after 100ms from 15sec to 15.1sec. It can be observed Fig. 7, is clear that the first wind turbine is tripped because of the lack of reactive power support, the voltage at bus 25kV, and drops to 0.91pu at t=13.43sec, and then the occurrence of phase-phase to ground fault, on t=15sec, and the second wind turbine will begin to accelerate as Fig 7(a). The second turbine is tripped by protection system, because of deficiency in reactive power and electrical torque in an induction generator. Therefore, the third wind turbine is responsible for supplying active and reactive power and delivering them to 25kV bus that after fault occurrence on t=15sec. The reactive power is injected to the 25kV bus via 400kvar fixed capacitor, which is connected to terminal wind turbines. After fault clearance, the reactive power injection decreases. With STATCOM is connected, wind turbine #1 is no trip but wind turbine #2 cannot continue its service because of insufficiency capacity of STATCOM to supply necessary reactive power and it is tripped as Fig. 7(b). It is seen from that active power of 25kV, power decrease after fault occurrence on t=15sec, and this reduction continues until removal of fault on t=15.1sec. However, active power of bus increase until it reaches to its stable quantity 6MW after several swings. With increase in capacity of STATCOM from 3Mvar to 8.5Mvar.



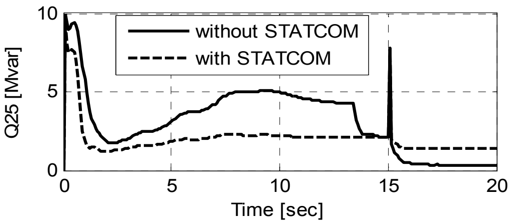
(a) Three wind turbine rotor speed without



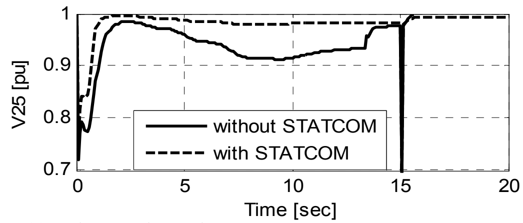
(b) Three wind turbine rotor speed with STATCOM



(c) Active power on bus 25kV



(d) Reactive power on bus 25kV

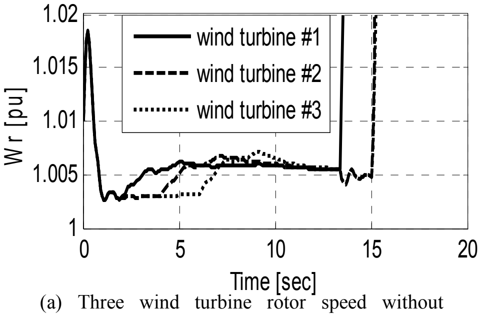


(e) Voltage on bus 25kV

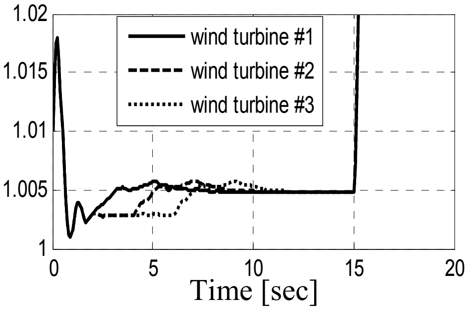
Fig. 7. Effects of phase-phase to ground fault on wind turbine # 2

C. Effect of Three Phase Fault on Wind Turbine #2

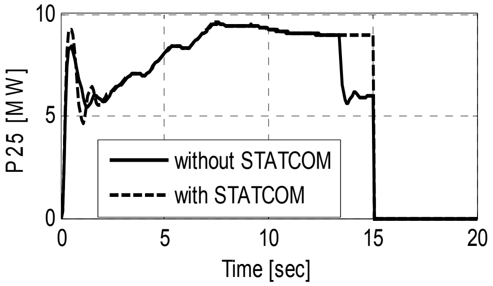
Fig. 8 shows the impact of change in wind speed and The studied system was subjected to three phase fault occurred at wind turbine #2 only and cleared after 100ms from 15sec. Without STATCOM, it is clear that the first wind turbine is tripped because of the lack of reactive power support, the voltage at bus 25kV, drops to 0.91pu at t =13.43sec. Then the occurrence of three phase fault, which the wind turbines #2, and #3 will begin to accelerate. Two wind turbines are tripped by protection system as shows Fig 8(a) at t=15.1sec and t=15.11sec respectively, because of deficiency in reactive power and electrical torque in an induction generator. When STATCOM is connected, three wind turbines cannot continue its service because of insufficiency capacity of STATCOM to supply necessary reactive power and it is tripped as Fig. 8(a), it is seen from that active power of 25kV bus power decrease to zero. after fault occurrence on t=15sec.



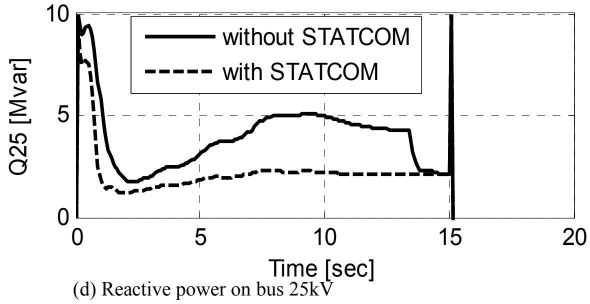
(a) Three wind turbine rotor speed without



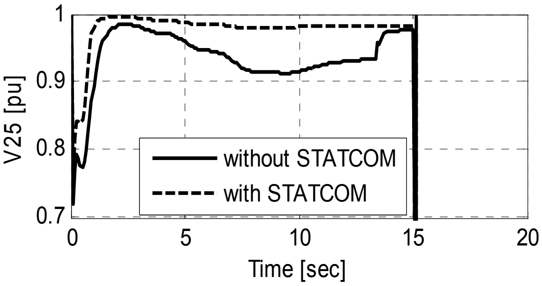
(b) Three wind turbine rotor with STATCOM



(c) Active power on bus 25kV



(d) Reactive power on bus 25kV



(e) Voltage on bus 25kV

Fig. 8. Effects of three phase fault on wind

V. CONCLUSION

Power system with wind farms performance can be improved using FACTS devices such as STATCOM . The dynamic model of the studied power system is simulated using Simulink Matlab package sofware . To validate the effect of the STATCOM controller of power system operation , the system is subjected to different disturbances such as faults and power operating conditions . The digital results prove the powerful of the proposed STATCOM controller in terms of Stability improvement, power swings damping, voltage regulation, increase of power transmission and chiefly as a supplier of controllable reactive power to accelerate voltage recovery after fault occurrence.

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VII. BIOGRAPHIES

G. Elsady was born in Luxor, Egypt. He received his B.Sc and M.Sc degrees in electrical engineering from Assiut University, Assiut, Egypt in 1982 and 1989 respectively . However PhD degree has been get from Assiut university and university of New Brunswick, Fredericton, Canada as channel system in 1995. He joined electrical engineering department as a Demonstrator, and Assistant Lecturer during the period 1982-1992. From 1993-1995 he was Research Assistant at university of New Brunswick, Canada . He worked at electrical engineering department as an assistant professor from 1995-2000, and from 1995- 2006 he was Associate Professor. He is Professor from 2006 in electrical power system . His Research interests

Y. A. Mobarak was born in Egypt. He received his B.Sc. and M.Sc. degrees in electrical engineering from South Valley University, Aswan, Egypt, in 1997 and 2001 respectively and Ph.D. from Cairo University, Egypt, in 2005. He joined Electrical Engineering Department, High Institute of Energy, South Valley University as a Demonstrator, as an Assistant Lecturer, and as an Assistant Professor during the periods of 1998–2001, 2001–2005, and 2005–present respectively. He joined Artificial Complex Systems, Hiroshima University, Japan as a Researcher 2007–2008. His research interests are power system planning, operation, and optimization techniques applied to power systems. Also, his research interests are Nanotechnology materials via addition nano-scale particles and additives for usage in industrial field.

A-R. Youssef was born in Egypt. He received his B.Sc. degrees in electrical engineering from Faculty of Engineering, Aswan, Egypt, in 2005. He is working on the M.Sc. degree since 2008 to present. His research interests are power system planning, operation, and optimization techniques applied to power systems. He is also working on the Qena, Faculty of Technology, Higher Institute of Education.