In this article, Static VAR Compensator (SVC) has been used to improve transient stability and power oscillation damping of a wind farm connected to power system. Different fault types and different fault durations were considered for the study to investigate the effect of the SVC based FLC on system stability. Different locations are considered for the SVC at the studied system. The proposed controller provides the wind farm system with damping effect during transient condition and provides much smoother and quicker response after fault clearance. The proportional plus integral (PI) controller is used for the comparative study.

Keywords: Doubly Fed Induction Generator – Fuzzy logic control – Static VAR Compensators–Wind Farm

1. INTRODUCTION

Energy consumption increase, the deficit in fossil fuel and increased energy demand turned the world’s attention towards the renewable energy hoping that it may provide some of its energy needs. Wind energy becomes one of the mainstream power sources in many countries all over the world. Besides, being consumer and environment friendly, it requires shorter construction time. Due to technical development it becomes one of the most competitive sources of renewable energy. However, wind power has some disadvantages. Such as, wind powered generators are induction generators (IG). That absorbs reactive power during its normal operating condition. This may cause low voltage and dynamic instability in the power system connected to. There are two major types of IG, which are used very widely. The first one is the squirrel cage induction generator and the second one is the doubly fed induction generator (DFIG) [1-5].

DFIG is a ‘special’ variable speed induction generator that is widely used as modern large wind turbine generators [6]. It's one of the most important generators for wind energy conversion systems. Both grid connected and stand-alone operation are feasible. The most important advantages of the variable speed wind turbines as compared with conventional constant speed system are the improved dynamic
behavior, resulting in the reduction of the drive train mechanical stress, electrical power fluctuation, and also increasing of captured power [7].

Many studies in system stability propose flexible AC transmission system (FACTS) devices as an effective method to improve system stability. FACTS controllers such as TCSC, SVC, STATCOM, SSSC, UPFC, IPFC, HPFC can enhance different power system performance parameters such as voltage profile, damping of oscillations, load ability, reduce the active and reactive power losses, sub-synchronous resonance (SSR) problems, transient stability, and dynamic performance [8]. Wind energy system (WES) could be effectively stabilized with DFIG system or STATCOM system as described in [9]. Using STATCOM and SVC significantly increase system stability. I.e. SVC and STATCOM devices increase the buses voltage, power limits, line powers, and loading capability of the network [10].

THE static VAR compensator (SVC) is a shunt type of FACTS devices using power electronics to regulate voltage, control power flow and improve transient stability in power system. The SVC regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system [11]. It has been widely used in power systems for voltage regulation, dynamic stability enhancement and power factor correction [11]-[15]. Many techniques have been used in the control of SVC such as fuzzy logic control (FLC) [16]-[17], neural network [5] and neuro fuzzy logic [18].

FLC is one of the best and most successful techniques among expert control strategies, and is well known as an important tool to control non-linear, complex, and ill-defined systems. FLC set theory provides an effective control based on the knowledge and technical experience of operators and the establishment of intelligent control is founded to be favor in industry [5].

2. WIND TURBINE DOUBLY FED INDUCTION GENERATOR

The wind turbine (WT) with DFIG system is an induction type generator in which the stator windings are directly connected to the three-phase grid and the rotor windings are connected to grid through three-phase back-to-back pulse width modulation (PWM) converters. The back-to-back PWM converter includes three parts: rotor side converter (RSC), grid side converter (GSC) and DC link capacitor placed between the two converters. It's controller includes three parts: rotor side converter controller, grid side converter controller and wind turbine controller as shown in Fig. (1), in which the grid-side converter and rotor-side converter are controlled independently of each other [4]. The main idea is that the rotor-side converter controls the active and reactive power by controlling the rotor current components, while the stator-side converter controls the DC-link voltages and ensures a converter operation at unity power factor (zero reactive power). Depending on operating conditions of the rotor, the power is fed into or out of the rotor. In an over synchronous condition, power flows from the rotor via the converter to the grid, whereas power flows in the opposite direction in a sub-synchronous condition. In both cases, the stator feeds power into the grid [19].

2.1 Wind Turbine Model

The wind turbine is characterized as in [20] by non-dimensional curves of the power coefficient $C_p$ as a function of both tip speed ratio $\lambda$ and the blade pitch angle
\( \beta \), The tip speed ratio \( \lambda \) is the ratio of linear speed at the tip of blades to the speed of the wind. It can be expressed as follows:

\[
\lambda = \frac{\Omega R}{V_w}
\]  

(1)

where \( R \) is the WT rotor radius, \( \Omega \) is the mechanical angular velocity of the WT rotor and \( V_w \) is the wind velocity. For the wind turbine used in the study, the following form approximates \( \beta C_p \) as a function of \( \lambda \) and \( \beta \):

\[
C_p = (0.44 - 0.016\beta)\sin\left(\frac{\pi(\lambda - 3)}{15 - 0.3\beta}\right) - 0.00184(\lambda - 3)\beta
\]  

(2)

The mechanical torque of the wind turbine, \( T_m \) can be calculated using equation [3]:

\[
T_m = \frac{1}{2} \sigma AC_p V_w^2 / \lambda
\]  

(3)

where \( \rho \) is the air density and \( A \) is the swept area by the blade.

---

**2.2 DFIG Mathematical Model [19,21]**

The voltage and magnetic flux of the stator can be written as in equations (4-7).

\[
V_{ds} = R_s i_{ds} + \frac{d\lambda_{ds}}{dt} - \omega_s \lambda_{qs}
\]  

(4)

\[
V_{qs} = R_s i_{qs} + \frac{d\lambda_{qs}}{dt} + \omega_s \lambda_{ds}
\]  

(5)

\[
\lambda_{ds} = L_s i_{ds} + L_i m i_{dr}
\]  

(6)

\[
\lambda_{qs} = L_s i_{qs} + L_i m i_{qr}
\]  

(7)

The voltage and magnetic flux of the rotor can be written as in equations (8-12).

\[
V_{dr} = R_r i_{dr} + \frac{d\lambda_{dr}}{dt} - (\omega - \omega_s) \lambda_{qr}
\]  

(8)

\[
V_{qr} = R_r i_{qr} + \frac{d\lambda_{qr}}{dt} + \omega_s \lambda_{dr}
\]  

(9)

\[
\lambda_{dr} = L_m i_{ds} + L_r i_{dr}
\]  

(10)

\[
\lambda_{qr} = L_m i_{qs} + L_r i_{qr}
\]  

(11)
where $\lambda_s$ and $\lambda_r$ are the stator and rotor magnetic flux; $L_s$, $L_r$, and $L_m$ are the stator, rotor, and magnetizing inductances; $V_s$ and $I_s$ are the stator voltages and currents; $V_r$ and $I_r$ are the rotor voltages and currents; $R_r$ and $R_s$ are the rotor and stator resistances; $\omega_s, \omega_r$ are the synchronous and rotate angular frequencies, respectively. $\omega_{slip}$ is the slip frequency.

$$\omega_{slip} = \omega_s - \omega_r$$

### 3. STATIC VAR COMPENSATOR (SVC)

Static VAR compensators, commonly known as SVCs and provides an excellent source of rapidly controllable reactive compensation for dynamic voltage control through its utilization of a thyristor switching/controlled reactive devices that have a faster control over the bus voltage and require more sophisticated controllers compared to the mechanical switched conventional devices. SVCs are shunt connected FACT's devices capable of generating or absorbing reactive power by controlling of output capacitive or inductive current. Fig. (2) shows the SVC configurations: the Thyristor Controlled Reactor (TCR), the Thyristor Switched Reactor (TSR) and the Thyristor Switched Capacitor (TSC) or a combination of all three in parallel configurations. The TCR uses firing angle control to continuously increase or decrease the inductive current whereas in the TSR the connected inductors are switched in and out stepwise thus with no continuous control of firing angle[22]. One of the major reasons for installing a SVC is to improve dynamic voltage control and thus increase system loadability and provide damping of system oscillation [23]. Also, SVC increases power transfer during low voltage conditions while fault on the system by decreasing generator acceleration and vice versa when the fault is cleared. So, it reduces the adverse impact of the fault on the generator's ability to maintain synchronism. The SVCs in use nowadays are of variable susceptance type [16].

![Figure 2. Systematic of TSC/TCR (SVC).](image)

### 3.1 Operating Principle of SVC

Fig. (3) shows Schematic Diagram of SVC control system simulated in MATLAB. The control system consists of: A measurement system for measuring the positive-sequence voltage to be controlled, A voltage regulator that uses the voltage error (difference between the measured voltage $V_m$ and the reference voltage $V_{ref}$) to determine the SVC susceptance $B$ needed to keep the system voltage constant, A distribution unit that determines the TSCs (and eventually TSRs) that must be switched in and out, and computes the firing angle $\alpha$ of TCRs and A synchronizing
system using a phase-locked loop (PLL) synchronized on the secondary voltages and a pulse generator that send appropriate pulses to the thyristors [11]. The SVC can be operated in two different modes: In voltage regulation mode and in Var control mode (the SVC susceptance is kept constant) [22].

![Figure 3. SVC control system](image)

## 3.2 SVC Mathematical Model [17]

TCR is designed by an inductance coil $L$ connected in series with two anti-parallel poled thyristors. Through the variation of the firing angle $\alpha$, the amplitude of the fundamental reactive current can be controlled as follow:

$$ I = \frac{V}{\pi \omega L} (2\pi - 2\alpha + \sin(2\alpha)) $$

(13)

Where $V$ is the amplitude of the voltage, $\omega$ is the angular frequency of the voltage and $L$ is the inductance of the thyristor. When the firing angle $\alpha$ is $90^\circ$, TCR is full conduction and the current reach its maximum. When the firing angle $\alpha$ is $180^\circ$, TCR is disconnected and the current reaches zero. By associating a fixed capacitor to the TCR (Fig. 4), the resulting SVC susceptance $B_{SVC}$ is given by:

$$ B_{SVC} = B_C - B_{TCR} = -\frac{1}{X_C X_L} \left( X_L - \frac{X_C}{\pi} \left[ 2(\pi - \alpha) + \sin(2\alpha) \right] \right) $$

(14)

TSC is designed by a fixed condenser switched on and off using a bidirectional thyristors interconnected in series. So, its current varies from 0 to $I_{max}$. The condenser is connected to a coil in order to avoid a resonance with the supply network. The current that flows through the capacitor is given by the following expression:

$$ i(\omega t) = V \frac{n^2}{n^2 - 1} \omega C \cos(\omega t) \ , \text{ where } n = \frac{1}{\sqrt{\omega^2 LC}} = \frac{X}{\sqrt{X_L}} $$

(15)

and $V$ is the fundamental voltage.

The combination of both TCR and TSC provides a good dynamic compensation. The combined reactances are given by

$$ X_{SVC} = j \omega L - \frac{j}{\omega C} $$

(16)

## 3.3 SVC V-I Characteristics

When the SVC is operated in voltage regulation mode, the SVC voltage varies between $V_{min}$ and $V_{max}$ as shown in Fig. (4). It is aimed to maintain the voltage at a
desired constant value. The calculation of the slope allows us to know the voltage drop. The characteristic equation of the slope is given as in [17] by equation (17).

\[
Slope = \frac{\Delta V_{C_{\text{max}}}}{I_{C_{\text{max}}}} = \frac{\Delta V_{L_{\text{max}}}}{I_{L_{\text{max}}}} \tag{17}
\]

The V-I characteristic and operating region of SVC described by three regions as in [22] as follows:
1) Regulation zone: this zone is governed by (18)

\[
V = V_{ref} \times X_s \times I \quad (B = B_{C_{\text{max}}}) \tag{18}
\]

2) Zone of under-voltage: in this zone the SVC behaves like a pure capacitor.

\[
V = -\frac{I}{B_{C_{\text{max}}}} \quad (B = B_{C_{\text{max}}}) \tag{19}
\]

3) Zone of over-voltage: in this zone, the SVC behaves like a pure inductance.

\[
V = \frac{I}{B_{L_{\text{max}}}} \quad (B = B_{L_{\text{max}}}) \tag{20}
\]

\(V\) is the positive sequence voltage (p.u.)
\(I\) is the reactive current (p.u./P_{base}) (I > 0 indicates an inductive current)
\(X_s\) is the Slope or droop reactance (p.u./P_{base})
\(B_{C_{\text{max}}}\) is the maximum capacitive susceptance (p.u./P_{base}) with all TSCs in service, no TSR or TCR
\(B_{L_{\text{max}}}\) is the Maximum inductive susceptance (p.u./P_{base}) with all TSRs in service or TCRs at full conduction, no TSC.

![Figure 4. The V-I Characteristic of SVC](image)

4. PROPORTIONAL INTEGRATOR (PI) SVC CONTROL

Due to simplest structure, easy designing and low cost, PI controller is used in SVC as voltage regulator in most industries [11]. The SVC can be operated to provide reactive power control or closed-loop AC voltage control. For closed-loop AC voltage control, the line voltage, as measured at the point of connection, is compared to a
reference value and an error signal is produced. This is passed to a PI controller to generate the required susceptance value \( B \) [24]. The SVC based PI controller is shown in Fig. (5).

![Figure 5. SVC – PI controller](image)

5. FUZZY LOGIC CONTROL

Fuzzy Logic has attracted considerable attention as a novel computational system because of the variety of advantages it offers over the conventional computational systems [11]. Fuzzy logic controllers have been successfully applied to control nonlinear dynamic systems [12,13] especially in the field of adaptive control by making use of on-line training. Unlike other classical control methods, such controllers are model free controllers, i.e. they do not require an exact mathematical model of the controlled system. Moreover, rapidity and robustness are the most profound and interesting properties in comparison to the other classical schemes [25]. One problem in design of a SVC for good performance is the tuning of PI controller which may not be achieved in a simplistic manner. Fuzzy controller is one of the nonlinear and robust control methods which are based on expert knowledge and there is no need to have the accurate model of the system. There are two main types of Fuzzy Logic Controllers (FLCs): Mamdani’s type and Takagi- Sugeno (T-S) [24].

5.1 Fuzzy Logic Principles to Control a SVC

Fuzzy logic can be used to develop the control laws such as the calculation of the susceptance \( B \) or in the Power System Stabilizers (PSS). Fuzzy logic enables the formalization of the uncertainty due to a global comprehensive knowledge of a complex nonlinear system. This approach involves three basic steps: the fuzzification, the elaboration of the inference rules and the defuzzification. In this work due to the simplicity of Mamdani’s model and ease of implementation in hardware, Mamdani’s type is considered in this paper. Our main objective is to replace the PI regulator with a fuzzy controller in order to determine the susceptance \( B \) in the SVC device as shown in Fig. (6). Input/Output membership function of FLC is shown in Fig. (7).

![Figure 6. SVC – Fuzzy control](image)
6. STUDIED SYSTEM DESCRIPTION

A power system has a wind farm consists of six 1.5 MW wind turbines connected to a 25 kV distribution system exporting power to a 120 kV grid through a 30 km 25 kV feeder. A 2300V, 2 MVA plant consisting of a motor load (1.68 MW induction motor at 0.93 PF) and of a 200 kW resistive load is connected on the same feeder at bus B25. A 1.5 MW load is also connected on the 575 V bus of the wind farm [6,26].

The single-line diagram of this system is illustrated in Fig (8). A SVC of 6 MVAR capacitive and -2.5 MVAR inductive Reactive power is connected on the 575 V bus [24] which is taken as the monitoring point of the whole studied wind farm for monitoring: the total exported (generated) active power from the wind farm to the grid, the total absorbed reactive power from the grid, flowing current and the terminal voltage at B575 of the wind farm. Each wind turbines has a protection system monitoring voltage, current and generator speed. The simulation is carried out at wind speed 8m/sec, and zero pitch angle. The wind farm must stay connected during fault, with the voltage at interconnection point dropping to zero. The simulation model is carried out using the MATLAB software. The wind farm DFIG parameters are listed in Table 1 [26], the set parameters of the protection system of wind farm are illustrated in Table 2 [27].

| Table 1. DFIG parameters |
|---------------------------|
| Generator nominal power (MW) | 1.5/0.9 |
| Nominal phase to phase voltage (V) | 575 |
| Stator resistance (p.u.) | 0.00706 |
| Rotor resistance | 0.005 |
| Stator leakage inductance (p.u.) | 0.171 |
| Rotor leakage inductance (p.u.) | 0.156 |
| Magnetizing inductance (p.u.) | 2.9 |
| Base frequency (Hz) | 60 |
| Pairs of poles | 3 |
| Inertia constant (s) | 5.04 |
| Friction factor (p.u.) | 0.01 |
Table 2. Protection system parameters

| Parameter                | Maximum | Minimum | Time delay |
|--------------------------|---------|---------|------------|
| AC Voltage (pu)          | 0.75    | 1.1     | 0.1        |
| DC Voltage (pu)          | 1900    | 0.1     |            |
| Rotor Speed (pu)         | 1       | 1.05    | 5          |
| AC Current (pu)          | 1.1     | 10      |            |
| AC Current un balance    | 0.4     | 0.2     |            |
| Voltage un balance       | 0.05    | 0.2     |            |

7. SIMULATION RESULTS

Case (1): Single line to ground fault at bus B25 start at 1 sec and sustain for 100ms. The results show that the SVC with the proposed FLC provides smooth and much quick response i.e. the system catch the pre fault value quickly and without any appreciable oscillation. Also, SVC based PI controller provide not bad performance as shown in Fig. (9).
Case (2): Double line to ground fault at 1 sec and sustained for 100 ms at bus B25. As shown in Fig. (10), the results demonstrate that even with stronger fault the proposed FLC is very effective control method. The fault within the limit of the wind farm protection devices so it still connected with the grid with or without SVC.
Case (3): A three line to ground fault at B25 start at 1 sec and sustained 80 ms. The simulation results show that SVC with both controller support the wind farm to stay connected to the grid during these sever disturbance. But the system without SVC could not support the system i.e. the protection devices disconnect the wind farm. The proposed controller provides better damping performance, lower oscillation and fast response, as shown in Fig. (11).

![Graphs showing voltage, current, power, and reactive power responses for different cases.](image)

**Figure 11. Three line to ground fault**

Case (4): Different fault durations effect are studied under three line to ground fault at bus B25 with 50 ms, 80 ms and 100 ms durations respectively with the proposed FLC control system. With increasing fault duration system oscillation increased and the system response is slower. At fault duration 100 ms the system could not support the wind farm any more. The system protection trip out and disconnect the wind farm from grid as shown in Fig. (12).
Case (5): The effect of SVC location on the system performance are investigated under three line to ground fault 80 ms with SVC connected at wind farm and SVC connected at B25. The simulation results shown that when the SVC is near the wind farm it provides better performance as shown in Fig. (13).
It can be concluded from the simulation results that the SVC with both controller provide better performance i.e. the SVC support the system reactive power. Fuzzy control technique is a robust control methods i.e. FLC controller provides smoother much quicker response and remarkably improve damping performance of the studied system under sever disturbance condition. The SVC location affect greatly on the performance of wind farm. When the SVC is close to the wind farm it could support power system during transient state it provides much better performance and quicker response.

8. CONCLUSION

Figure 13. SVC Different location
REFERENCES

[1] N. Sreekanth, N. Pavan Kumar Reddy, "PI & Fuzzy Logic Based Controllers STATCOM for Grid Connected Wind Generator", *International Journal of Engineering Research and Applications (IJERA)*, Vol. 2, No.5, September-October 2012, pp. 617-623.

[2] Garg, Amit, and Sanjay Kumar Agarwal, "Voltage Control and Dynamic Performance of Power Transmission System Using STATCOM and its Comparison with SVC", *International Journal of Advances in Engineering & Technology*, Vol. 2, No.1, 2012, pp. 437-442.

[3] SINGH, Bindeshwar, "Introduction to FACTS Controllers in Wind Power Farms: A Technological Review", *International Journal of Renewable Energy Research (IJRER)*, Vol. 2, No.2, 2012, pp. 166-212.

[4] TANG, Yufei, et al, "Reactive Power Control of Grid-Connected Wind Farm Based on Adaptive Dynamic Programming", *Neurocomputing*, 125, 11 February 2014, pp. 125–133.

[5] S. Khanmohammadi, M. Tarafdar Hagh, M. Abapour, "Fuzzy logic based SVC for reactive power compensation and power factor correction", The 8th International Power Engineering Conference (IPEC 2007), pp. 1241-1246.

[6] Abhijeet Awasthi, Ritesh Diwan, Mohan Awasthi,"Study for Performance Comparison of SFIG and DFIG Based Wind Turbines", *International Journal of Latest Trends in Engineering and Technology (IJLTT)*, Vol. 2, No.4, July 2013, pp. 1-10.

[7] N. HAMDI, A. BOUZID, "Active and Reactive Power Control of a DFIG for Variable Speed Wind Energy Conversion using a New Controller", *International Journal of Computer Applications*, Vol. 67, No.16, 2013, pp. 1-6.

[8] SINGH, Bindeshwar, "Introduction to FACTS Controllers in Wind Power Farms: A Technological Review", *International Journal of Renewable Energy Research (IJRER)*, Vol. 2, No.2, 2012, pp. 166-212.

[9] K.E. Okedu, "A Study of Wind Farm Stabilization Using DFIG or STATCOM Considering Grid Requirements", *Journal of Engineering Science and Technology*, 3, 2010, pp. 200-209.

[10] Mehrdad Ahmadi Kamarposhti, Mostafa Alinezhad, "Comparison of SVC and STATCOM in Static Voltage Stability Margin Enhancement", *International Journal of Electrical and Electronics Engineering*, Vol. 4, No.5, 2010, pp. 323-328.

[11] Roopesh Kumar, Ashish Choubey, "Voltage Stability Improvement by using SVC with Fuzzy Logic Controller in Multi-Machine Power System", *International Journal of Electrical and Electronics Research*, Vol. 2, No.4, 2014, pp. 61-66.

[12] BOYNUEGRI, A.R., et al, "Voltage regulation capability of a prototype Static VAR Compensator for wind applications", *Applied Energy*, 93, 2012, pp. 422-431.

[13] NWOHU, Mark Ndubuka, "Voltage Stability Improvement using Static Var Compensator in Power Systems", *Leonardo Journal of Sciences*, Vol. 8, No.14, 2009, pp. 167-172.

[14] D. Harikrishna, R.S. Dhekekar, N.V. Srikanth, "A novel approach to dynamic stability enhancement using PID damped fuzzy susceptance controlled SVC", Power Systems Conference and Exposition (PSCE), IEEE/PES. IEEE, 2011, pp. 1-6.
[15] Ismail K, Said and Marouf Pirouti, "Neural network-based load balancing and reactive power control by Static VAR compensator", *International Journal of Computer and Electrical Engineering*, Vol. 1, No.1, April 2009, pp. 25-31.

[16] K.L. Lo, Laiq KHAN, "Fuzzy logic based SVC for power system transient stability enhancement", Electric Utility Deregulation and Restructuring and Power Technologies, in Proceedings DRPT, International Conference on, IEEE, 2000, pp. 453-458.

[17] MANSOUR, Ibrahim, *etal*, "Fuzzy logic control of a SVC to improve the transient stability of ac power systems", Industrial Electronics, IECON'09 35th Annual Conference of IEEE. 2009, pp. 3240-3245.

[18] S. Sabha, D. Prasad, R. Shivakumar, "Power System Stability Enhancement by Neuro Fuzzy Logic Based SVC for Multi Machine System", *International Journal of Engineering and Advanced Technology (IJEAT)*, Vol. 1, No.4, April 2012, pp. 207-2011.

[19] Gilsung Byeon, In Kwon Park, Gilsoo Jang, "Modeling and control of a doubly-fed induction generator (DFIG) wind power generation system for real-time simulations", *Journal of Electrical Engineering and Technology*, Vol. 5, No.1, 2010, pp. 61-69.

[20] Ezzeldin S. Abdin, Wilson Xu, "Control Design and Dynamic Performance Analysis of a Wind Turbine-Induction Generator Unit", *Energy Conversion, IEEE Transactions*, Vol. 15, No.1, 2000, pp. 91-96.

[21] LIMA, Francisco KA, *etal*, "Rotor Voltage Dynamics in the Doubly Fed Induction Generator during Grid Faults", *Power Electronics, IEEE Transactions*, Vol. 25, No.1, 2010, pp. 118-130.

[22] Naimul Hasan, Ibraheem, Shuaib Farooq, "Dynamic Performance Analysis of DFIG Based Wind Farm STATCOM and SVC", *International Journal of Emerging Technology and Advanced Engineering (IJETA)*, Vol. 2, No.7, July 2012, pp. 461-469.

[23] MITHULANANTHAN, Nadarajah, *etal*, "Comparison of PSS, SVC, and STATCOM controllers for damping power system oscillations", *Power Systems, IEEE Transactions*, Vol. 18, No.2, 2003, pp. 786-792.

[24] Mehdi NARIMANI, Rajiv K. VARMA, "Application of Static Var Compensator (SVC) with fuzzy controller for grid integration of wind farm" Electrical and Computer Engineering (CCECE), 23rd Canadian Conference on, IEEE, 2010, pp. 1-6.

[25] Tamer ABDELAZIM, O.P. MALIK, "Intelligent SVC control for transient stability enhancement", Power Engineering Society General Meeting, IEEE, 2005, pp. 1701-1707.

[26] M. AZOUZ, *etal*, "Fuzzy logic control of wind energy systems", Proceedings of the 14th International Middle East Power Systems Conference (MEPCON’10), Cairo University, Egypt, 311, December 2010, pp. 935-940.

[27] Omar NOURELDEEN, Mahmoud RIHAN, Barkat HASANIN, "Stability Improvement of Fixed Speed Induction Generator Wind Farm Using STATCOM during Different Fault Locations and Durations", *Ain Shams Engineering Journal*, Vol. 2, No.1, 2011, pp. 1-10.