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Research Article

PSO-FUZZY BASED CONTROL OF STATIC VAR COMPENSATOR FOR STABILITY IMPROVEMENT OF GRID CONNECTED WIND FARM

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ABSTRACT
The penetration of wind power as a one of the renewable energy resources to meet load at demand side in power system is greatly increasing. Therefore there is a urgent need to study the impact of wind power on the stability of power system. The increasing power demand has led to the growth of new technologies that play an integral role in shaping the future energy market. Keeping in view of the environmental constraints, grid connected wind turbines are promising in increasing system reliability. This paper presents the impact of Static Var Compensator known as SVC on the stability of power systems connected with wind energy conversion systems. In this paper, to enhance the performance of SVC on the stability of wind energy grid connected system, the parameter tuning of SVC controllers which is an important problem in the stabilizing is optimized. In this paper to optimize the parameter of fuzzy based SVC controller, particle swarm optimization approach (PSO) is implanted and utilized.

Keywords: *Wind Turbines, Static Var Compensator, Stability*

INTRODUCTION
In recent years, power systems became more complex, and constantly, load demands have been changed so the design of larger wind farm has become more important.
The increasing use of wind power plants in power systems has also brought some problems with it. Some of the important problems are the load demands depending on the time change in the wind plants in the system. Load changes are caused to reduction or rise in voltage and current values at the ends of the receiver. To eliminate these problems, FACTS devices are used effective. Jowder examined transient stability study of wind plants by using Static Series Synchronous Compensators in the power system infinite bus that is connected to the network. In this study, wind power plants may occur in the terminal and the output voltage oscillations were eliminated (Jowder, 2007). Joshi and Mohan was studied induction generator of voltage, current and torque characteristics at the time of breakdown in their study by using TCSC that is connected to the transmission lines as series in wind plant that connected to grid (Joshi *et al.*, 2006). Qiao and Harley (2009) were also realized in real time control of wind plant which forms double-fed induction generator. In case of temporary stability, de Toledo and Xie (2005) were examined STATCOM effects in the wind plants that have induction generators. Qi *et al.*, (2008), in their study examined the effects of voltage and reactive power characteristics in fixed speed wind plants by using STATCOM. Qiao *et al.*, (2006), were made active–reactive power, voltage variations, the rotor angle, oscillation damping and power flow control of wind plant in power system which has many generators by using STATCOM and SSSC. Suul and Undeland (2008), in their study were observed slide-moment characteristic in low power wind plant which has induction generator by using STATCOM and SVC. Papantoniou and Coonick (1997), were shown system's voltage, current, and the distribution of the total harmonic by using Combined Power Flow Control (UPFC) in the wind farm. Yanmaz and Atlas (2008), were examined load changes by the STATCOM in the power system which has infinite power bus. Voltage and reactive power variation in the bus were compared with Proportional Integral (PI) and Fuzzy Logic (FL) control methods. Eminog˘lu *et al.*, (2003), were found voltage changes and power coefficient of variation by using Static VAr Compensators (SVC) at different times in a power system that

used exponential variable loads. They were investigated active power and reactive power changes in terms of stability using SVC and TCSC depending on different loads in power system.

SVC System Conrol

A SVC is a shunt connected power electronics based device which works by injecting reactive current into the load, thereby supporting the voltage and mitigating the voltage sag. SVCs may or may not include energy storage, with those systems which include storage being capable of mitigating deeper and longer voltage sags. Figure 1 shows a block diagram of a SVC. This model is based on representing the FACTS controller as variable impedance. A fixed capacitor (FC) with a thyristor controlled reactor (FC–TCR) configuration of the SVC is used in this analysis.

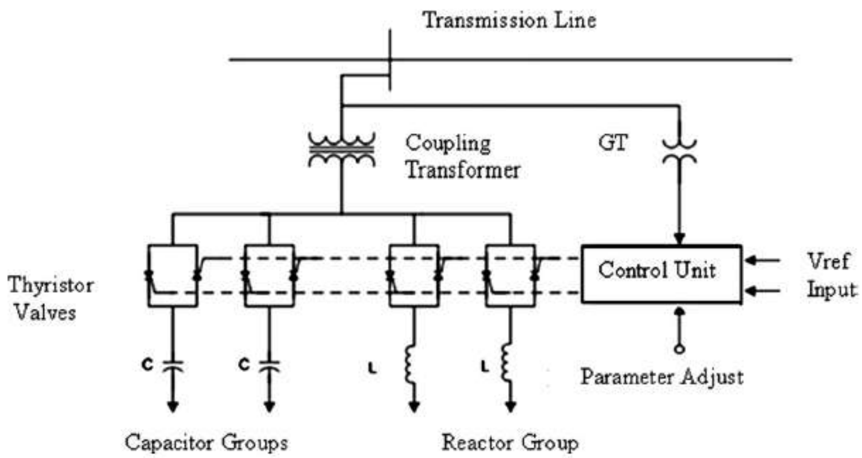

Figure 1: The FC–TCR configuration of the SVC

The controller is composed of a fixed capacitor (***Xc***); fixed reactor (***Xl***); and a bi-directional thyristor valve that is composed of two thyristors. The SVC is usually connected to the transmission system through a step-down transformer which can be treated as other transformers. This model can be represented with the following equations:

$$\mathrm{V} - \mathrm{V}_{\mathrm{ref}} + \mathrm{X}_{\mathrm{SL}}\mathrm{I} = 0$$

$$B_e - (2\alpha - \sin\alpha - \pi(2 - \frac{X_l}{X_c}))\pi X_l = 0$$

$$I_{SVC} - V_i B_e = 0$$

$$Q_{SVC} - V_i^2 = 0$$

Vi; SVC is the voltage magnitude of the bus at which SVC is connected, $\boldsymbol{V_{SVC}}$ is the voltage across the controller, $\boldsymbol{X_{TH}}$ is the impedance of the step-down transformer, $\boldsymbol{Q_{SVC}}$ is the reactive power that the SVC injects into the power network, $\boldsymbol{I_{SVC}}$ is the current through SVC, ***Be*** is the equivalent admittance of SVC, $\boldsymbol{V_{SVCref}}$; is a reference voltage for the controller, $\boldsymbol{X_{SL}}$ is the SVC control slope, $\boldsymbol{\alpha_{SVC}}$ is the firing angle and $\boldsymbol{\alpha_{SVCmin\ x}}$ ***;*** $\boldsymbol{\alpha_{SVCmax}}$ represent the lower and upper limits on the firing angle (Boynuegri *et al.,* 2012). Assuming balanced, fundamental frequency operation an adequate stability model can be developed assuming sinusoidal voltages (Molinas *et al.,* 2008). SVC is basically a shunt connected static var generator/absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power system variables; typically, the controlled variable is the SVC bus voltage. One of the major reasons for installing an SVC is to improve voltage control, and thus, increase system load ability. An additional stabilizing signal, and supplementary control superimposed on the voltage control loop of an SVC can provide damping of system oscillations during transient faults and disturbances (Figure 2).

The state equation for SVC can be written as:

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$$B_{SVC} = \frac{K}{T}(V_{ref} - V_{meas} + u) - \frac{1}{T}V_{SVC}$$

where $\boldsymbol{B_{SVC}}$ the SVC susceptance, $\boldsymbol{u}$ is the stabilizing loop output. Here, $\boldsymbol{V_{ref}}$ is chosen as 1.0 per-unit and $\boldsymbol{V_{meas}}$ is the PCC voltage.

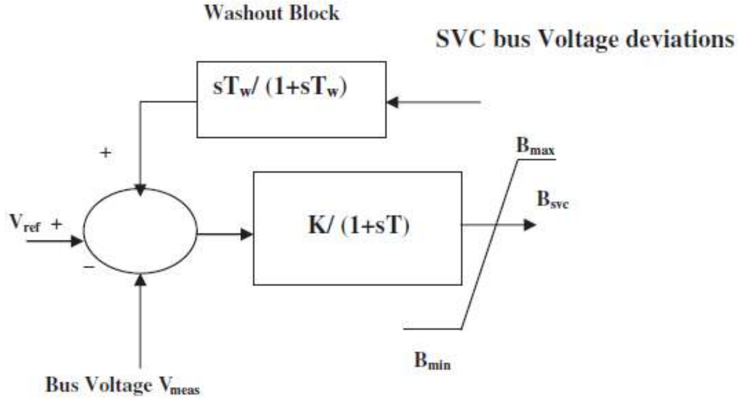

Figure 2: Structure of SVC controller with stabilizing loop

Parameter Tuning of Facts Controllers

The parameter tuning of FACTS controllers is an important problem as the stabilizing effect will depend on the gain of the controllers. The tuning is posed as an optimization problem with the objective as minimizing the oscillations of PCC voltage from the desired value and is given by:

$$\text{Minimize} \quad F = \sum_k \left[(V_{ref} - V_k)^2 + (\omega_{ref} - \omega_k)^2\right]$$

$$K_{\min} \le K \le K_{\max}$$

where V_{ref} = 1.0 per-unit and F is the sum squared deviation index of the PCC voltage. The optimization problem is solved using sequential quadratic programing in MATLAB.

Fuzzy Control Algorithm

The desired switching signals for the SVC system controller are determined according to the error in the filter current using fuzzy logic controller. The parameters for the fuzzy logic current controller used in this paper are as follow (Al-Kandari, 2006).

The design uses centrifugal defuzzification method.

- There are two inputs; error and its derivative and one output, which is the command signal to the PWM of the filer inverter.
- The two input uses Gaussian membership functions while the output use triangle membership function. Figure 3 shows the degree of membership for the error and its derivative and the command signal respectively.

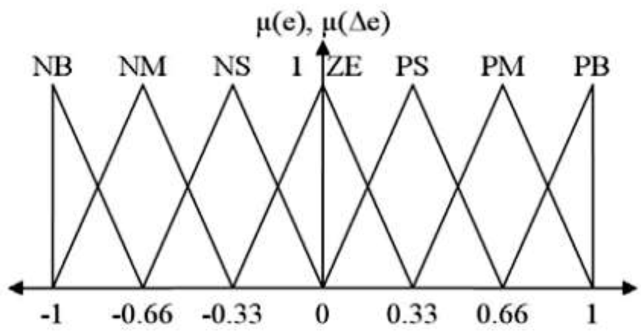

Figure 3: Membership functions for (e) and (Δe)

Particle Swarm Optimization

In a PSO system, Birds' (particles) flocking optimizes a certain objective function. Each particle knows its current optimal position (***pbest***), which is an analogy of personal experiences of each particle. Each particle also knows the current global optimal position (***gbes***t) among all particles in the population. Through specific equations, each particle adjusts its position and determines the search direction according to its search memory and those of others (Mohammadi *et al.*, 2012).

Using the PSO, the velocity can be represented under Eq. (8) in the PSO algorithm. Using Eq. (7), a certain velocity can be calculated as the position of individuals gradually moves closer to ***pbest*** and ***gbest***. The current position can be modified by:

$$v_{i,d}^{j+1} = K \times \left[v_{i,d}^{j} + c_1 \times \mathrm{rand}(0,1) * (Xbest_{i,d}^{j} - X_{i,d}^{j}) + c_2 \times \mathrm{rand}(0,1) \times (Gbest^{j} - x_{i,d}^{j}) \right]$$

$$X_{i,d}^{j+1} = X_{i,d}^{j} + V_{i,d}^{j}$$

Where

$$K = \frac{2}{\left| 2 - c - \sqrt{c^2 - 4c} \right|}, c = c_1 + c_2 > 4$$

c_1, c_2 is the acceleration constant, in this paper, $c_1 = c_2 = 4.05$.

RESULTS AND DISCUSSION

Simulation and Results

In this section the simulated of test system in presence of SVC as shown in Figure4 is presented. As shown in this system wind energy as a renewable energy based DFIG is connected to system affects the stability of system.

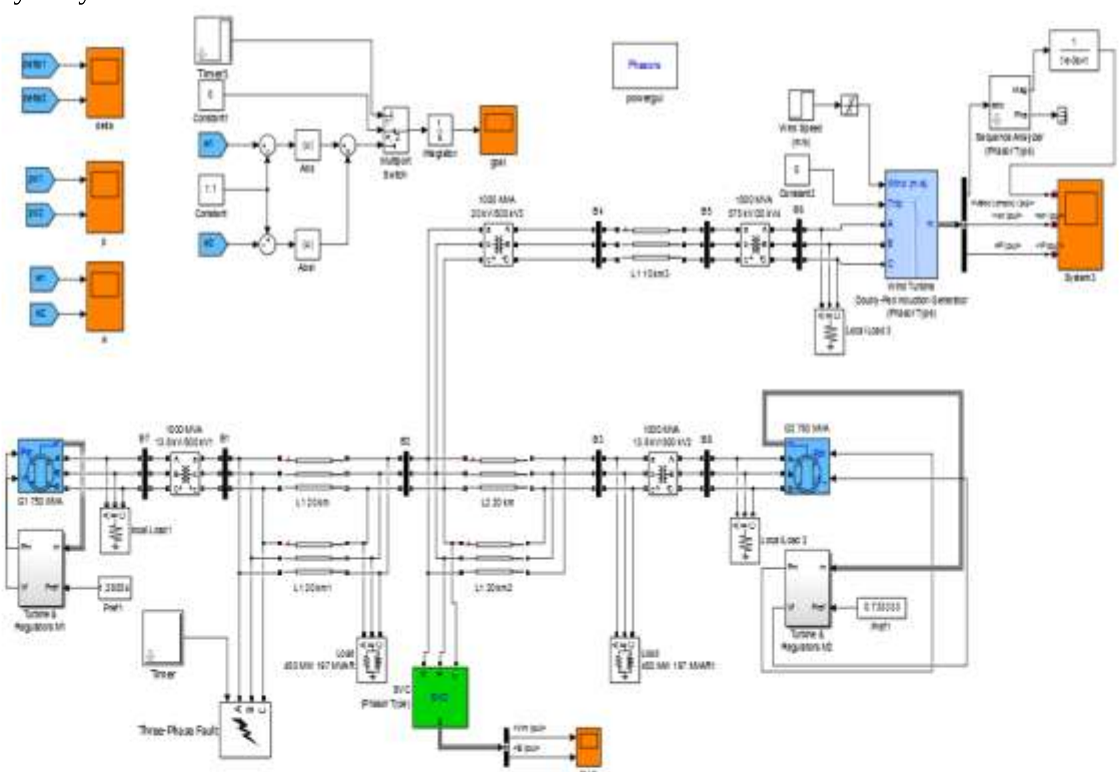

Figure 4: Wind Connected Power System with presence of SVC

The configuration of SVC is shown in Figure 5.

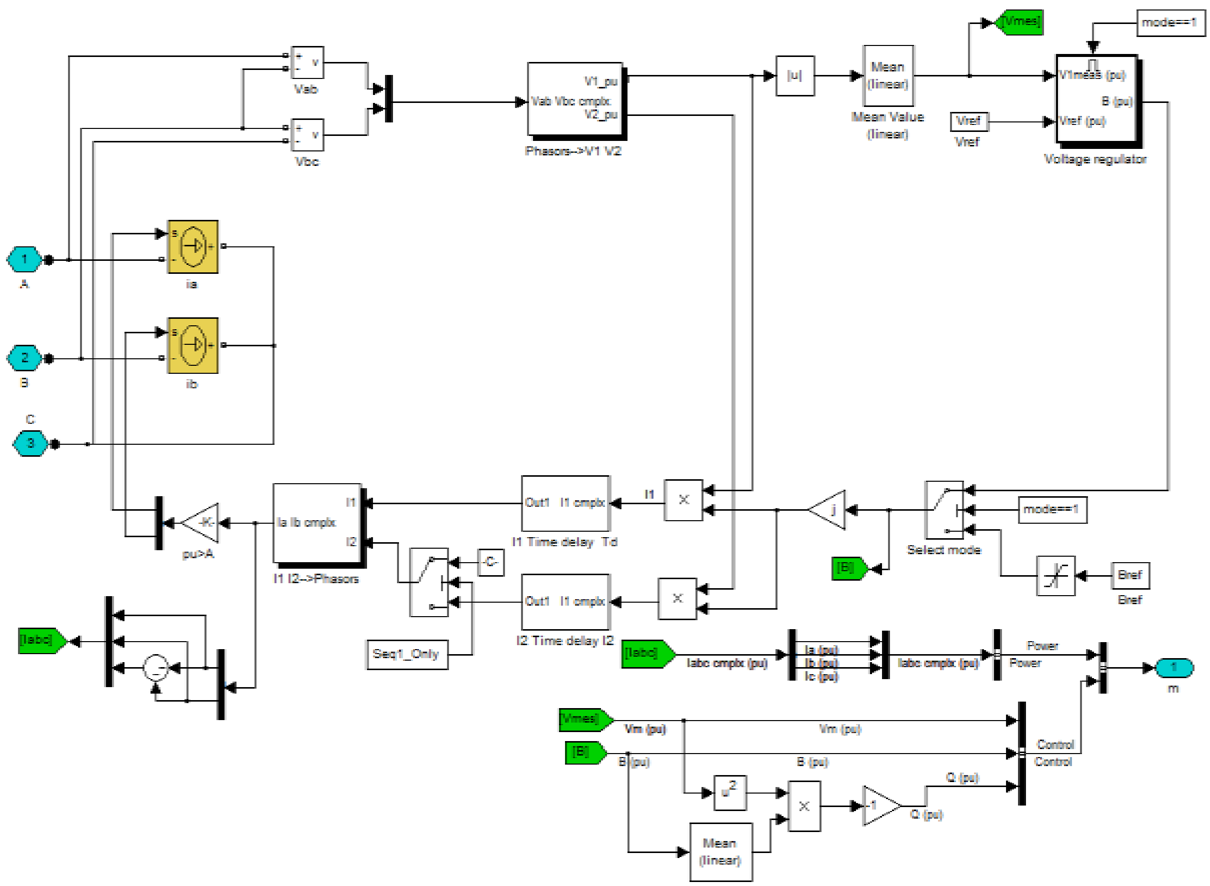

Figure 5: The Model of SVC

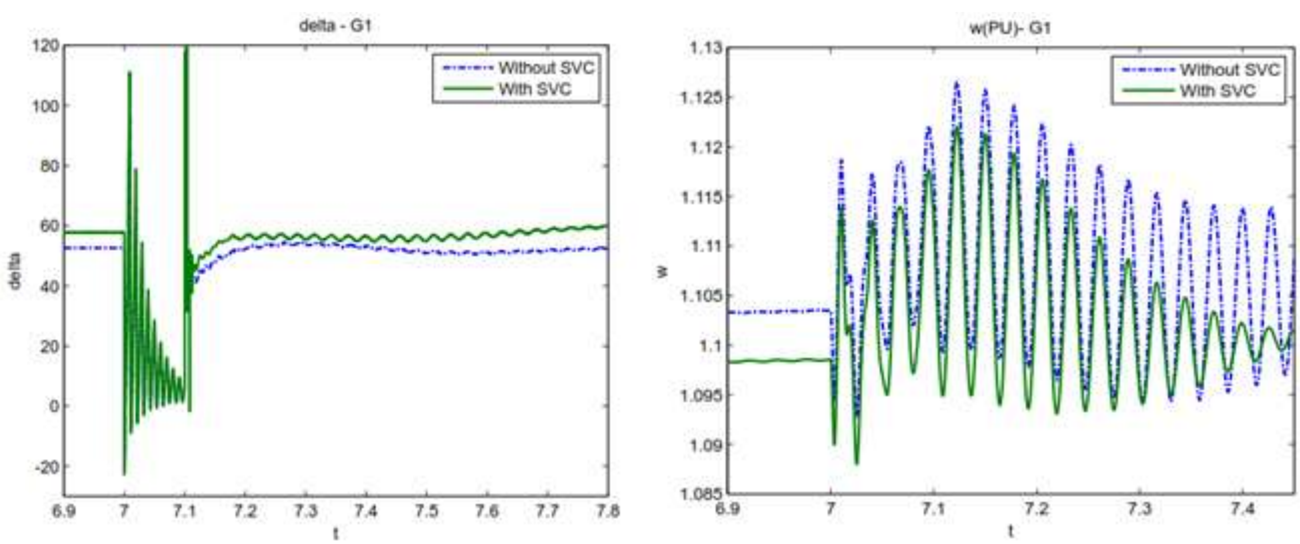

Figure 6: The angle and speed of G1 without and with SVC

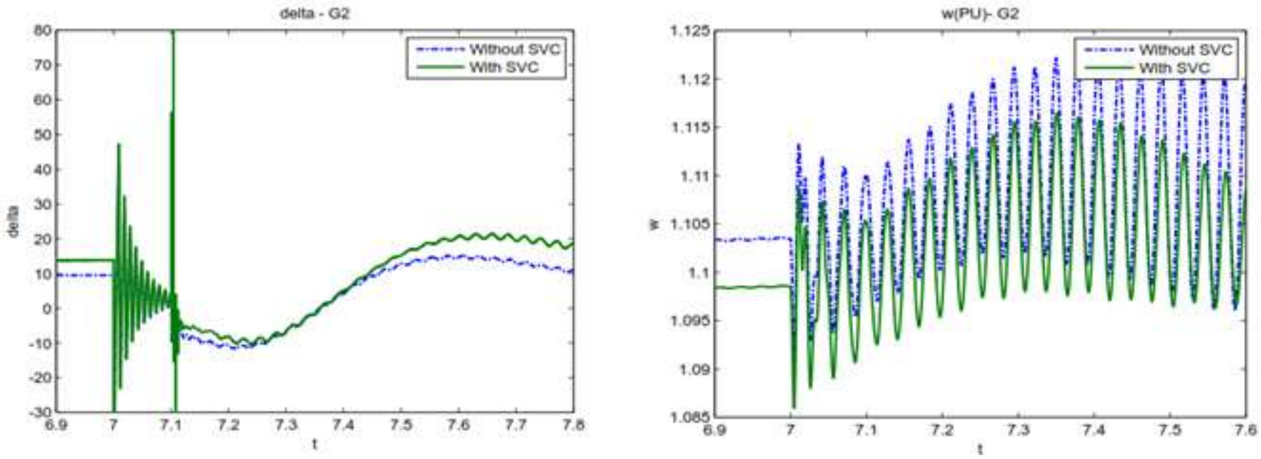

Figure 7: The angle and speed of G2 without and with SVC

The results of simulation versus the speed and angle of two generators, G1 and G2 are presented in Figures 6-7.

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