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Research Article

VOLTAGE AND POWER STABILITY ANALYSIS OF POWER SYSTEM USING GA-FUZZY BASED CONTROLLER OF SVC DURING CONNECTION OF DOUBLY FED INDUCTION GENERATOR TO NETWORK

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ABSTRACT
This paper deals with voltage and power stability improvement of wind energy grid connected power system. The wind generator model considered is a variable speed doubly fed induction generator model. Doubly Fed Induction Generator (DFIG) is widely utilized in large wind power plants. Therefore the dynamic behavior of DFIG wind turbines is necessary to be studied.

Under grid connected mode, DFIGs not only to contribute active power generation but also to the reactive power independently but due to limited reactive power capability and remote location of wind turbines it cannot provide the sufficient reactive power support without any external dynamic reactive power compensation device. As stated that the problem of voltage instability can be solved by using dynamic reactive compensation. This research presents the impact of Static Var Compensator (SVC) on the dynamic stability of power system connected to DFIGURE On the other hand, the parameter tuning of FACTS controllers is an important problem as the stabilizing effect will depend on the gain of the controllers. Therefore in this paper the optimizing of Fuzzy based SVC controller using genetic algorithm is presented and discussed.

Keywords: *Voltage Stability, Genetic Algorithm, Fuzzy Approach, Wind Turbines*

INTRODUCTION
During the last decade, wind power has been the world's fastest growing energy source (Mehdi *et al.*, 2012) and many large WFs have been installed and integrated into power systems, caused the share of wind power to reach a considerable level (Abad, *et al.*, 2008). As long as wind power penetration is insignificant, SGs determine the overall dynamic behavior of power systems, but introduction of large amounts of new wind generation can affect the stability of power systems (Saad-Saoud *et al.*, 1998). These effects in the fields of frequency stability (Salman and Teo, 2003), transient stability, voltage stability (Slootweg, 2002) and small signal stability have been treated and addressed in recent research. Among them, the small signal stability problem of power systems with high penetration levels of wind power is one of the major challenging fields. Small signal stability is the ability of the power system to maintain synchronism when subjected to small disturbances. In today's power systems, the small signal stability problem is usually the lack of sufficient damping torque for system oscillations (Zhou *et al.*, 2004). It is important to propose a suitable method to enhance flexible power flow control, damping of power system oscillations, and improving transient stability of the system. Most of the flexible ac transmission system (FACTS) devices have been used for damping of power system oscillations and flexible power control (Wang, 1999). FACTS with energy storage system such as static synchronous compensator (STATCOM), static var compensator (SVC) with super conducting magnetic energy storage system (SMES), and energy capacitor system (ECS) composed of double layer capacitor have already been proposed to improve transient stability of fixed speed wind farm (Muyeen *et al.*, 2006; Zhou *et al.*,

2004; Muyeen *et al.*, 2008). However, the installation of FACTS devices at a wind farm composed of fixed speed wind generators increases the system overall cost.

Static Var Compensator, Modeling and System Control

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.

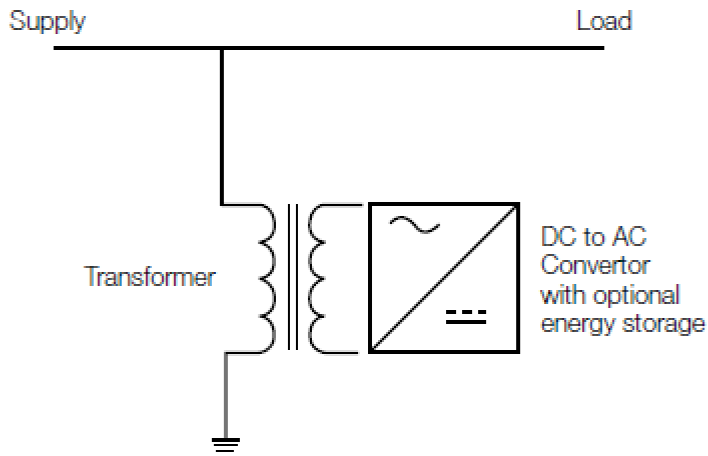

Figure 1: Basic structure of SVC

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.

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 $\boldsymbol{\alpha_{SVCmin\ x}}$ ***;*** αSVCmax 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 dynamic 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:

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

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.

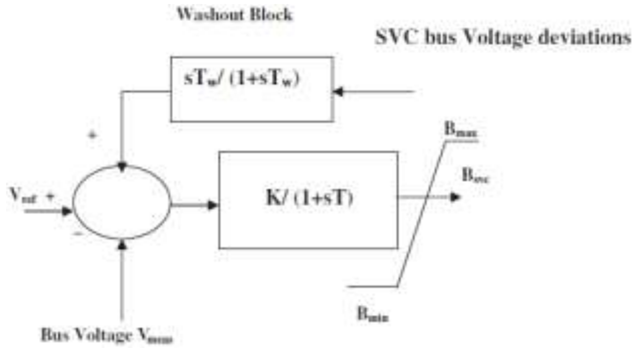

Figure 2: Structure of SVC controller with stabilizing loop

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:

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

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

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

As shown in Figure3 the fuzzy control algorithm is implemented to control the load phase voltage based on processing of the voltage error e(t) and its variation Δe (t) in order to improve the dynamic of SAF.

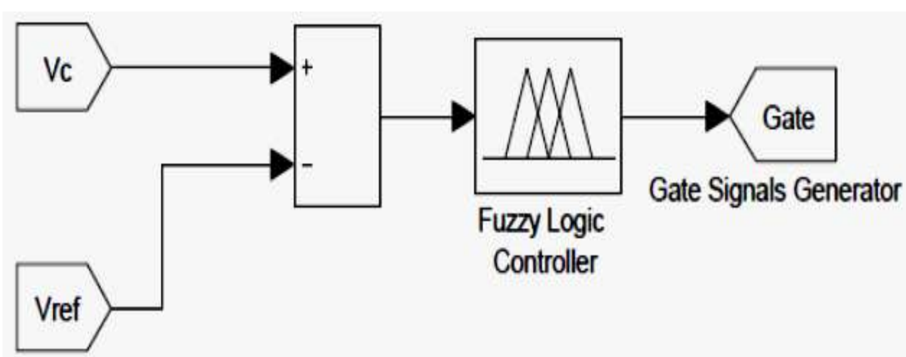

Figure 3: Fuzzy controller structure block diagram

The main advantages of fuzzy control are its linguistic description, independence of mathematical model, robustness, and its universal approximation (Al-Kandari AM., 2006). As shown in Figure4 the fuzzy logic controller is consisting of four stages: fuzzification, knowledge base, inference mechanism and defuzzification.

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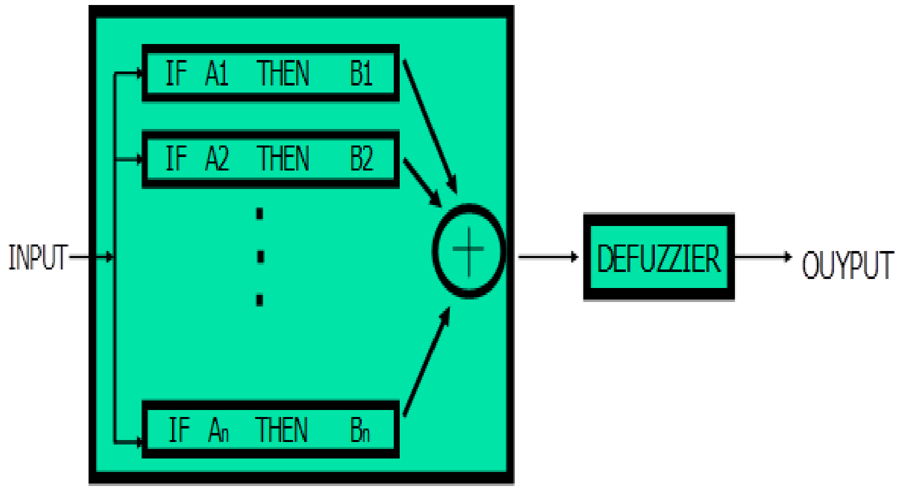

Figure 4: the basic scheme of fuzzy logic controller

The knowledge base is composed of a data base and rule base and is designed to obtain good dynamic response under uncertainty in process parameters and external disturbances.
As shown in Figure4 the data base consisting of input and output membership functions provides information for the appropriate Fuzzification operations, the inference mechanism and defuzzification. The inference mechanism uses a collection of linguistic rules to convert the input conditions into a fuzzified output. Finally, defuzzification is used to convert the fuzzy outputs into control signals.
In designing of a fuzzy control system, the formulation of its rule set plays a key role in improvement of the system performance. These rules are listed in Table 1.

Table 1: Fuzzy rule set used in fuzzy controller of series active filter

e(n)	Ce(n)						
	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Genetic Algorithm
As shown in Figure 5 Genetic Algorithm (GA) comprises three different phases of search. The first is the production operator which makes one or more copies of any individual that possesses a high fitness value (Deependra *et al.*, 2007). The second operator is the recombination or crossover operator. This operator selects two individuals within the generation and a crossover site and carries out a swapping operation of the string bits to the right hand side of the crossover site of both individuals. Crossover operations synthesize bits of knowledge gained from both parents exhibiting better than average performance. The third operator is the 'mutation', acts as a background operator and is used to explore some of the invested points in the search space by randomly flipping a 'bit' in a population of strings.

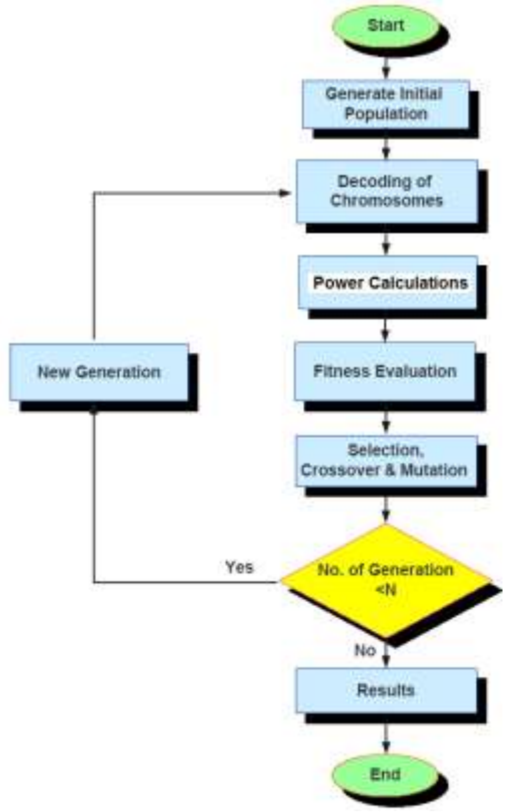

Figure 5: The block diagram of GA based optimization problem

RESULTS AND DISCUSSION

Simulation and Results

In this section, the SVC configuration based fuzzy controller is shown in Figure6. The model of wind turbine is indicated in Figure 7.

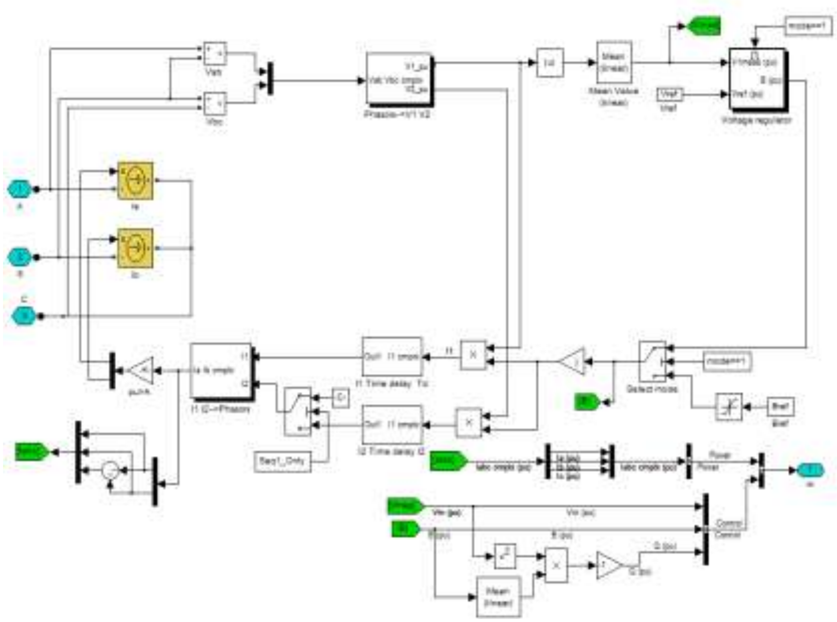

Figure 6: The SVC configuration

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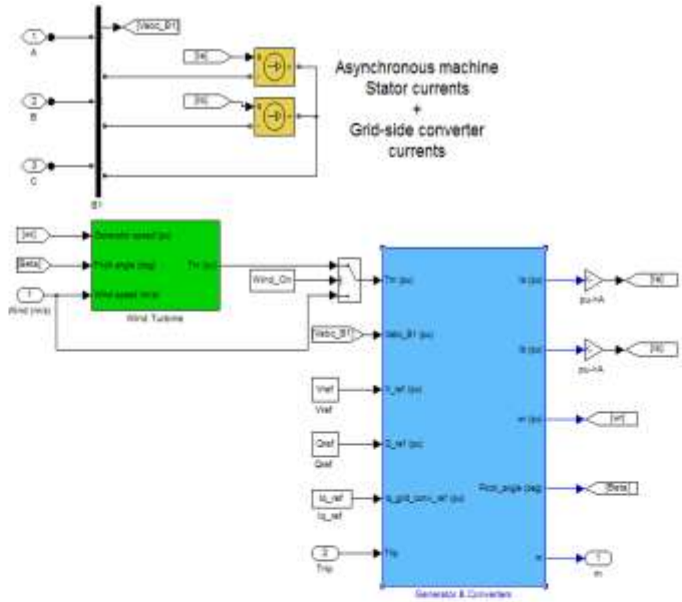

Figure 7: The model of wind turbine

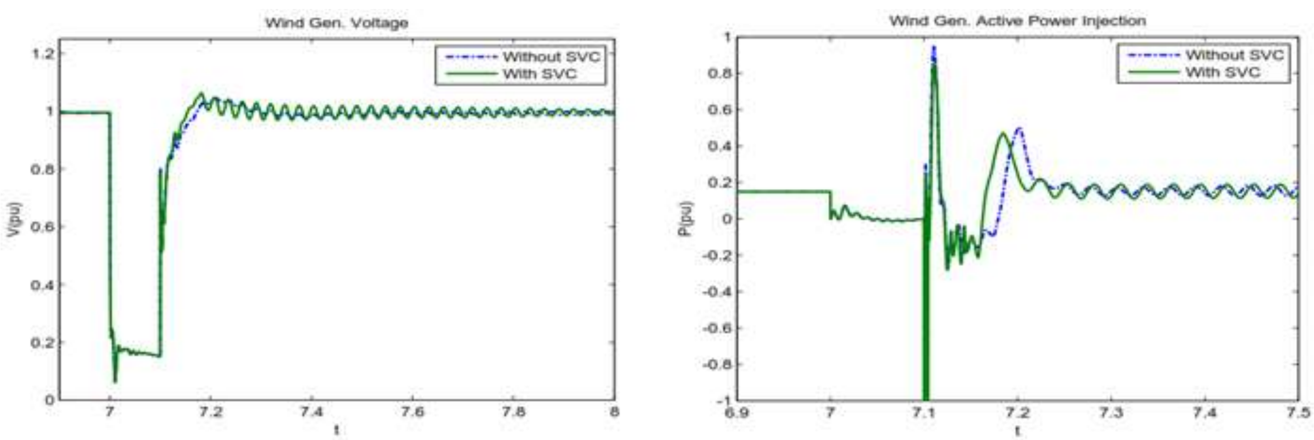

Figure 8: Voltage and active power injection of generator G1 before and after SVC

The voltage and active power injected by generator while connecting of wind turbine to system, before and after connection of SVC is presented in Figure 8.

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