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Analysis and Impact of D-STATCOM, Static Var Compensator, Fuzzy Based SVC Controller on the Stability of a Wind Farm

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ABSTRACT

In recent years, applications of facts systems have been developed for the compensation of active and reactive power. Facts systems are electronics devices that are connected to the wind farm. This paper presents the impacts of some of these devices on the stability of a wind farm, especially D-STATCOM, Static Var Compensator and Fuzzy SVC controller. First, a presentation of D-STATCOM, SVC, then fuzzy logic controller. In simulation study, the D-STATCOM ensures the stability of the voltage and current at the point of connection with the electrical grid. Finally, Comparing the SVC to the F-SVC simulations, we notice that the F-SVC is more performed than SVC for the compensation of the active and reactive power.

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1. INTRODUCTION

Renewable energy is defined as an energy that is collected from replenished natural resources (wind, sun, geothermal heat…), renewable technologies are: wind power, solar power, hydro electricity, biomass and others… Over the past decade wind energy has received greater attention with a special focus on the development of wind systems technologies and their integration into the electrical grid. To promote the integration of wind farms into the grid, FACTS systems are widely used; they improve the quality of electricity by controlling the active and reactive power at the point of connection to the grid. The turbines (doubly fed induction machines) present also many advantages; it improves stability and frequency of the voltage across the control of active and reactive power [1].

2. REACTIVE POWER MANAGEMENT OF WIND FARMS

Different approaches for control of voltage and power management exist, in general researchers use variable devices; STATCOM, SVC, DVR, OLTC, SDBR, FACT Devices, UPFC or UPQC or in combination with other device. The D-Statcom and Static Var compensator devices are discussed in this paper.

2.1. Use and Configuration of D-STATCOM

The D-STATCOM is a power electronic device connected in parallel to a wind farm; it provides for the grid a controlled -in phase and amplitude-AC current, it can absorb or provide reactive power [2]-[3].
It comprises of:

a. Capacitor batteries; which are considered like continuous voltage source
b. A voltage converter based IGBT, SCR

c. An AC filter

These equipments are connected to the electrical grid via a coupling transformer as it is shown in Figure 2. The operation of the D-STATCOM is illustrated in Figure 3.

a. When the secondary voltage VD is lower than the bus voltage VB; D-STATCOM acts as an inductor, it absorbs the reactive power of the bus.
b. When the secondary voltage VD is higher than the bus voltage VB; D-STATCOM acts as a capacitor generating reactive power to the bus [4].

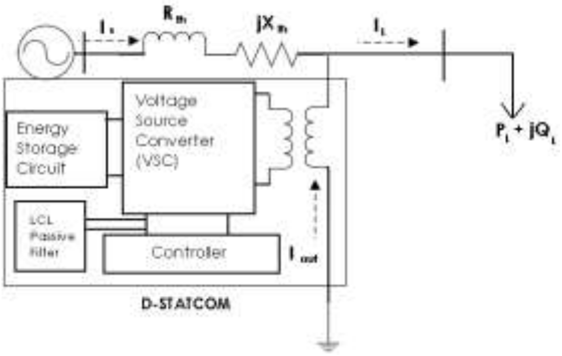


Figure 2. Schema of D-Statcom

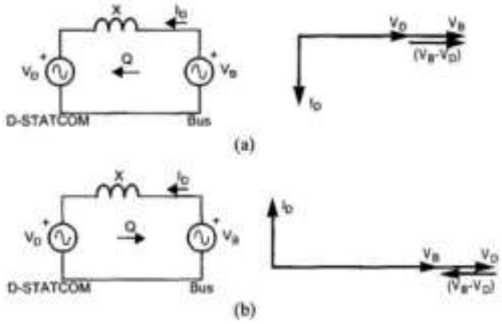


Figure 3. operation of D-STATCOM (a)Inductive operation(b) capacitive operation

2.2. Static Var Compensator

The Static Var compensator (SVC) is used to maintain the voltage in transitional regimes [5], the basic structure (Figure 4) of this controller is the association of:

a. TCR (Thyristor controlled reactor) consists of a reactor placed in series with the thyristor valve, the value is continuously variable according to the firing angle of the thyristors.
b. TSC (Thyristor swithed capacitor) consists of power capacitor controlled by thyristors connected in parallel to the network through a coupling transformer. [6] The capacitors are switched ON and OFF by Thyristor.

During inductive operation, the reactive power Qsvc and the input current are positive. When in capacitive operation, reactive power Qsvc and the current are negative. Qsvc varies between the inductive Qind and capacitive Qcap value [7]:

$$\mathbf{Q_{cap}} = \frac{V_{svc}^2}{X_c}, \quad \mathbf{Q_{ind}} = \left(\frac{V_{SVC}^2}{X_L}\right) - \left(\frac{V_{SVC}^2}{X_C}\right) \tag{1}$$

With; X_C: the capacitive reactance, X_L: the reactance of the inductor

The SVC model in this paper is a detailed model of a particular SVC topology (using thyristor-controlled reactor (TCR) and hyristor-switched capacitors (TSCs). By the control of the firing angle α of the thyristor element, SVC monitors the primary voltage and acts on thyristors pulses in order to obtain the susceptance required by voltage regulator [8].

When α=90°, the inductor is fully activated

When α=180° the inductor is disabled

The control strategy is based on keeping the transmission bus voltage within certain narrow limits defined by a controller droop and the firing angle α limits (90° < α> 180°) [9].

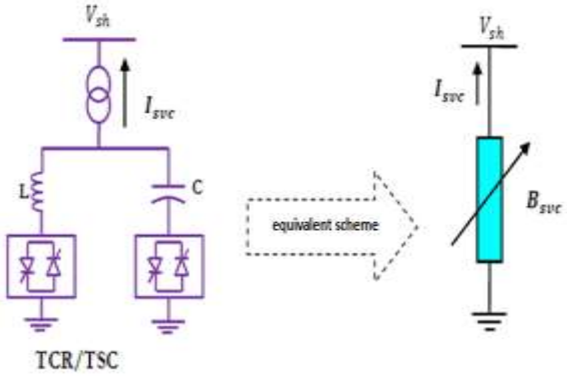


Figure 4. SVC equivalent schema

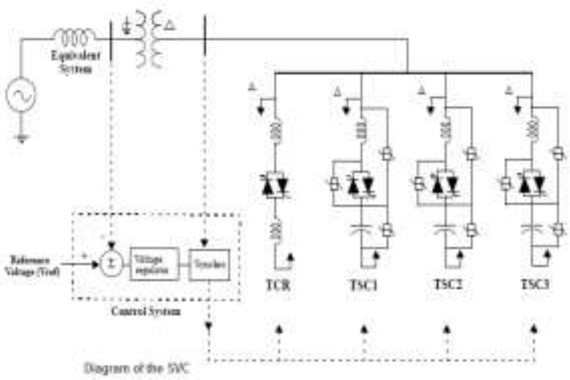


Figure 5. SVC diagram

2.3. PI Controller

PI controllers are widely used, especially for regulation of dynamic system in industry, Its two constant parameters; the integral and proportional values are calculated in proportion of the nominal operation point of the system. A PI controller has many advantages, it combines the properties of P and I regulators; it presents good performance, simple implementations and structure. But the main weakness of the PI controller is that it fails when the controlled issue is nonlinear and uncertain. To overcome this problem a derivative mode can be introduced in order to predict what will happen with the error in the near future and thus to decrease a reaction time of the controller. In our study the Fuzzy Logic Controller (FLC) is used [10].

2.4. Fuzzy Logic Controller

The fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities.The combination of the PI controller with the fuzzy logic controller (FLC) offers good performance to the system, that's why the voltage regulator of the SVC is using PI controller (Figure 6) [11]. There are two types of FLC: Mamdani and Takagi-Sugeno, for our simulation the Takagi-sugeno type is used; The FLC is in place of the integral term while the proportional term is kept unchanged.

The main components of the FLC [12]-[14] (Figure 7) are:

a. Fuzzification
b. Fuzzy rule base
c. Fuzzy inference engine
d. Defuzzification where the procedure for defuzzifying the result is determined

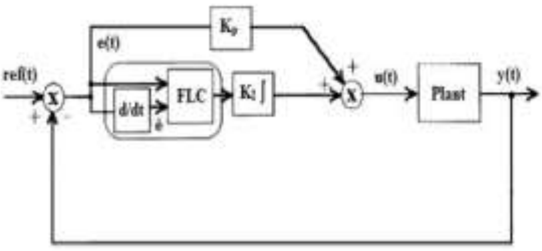


Figure 6. The proposed PI controller of the SVC combined with FLC

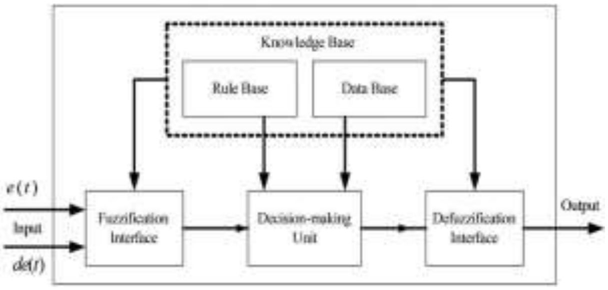


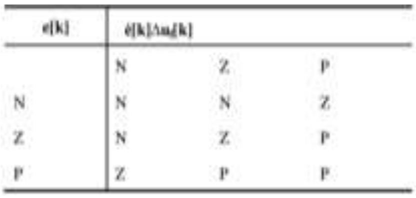
Figure 7. The basic configuration of a fuzzy logic controller

The membership values or functions (MF) are created, there are different types of MF; in this simulation we use:

a. The triangular type

b. Two inputs (The error e(k) and derivative error ė(k)) and a single output that will result in total of 9 rules (as shown in Figure 8)
c. Three fuzzy sets; positive (P), zero (Z) and negative (N)

As for this controller, linear type of output MF is utilized. Both inputs and output of the FLC run at normalized universe [-1 1].



e[k]	ė[k]/Δu[k]		
	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P

Figure 8. Rule base of the fuzzy controller

3. SYSTEM SIMULATION: PART 1

3.1. Simulation of Wind Farm

This simulation contains two wind farms connected to the grid (Figure 9) each one is composed of six turbines with a power of 1.5 MW. These turbines are based DFIG [15]-[16], PWM converter based on IGBT AC/DC/AC. The stator is connected directly to the network under the 60Hz frequency. DFIG technology allows maximum extraction of wind energy for different speed [17]. The system is simulated in Matlab/Simulink environment with discrete mode, the Statcom contains power electronic converters which are not compatible for phasor type of simulation.

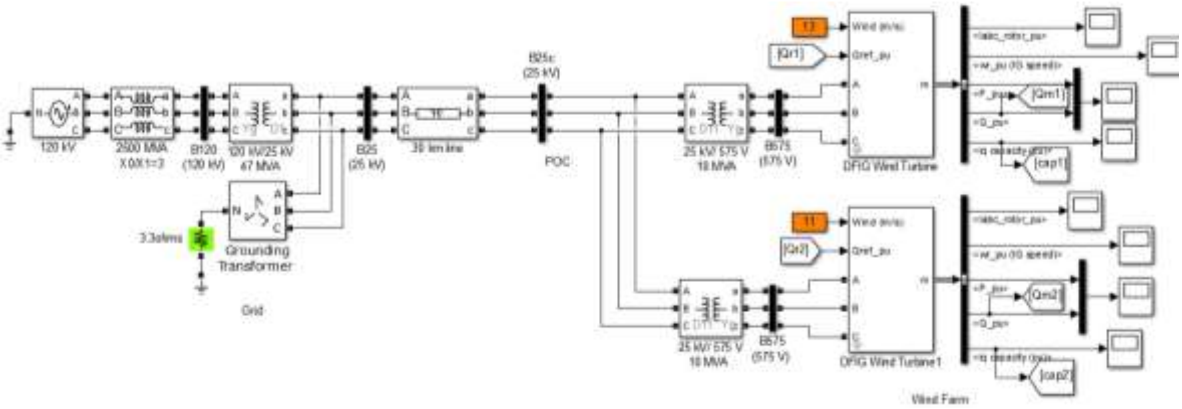


Figure 9. Simulink Schema of the wind farm

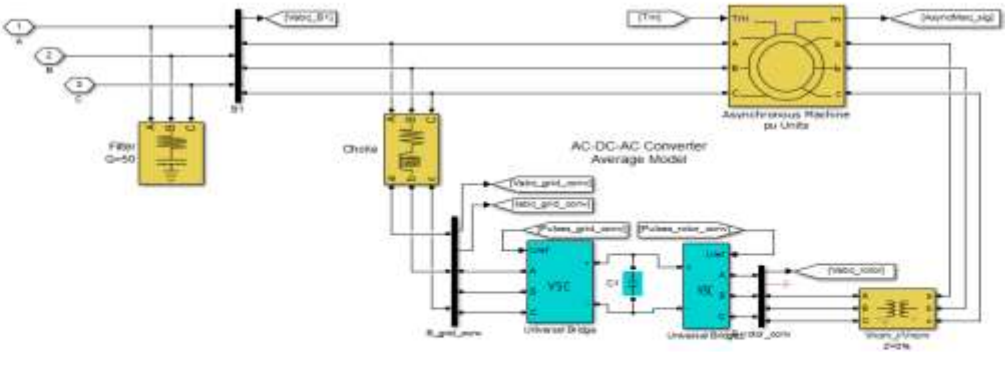
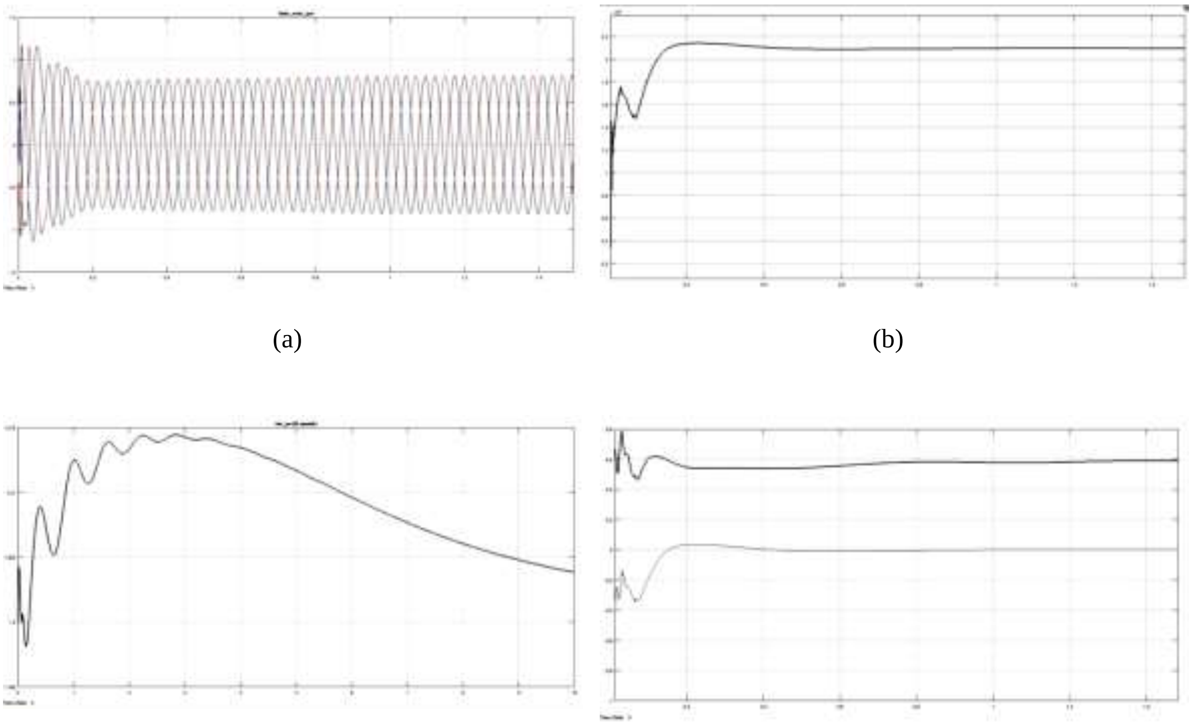


Figure 10. Simulink schema of the turbine

3.2. Simulation Results of Wind Farm



(a) (b)

(c) (d)

Figure 11. Result output of the wind farm, from top to bottom; (a) Iabc_rotor : rotor current, (b) Vabc at POC(point of connection), (c) Wr: rotation speed, (d) active power P & reactive power at POC

3.3. D-STATCOM Connected to Wind Farm

The D-STATCOM is connected in parallel with the wind farm as it is shown in Figure 12.

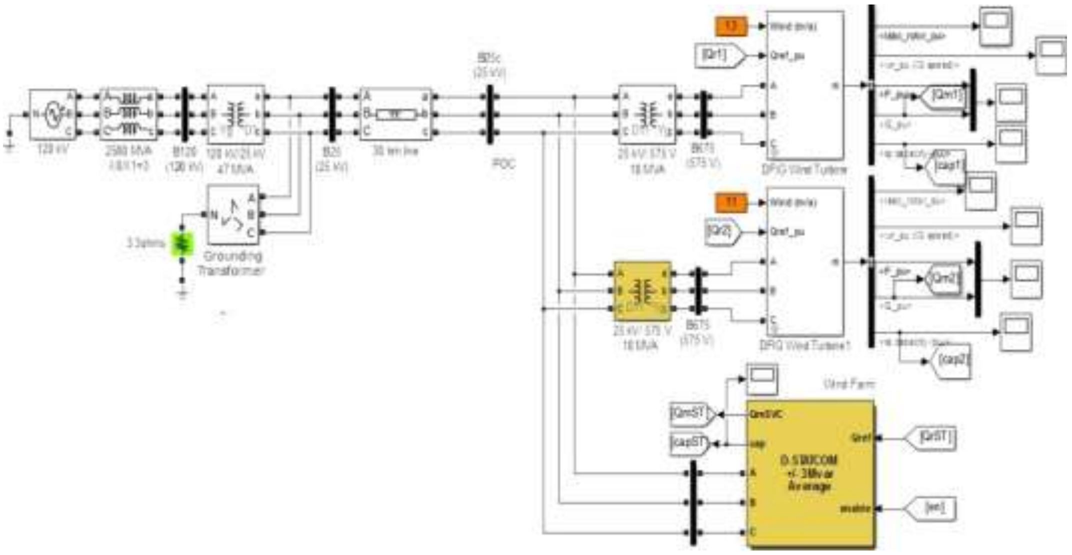
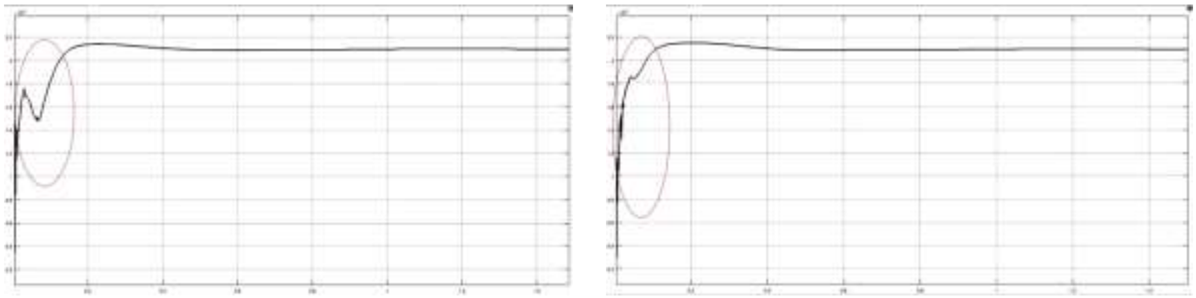


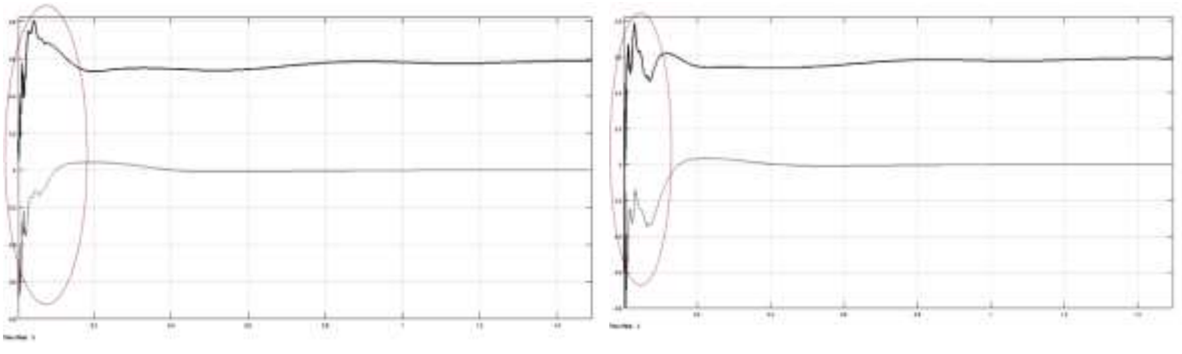
Figure 12. Simulink schema of the D-STATCOM connected to the wind farm

3.4. Simulation Results of D-STATCOM Connected to the Wind Farm



(a) (b)

Figure 13. The D-STATCOM impacts ((a) voltage Vabc at POC of the wind farm (b) voltage at Vabc at POC of D-STATCOM connected to wind farm)



(c) (d)

Figure 14. The D-STATCOM impacts (a) active and reactive power at POC of the wind farm, (b) active and reactive power at POC of D-STATCOM connected to wind farm

3.5. Interpretation

At the point of connection of the wind farm to the grid, a large compensation of reactive power is noted. The addition of the D-STATCOM has reduced the voltage deviation level as it is shown in Figure 13; where voltage and current peaks are clearly mitigated. In Figure 14 we notice that the D-STATCOM provides increased stability of the transitional regime and damps the oscillations of the active and reactive power.

4. SIMULATION SYSTEM PART 2

4.1. Simulation of Wind Farm

This second part concerns the simulation of a 9MW wind farm connected to the grid (Figure 15). It is consisting of six turbines with a power of 1.5 MW each one. The system is simulated in Matlab/ Simulink environment with phasor mode. The SVC is compatible for phasor type of simulation which justify the use of wind turbine (phasor type) as shown in Figure 15.

4.2. Simulation Results of the Wind Farm

According to the simulation results (Figure 16), we see that the current I_{plant} at the POC undergoes a peak and oscillations; which means that the wind farm loses its stability. The reactive power undergoes a peak and oscillations especially at the beginning; but less than those of active power. So the wind farm is not stable as necessary.

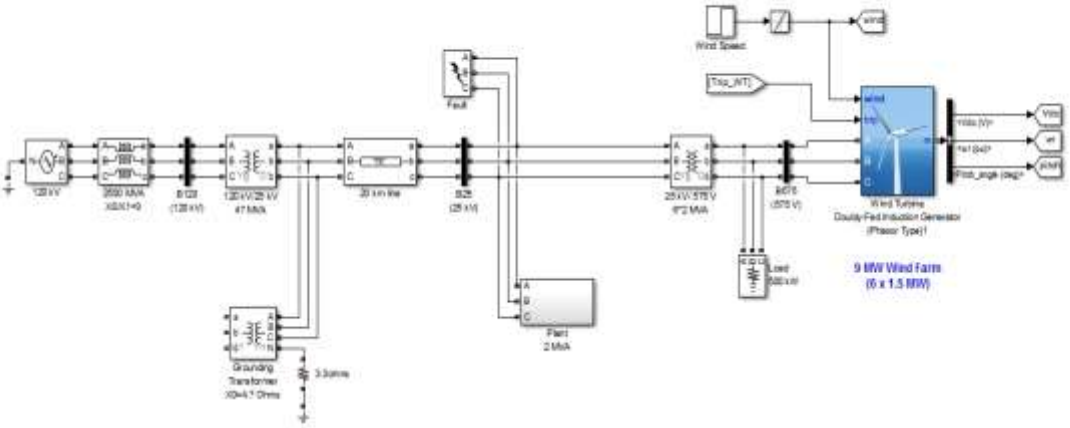


Figure 15. Simulink schema of the wind farm

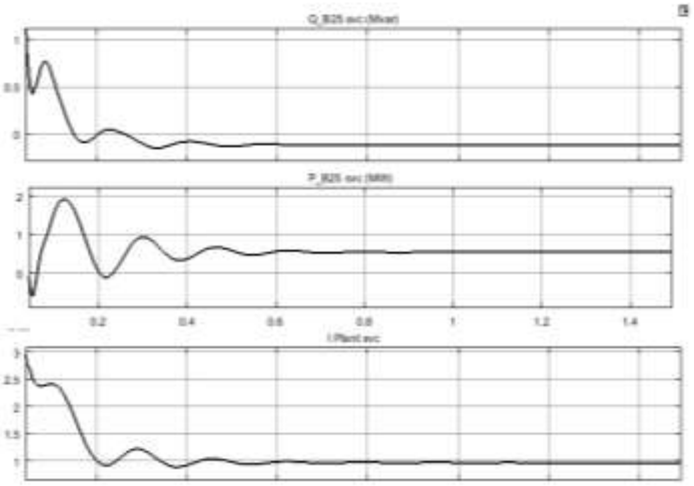


Figure 16. Result output of the wind farm, from top to bottom: I_{plant}: current at the point of connection of wind farm with the plant, P et Q: active and reactive power of the wind farm

4.3. SVC Connected to Wind Farm

The SVC is connected to the same wind farm in order to see the impact of this device on the stability of the wind farm. The SVC must be connected at the point of connection to the grid as shown in Figure 17.

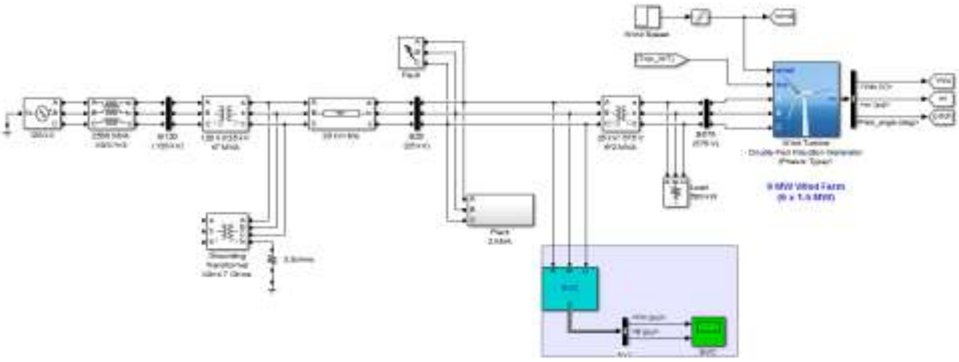


Figure 17. SVC connected to wind farm

4.4. Simulation Results of SVC Connected to the Wind Farm

After adding the SVC, we can see clearly in Figure 18 that the oscillations of the current Iplant at POC are clearly reduced as well as for the peak at the beginning of the simulation; which means that the wind farm is better stabilized than the last simulation. The peak of the reactive power is compensated and the oscillations of the active power are obviously decreased; thus the SVC enhances the stability of the wind farm.

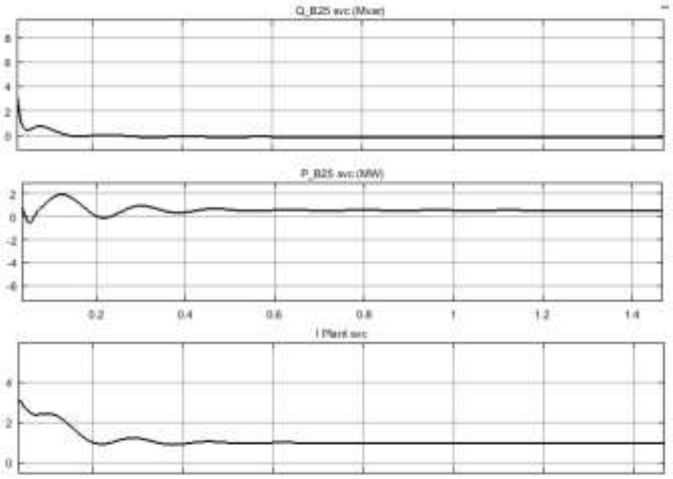


Figure 18. Result output of the wind farm connected to the SVC P et Q: active and reactive power of the wind farm I_{plant}: current at the point of connection of wind farm with the plant

4.5. Fuzzy Logic SVC Controller Connected to Wind Farm

In the last simulation, the F-SVC controller is connected to the same wind farm in order to evaluate the performance of the use of the fuzzy logic controller. The F-SVC controller must be connected at the point of connection to the grid. Figure 19 illustrates the simulink schema of the F-SVC in the voltage regulator subsystem of the SVC.

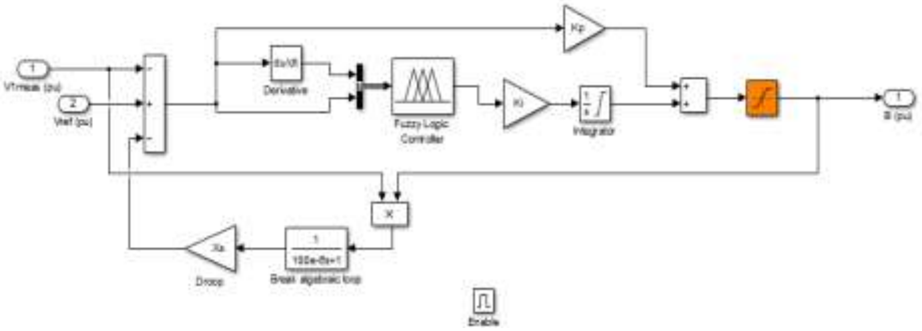


Figure 19. Schema of the F-SVC in the voltage regulator

4.6. Simulation Results of F-SVC Connected to the Wind Farm

We observe that the signals of voltage and current at the POC of wind farm are less oscillated and more stabilized with the use of the fuzzy logic controller than the conventional SVC. Also for the active and reactive power, these signals have been stabilized faster with the F-SVC controller and less oscillated compared with the system based on simple SVC.

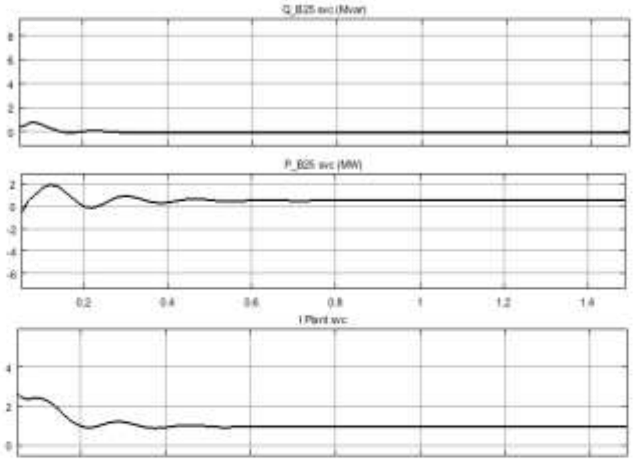


Figure 20. Result output of the wind farm connected to the F-SVC P et Q: active and reactive power of the wind farm I_{plant}: current at the point of connection of wind farm with the plant

5. CONCLUSION

This paper presents two of the most important strategies for the compensation of active and reactive power of a wind farm.

a. First a wind farm based on doubly fed induction machine was modeled and simulated, in the second simulation a D-STATCOM is connected in parallel; it acts on the stability of the voltage and current through the compensation of the reactive power.
b. The second strategy is to connect a simple SVC in parallel of the wind farm, then a F-SVC; the type of the fuzzy logic controller is Takagi Sugeno. From simulations the F-SVC controller shows better stabilization and a big difference in the oscillations of current, active and reactive power.

Finally; comparing to the conventional SVC controller, we conclude that the FSVC is more efficient for the compensation of active and reactive power

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