

Stability Analysis of Wind Farm Connected Multi Machine System using Fuzzy Controller Based STATCOM and SVC



Varun Kumar , A S Pandey, S K Sinha

Abstract— Large capacity wind farm are used to fulfil the demand of power now days. Stability of these wind farms is the main concern when integrating with the large power system. FACTS devices are employed with the system to advance the dynamic time responses of the system. In this paper a comparative analysis of STATCOM and SVC has been done. At the place of conventional controllers like P, PI, PID fuzzy logic control (FLC) has been used in the FACTS devices used. These FACTS devices are used to improve the power quality of the overall system. To inspect the system performance and analyze the behavior of the system a three phase to ground fault has been taken into account at two different locations, the software used for modelling and simulation is MATLAB/Simulink. Results demonstrate damping and oscillations of Fuzzy controlled STATCOM and SVC based system. The comparative analysis shows that the system with FLC based STATCOM has better performance than the FLC based SVC and fast fault clearance.

Keywords— wind farm integrated power system, Stability, STATCOM, SVC, fuzzy logic control (FLC)

I. INTRODUCTION

Due to decreasing availability of fossil fuels and increasing concern for clean energy, renewable energy systems are in much demand nowadays. Wind energy systems (WES) are the most employed system for generating electricity worldwide. In the year of 2017 wind energy systems total installed capacity is reached up to 539 GW all over the world and India ranks 5th in generating power through wind energy systems and added 23 GW power in the world power in the year of 2017[3]. In WES mainly SCIG, PMSG, DFIG generators are preferred, among these DFIG have been widely used [5]. Wind farms integrated with utility grid (UG) is used frequently, hence their transient stability and dynamic time response analysis is a point of great concern for researchers to enhance the performance of wind energy systems connected with large power systems.

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II. SYSTEM CONFIGURATION

In this paper the system used is a WSCC 9 bus power system. Figure 1 displays the single line diagram of the power system on which study is performed and its parameters. A 90 MW DFIG based wind farm is fed to WSCC 9 bus power system instead of connecting a generator at number 3 with same generated power shown in figure 9. The FACTS devices used are of 40 MVAR capacity. Table I gives the parameters of the wind turbine used. The simulation studies and modelling is performed on MATLAB/Simulink environment.

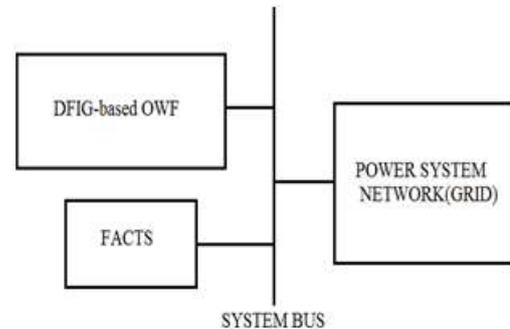


Fig. 1 block diagram of studied system

A. Wind farm model

DFIG with variable speed wind turbine has numerous benefits when compared with SCIG and PMSG [4,9]. The advantages of using DFIG over SCIG and PMSG is high efficiency, reactive power compensation is fast and efficient. DFIG is a wound rotor induction generator [1]. In this case the three-phase stator winding is directly connected to the supply network and the rotor winding is connected through the back to back converter. The converter can be specified as a grid side converter (RSC) and a rotor side converter(RSC), with the converter, dc link capacitors also connected. The use of RSC is to control active and reactive power and the GSC is to control the DC link voltage and maintain the converter operation at unity power factor. The power consumed by converters is 20-30% of the total power.

B. Fuzzy logic control

With respect to classical controllers like PI and PID, Fuzzy logic controller is much more precise and robust control technique. It is suitable for non-linear loads and require less storage.



Fuzzy Logic control technique can be divided into following parts i.e. fuzzification, rule base, inference engine and defuzzification. In this study Mamdani’s type FLC has been used. In fuzzification module seven linguistics of fuzzy using triangular membership function is used shown in figure 4. This system is two input and one output. The input linguistic variable is error and change in error. The linguistic variables are following NB (negative big), NM (negative medium), NS (negative small), Z(zero), PS (positive small), PM (positive medium), PB (positive big). In rule base if – then rules are used and is designed by expert person. The FLC rules has two input and one output and each has 7 linguistics which gives out 49 rules [7]. The rules for FLC is shown in table I and surface view of the output can be presented as shown in figure2.

TABLE: I FLC rules

E/CE	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

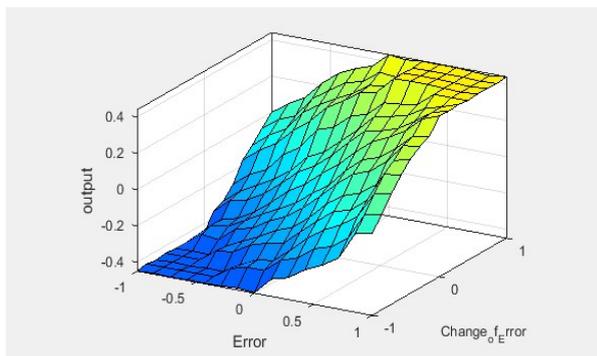


Fig.2 MATLAB/simulink Surface view of FLC rules

C. FLC based SVC

SVC (static var compensator) is a thyristor switched reactor (TSR), thyristor control reactor(TCR), thyristor switched capacitor (TSC) or a parallel combination of these reactors. It is a shunt connected device and by varying firing angle of SCR output power is controlled [6]. The control parameter in SVC is susceptance (β) which is given as

$$B = \frac{2\beta - \sin 2\beta - \pi \omega^2 LC}{\pi \omega L} \tag{1}$$

Where, β = π-α, α is firing angle

And the reactive power compensation is given as

shift of the PWM inverter is provided by current regulators output [8].

$$Q = -BSVCV^2(2)$$

The MATLAB/Simulink model of SVC based FLC is shown in figure 2. The change in error and error signal is generated by comparing system voltage with reference voltage. SVC’s susceptance is generated by FLC output. The output of the SVC is used for regulation of PWM inverter by changing the firing angle. The dynamic voltage control of the system can be achieved by using SVC in the system. SVC reduces the impacts of faults or the disturbances on the system [11].

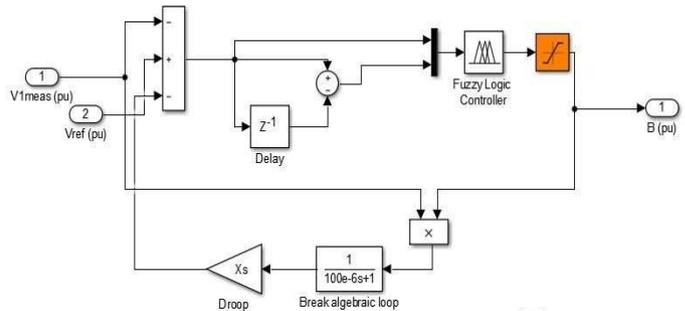


Fig.3 Simulink model of FLC based SVC

D. FLC based STATCOM

STATCOM is a shunt-connected device that regulates system voltage by generating reactive power at a low system voltage or by absorbing reactive power at a high system voltage. A voltage source converter (VSC) is connected to the secondary side of the transformer to ensure proper reactive power fluctuations. The real (P) and reactive power (Q) can be given as follows:

$$P = \frac{V_1 V_2 \sin \delta}{X} \tag{3}$$

$$Q = \frac{V_1(V_1 - V_2 \cos \delta)}{X} \tag{4}$$

V1, V2 voltages(Line to line)

X Reactance of the interconnection of transformer and filters

Δ Phase angle of V1 with respect to V2

The STATCOM is employed to the system for improvement of dynamic and transient stability of WECs and improving overall power quality of the system [2,4]. Figure 3 shows the design of the FLC based AC voltage regulator. The voltage of the system is being measured at PCC (point of common coupling) and then is compared with reference value. The output of the FLC is Iqref that is then compared with STATCOM reactive current Iq and the phase

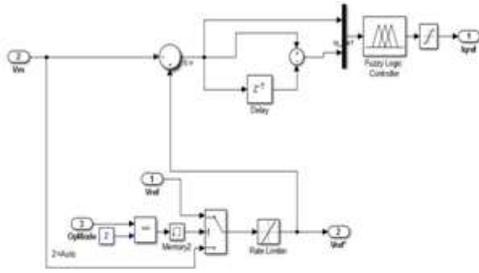


Fig.3 Simulink model of FLC based STATCOM

III. PERFORMANCE ANALYSIS

For the system performance analysis, a three-phase fault is applied at two different locations that is one near the connection point of wind farm and other is far from the connection point, the fault locations are bus 3 and bus 8.

A. Fault analysis at bus number 3

When a fault of duration 0.1 seconds is applied at bus number 3. Buses B6, B7, B8, B9 voltages, response of generator G1, G2 and the wind farm response is shown in figure 5 and figure 6, 7 and 8 respectively. from the figure it can be concluded that the transients, overshoot and settling times are less with STATCOM than with SVC. Bus number 3 being closer to wind farm should have less transients and faster settling time response in comparison with other buses. In STATCOM performance it can be seen that the transients are less and settles down faster than svc. The overshoots are also less in comparison with SVC and system without FACTS. By using STATCOM with FLC the overall power quality of the system improves.

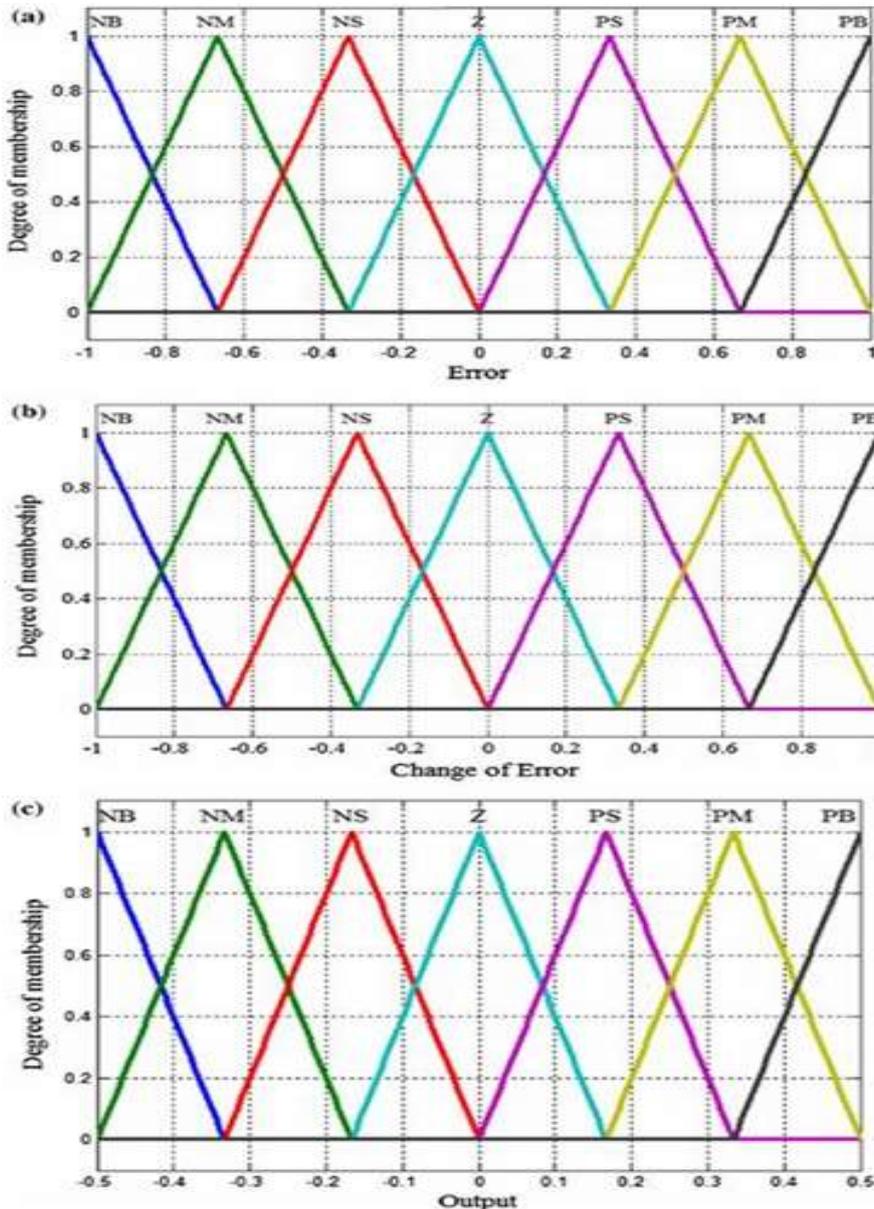


Fig.4 Membership function for input and output

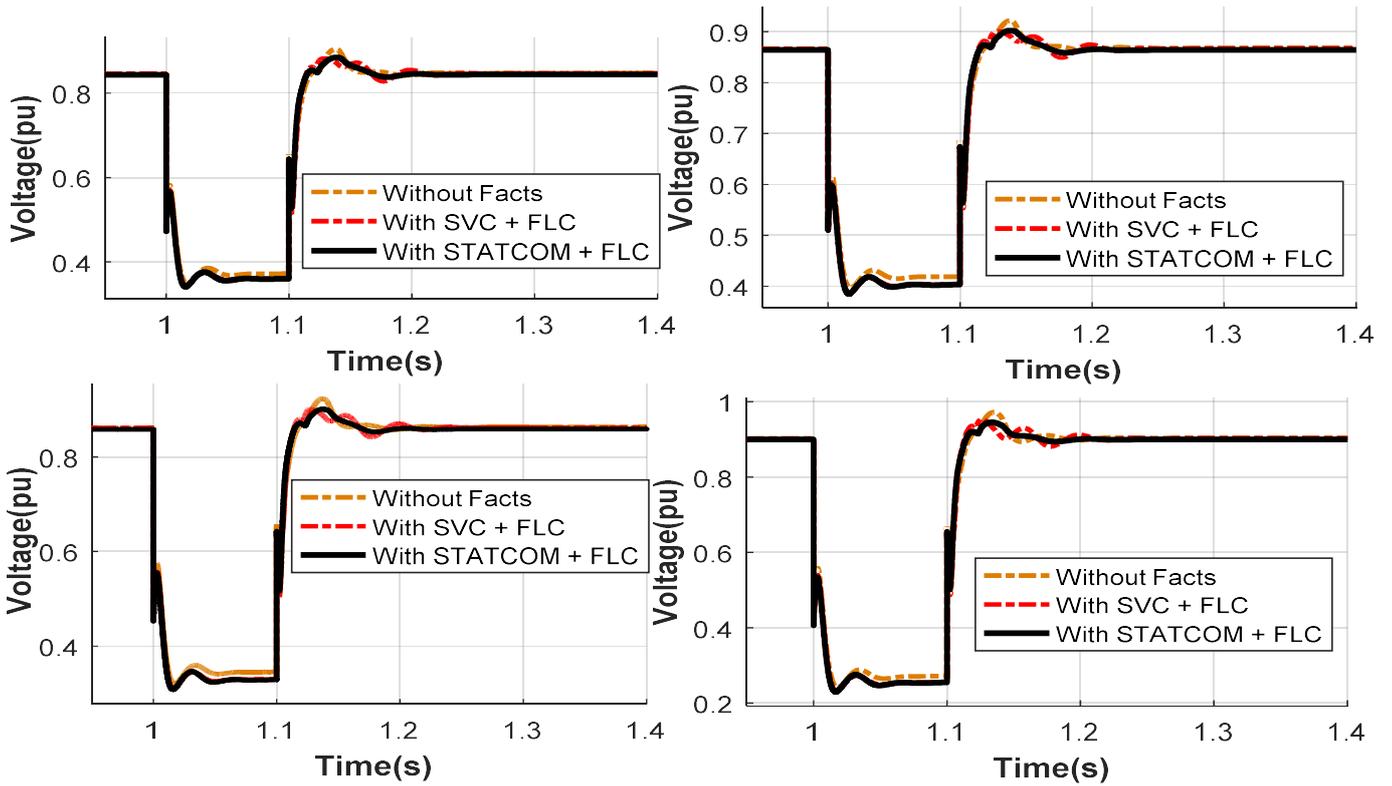


Fig.5 Response of bus 6, 7, 8 and 9 voltages

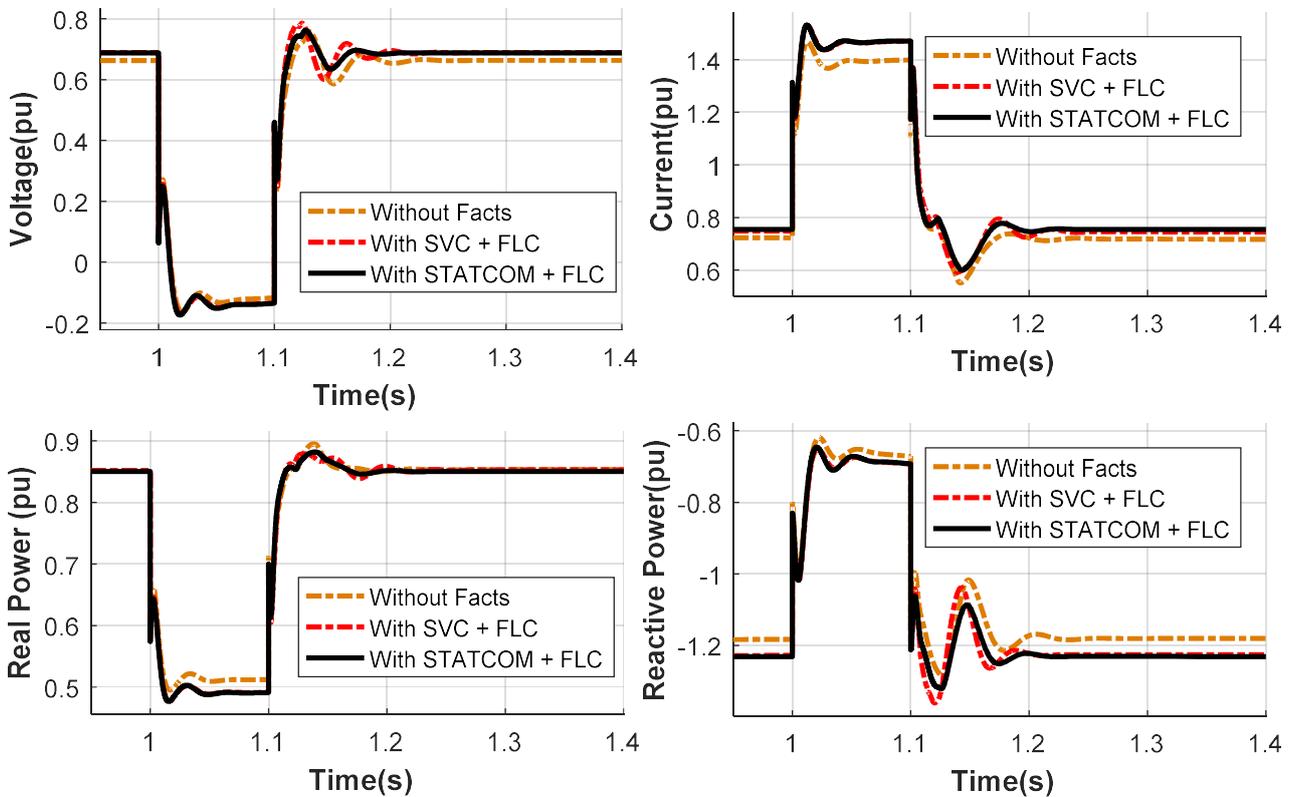


Fig.6 Response of Generator 1

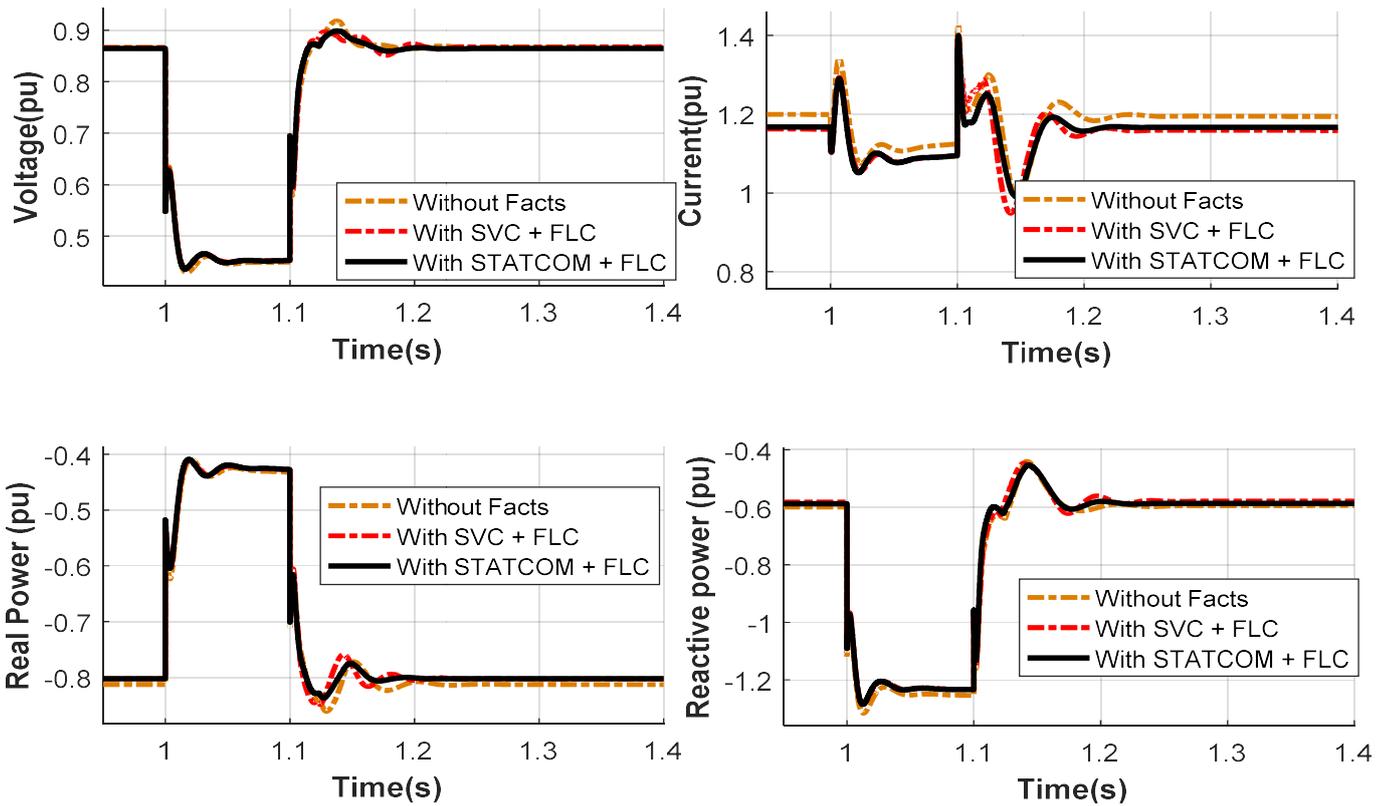


Fig.7 Response of Generator 2

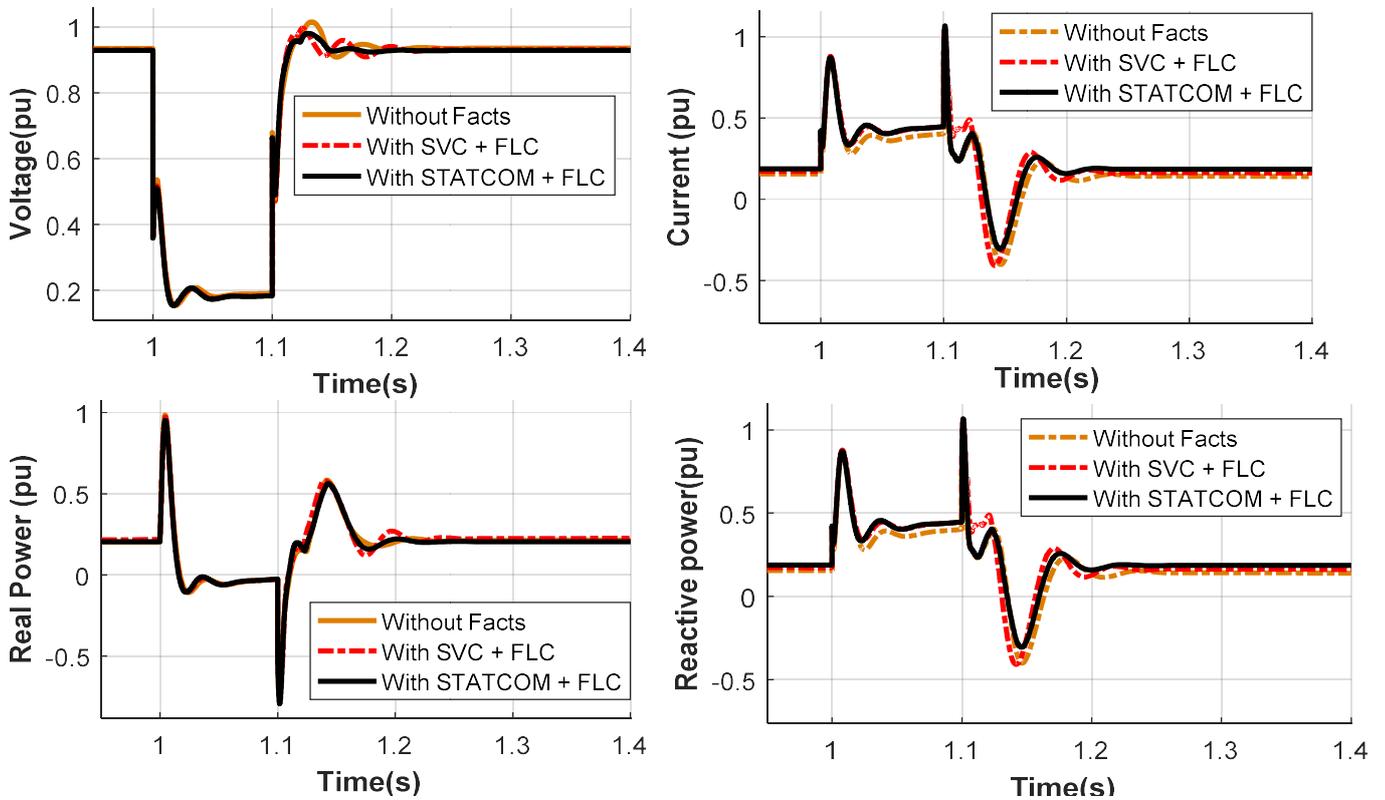


Fig.8 Response of wind farm parameters

B. Fault analysis at bus number 8

When a fault of duration 0.1 seconds is applied at bus number 8 which is far from wind farm connection point in compare to bus number 3 which is near to wind farm. The response of buses B6, B7, B8, B9, generator 1,2(voltage currents, real and reactive power), wind farm is shown in figure 9,10,11and 12 respectively. from the figure it can be concluded that the transients, overshoot and settling times are less with STATCOM than with SVC. The comparison of settling time of wind farm parameters when fault on bus 3 and bus 8 can be shown in table II. From table II it can be concluded that the fault on bus8 takes longer time to settle down in comparison to bus 3 which is near to the wind farm

and respectively comparison of buses parameters. From the table III, it can be concluded that the time response of all system Bus voltages are improved by using STATCOM device. The system with STATCOM have lesser settling time. Furthermore, STATCOM provides enhanced and improved performance than with SVC. And the time taking to reach steady state is less when fault takes place at bus number 3 which is near to the wind farm connection point in comparison to fault taking place on bus number 8 which far from the connection point. It can be concluded that the dynamic time response of the system devices parameters gets better and improved by using STATCOM in comparison with SVC.

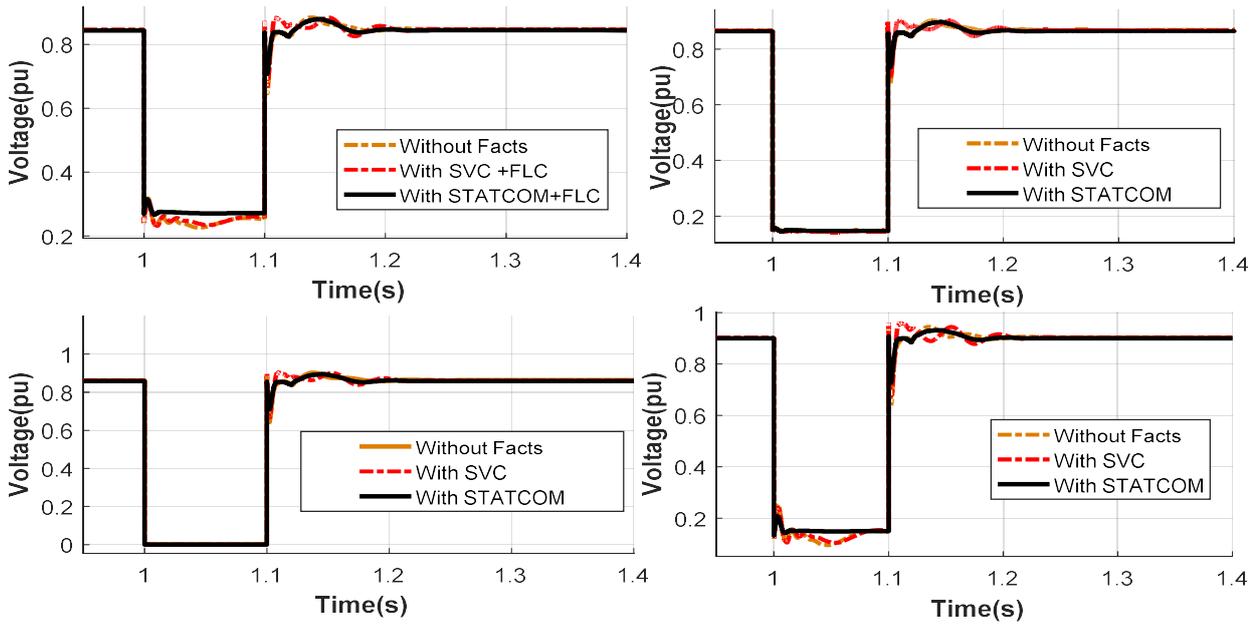


Fig.9 Response of bus 6,7,8,9

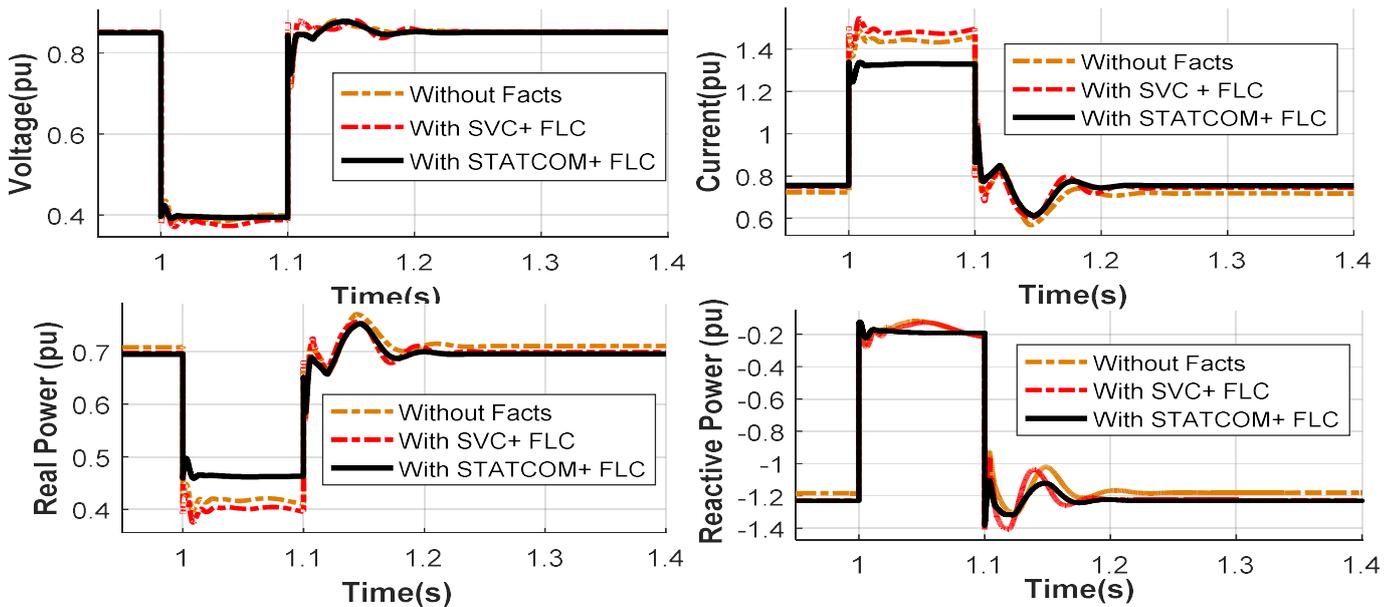


Fig.10 Response of generator 1

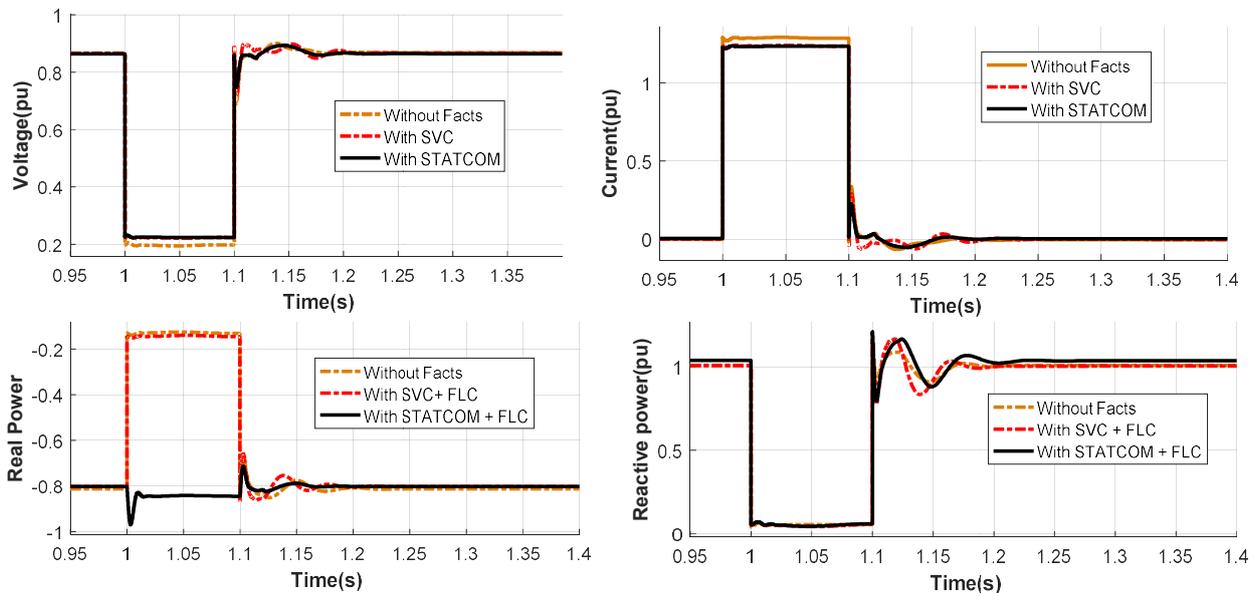


Fig.11 Response of generator2

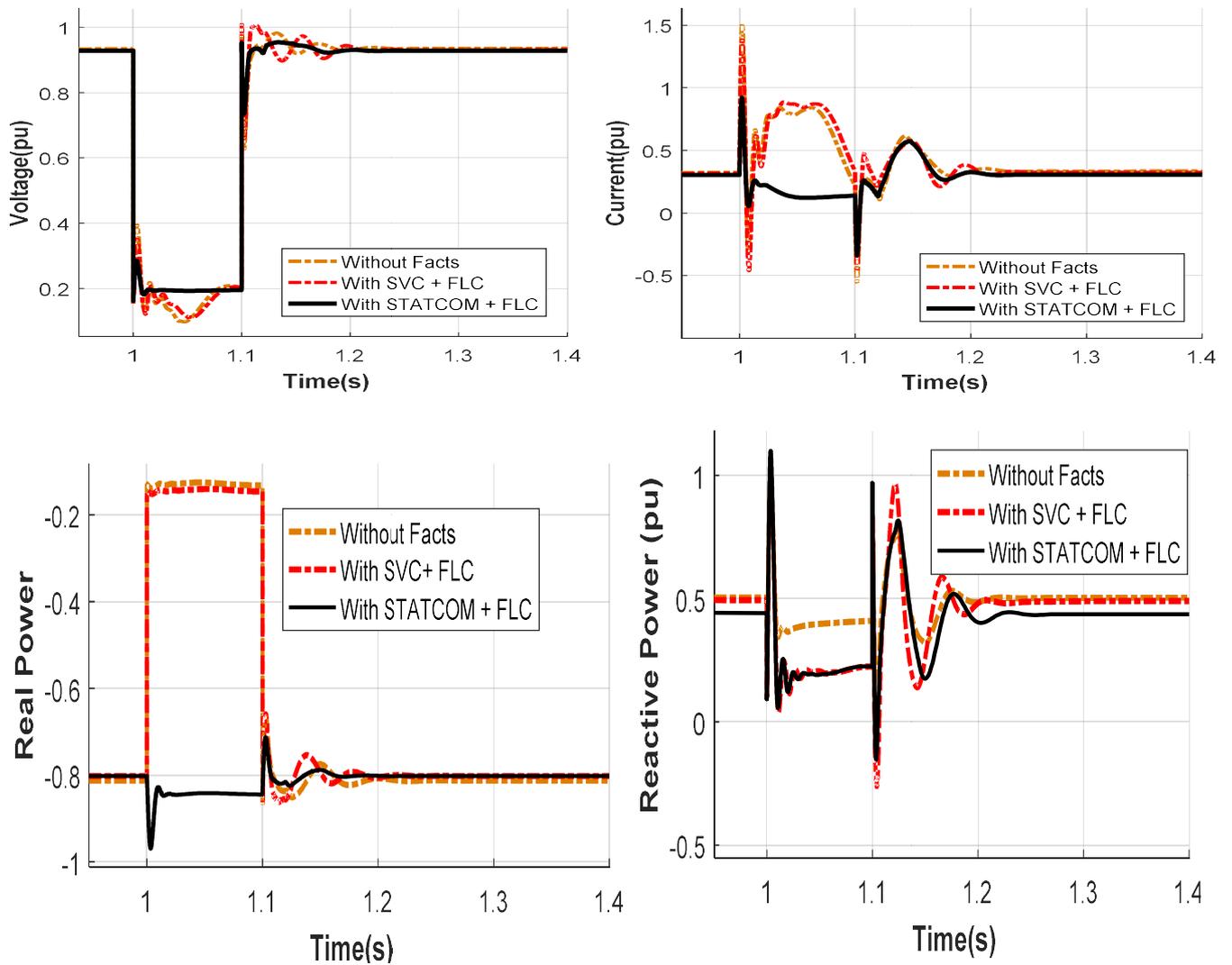


Fig. 12 Response of Wind farm

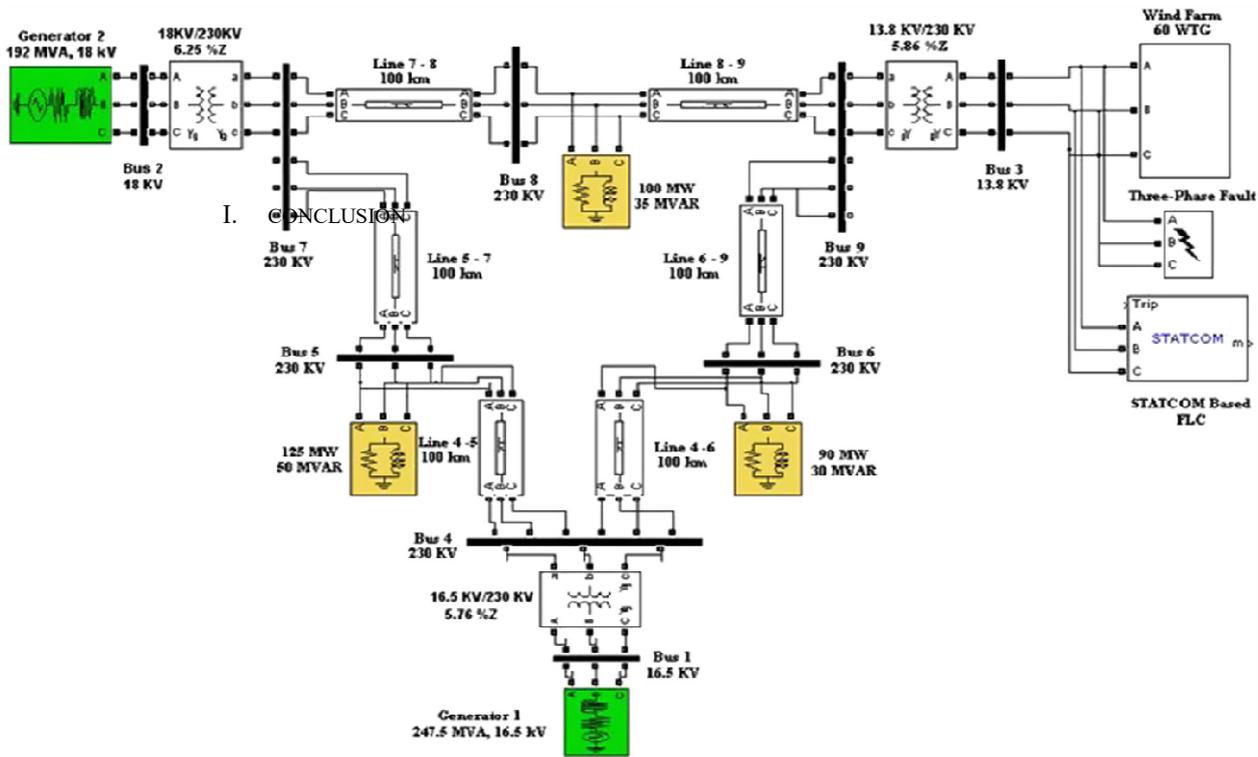


Fig 13 Test system-WSCC Nine bus system

IV. CONCLUSION

In this paper, the stability analysis of Western System Coordinating Council (WSCC) nine bus system connected with 90 MW DFIG based wind farm has been performed as shown in fig 13. To perform the analysis a three phase to ground fault has been given at various locations. The locations selected are based on the location of wind farm connection point with the multi machine power system, the locations selected are bus number 3 and bus number 8 that is bus number 3 being the nearest connection point of common coupling and bus number 8 which is far from the PCC (point of common coupling) .the locations has been chosen to compare the performance of the system faults takes place at different point from the wind farm connection point.The FLC controlled SVC and STATCOM has been connected at the nearest connection point of wind farm and multi machine power system. The study of comparison has been done between SVC and STATCOM’s performance when applied for reactive power Compensation to improve the system performance when the system is subjected to a severe three phase to ground fault at two different locations. The comparison study of SVC and STATCOM shows that the performance of STATCOM based FLC is better than that of SVC based FLC, with STATCOM the settling time and overshoot is less than comparing with SVC. Both the FACTS devices supplied or absorbed the necessary reactive power to the power system under disturbance or the fault condition. FLC controller provides better damping performance.And finally it can be concluded that the system performance is improved in the sense of power quality by using a FLC based STATCOM, and results shows

that the performance of STATCOM is better than SVC. From the study done it could be finally stated that the FLC based STATCOM shows improved performance than with the FLC based SVC when system is subjected to any severe fault or disturbance.

TABLE II Comparison of wind farm parameters when faults onbus 8 and bus 3

Parameter	FACTS Device	Settling Time (sec)	
		Fault on bus 8	Fault on bus 3
Voltage B6	STATCOM	1.22	1.17
	SVC	1.24	1.21
Voltage B7	STATCOM	1.21	1.18
	SVC	1.24	1.23
Voltage B8	STATCOM	1.2	1.18
	SVC	1.25	1.23
Voltage B9	STATCOM	1.22	1.18
	SVC	1.25	1.23

TABLE III Comparison of Buses 6,7,8,9 parameters when faults on bus 8 and bus 3

Parameter	FACT Device	Settling Time (sec)	
		Fault on bus 8	Fault on bus 3
Voltage	STATCOM	1.21	1.17
	SVC	1.24	1.22
Current	STATCOM	1.22	1.17
	SVC	1.25	1.20
Active Power	STATCOM	1.23	1.20
	SVC	1.25	1.22
Reactive power	STATCOM	1.21	1.29
	SVC	1.22	1.21

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