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Dynamic Stability Improvement of Grid Connected PMSG Based Offshore Wind Farm Using a STATCOM

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ABSTRACT: This paper presents the dynamic stability improvement of the offshore wind farm(OWF) connected to power grid using a static synchronous compensator(STATCOM) .The offshore wind farm is simulated by taking the four parallel operated permanent magnet generators(PMSG) of 5MW and the onshore power system is simulated by synchronous generator fed to an infinite bus through two parallel transmission lines. The STATCOM controller is implemented using two types of controllers: conventional PID controller and Fuzzy logic controller(FLC). The PID controller is designed using pole placement approach and the fuzzy logic controller is implemented using sugeno type fuzzy interface system. At the end the response with respect to both are compared.

KEYWORDS: Dynamic stability, PMSG, Static synchronous compensator, PID controller, Fuzzy logic controller(FLC).

I.INTRODUCTION

In present days due to increase in the demand of electrical generation, the larger renewable electrical energy generation is best choice than conventional generation from the fossil fuels. Since oceans cover more than 70% surface of earth, the OWF can be extensively developed at the specific locations of the world in the future. In present OWF is more used by European countries.

One of the simple methods of running OWF is to connect the output terminals of several permanent magnet synchronous generators(PMSGs) together and then connected to power grid through full rated power converters, step up transformers and undersea cables. Currently, wind doubly-fed induction generators(DFIGs) and wind permanent-magnet synchronous generators have been widely used in high offshore wind farms(OWFs). Due to large interconnections and fast acting controllers there is low frequency oscillations are exist in the rotor of generators in addition to disturbances like grid fault or control device failures in high capacity generation system. The stability related to these oscillations is termed as dynamic stability. The dynamic stability is the extension of study state stability by taking the effect of controllers. To compensate the fluctuating components the STATCOM is presented in this paper.

The dynamic model based on small signal stability of wind turbine(WT) using a PMSG with its power converters and controllers was proposed in[1]. The control strategy of a hybrid wind farm containing a large number of induction machine (IM)-based wind turbine generators(WTGs) and very few PMSG-based WTGs to compensate the reactive power requirement of the IM during faults and mitigate power fluctuations during wind gusts was proposed in [2]. A simple coordinated control of dc-link voltage and pitch angle of a PMSG-based WTG to smooth wind power fluctuations was proposed [3]. A variable-blade pitch of a WTG and design of an output feedback linear quadratic controller for a STATCOM to perform mechanical power control and voltage control under different operating conditions were studied in [4]. The dynamic results of stability improvement of power system using STATCOMs and damping controller design of STATCOMs were presented in[5]. Dynamic characteristics of a power system with a STATCOM and a static synchronous series compensator (SSSC) through digital simulations were compared in [6]. The application of a STATCOM to damp torsional oscillations of a series-capacitor compensated ac system was shown in [7]. The characteristics of using PSS, static VAR compensator (SVC), and STATCOM for damping undesirable inter area oscillations of a power system were compared in [8].

This paper is organized as below. The configuration and the employed model for studied OWF with STATCOM. The design procedure for the PID controller of proposed STATCOM and fuzzy logic controller were depicted. This paper focus on the dynamic stability of the studied system with the above two controllers and are compared with without controller under three phase short circuit fault is described. Finally, specific conclusions of this paper are described.

II. CONFIGURATION OF THE STUDIED SYSTEM

Fig.1 shows the configuration of studied system. The wind farm is modeled with four parallel operated PMSG based wind turbine generators of 5MW each. To maintain the grid interconnection standards the PMSGs are joined at common offshore ac bus through full rated power converter and 3.3/23 kV transformers. The wind farm is interconnected to onshore power system through step up transformer of 23/161 kV and the cable at the point of common coupling(PCC) of onshore power system. The onshore power system is modeled as one-machine infinite-bus(OMIB) system. The OMIB system is modeled with the synchronous generator(SG) of 615MVA is connected to the grid through step up transformer of 15/161 kV and two parallel transmission lines(TL1 and TL2). The STATCOM of ±5MVAR is connected at the common offshore ac bus.

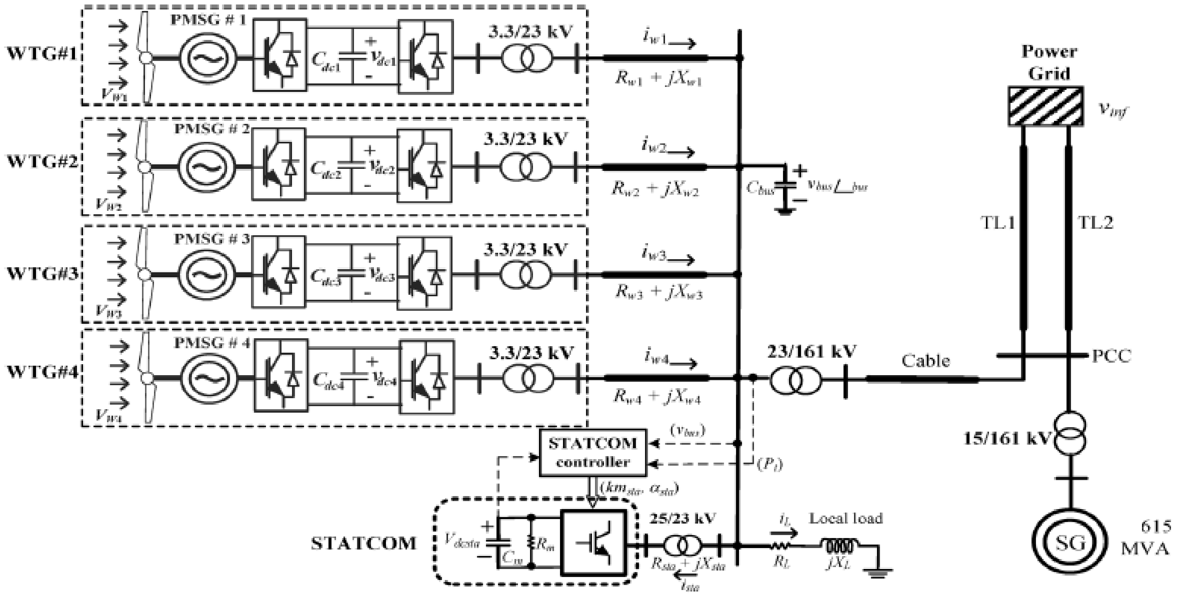

Fig. 1 Configuration of studied offshore wind farm with STATCOM

The employed mathematical models of studied system are described below.

1) *Wind turbine*

The captured mechanical power (in W) by wind turbine is

$$P_m=\frac{1}{2}\rho.A_r.V_w^{3}.C_p\,(\lambda,\beta) \qquad (1)$$

Where ρ air density (kg/m^2), A_r is the blade swept area(m^2), V_w is the wind speed in (m/s) and C_p is the dimensionless power coefficient of wind turbine. The cut in, rated and cutout wind speeds of studied wind turbine are 4, 14 and 25 m/s respectively.

2) *Mass spring damper system*

The each WT is directly connected to rotor shaft of wind PMSG and it can be represented by a two inertia reduced order equivalent mass spring damper model is shown in fig.2.

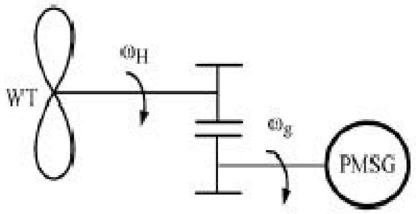

Fig. 2 Two inertia reduced order model of each WT connected rotor shoft of wind PMSG

The per unit equations of motion for the two inertia reduced order model of coupling of WT to the PMSG is expressed by

$$2H_h\, p(\omega_h)=T_m-K_{hg}\theta_{hg}-D_{hg}\omega_h \tag{2}$$
$$2H_g\, p(\omega_g)=K_{hg}\theta_{hg}+D_{hg}\omega_h-T_e \tag{3}$$
$$p(\theta_{hg})= \omega_h(\omega_h-\omega_g) \tag{4}$$

Where p is the differential operator with respect time; H_h and H_g are the inertias of the hub and the PMSG respectively; ω_h and ω_g are the angular speeds of the hub and the PMSG, respectively; $D_{hg,}$ K_{hg} and θ_{hg} are the mechanical damping coefficient, spring constant, and rotor-angle difference between the hub and the PMSG, respectively; T_m and T_e are the mechanical input torque and the electromagnetic torque of the PMSG, respectively.

3) *PMSG and power converters*

The p.u. d-q axis equivalent circuit model of studied PMSG, where q-axis is fixed on the machine rotor and rotate at rotor speed, can be expressed by

$$v_{qs} = -r_s i_{qs} + \frac{p\psi_q}{\omega_b} + \frac{\omega_r}{\omega_b}\psi_d \tag{5}$$

$$v_{ds} = -r_s i_{ds} + \frac{p\psi_d}{\omega_b} - \frac{\omega_r}{\omega_b}\psi_q \tag{6}$$

In the above Ψ_q and Ψ_d are given by

$$\Psi_q=-(X_{mq}+X_{ls})i_{qs}=-X_q i_{qs} \tag{7}$$
$$\Psi_d=-(X_{md}+X_{ls})i_{ds}+X_{md}i'_m=-X_d i_{ds}+X_{md}i'_m \tag{8}$$

where Ψ is the per-unit flux linkage, v_s is the per–unit stator winding voltage, i_s is the per-unit stator winding current, X_m is the per-unit magnetization reactance, X_l is the per-unit leakage reactance, i'_m is the per-unit magnetization current, ω_r is the per-unit rotational speed, and ω_b is the per-unit base speed.

The PMSG in the wind turbine model is shown in fig.3.

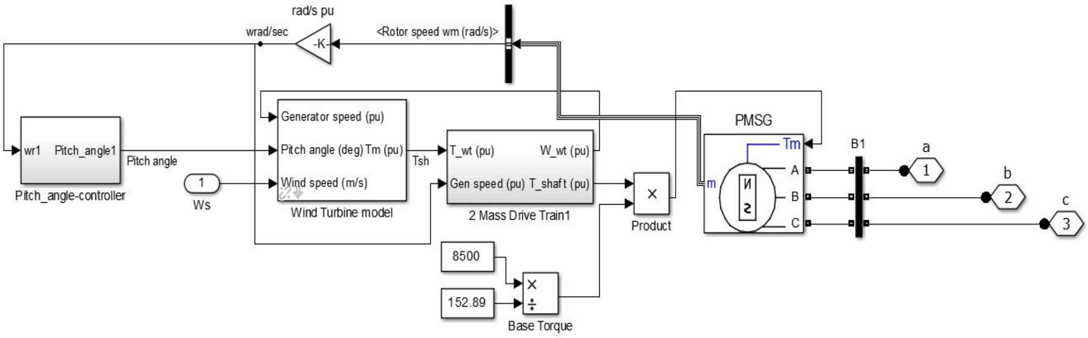

Fig. 3 PMSG in wind turbine model

The power converters used to control the gird parameters is shown in Fig. 4.

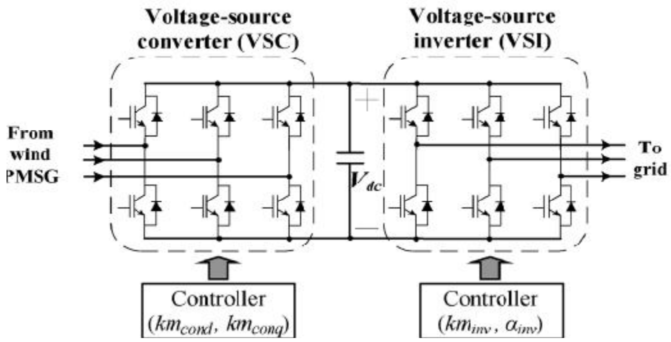

Fig. 4 power converters of the studied wind PMSG

The input – axis per-unit voltages of the voltage-source converter (VSC) converter of a wind PMSG can be expressed by

$$v_{cond}=km_{cond}v_{dc} \quad (9)$$

$$v_{conq}=km_{conq}v_{dc} \quad (10)$$

The output – axis per unit voltages of the VSC inverter of a wind PMSG can be written by

$$v_{invd}=km_{inv}\sin(\alpha_{inv})v_{dc} \quad (11)$$

$$v_{invq}=km_{inv}\cos(\alpha_{inv})v_{dc} \quad (12)$$

In Matlab/Simulink model this power converter is implemented using the universal bridge with IGBTs as the power electronic devices.

4) *STATCOM controller*

The proposed control circuit of the studied STATCOM is shown in Fig. 5.

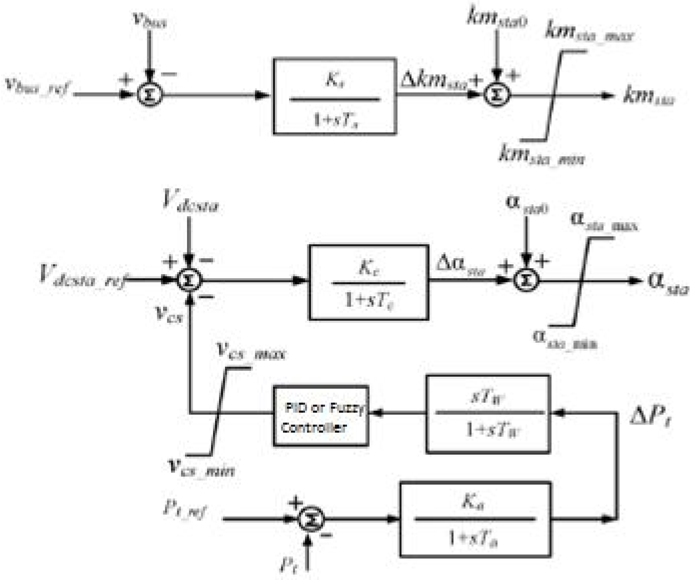

Fig. 5 the control diagram for employed STATCOM

The per unit d and q axis output voltages of the proposed STATCOM are

$$v_{qstat}=V_{dcsta}km_{sta}\cos(\theta_{bus}+\alpha_{sta}) \quad (13)$$

$$v_{dstat}=V_{dcsta}km_{sta}\sin(\theta_{bus}+\alpha_{sta}) \quad (14)$$

$$(C_m)p(v_{dcsta}) = \omega_b[I_{dcsta}(V_{dcsta}/R_m)] \tag{15}$$

Where

$$I_{dc} = i_{qsta} km_{sta} \cos(\theta_{bus} + \alpha_{sta}) + i_{dsta}\ km_{sta} \sin(\theta_{bus} + \alpha_{sta}) \tag{16}$$

The STATCOM controllers of PID and FLC are used in this system are explained in the sections III & IV.

III. PID CONTROLLER

PID controller is one of the most common controlling devices in the market. Because of its very simple control structure and the linear control methodology, PID control is important in many industries and has been widely used in electrical, mechanical, hydraulic, fluidic, and pneumatic systems. A PID controller continuously calculates an error value as the difference between a measured process variable and a desired set point.

The STATCOM controller with PID controller is shown in fig.6.

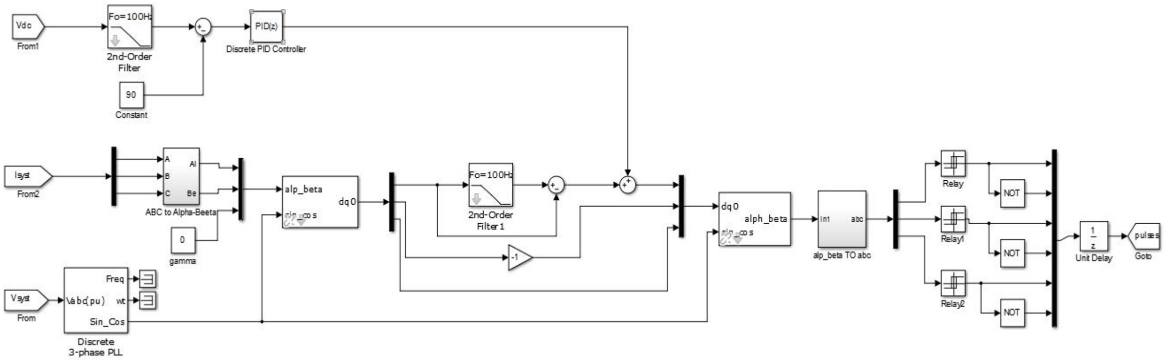

Fig. 6 The control circuit of STATCOM using the PID controller

IV. FUZZY CONTROLLER

Since power system dynamic characteristics are complex and variable, conventional control methods cannot provide desired results. Intelligent controller can be replaced with conventional controller to get fast and good dynamic response in load frequency problems. Fuzzy Logic Controller (FLC) can be more useful in solving large scale of controlling problems with respect to conventional controller are slower. Fuzzy logic controller is designed to minimize fluctuation on system outputs. There are many studied on power system with fuzzy logic controller. A fuzzy logic controller consist of three sections namely fuzzifier, rule base and defuzzifier as shown in fig.7.

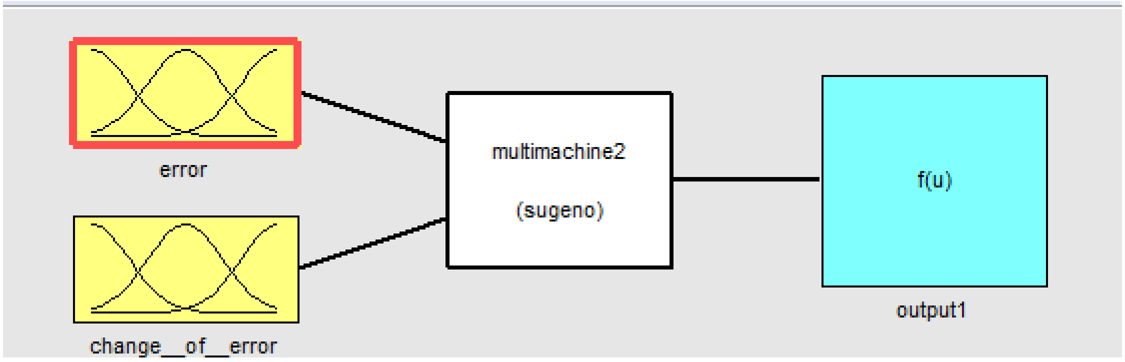

Fig. 7 Fuzzy interference system

The error e and change in error de are inputs of FLC. Two inputs signals are converted to fuzzy numbers first in fuzzifier using 49 membership functions using fuzzy logic tool box shown in table 1. The variables used for inputs are positive big(PB), positive medium(PM), positive small(PS), zero(ZR),negative Small(NS),negative medium(NM), negative big(NB). The variables used for output are increase big(IB), increase medium(IM), increase small(IS), constant value(KV),decrease small(DS), decrease medium(DM), decrease big(DB). The rules will be formed according to application. Rules which had developed in FIS should be saved in a file by exporting it to file, for each and every operation with fuzzy model the FIS file with rules should import from file and should be exported to workspace then only the model will run and output will shown. The membership functions of inputs of this system are shown in fig.8.

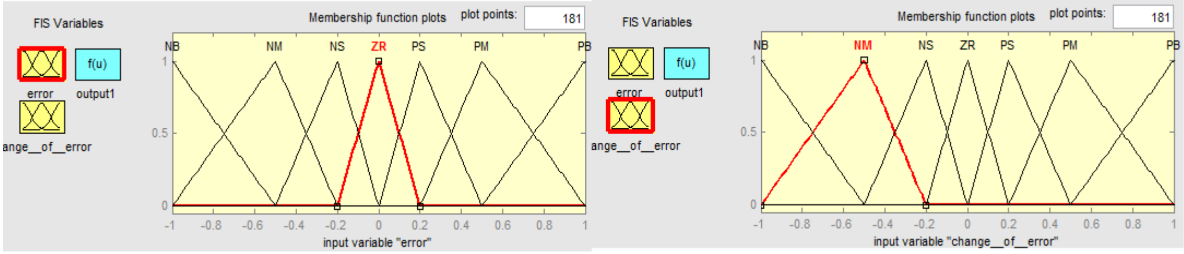

Fig. 8 the membership functions of FLC

Table 1: Fuzzy logic rule box

Error / Change of error	PB	PM	PS	ZR	NS	NM	NB
NB	DB	DB	DB	DB	DM	DS	KV
NM	DB	DB	DB	DM	DS	KV	IS
NS	DB	DB	DM	DS	KV	IS	IM
ZR	DB	DM	DS	KV	IS	IM	IB
PS	DM	DS	KV	IS	IM	IB	IB
PM	DS	KV	IS	IM	IB	IB	IB
PB	KV	IS	IM	IB	IB	IB	IB

From the above rule box we can form the rule base with two inputs and one output, the rules as follows

Rule 1 : if (error is NB) and (change of error is PB) then (output is KV)

Rule 2 : if (error is NM) and (change of error is PB) then (output is IS)

Rule 3 : if (error is NS) and (change of error is PB) then (output is IM)

.

Rule 49: if (error is PB) and (change of error is NB) then (output is KV)

V. RESULT AND DISCUSSION

The Matlab/Simulink model is developed for the studied system with desirable ratings. The simulation diagram of the studied system is show in Fig 9.

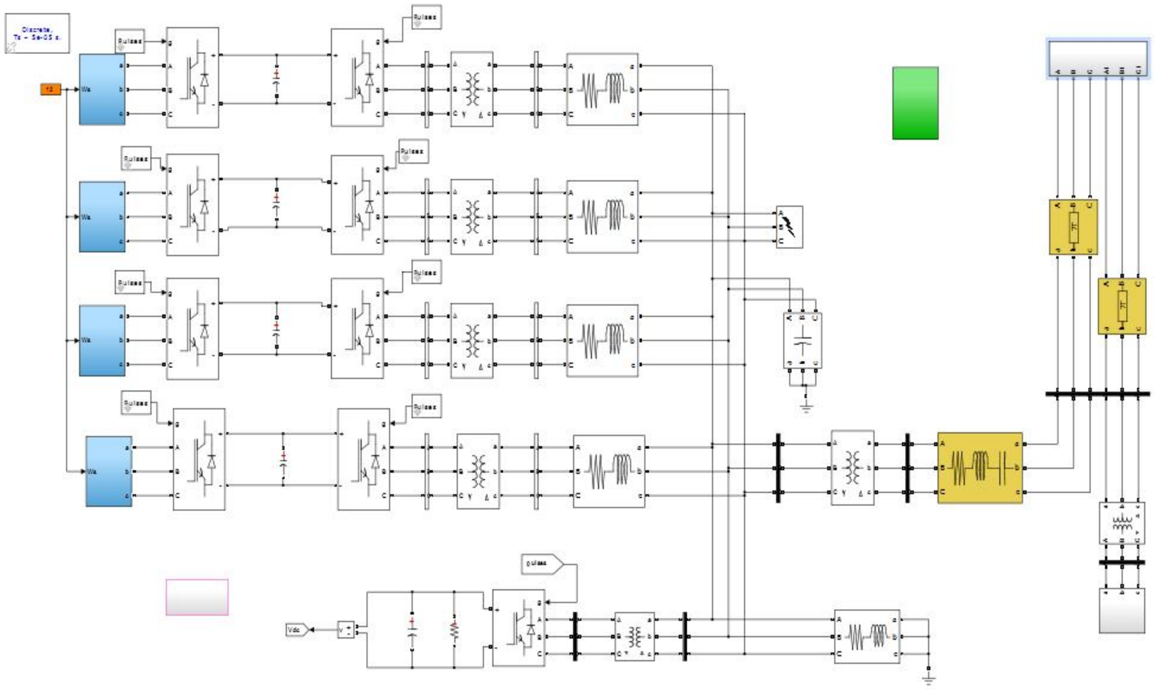

Fig. 9 Matlab/Simulink model of the studied system

The system is tested for dynamic response of the system by applying the fault at t=0.2s and cleared at t=0.21s.The active and reactive powers of the PMSG, STATCOM and the synchronous generator with the above disturbance are shown in the Fig. 10 to Fig.12. The rotor angle and angular velocity of the SG are shown in the Fig.12. The voltage waveforms at point of common coupling (PCC) and the STATCOM buses are shown in Fig.13.

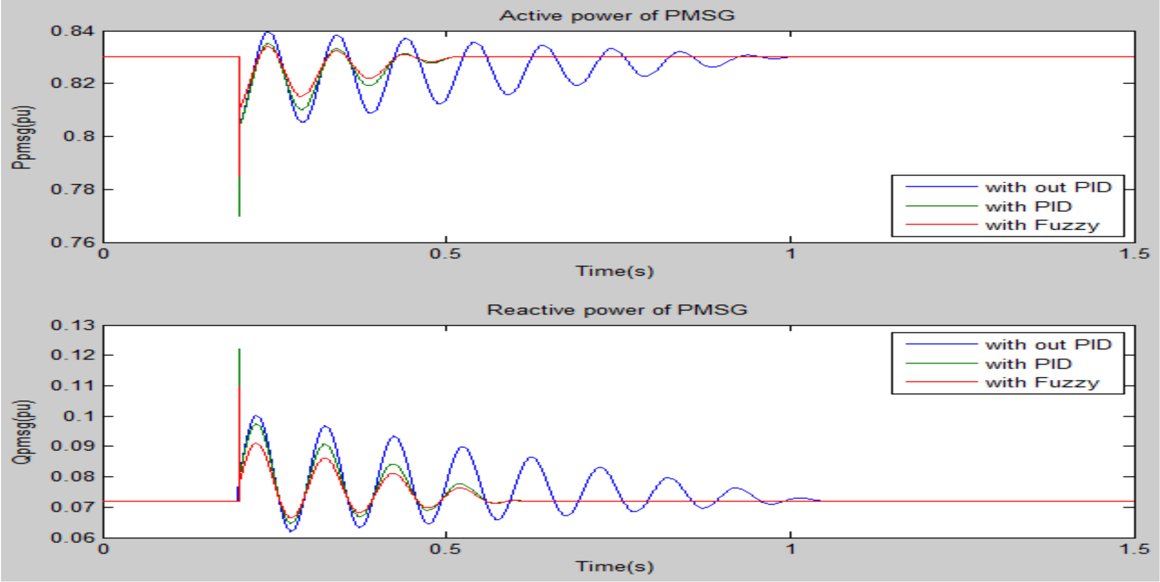

Fig. 10 P and Q supplied by PMSG

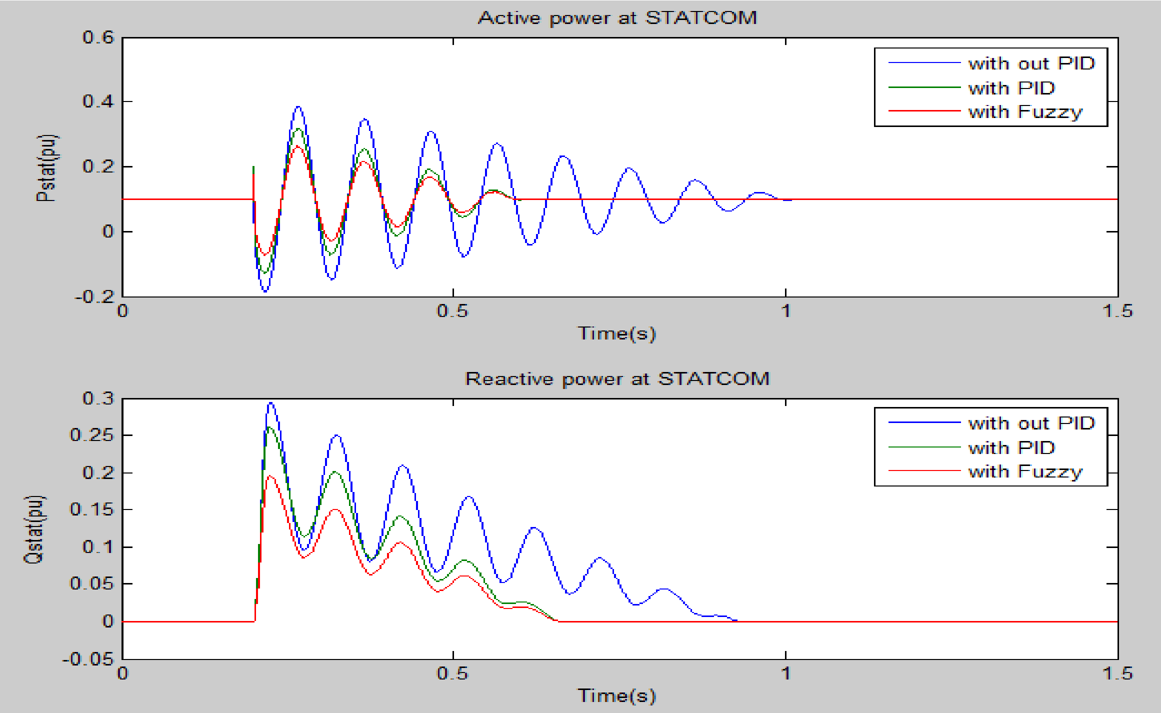

Fig. 11 P and Q supplied by STATCOM

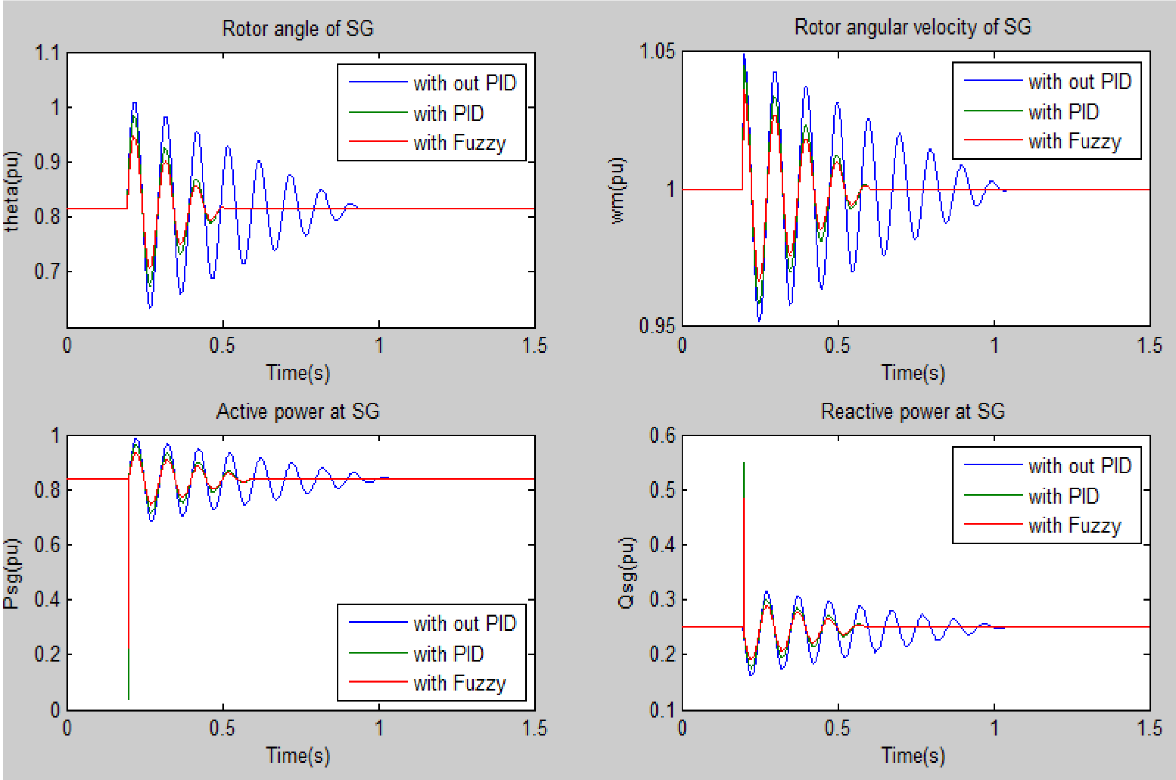

Fig. 12 rotor angle, angular velocity, P and Q of synchronous generator

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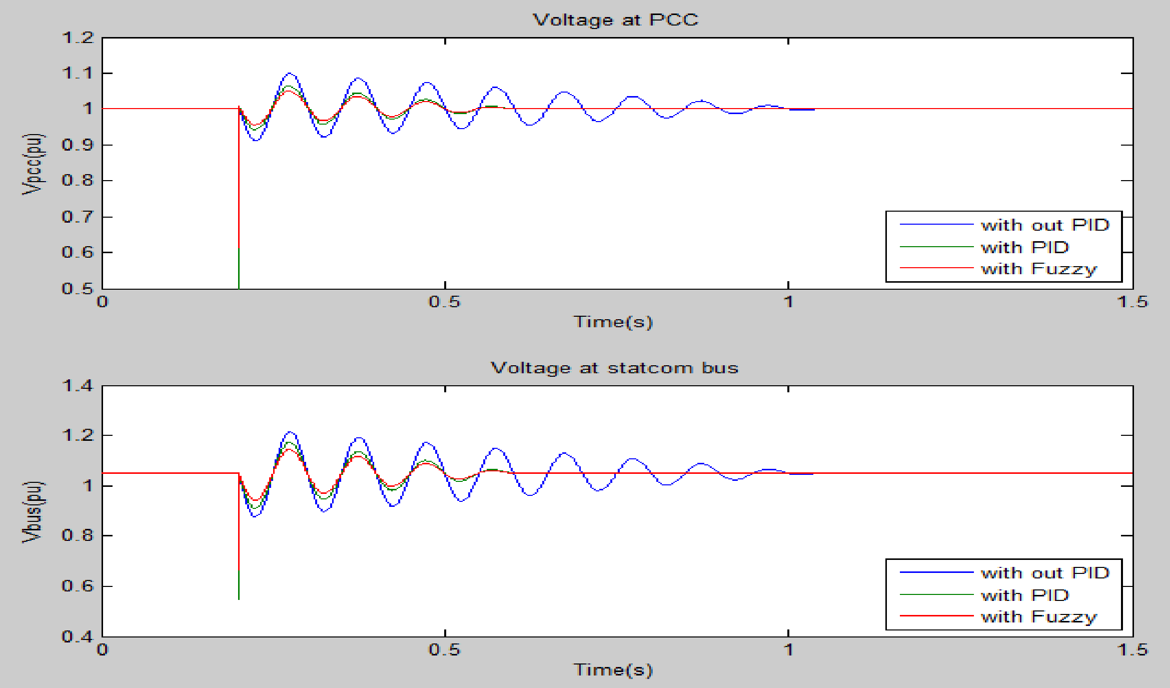

Fig. 13 Voltages at the PCC and STATCOM buses

By observing the all the above results, the system is disturbed by applying the fault at t=0.2s and cleared at t=0.21s. The reactive power demanded by the system during the fault is supplied by STATCOM. The outputs with fuzzy logic controller have the low magnitude of oscillations compared to the PID controller. Not only the reactive power but also the system voltage became steady at t=0.6s using the FLC and the synchronous generator rotor angle oscillations are reduced with the proposed STATCOM controllers.

VI.CONCLUSION

This paper has presented the dynamic stability improvement of an offshore wind farm using a STATCOM. The STATCOM controller is implemented with PID controller and Fuzzy logic controller. The three phase short circuit fault at the wind farm has been performed to demonstrate the effectiveness of proposed controllers. By observing the results with both the controllers, the Fuzzy logic controller has better performance with small oscillations compared to PID controller for the proposed system. So FLC is best choice than conventional PID controller for the studied system.

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