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A Fuzzy Logic Based Grid Connected Offshore Wind Farm Using STATCOM

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ABSTRACT: DFIG (Doubly Fed Induction Generator) based wind farm is gaining popularity these days because of its inherent advantages like variable speed operation and independent controllability of active and reactive power over conventional Induction Generators. When interconnected into power grid, it brings voltage stability problems during grid-side disturbances. So integration of DFIG-based wind farm to power grid is major concern for power system engineers today with the recent grid code requirements. This paper examines the use of Static Synchronous Compensator (STATCOM) as a dynamic reactive power compensator at the point of common coupling tomaintain stable voltage by protecting DFIG-based wind farm interconnected to grid. It can be concluded from the comparative simulated results that the proposed STATCOM joined with the designed hybrid PID plus FLC is shown to be superior for improving the stability of the studied system subject to a severe disturbance than the PID controller.

KEYWORDS: DFIG, Static Synchronous Compensator, offshore wind farm, PID, FLC.

I. INTRODUCTION

Emerging environmental concerns and attempts to curtail dependency on fossil fuel resources are bringing the renewable energy resources to the mainstream of the electric power sector. Among the various renewable resources, wind power is the most promising from technical and economical prospects. In recent years there has been a continuous increase in installed wind power generation capacity throughout the world. At the same time, grid interconnection of wind farm is the faster rate of growth than any form electricity generation. It is the result of latest technological advancements in wind energy conversion and the increased support from government and private institutions. With the increased penetration level of wind farm, the performance of the power system is degrading. Voltage instability problems occur in power system that can't supply the reactive power demand during disturbances like faults, heavy loading and voltage swelling/sagging [6]. This problem is more severe in case of weak power grids. Typically most wind farms are usually located at remote places, driven by wind and weather patterns with little up-front analysis performed regarding the existing power grid in that location. Such locations tend to be weaker points in the disturbance system which means they require special consideration in connecting wind farms to the grid [8].

II. DFIG-BASED WIND FARM

Wind farm in this paper consists of Doubly Fed Induction Generator i.e. DFIG [4], [5]. The DFIG is Wound Rotor Induction Generator with the stator windings directly connected to the constant-frequency three-phase grid and the rotor windings is fed by the rotor side converter (RSC) and the grid sideconverter (GSC) connected back-to-back as shown in theFig.1 below. RSC independently regulates stator active andreactive powers where as GSC keeps the DC link voltage constant independent of magnitude and direction of the rotor power. Generation of power at variable speeds ranging from sub-synchronous speed to super-synchronous speed can be achieved using DFIG leading to higher energy yield. DFIG wind turbines are nowadays more widely used especially in large wind farms because of their ability to supply power at constant voltage and frequency while the rotor speed varies. Currently many operators prefer unity power factor operation since it is the active power production that is rewarded. Reactive power is produced only if there are sufficient financial incentives although DFIG has the capability to control the overall system power factor within its capacity as its active and reactive power output can be controlled independently. The DFIG has some

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demerits during grid faults. DFIG stator is connected directly to the grid. So during grid fault, some undesirable high current may be induced in the rotor windings and the protection system may block RSC. DC-link capacitor voltage reaches high level during low terminal voltage because fault makes active power unbalance between RSC and GSC higher. As a result, utilities disconnect the DFIG immediately for its protection.

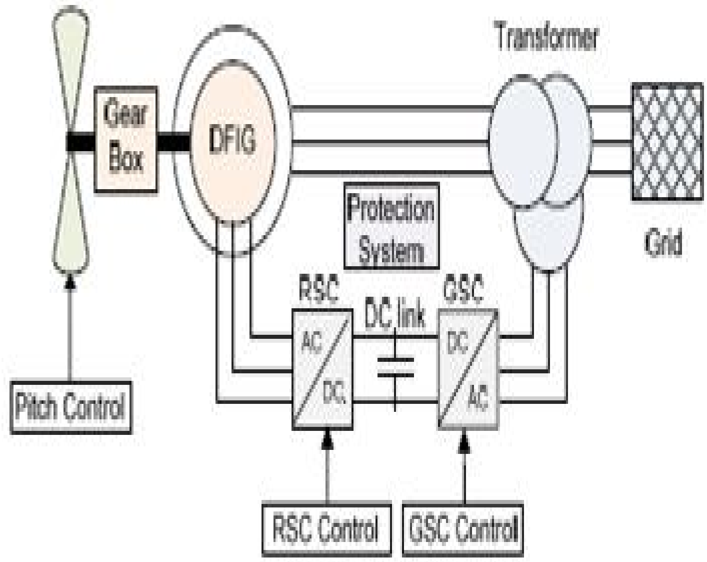


Fig.1 Typical Layout of DFIG

III. STATCOM

Static Synchronous Compensator (STATCOM) is a Flexible AC Transmission System (FACTS) device [2], [3]. It consists of a Voltage Source converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. It can continuously generate or absorb reactive power by varying the amplitude ofthe converter voltage with respect to the line bus voltage so that a controlled current flows through the tie reactancebetween the STATCOM and the distribution network. This enables the STATCOM to mitigate voltage fluctuations such as sags, swells, transient disturbances and to provide voltage regulation[9]. STATCOM is used extensively in power systems because of its ability to provide flexible voltage control [7]. STATCOM is the best option for dynamic compensation of reactive power because at voltages lower than the normal voltage range, the STATCOM can generate more reactive power than other FACTS devices like SVC. This is due to thefact that the maximum capacitive power generated by aSTATCOM decreases only linearly with voltage (at constant current) but it drops off as square of voltage for SVC. In addition, the STATCOM normally exhibits a faster response as it has no delay associated with the thyristor firing. Low cost Mechanically Switchable Capacitor (MSCs) can boost the steady state voltage but is ineffective to suppress voltage fluctuations (seconds to minutes) due to their slow dynamic response, a small rating STATCOM if combined with MSCs can not only suppresses voltage fluctuations but also reduce the operation times of MSCs so that maintenance and replacement cost of MSCs would be reduced. The general layout and equivalent circuit diagram of STATCOM is shown in Fig. 2

The real and reactive power injected by the STATCOM is given by following equations-

$$P = \frac{V_1 V_2 \, Sin\,\delta}{X}; \qquad Q = \frac{V_1 (V_1 - V_2 \, Cos\,\delta)}{X} \tag{1}$$

Provided that δ is angle of V_1 with respect of V_2.

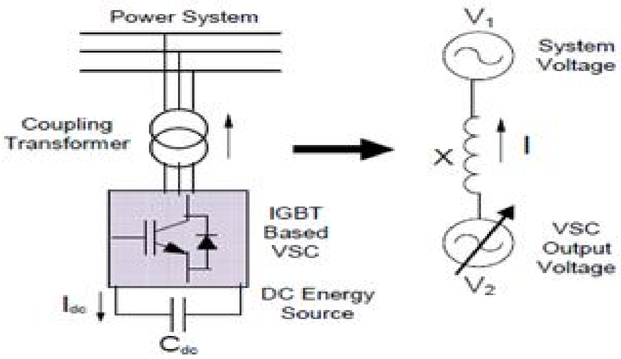


Fig.2 Equivalent Circuit of STATCOM

IV. THREE MACHINE NINE BUS SYSTEM

The well-known three machine nine-bus power system which is widely used in power system stability studies was shown in Fig.3. The complete parameters of this system may be referred to[15].

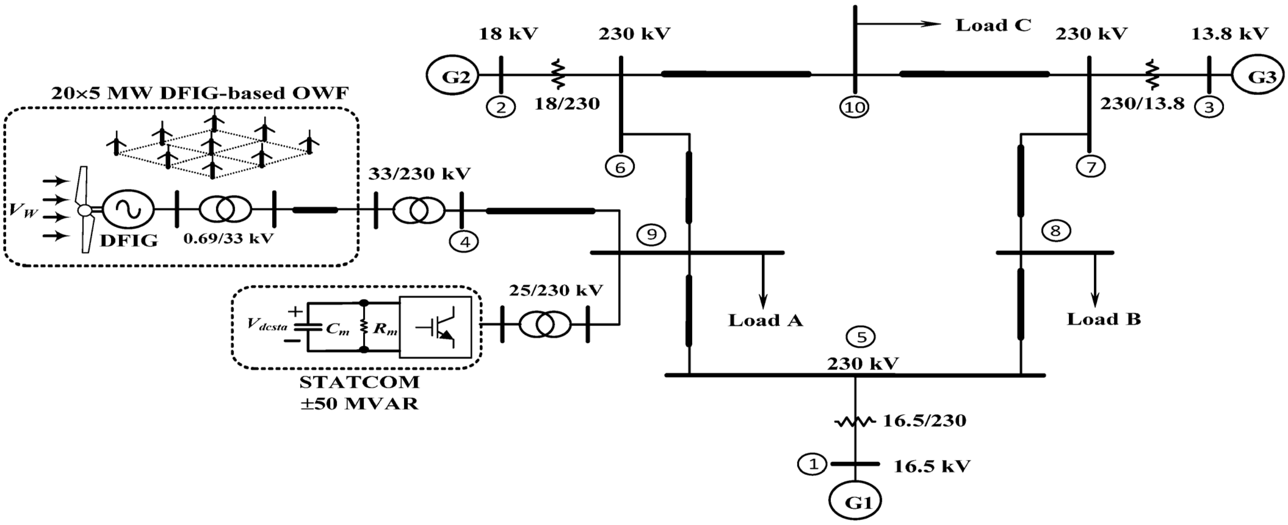


Fig.3 Configuration of the Studied System.

IV. DESIGN OF DAMPING CONTROLLERS FOR STATCOM

A. Design of a PID damping controller (Fig.4):

This subsection describes the design procedure and design results of the PID damping controller for the proposed STATCOM to achieve stability improvement of studied system [12], [13]. The transfer function H(s) of the PID damping controller for the STATCOM in s domain is given by

$$H(s) = \frac{U(s)}{Y(s)} = \frac{V_{CS}(s)}{\Delta\omega_{12}(s)} = \frac{sT_W}{1+sT_W}(K_P + \frac{K_I}{s} + sK_D) \quad (2)$$

where T_W is the time constant of the wash-out term while K_P, K_I, and K_D are the proportional gain, integral gain,and derivative gain of the damping controller,respectively.

Parameters of the Designed PID Damping Controller

K_P = -47.21, K_I=-183.23, K_D=-33.36

B. Design of an FLC plus to the Designed PID [11]:

This section employs the technique of FLC theorem to designthe hybrid PID plus FLC damping controller. To design the FLC controller, the following fundamental design steps for a FLC are employed and referred to [9] including: 1)fuzzification (FI), 2) decision-making logic (DML),3) defuzzification (DFI), and 4) knowledge base (KB). The rotor-speed deviation between G1 and G2, $\Delta\omega_{12}$, and its derivativep$(\Delta\omega_{12})$ .are fed to the FLC to generate three auxiliary gains (K_P ,K_I , and K_D) for adding to the three gains of the designed PID controller(K_P ,K_I , and K_D) in the previous subsection to control the phase angle of the STATCOM.These incremental gains from the FLC are updated to the gains of the PID controller using the following rules [14]:

$$K_{ph} = K_p + K_p'(3)$$

$$K_{ih} = K_i + K_i' \qquad (4)$$

$$K_{dh} = K_d + K_d'(5)$$

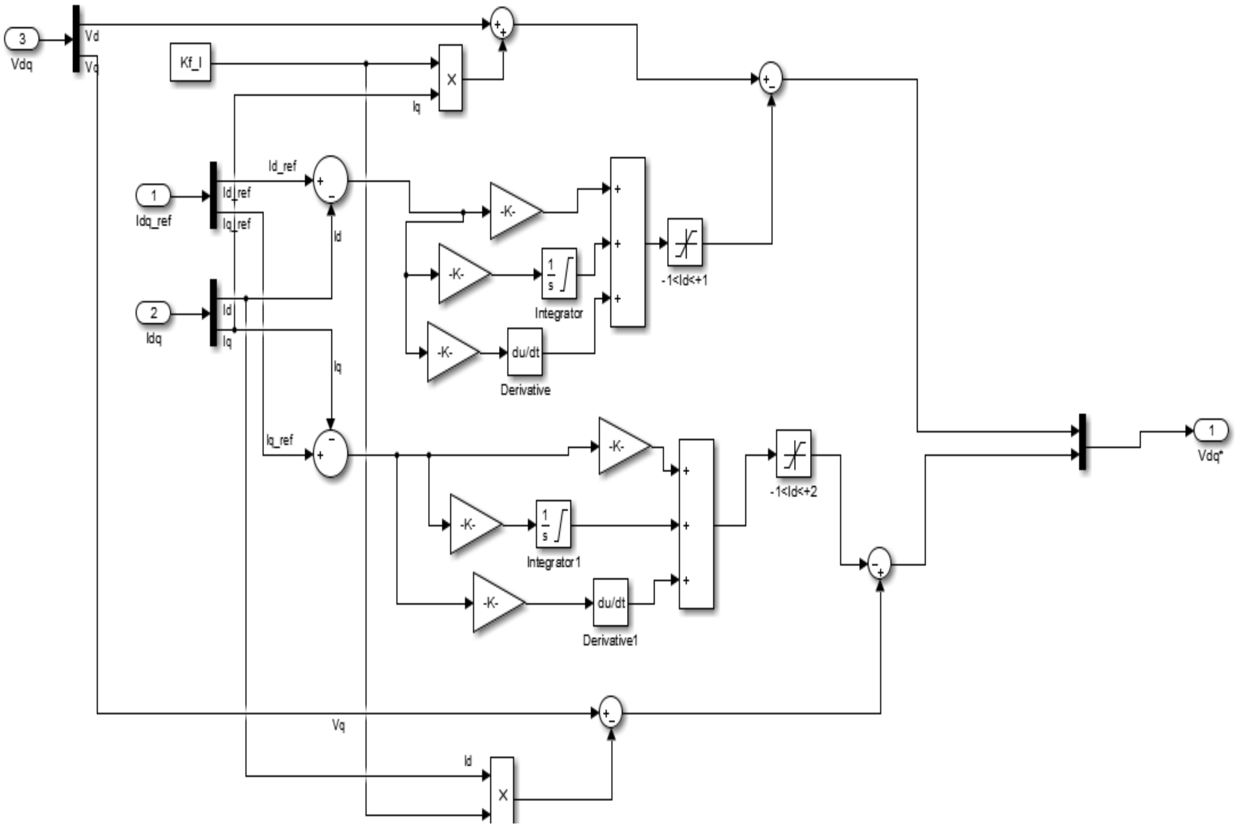


Fig.4 Simulink block of designed PID

The block diagram of proposed hybrid PID plus FLC is shown in Fig.5

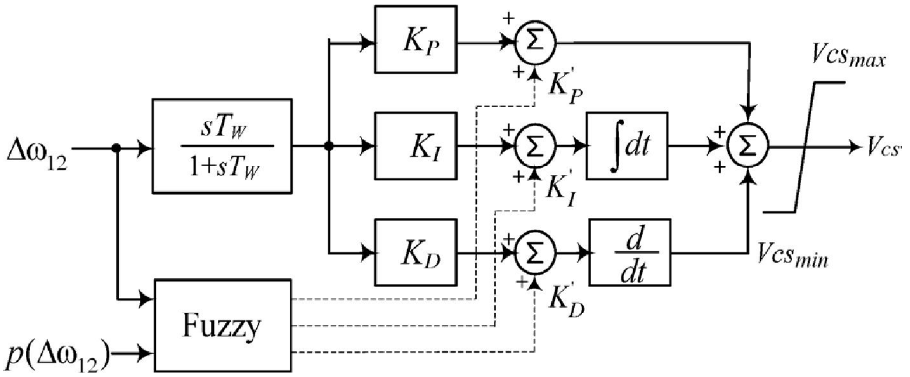
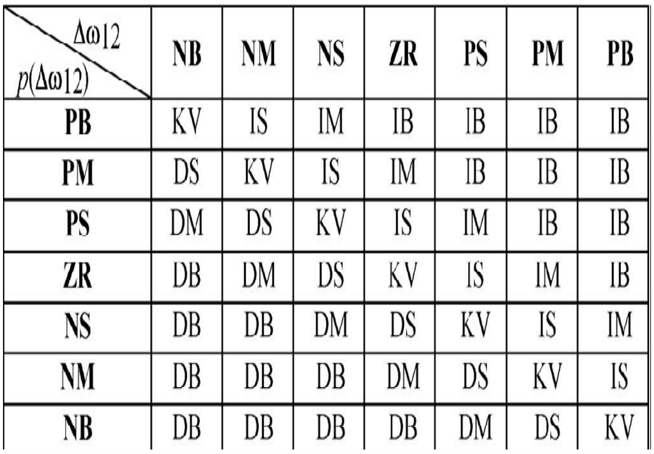


Fig.5 Hybrid PID plus FLC

This paper utilizes the Mamdani-type fuzzy inference system since it works well with linear, optimization, and adaptive techniques [14]. Seven linguistic variables for each input variable are used. These are NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZR (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). There are also seven linguistic variables for output variable, namely, IB (Increase Big), IM (Increase Medium), IS (Increase Small), KV (Keep Value), DS (Decrease Small), DM (Decrease Medium), and DB (Decrease Big). The control rules subject to the twoinput signals and the output signal are listed in Table I.

TABLEI
Control Rules of The Studied FLC



$\Delta\omega12$ / $p(\Delta\omega12)$	NB	NM	NS	ZR	PS	PM	PB
PB	KV	IS	IM	IB	IB	IB	IB
PM	DS	KV	IS	IM	IB	IB	IB
PS	DM	DS	KV	IS	IM	IB	IB
ZR	DB	DM	DS	KV	IS	IM	IB
NS	DB	DB	DM	DS	KV	IS	IM
NM	DB	DB	DB	DM	DS	KV	IS
NB	DB	DB	DB	DB	DM	DS	KV

V. RESULTS AND DISCUSSION

The performance of the studied system subjected to a three phase fault was observed in the presence of PID based STATCOM and is compared with that of without STATCOM. It was observed that system performance with respect to steady state and transient stability was improved with PID based STATCOM. And the corresponding waveforms were observed in MATLAB/SIMULINK environment are shown below.

A. System Performance without STATCOM

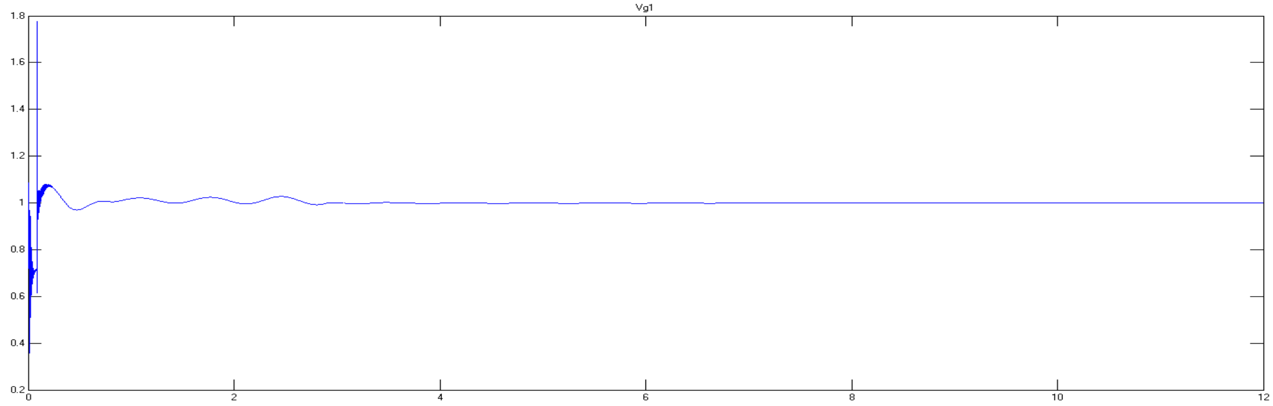


Fig.6 Generator1 Terminal Voltage

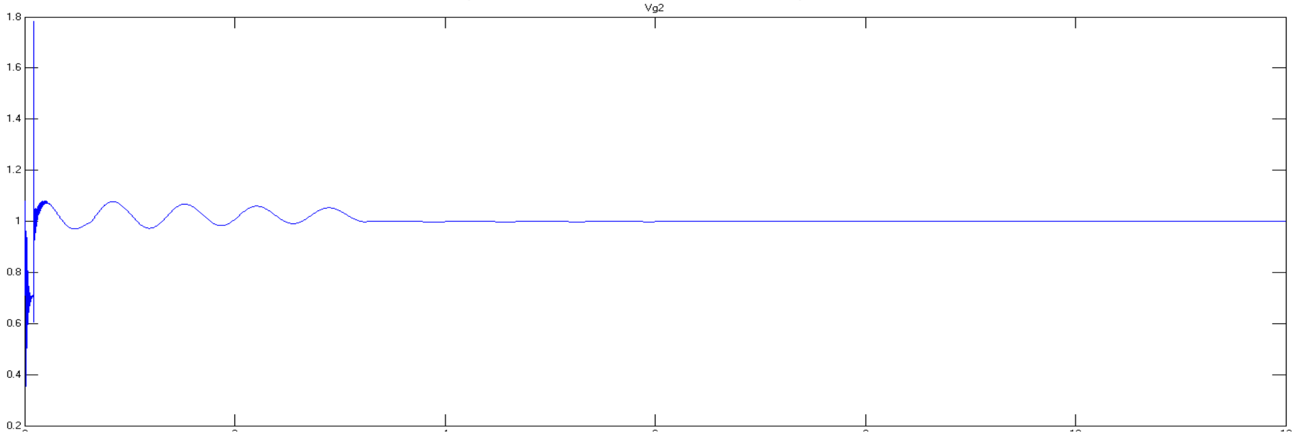


Fig.7 Generato2 Terminal Voltage

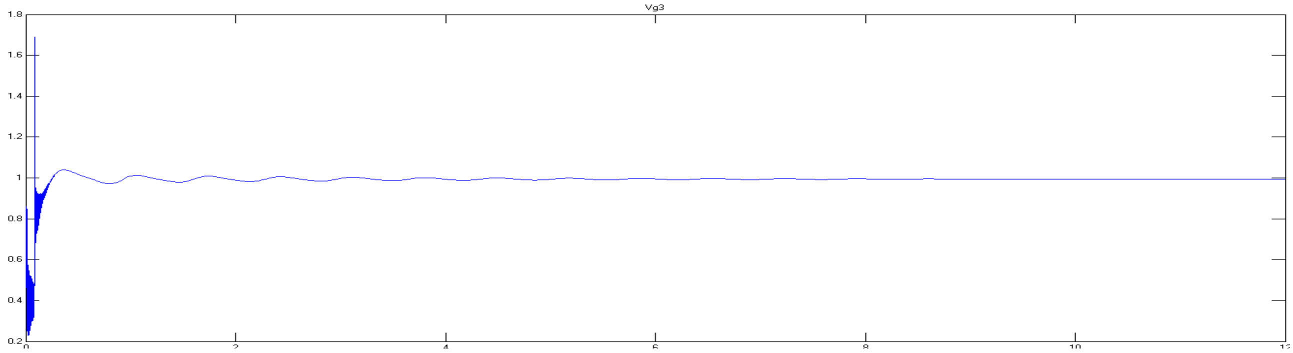


Fig.8 Generato3 Terminal Voltage

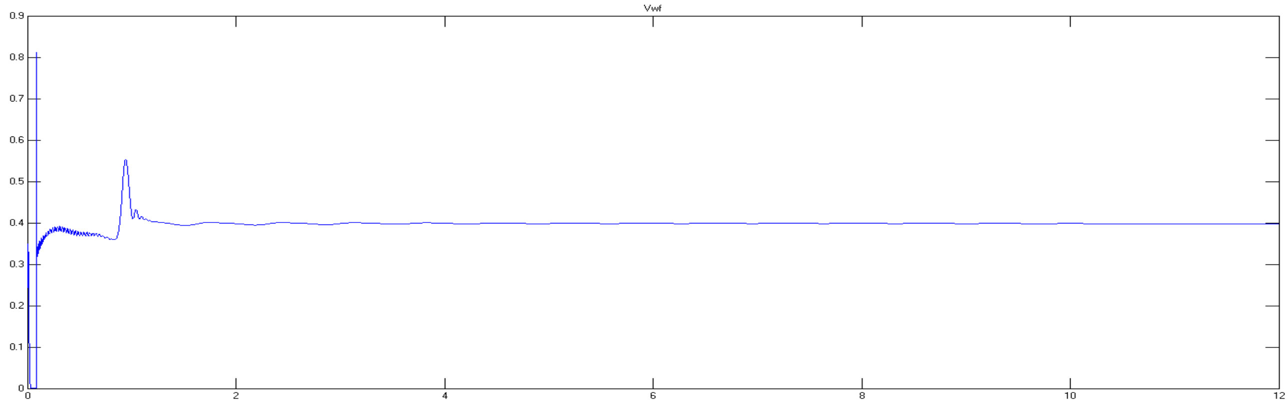


Fig.9 Wind Farm Terminal Voltage

From figures (6 -9), the terminal voltages of the three generators and wind farm have been shown and the performance is analysed without using STATCOM.

B.System Performance with STATCOM

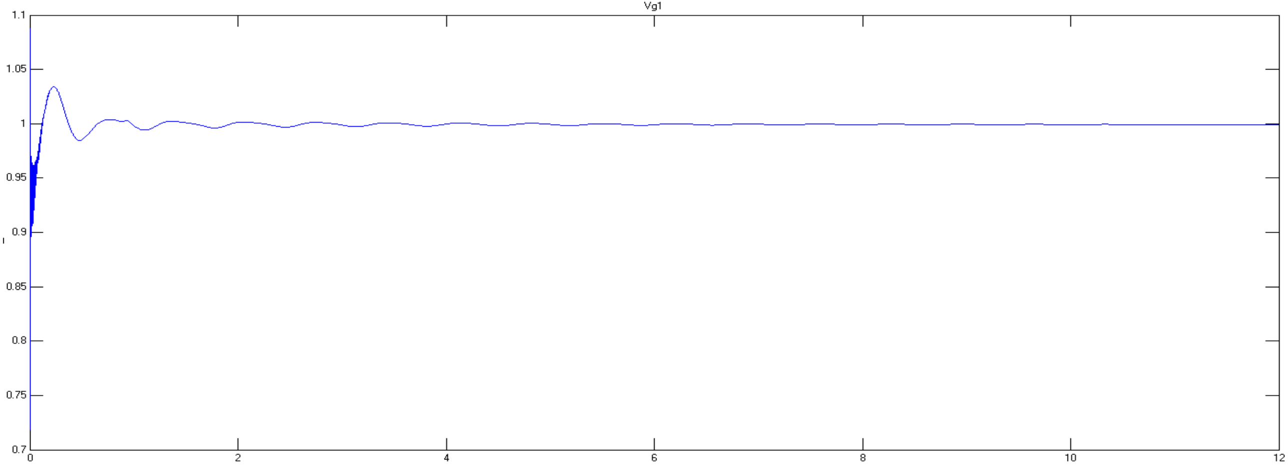


Fig.10 Generato1 Terminal Voltage

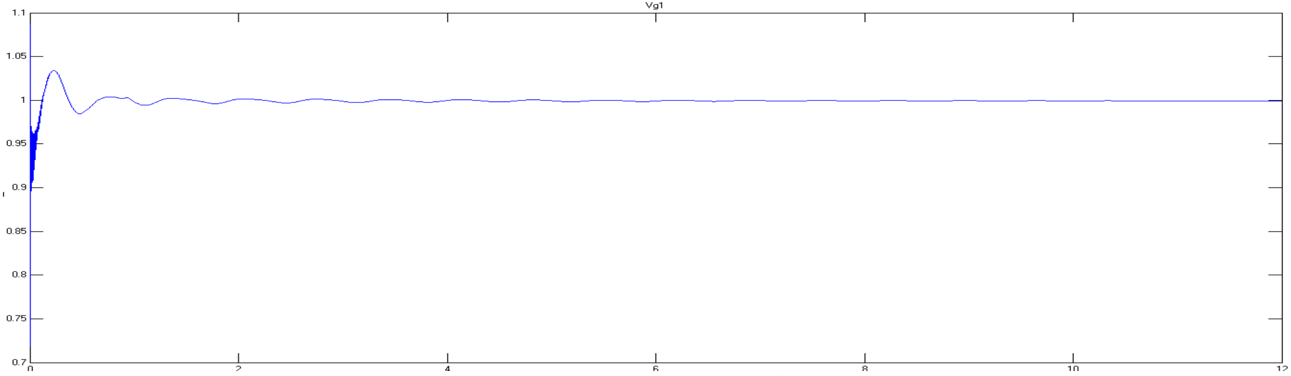


Fig.11 Generato2 Terminal Voltage

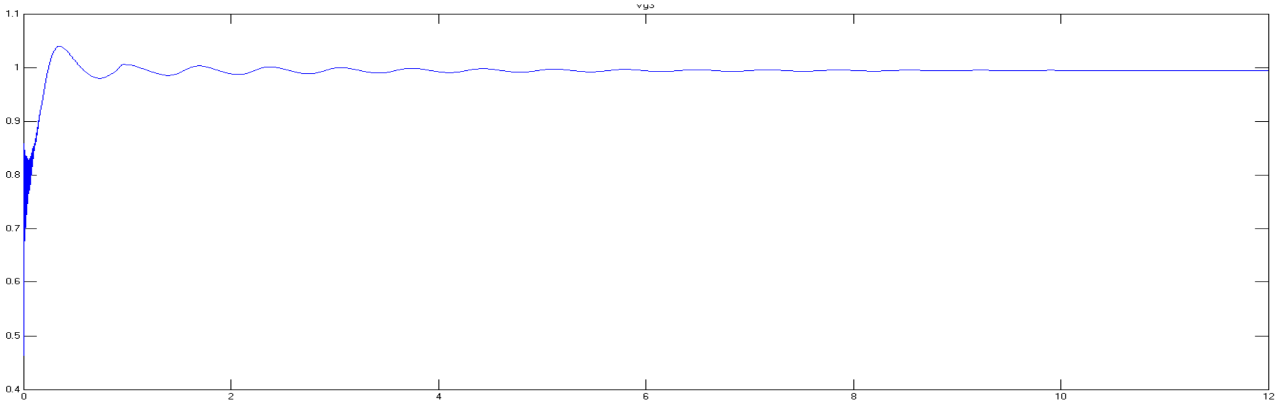


Fig.12 Generato3 Terminal Voltage

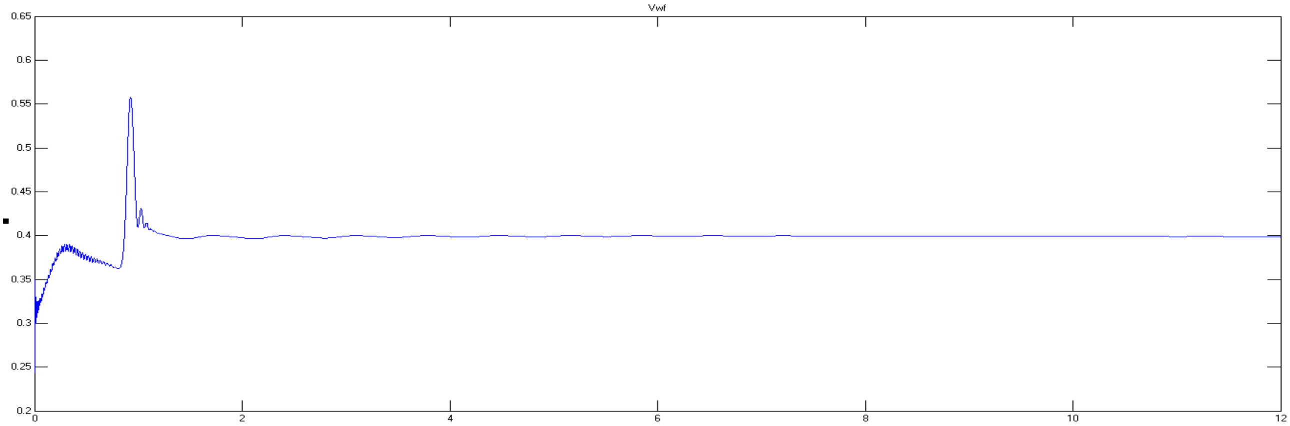


Fig.13 Wind Farm Terminal Voltage

From figures (10 -13), the terminal voltages of the three generators and wind farm have been shown and the performance is analysed by using STATCOM. The corresponding waveforms have been compared with tha of the system performance without SATATCOM.

V. UPFC BASED CONTROLLER

Among a variety of FACTS controllers, Unified Power Flow Controller (UPFC) is the most powerful and versatile device. The UPFC is a device which can control the flow of real and reactive power by injection of a voltage in series with the transmission line. Both the magnitude and the phase angle of the voltage can be varied independently.

The performance of the studied system is analysed with UPFC based controller and the corresponding results have been observed in MATLAB/SIMULINK environment.

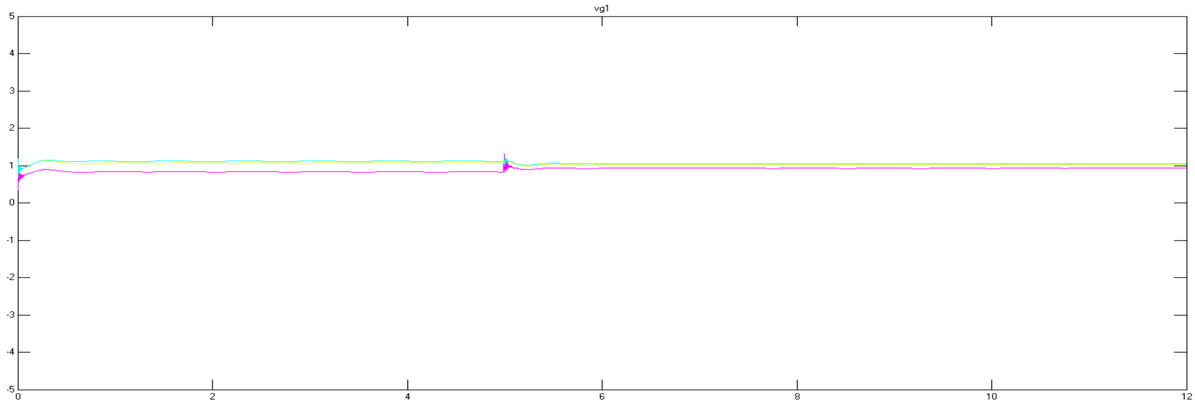


Fig.14 Generato1 Terminal Voltage

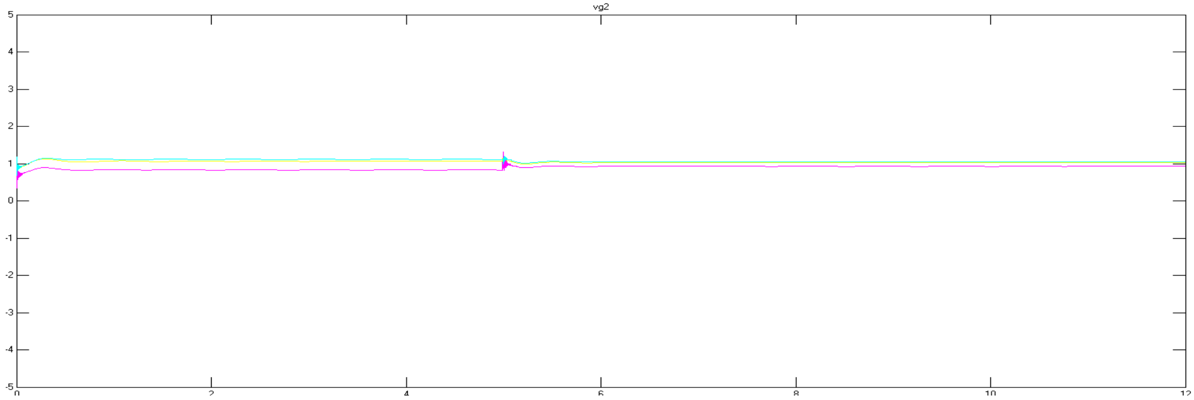


Fig.15Generato2 Terminal Voltage

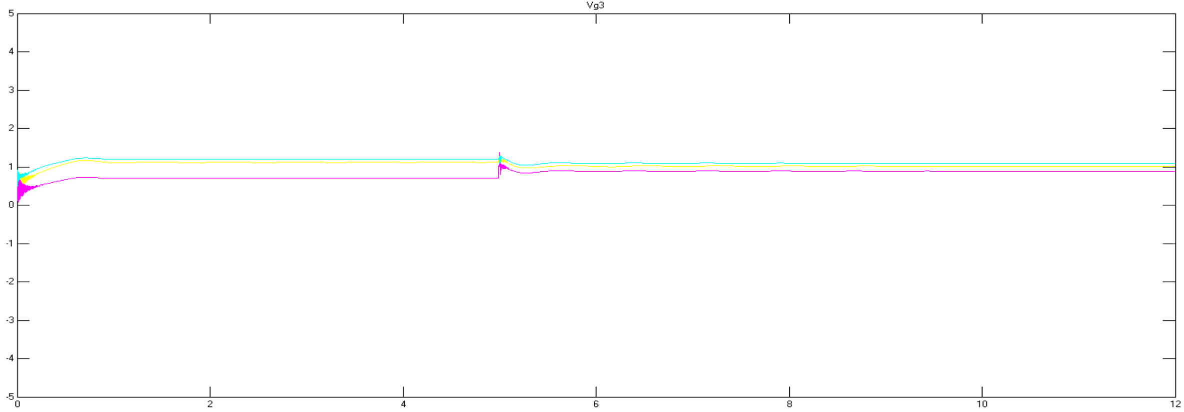


Fig.16 Generator3 Terminal Voltage

From figures (14 -17), the terminal voltages of the three generators and wind farm have been shown and the performance is analysed by using UPFC. The corresponding waveforms have been compared with that of the system performance with and without STATCOM.

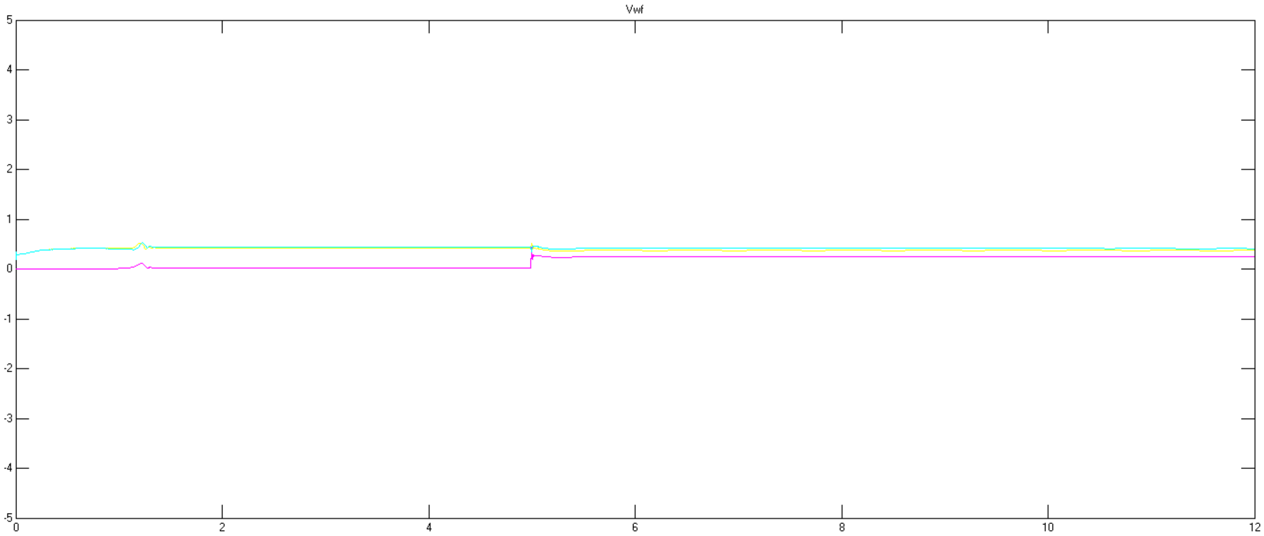


Fig.17 Wind Farm Terminal Voltage

VI. CONCLUSION

In this paper, the simulation results using a Static Synchronous Compensator (STATCOM) to achieve damping improvement of wind farm fed to a multi machine system is presented. A PID damping controller and a hybrid PID plus fuzzy logic controller (FLC) is designed to improve damping of the system. The performance of the system with Unified Power Flow Controller (UPFC) is also investigated.

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