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LFC of DFIG based Two Area System using TCPS, SSSC and SMES

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Abstract : The frequency and tie-line power in a system varies as the load changes. Therefore in order to damp the frequency, Load Frequency Control (LFC) is used. The function of the LFC is to minimizes the transient deviation and to make the steady state change in frequency, zero. This paper presents a Load frequency control (LFC) of Doubly Fed Induction Generator (DFIG) based two area system using Thyristor Controlled Phase Shifter (TCPS), Static Synchronous Series Compensator (SSSC) and Superconducting Magnetic Energy storage (SMES). Flexible AC Transmission Systems (FACTS) devices and SMES are used to damp out the frequency oscillations effectively in a power system. In order to maintain the system frequency at nominal value and the oscillations to settle down quickly a fast acting controller is desirable. In this paper a MATLAB based PID controller has been proposed in order to minimize the damping oscillation of the two-area interconnected power system. The results obtained with various combinations are presented and the results were encouraging.

Keywords: Load frequency control, Flexible AC Transmission System, Superconducting Magnetic Energy storage, Tuning of PID

I. INTRODUCTION

Power system is operated as an interconnected electric power system. The main objective of the interconnected power system is to satisfy the power balance equation i.e. the power generated should be equal to the demand and the loss, and thereby to maintain the frequency and voltage within a nominal value. The fulfillment of the objectives is of concern as the load in the power system varies continuously. The change in the load causes imbalance between the demand and the generation of the system, which leads to the frequency and voltage variation. The change in the load leads to the change in voltage magnitude and frequency. So in order to maintain the frequency in the power system within the tolerable limits Load Frequency Control (LFC) is used. The objective of the LFC is to maintain zero steady state error for frequency deviation and to track the frequent change in load demands. The main goal of the LFC is to maintain the frequency of each area and the tie-line power flow by adjusting the generation of the power [1, 2].

In today's scenario, renewable energy becomes a major player in the generation of the electric power. In which wind power generation on power networks contribute more for the network support and operation [3]. The converters used in wind energy have no contribution to the automatic Governor Control (AGC). But the influence of large wind power generation in the system influences the system inertia and robustness of frequency responses. A Wind Turbine based Generation System (WTGS) consists of a wind turbine, an electric generator and various control systems. The use of a DFIG on a wind turbine improves the efficiency of energy transfer from the wind. It also provides a significant contribution to network support and operation considering voltage control, transient performance, and damping [4]. Now days, multi-wind turbine generators are more preferred as it has high load withstanding capability and the cost of converter is less. In DFIG, the real power output from the stator and the grid side controller maintains the frequency. The DFIG can operate in both sub and super-synchronous modes with a rotor speed range nearer to the synchronous speed. In case of DFIG based power system the frequency is affected not only because of the load deviations, but also due to the varying wind speed. So in order to maintain the voltage and frequency due to load variations, LFCs are incorporated to the wind generator.

When load changes, primary control and secondary frequency control are used in order to achieve a fast response. Primary and secondary controls of LFCs are not only sufficient to maintain the electromechanical dynamics when the frequency deviations are high. Hence FACTS devices are incorporated to achieve fast response, better frequency stability and good tie-line power transfer. FACTS devices like Static Synchronous Series Compensators (SSSC), Thyristor Control Phase angle Stabilizer (TCPS) and Energy storage devices like Superconducting Magnetic Energy Storage system (SMES) are used [4]. Coordination of TCPS, SSSC and SMES are used to attain better stability margin of the frequency [5]. The devices controls the generator phase angle jumps and share the real power among tie-lines and the generators.

The performance of the FACTS incorporated power system can be further enriched by adding PID controllers which are commercially used are required. Still more than 90% of the industries use PID controllers because of their simplicity and clear functionality. The PID controller parameters are tuned for different control response and the response can be enhanced [6]. Many practitioners have stated that PID controllers tuned using conventional techniques are not robust.

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In this proposed work, MATLAB based tuning is used which gives better performances of dynamic responses.

II. TWO AREA POWER SYSTEM AND DFIG

The two area power system considered for study consists of two single area systems connected with a tie-line. The two areas are closely coupled electrically and they swing in unison. In a two area system, the individual areas are strong; but the tie line is weak. Each area has governor, turbine, generator and the power system. The generation is controlled by the opening and closing of the valve which is governed by the governor with a command ΔP_c. The linearized model of governor, turbine and generator are considered in this paper.

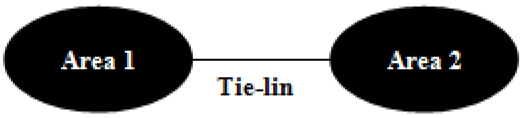

Fig. 1. Two Area Power Systems

The DFIG is a variable speed machine which delivers power to the grid through rotor and stator connected to the grid. The stator is connected directly to the grid, whereas the rotor is connected to the grid through a converter. DFIG with wound rotor induction generator is generally preferred. The advantages of DFIG with wound rotor are: (i) It can produce power for irregular mechanical wind turbine speeds; (ii) It can import and export reactive power which enhances the system stability [7, 8]. A dynamic model of DFIG based wind turbine control is considered in this paper. The controller generates a signal and provides a power set-point $\Delta P\omega^*$, which is based on speed and power. The change in the power set point is given by,

$$\Delta P_f^* = -K_{df}\frac{df}{dt} - K_{pf}\Delta f \qquad (1)$$

Where, K_{df} is a constant which weighs the frequency deviation and it controls the inertia constant; K_{pf} is a constant which provides the system damping. The response of the primary frequency control depends on the additional control loop when the grid frequency exceeds its limits. When the frequency decreases, the set-point torque increases with the reduction of speed of the rotor and then the kinetic energy increases. The change in power due to the wind source depends on the new reference point which depends on frequency change. The additional reference point by the conventional inertia control (ΔP_f*) and change in power reference point makes the speed to follow a desired speed reference. The constants of PID controller, K_{wp} and K_{wi} provide fast response and transient speed variations.

$$\Delta P_w^* = -K_{wp}(\omega^* - \omega) + K_{wi}\int(\omega^* - \omega)t \qquad (2)$$

The total wind energy power injection (ΔP_{WE}) is the sum of ΔP_f^* and ΔP_w^*. The power balance equation of the DFIG with change in inertia control is given by,

$$\Delta P_g + \Delta P_{WE} - \Delta P_{12} - \Delta P_d = \Delta P_f \qquad (3)$$

III. LINEARIZED MODEL OF SSSC, TCPS AND SMES FOR LOAD FREQUENCY CONTROL

The intrusion of FACTS devices increases the quality of supply and enhances the power system stability with the help of reliable and high speed electronic devices. The main objective of the FACTS devices in the power system is to enhance the power transfer capability and controllability in an ac system. To reduce the system frequency deviation, energy storage system like SMES and battery energy storage systems are also used. In the paper SMES is considered as it reduces the steady state values of time error and unpremeditated interchange aggregation and thereby improves the load frequency dynamics. In this paper FACTS devices TCPS and SSSC and Energy Storage device SMES are considered. The linearized model of TCPS, SSSC and SMES are briefed in this section [9-11].

A. Model of TCPS for LFC

TCPS is connected in series with the tie-line to reduce the frequency oscillations and to improve the tie-line power exchange. The real power flow is regulated to mitigate the frequency oscillations and to enhance power system stability. The error signal of it is the area frequency deviation or the Area Control Error (ACE). The error signal controls the TCPS error signal [12]. Fig. 2 shows the schematic diagram of two area system incorporated with TCPS.

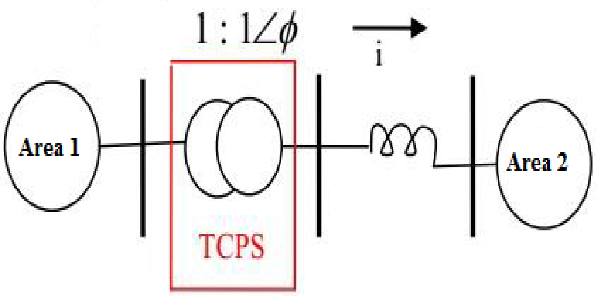

Fig. 2 Schematic Diagram of Two area system with TCPS

The phase shifter angle is given by,

$$\Delta\Phi(s) = \frac{K_\Phi}{1+sT_{TCPS}}\Delta\omega_1(s) \qquad (4)$$

Where, $K\varphi$ is the Gain of the TCPS and T_{TCPS} is the time constant of the TCPS. The tie line power flow equation with the inclusion of the TCPS is given by,

$$\Delta P_{tie12} = \frac{2\Pi T_{12}}{s}\left(\Delta f_1(s) - \Delta f_1(s)\right) + T_{12}K_f\Delta\Phi(s) \qquad (5)$$

When a frequency deviation occurs, a control signal is provided to the TCPS in order to change the TCPS phase angle and thereby control the tie-line power flow.

Now the phase shifter angle is given by

$$\Delta\Phi(s) = \frac{K_\Phi}{1+sT_{TCPS}}\Delta f_1(s) \qquad (6)$$

Change in the tie-line power flow(ΔP_{tie12}) becomes,

$$\Delta P_{tie12} = \frac{2\Pi T_{12}}{s}\left(\Delta f_1(s) - \Delta f_1(s)\right) + T_{12}K_f\frac{K_\Phi}{1+sT_{TCPS}}\Delta f_1(s) \qquad (7)$$

The model of the TCPS in tie-line is shown in Fig. 4.

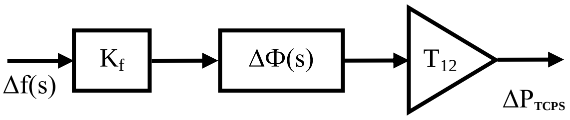

Fig. 3. TCPS model in series with the tie-line

B. Model of SSSC for LFC

Static Synchronous Series Compensator (SSSC) is connected in series with the tie-line and it consists of a series-connected voltage source with a transformer leakage reactance. The SSSC controls the power flow among the two area by shifting its characteristics from capacitive to inductive. In SSSC the output voltage is controlled and the dynamic control of the power flow is achieved. The characteristic of high speed performance makes the SSSC possible in LFC with the conventional governor control.

The linearized model of the SSSC is developed from the characteristic of power flow control. The active power controlled by SSSC is $\Delta P_{SSSC.}$

$$\Delta P_{SSSC} = -\frac{P_{12}}{XI}\Delta V_{SSSC} \qquad (8)$$

where X is the reactance of the tie-line, V_{sssc} is the outpurt voltage of SSSC and I is the current in the tie-line.

The linearized real power flow equation of the tie-line is given by,

$$\Delta P_{tie12} = \frac{2\Pi T_{12}}{s}\left(\Delta f_1(s) - \Delta f_1(s)\right) + \Delta P_{SSSC} \qquad (9)$$

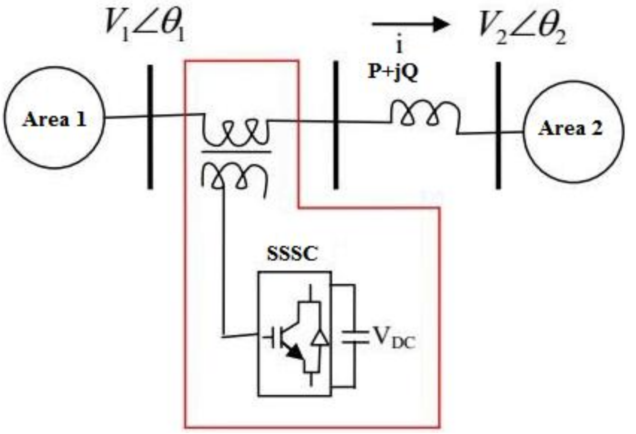

Fig 4. Schematic Diagram of Two area system with SSSC

The structure of SSSC for the frequency stabilization is modeled as a first order controller with gain constant K_{SSSC}, a proportional block with the time constant of T_{SSSC}. The model has a lead lag structure and a two stage phase compensation block along with the first order controller. T_1 and T_2 are the time constants of the phase compensation block and T_3 and T_4 are the time constants to provides the phase-lead characteristics.

$$\Delta V_{SSSC} = \left(\frac{1+sT_1}{1+sT_2}\right)\left(\frac{1+sT_3}{1+s_4}\right)\left(\frac{K_{SSSC}}{1+sT_{SSSC}}\right)\Delta\omega_1(s) \qquad (7)$$

When a frequency change occurs, an error signal is provided to the SSSC unit which in turn makes the SSSC to provide a control voltage V_{SSSC}, and in turn tie-line power flow is controlled. The change in the tie-line power flow with the SSSC is given by,

$$\Delta P_{tie12} = \frac{2\Pi T_{12}}{S}\left(\Delta f_1(s) - \Delta f_2(s)\right) + K_1\Delta V_{SSSC}$$

(8)

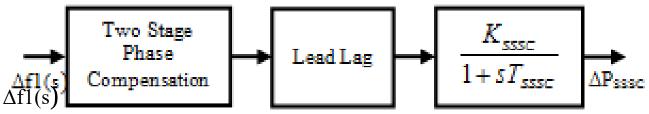

Fig. 5. SSSC model in series with tie line

C. Model of SMES for LFC

Super conducting Magnetic Energy Storage system (SMES) is a energy storage which could store energy in low loss superconducting magnetic coil. SMES is preferred in frequency stability enhancement because of its quick response and long life. In LFC, SMES is used as a frequency stabilizer which have a bidirectional flow of power from and to the grid[14]. The current deviation of the inductor is the negative feedback signal in the control loop and the current is maintained with nominal value. The SMES acts as a second order lag lead compensator. The power exchange in the tie-line with SMES by considering K_{SMES} and T_{SMES} as gain constant and time constant of SMES is given by,

$$\Delta P_{SMES} = K_f\left(\frac{1+sT_1}{1+sT_2}\right)\left(\frac{1+sT_3}{1+sT_4}\right)\left(\frac{K_{SMES}}{1+sT_{SMES}}\right)\Delta f_1(s) \qquad (10)$$

IV. TUNING OF PID CONTROLLER

PID controller is preferred because of its feasibility, easy to us, reduced time constants thus making faster response. The major concern in the PID is to ensure effective tuning. Tuning is done in order to obtain a robust design with desired response. While tuning the PID controller the proportional, integral and derivative parameters are calculated. It is so difficult to find the set of gains for the controller as it is complex. The tuning is done by using traditional tuning methods and various meta-heuristics algorithms, but they are iterative and time consuming. Rule-based methods also have some limitations as they are not suitable for some plants. Tuning makes a perfect balance between the performance and robustness can be obtained. The PID gains are determined based on the response time, bandwidth, transient response and phase margin.

In this paper PID controller of MATLAB simulink is used as the controller [13]. The main objective while tuning the PID controller are to minimize the settling time and to obtain zero steady state error.

The steps involved in the PID controller tuning in simulink are:

i. Open the PID tuner and set the value of P as 1 and D and I as zero. The controller parameter D influences the transient response whereas the I influences the steady state response.
ii. The PID tuner of the MATLAB simulink automatically computes an initial controller by identifying the input and output.
iii. Update the PID controller block and check whether the requirement is met.
iv. If the requirement is not met adjust the response time and transient behaviour slider.
v. Update the PID block controller block.
vi. Obtain the response of the system.

V. RESULTS AND DISCUSSIONS

The system considered for analysis is developed in MATLAB/simulink. The system developed is simulated for 0.01 p.u load perturbation at time, zero seconds and the wind power availability is considered as 0.5 p.u. The investigation is performed under two systems, namely model of the Two Area LFC with DFIG based Wind Turbine System with TCPS/ SSSC /SMEC and the same incorporated with PID controller. The test system models of the two system are provided in Fig. 5 and Fig. 6.

The frequency deviation of Area-1 and Area-2 for the system considered with SSSC is

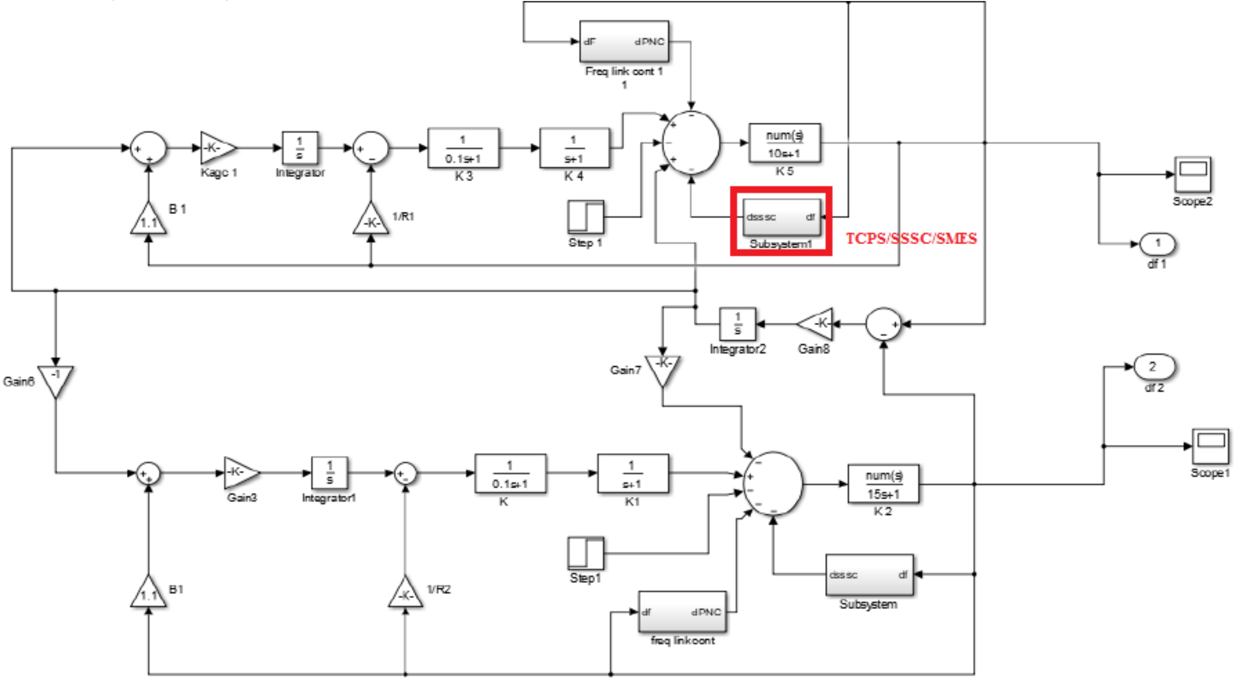

Fig. 5 Model of the Two Area LFC with DFIG based Wind Turbine System with TCPS/ SSSC /SMEC

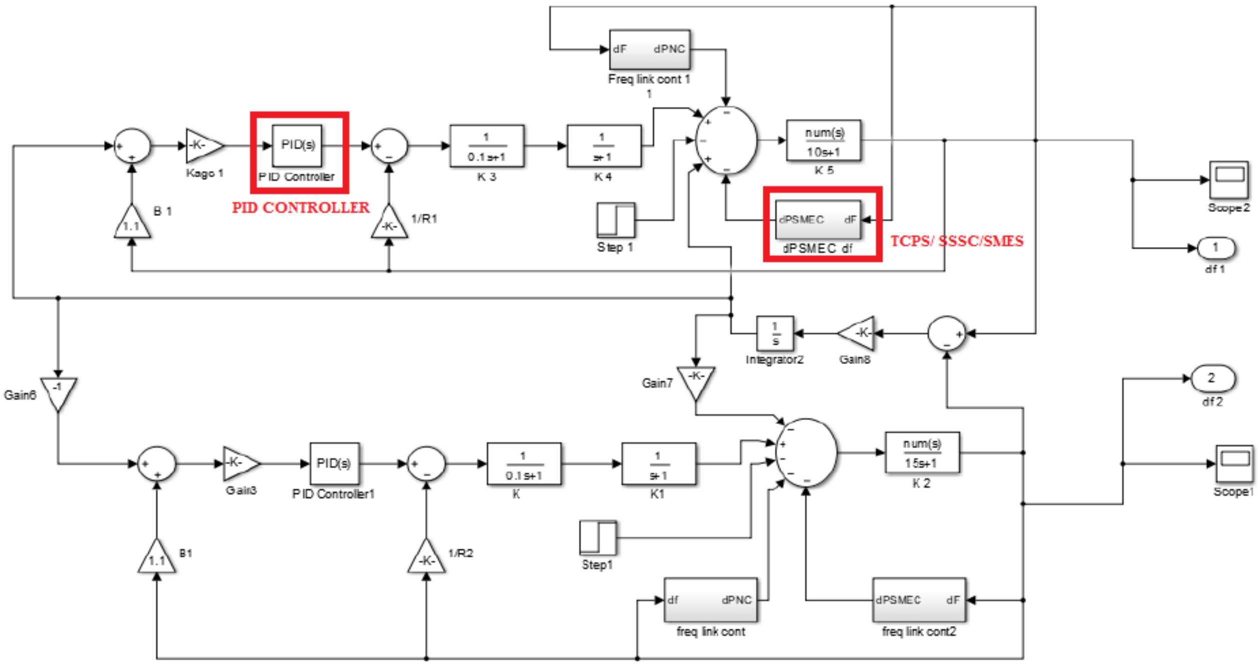

Fig. 6 Model of the Two Area LFC with DFIG based Wind Turbine System with TCPS/ SSSC / SMEC incorporated with PID controller

illustrated in Fig. 7 and Fig.8.From the plot is revealed that the system without a controller and tuned PI is unable provide zero steady state error for the system of consideration. The tuned PD and PID controllers have achieved zero steady state error. The tuned PD has also shown the impact of D in it by reducing the transient behaviour.Though the PID controller has caused high peak overshoot value the settling time has reduced abruptly.

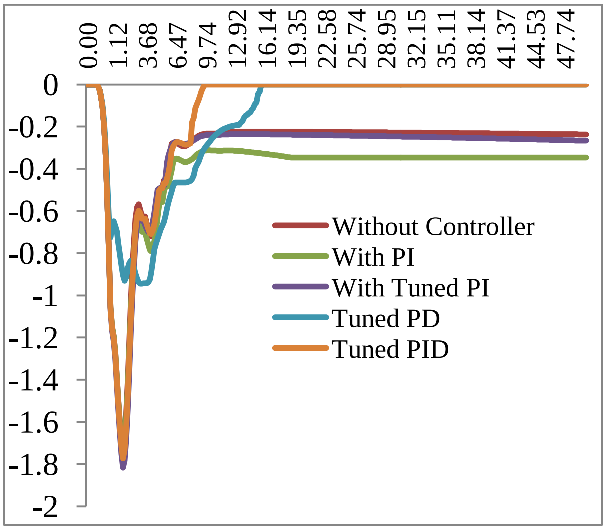

Fig. 7. Frequency deviation of Area -1 with SSSC

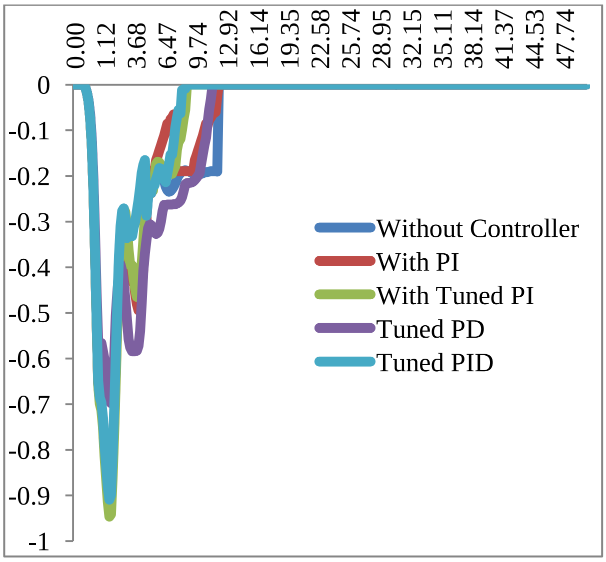

Fig. 8. Frequency deviation of Area -2 with SSSC

The frequency deviation of Area 1 and 2 with the TCSC is provided in Fig. 9 and Fig. 10. The incoporation of TCSC in the system considered causes high fluctuating effect. But the controllers were able to achieve a zero steady state error. Here too the tuned PID controller provided minimal settling time. The peak overshoot value with the TCSC has reduced much to a value of -0.028 whereas it was -0.96 in the case of SSSC. Another major impact of TCSC with the system is the reduced settling time of about 6 secs whereas it is about 12 secs in SSSC.

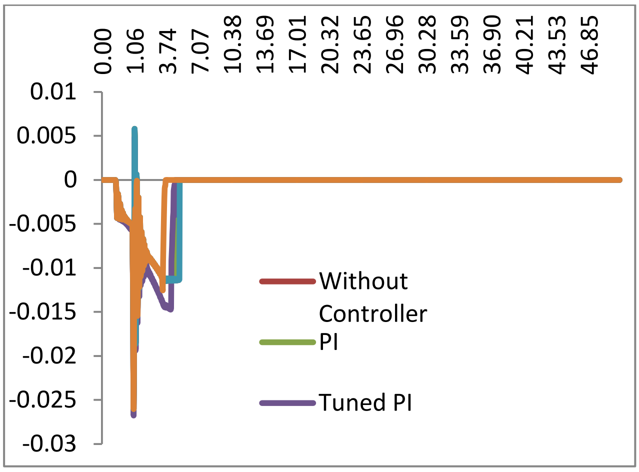

Fig. 9 Frequency deviation of Area 1 with TCSC

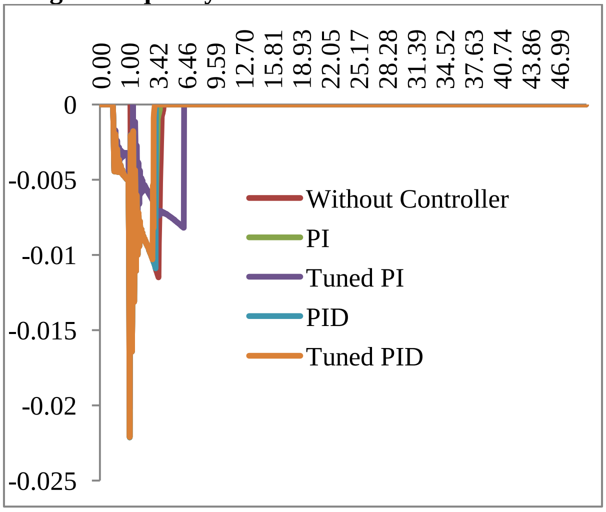

Fig. 9 Frequency deviation of Area 2 with TCSC

Fig. 11 and Fig. 12 depicts the frequency deviations with SMES. The maximum peak overshoots and settling time for the proposed system is -1.2 p.u and 13.5 secs. With the implementation of the tuned PID the settling time has reduced to about 9.10 secs.The implementation of the SMES has damped the frequency oscillations.

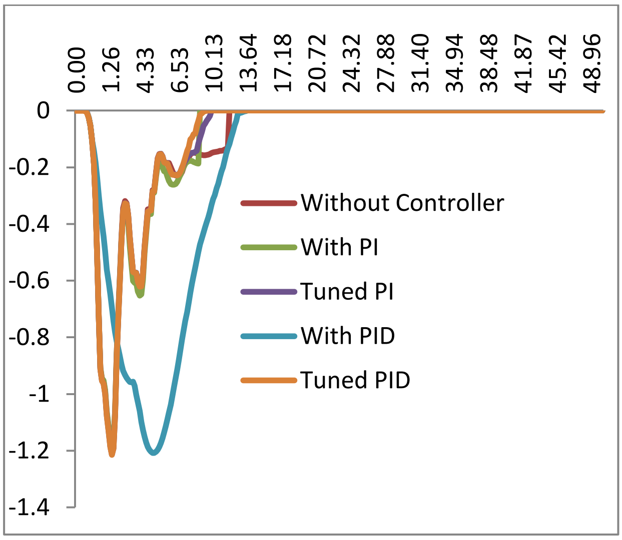

Fig. 10 Frequency deviation of Area-1 with SMES

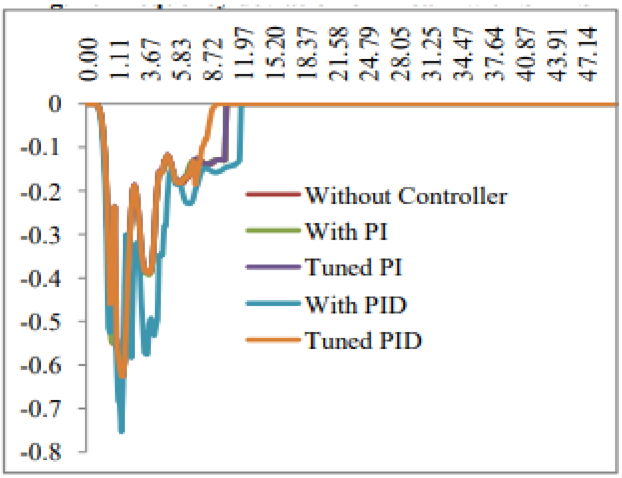

Fig. 11 Frequency deviation of Area-2 with SMES

While considering the performance of the FACTS and SMES with proposed system it was found that TCSC provides a lower peak overshoot and settling time.

The various control parameters of the PID controller is provided in Table 1.

Controller	Parameter	Values		
		SSSC	*TCSC*	*SMES*
P	Kp	0.05	0.05	0.05
PI	Kp	1	1	1
	Ki	0.05	0.05	0.05
Tuned PI	Kp	4.263	2.1358	-2.637
	Ki	0.0079	0.0009	0.0006
PD	Kp	4.623	4.623	4.623
	Kd	0.05	0.05	0.05
Tuned PD	Kp	0.417	0.168	0.0327
	Kd	0.00675	0.0005	0.0004
PID	Kp	1	1	0.05
	Ki	1	1	1
	Kd	0.05	0.05	0.05
Tuned PID	Kp	2.143	0.0643	0.174
	Ki	8.816	-3.892×10^{-7}	8.918×10^{-6}
	Kd	50	-5.365	0.819

The system parameters of the model are provided in Table 2.

System Parameters			
He1	3.5	Tp1	10
He2	3.5	Tp2	15
Kagcl	0.05	Tt1	1
Kagc2	0.05	Tt2	1
Kp1	12	$W_{max.}$ W_{min}	14, 0.0
Kp2	12	B1	1.1
Kwi1	0.1	$P_{max,}$ P_{min}	3, 0.0
Kwi	1.58	K	20.1378
Kwi2	0.1	T1	1.5025
Kwp2	0.161	T2	0.5386
R1	3	T3	0.06268
R2	3	T4	0.05075
Th1	0.1	T_{sm}	10.5
Th2	0.1	K1	20.2188
Tr1	0.1	T_{sm1}	10.2151
Tr2	0.1	Kfi	1.5
Tw1	6	T_{ps}	0.1
Tw2	6	T12	0.86

VI. CONCLUSION

The load frequency control of DFIG based two area load frequency control with FACTS devices like TCPS and SSSC and SMES was dealt in this paper. The frequency deviation of the two areas of the system were analyzed with TCPS, SSSC and SMEC. Then the performance was analyzed by introducing a PID controller. The PID controller was tuned so that the peak overshoot and settling time is reduced. Various plots corresponding to the frequency deviation of both the areas were presented. The system considered, when operated without controller, the peak overshoot value and the settling time were high. But with the intrusion of the PID controller and by tuning it, it is low and oscillation were quiet reduced. It was found that TCPS has better control over than SMES and SSSC in controlling the real power and frequency deviation of the system. It is inferred that D influence the transient behavior of the frequency response and whereas the I influence the steady state response of the LFC. The results can be further tuned using algorithms like fuzzy logic and stochastic algorithms.

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