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A Technique for Enhancement of Power System Dynamic Stability

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ABSTRACT:*This paper presents a technique for power system dynamic stability enhancement. This technique consists of IPFC with Lead-Lag Controller. Low power frequency oscillation has been kept into mind for Power system dynamic stability prospect. SMIB System and Phillip Heffron model of equivalent SMIB System are being used for modelling and analysis purposes respectively.Matlab Simulation provides the time domain analysis of the System.*
Keywords: *IPFC, SMIB, Lead-Lag Controller and Phillip Heffron Model*

I. INTRODUCTION

Power system may be subjected to low frequency disturbances that might cause loss of synchronism and an eventual breakdown of entire system. The oscillations, which are typically in the frequency range of 0.2 to 3.0 Hz, mightbe excited by the disturbances in the system or in some cases, might evenbuild up spontaneously. These oscillations limit the power transmissioncapability of a network and sometimes, even cause a loss of synchronism and an eventual breakdown of the entire system. For this purpose, Power System Stabilizers (PSS) are used to generate supplementary control signals for the excitation system in order to damp these low frequency power systemoscillations.
The use of power system stabilizers has become popular in the form of POD controller. By the virtue of advancement in technology, FACTScontroller replaces the Conventional Power System Stabilizer [1].

In this work, we deal with damping out the low power frequency oscillation. Small deviation (0.01p.u.) in the mechanical power (Mechanical Torque) has taken into consideration for the purpose of analysis. A model of Power System named as "Phillip Heffron Model" has been implemented for the time domain analysis. An Interline Power Flow Controller (IPFC) and Lead- Lag controller have been used as a FACTS controller and supplementary controller respectively.

POWER SYSTEM MODELLING

Fig. 1 shows a single machine infinite bus installed with Interline Power Flow Controller [3] which consists of two, three phase GTO based voltage source converters, each providing a series compensation for the two lines incorporated in the system. VSCs are connected to the transmission line through their series coupling transformers. Hence the configuration allows the control of real and reactive power flow of line 1. Here $m_{1\&}$m2are the amplitude modulation ratio and δ_1 and δ2 are phase angle of the control signal of each VSCs respectively, which are the input control signals of IPFC.V_s, V_b, V_{pq1}, and V_{pq2} are the terminal voltage of generator, voltage of infinite bus, and voltage of VSCs respectively.

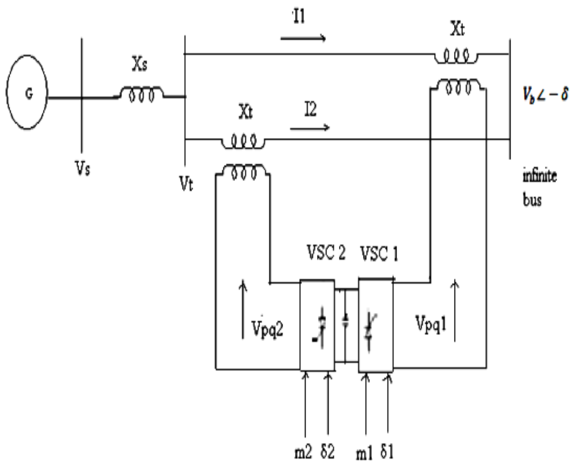

Fig.1: Single Machine Infinite Bus installed with IPFC

Linearized model of SMIB installed with IPFC [2] can be represented as:

$\Delta\dot{\delta} = \omega_0\Delta\omega$

$\Delta\dot{\omega} = (-\Delta P_e - D\Delta\omega)/M$

$\Delta\dot{E}_q' = \left(-\Delta E_q + \Delta E_{fd}\right)/T_{d0}'$

$\Delta \dot{E}_{fd} = -\frac{1}{T_A}\Delta E_{fd} + \frac{K_A}{T_A}\Delta V_t - - - - - (1)$

Where,

$$\Delta P_e = K_1\Delta\delta + K_2\Delta E_q' + K_{pv}\Delta V_{DC} + K_{pm_1}\Delta m_1 + K_{p\delta_1}\Delta\delta_1 + K_{pm_2}\Delta m_2 + K_{p\delta_2}\Delta\delta_2 \qquad - - - - - - - - - (2)$$

$$\Delta E_q' = K_4\Delta\delta + K_3\Delta E_q' + K_{qv}\Delta V_{DC} + K_{qm_1}\Delta m_1 + K_{q\delta_1}\Delta\delta_1 + K_{qm_2}\Delta m_2 + K_{q\delta_2}\Delta\delta_2 \qquad - - - - - - - - - (3)$$

$$\Delta V_t = K_5\Delta\delta + K_6\Delta E_q' + K_{vv}\Delta V_{DC} + K_{vm_1}\Delta m_1 + K_{v\delta_1}\Delta\delta_1 + K_{vm_2}\Delta m_2 + K_{v\delta_2}\Delta\delta_2 \qquad - - - - - - - - - (4)$$

$$\Delta\dot{V}_{DC} = K_7\Delta\delta + K_8\Delta E_q' + K_9\Delta V_{DC} + K_{cm_1}\Delta m_1 + K_{c\delta_1}\Delta\delta_1 + K_{cm_2}\Delta m_2 + K_{c\delta_2}\Delta\delta_2 \qquad - - - - - - - - - (5)$$

By substituting (2-5) with (1), we can obtain the state variable equation of SMIB Power system installed with IPFC:

$$\begin{bmatrix}\Delta\dot{\delta}\\ \Delta\dot{\omega}\\ \Delta\dot{E}_q'\\ \Delta\dot{E}_{fd}\\ \Delta\dot{V}_{DC}\end{bmatrix} = \begin{bmatrix} 0 & \omega_0 & 0 & 0 & 0\\ -\frac{K_1}{M} & -\frac{D}{M} & -\frac{K_2}{M} & 0 & -\frac{K_{pv}}{M}\\ -\frac{K_4}{T_{d0}'} & 0 & -\frac{K_3}{T_{d0}'} & \frac{1}{T_{d0}'} & -\frac{K_{qv}}{T_{d0}'}\\ -\frac{K_A K_5}{T_A} & 0 & -\frac{K_A K_6}{T_A} & -\frac{1}{T_A} & -\frac{K_A K_{vv}}{T_A}\\ K_7 & 0 & K_8 & 0 & K_9\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta\omega\\ \Delta E_q'\\ \Delta E_{fd}\\ \Delta V_{DC}\end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0\\ -\frac{K_{pm_1}}{M} & -\frac{K_{p\delta_1}}{M} & -\frac{K_{pm_2}}{M} & -\frac{K_{p\delta_2}}{M}\\ -\frac{K_{qm_1}}{T_{d0}'} & -\frac{K_{q\delta_1}}{T_{d0}'} & -\frac{K_{qm_2}}{T_{d0}'} & -\frac{K_{q\delta_2}}{T_{d0}'}\\ -\frac{K_{vm_1}}{T_A} & -\frac{K_{v\delta_1}}{T_A} & -\frac{K_{vm_2}}{T_A} & -\frac{K_{v\delta_2}}{T_A}\\ K_{cm_1} & K_{c\delta_1} & K_{cm_2} & K_{c\delta_2}\end{bmatrix}\begin{bmatrix}\Delta m_1\\ \Delta\delta_1\\ \Delta m_2\\ \Delta\delta_2\end{bmatrix}$$

$- - - - (6)$

The PH model of the corresponding linearized model is shown in fig. 2. In this fig, there are so many constants. These constants are functions of the system parameters and initial operating condition.

The controlled vector u is defined as:

$\Delta u = [\Delta m_1 \quad \Delta\delta_1 \quad \Delta m_2 \quad \Delta\delta_2]^T$

Where $\Delta m_1, \Delta\delta_1, \Delta m_2, \Delta\delta_2$ represent the linearization of the input control signals of the IPFC. Under this work,only one input control signal is taken into consideration at a time for the analysis purpose, viz either we take $\Delta U = \Delta m_1$ or $\Delta U = \Delta\delta_1$, $\Delta U = \Delta m_2$ or $\Delta U = \Delta\delta_2$. And K_p, K_q, K_v and K_c are the row vectors defined as:

$K_p = \left[K_{pm_1} \quad K_{p\delta_1} \quad K_{pm_2} \quad K_{p\delta_2}\right]$

$$K_q = [K_{qm_1} \quad K_{q\delta_1} \quad K_{qm_2} \quad K_{q\delta_2}] - - - - - - - - (7)$$
$$K_v = [K_{vm_1} \quad K_{v\delta_1} \quad K_{vm_2} \quad K_{v\delta_2}]$$
$$K_c = [K_{cm_1} \quad K_{c\delta_1} \quad K_{cm_2} \quad K_{c\delta_2}]$$

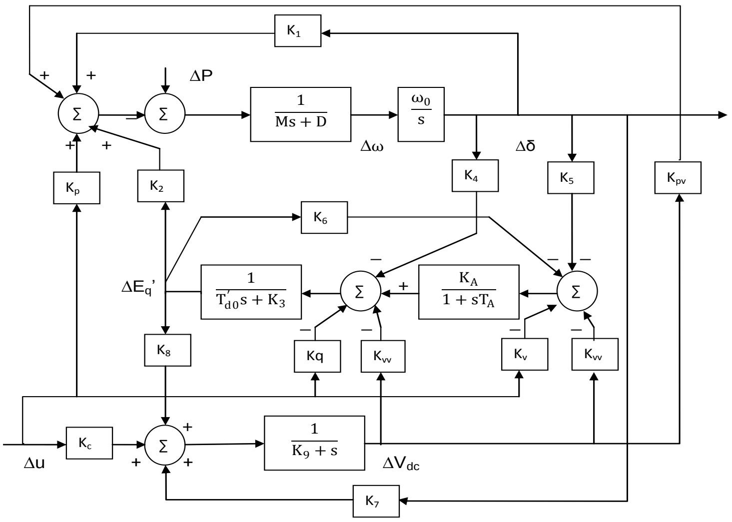

Fig. 2 : PH model of SMIB system installed with IPFC

DESIGN OF DAMPING CONTROLLER

Damping Controllers are designed to produce an electrical torque in phase with the speed deviation that damp out the power system oscillations. For using IPFC as damping controller, there is a requirement of supplementary damping controller. We have usedLead- Lagcontroller as supplementary controller. In this supplementary controller either Δω or Δδ is taken as input.

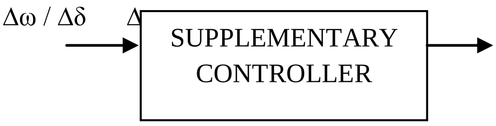

Fig. 3: Block diagram of Supplementary controller

Lead Lag Controller:

To get fast response and good steady-state accuracy, a Lead-Lag controller is used. It also increases the low frequency gain and system bandwidth. In general, the phase lead portion of this compensator provides large bandwidth and hence has shorter rise time and settling time, while the phase lag portion provides the major damping of the system. In the lead-lag controller, phase lead and lag occur at different frequency regions. The phase lag occurs in a low frequency region, whereas phase lead occurs in a high frequency region.

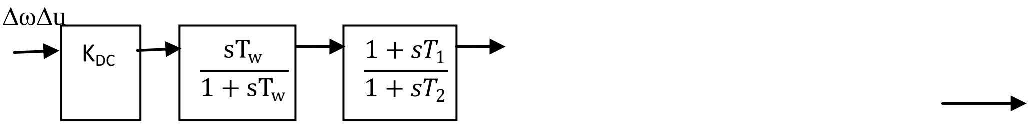

Fig. 4: structure of lead-lag as supplementary controller

Steps for calculating supplementary controller parameters:

1. Computation of natural frequency of oscillation ω_n by using relation

$$\omega_n = \sqrt{\frac{K_1 \omega_0}{M}}$$

K_1 is the constant of model, computed for operating condition and system parameters.
ω_0 is frequency of operating condition (rad/sec)
ω_n is natural frequency of oscillation (rad/sec)

2. Computation of ∟GEPA (phase angle between Δu and ΔP) at s=jω_n
3. Design of Phase lead lag compensator: the phase lead/lag compensator is designed to provide the required degree of phase compensation. for 100% compensation,

∟G_c (jω_n) +∟GEPA (jω_n) =0

Assuming one lead-lag network at $T_1=\propto T_2$, the transfer function becomes, $G_c(s) = \frac{1+s\propto T_2}{1+sT_2}$

Where $\alpha = \frac{1+\sin\gamma}{1-\sin\gamma}$

$T_2 = \frac{1}{\omega_n\sqrt{a}}$

4. Computation of optimum gain K_{DC}

The value of gain setting to achieve the required amount, damping torque D_{IPFC} can be provided by IPFC supplementary damping controller.

The signal washout is the high pass filter that prevents steady changes in the speed from modifying the IPFC input parameter. The value of the washout time constant T_w should be high enough to allow signals associated with oscillations in rotor speed to pass unchanged.Tw is not yet critical, may range from 1s to 20s.

II. SIMULATION AND RESULT

To analyse the performance of IPFC controller, simulation work is done for circuit given in fig. 2. All the simulation is done for a step change (i.e. 0.01 p.u.) in mechanical power. All the constant values are mentioned in the Appendices. Simulation work is divided in two parts:-

1. Without any supplementary controller
2. With Lead-Lag controller

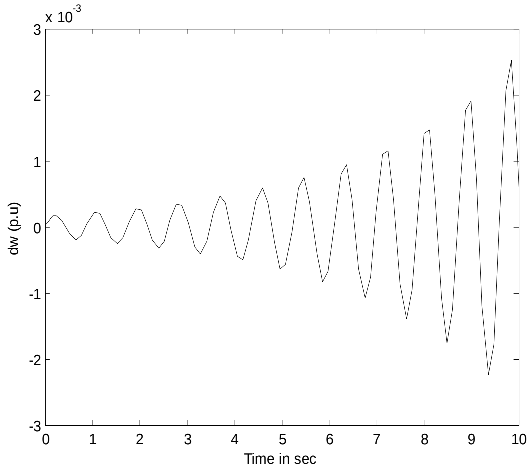

Fig. 5: Response of speed deviation (Δω) without any supplementary controller

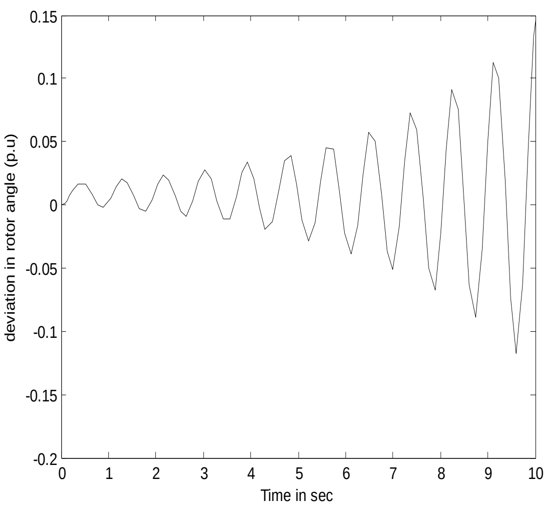

Fig. 6: Response of Rotor angle deviation (Δδ) without any supplementarycontroller

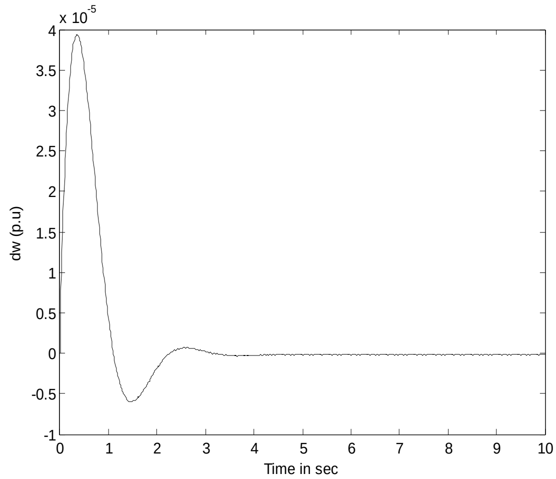

Fig. 7: Response of speed deviation (Δω) for $m_1$of IPFC controller with Lead-Lag controller

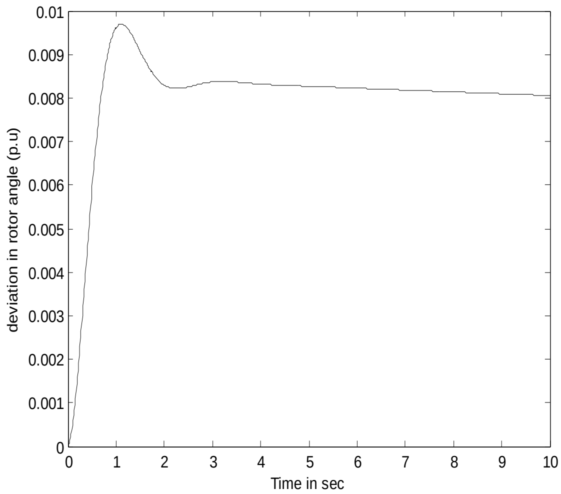

Fig. 8: Response of Rotor angle deviation (Δδ) for $m_1$of IPFC controller with Lead-Lag controller

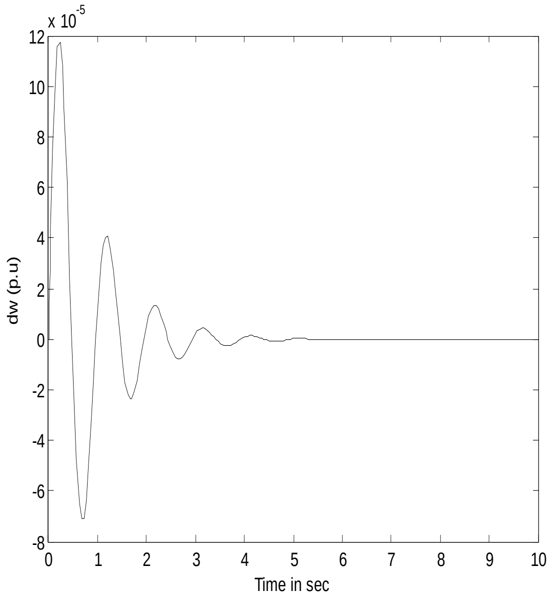

Fig. 9: Response of speed deviation (Δω) for $\delta_1$of IPFC controller with Lead-Lag controller

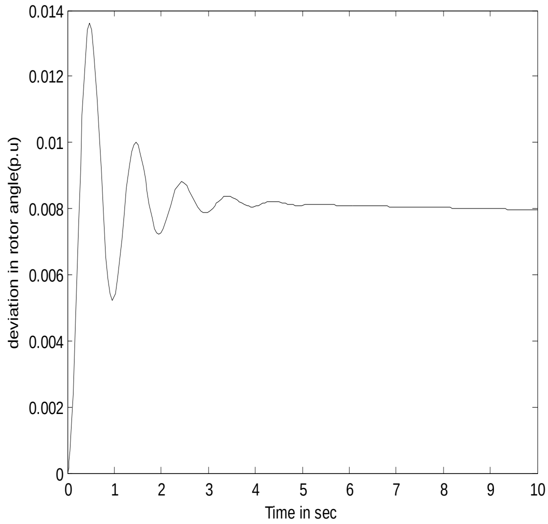

Fig. 10: Response of Rotor angle deviation (Δδ) for $\delta_1$of IPFC controller with Lead-Lag controller

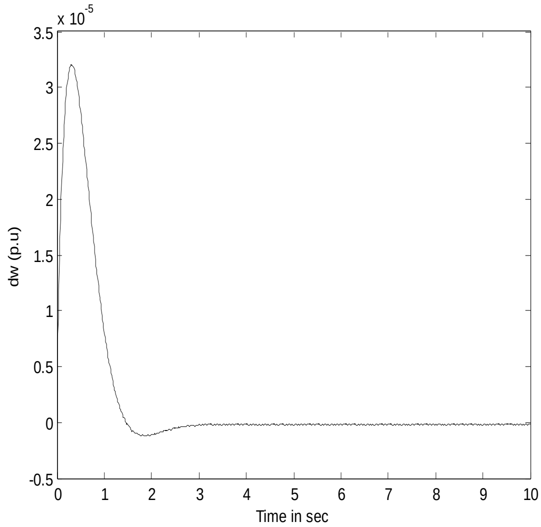

Fig. 11: Response of speed deviation (Δω) for $m_2$of IPFC controller with Lead-Lag controller

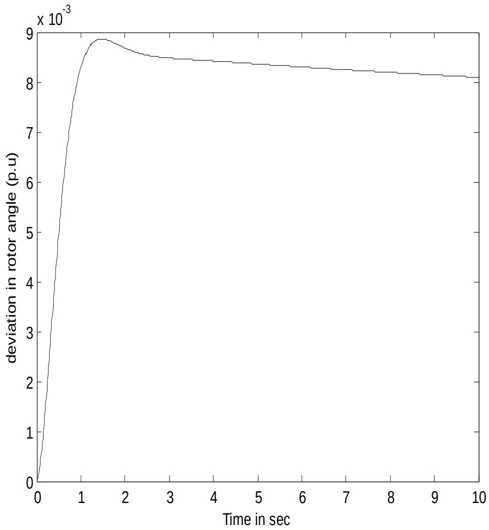

Fig. 12: Response of Rotor angle deviation (Δδ) for $m_2$of IPFC controller with Lead-Lag controller

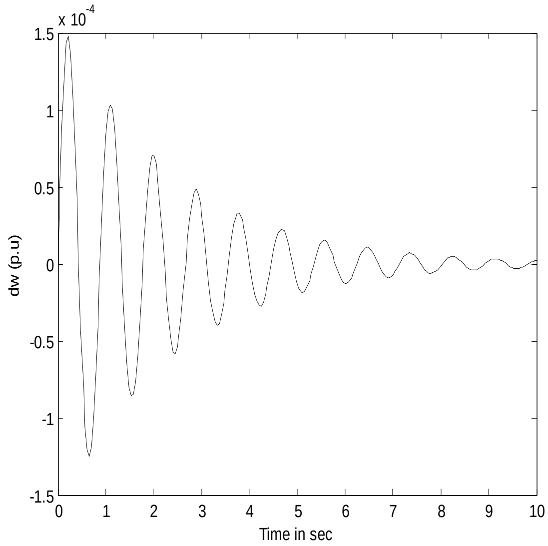

Fig. 13: Response of speed deviation (Δω) for$\delta_2$of IPFC controller with Lead-Lag controller

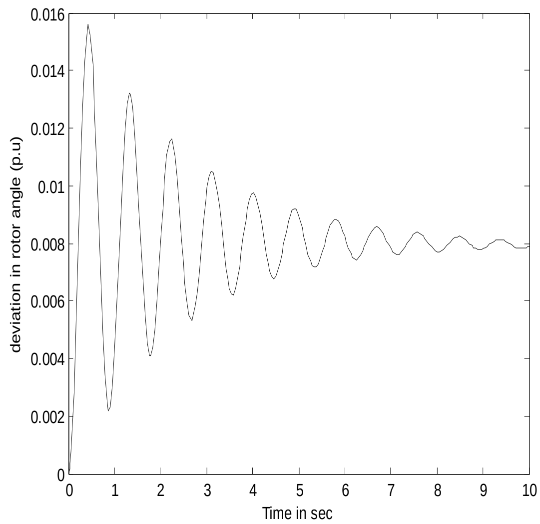

Fig. 14: Response of rotor angle deviation (Δδ) for $\delta_2$of IPFC controller with Lead-Lag controller

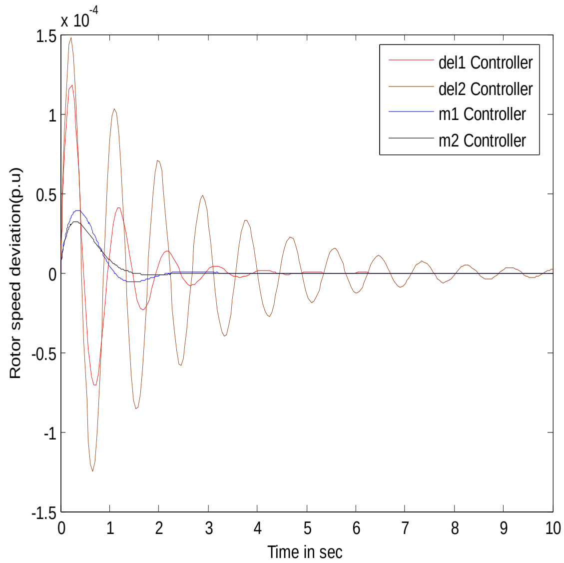

Fig. 15: Response of speed deviation (Δω)

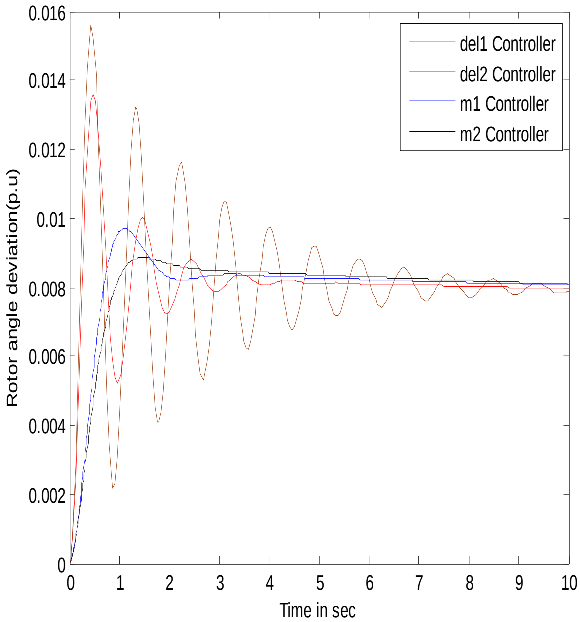

Fig. 16: Response of rotor angle deviation (Δδ)

III. CONCLUSION

Responses shown in fig.5,6 are of IPFC withoutusing supplementary controller. Responses shown in fig. 7-14 areobtained using Lead-Lag controller for all the four input (m_1, m_2, δ_1 and δ_2) of IPFC controller respectively. From the response of fig 15 and 16, we observe that m_2 input parameter of IPFC controller gives best among all.

Hence, it can be concluded that using Lead-Lag as supplementary controller, IPFC controller gives better damping capability thanIPFC controller only.

IV. APPENDICES

A: Parameters of SMIB System with IPFC

Generator	**M=8.0 MJ/MVA**	**T_{do}'=5.044s**	**X_d=1.0 pu**
	X_q=0.6pu	**X_d'=0.3pu**	**D=0**
Reactances	**X_s=0.15pu**	**X_{t1}=0.1pu**	**X_{t2}=0.1pu**
	X_t=0.1pu	**X_{L1}=0.5pu**	**X_{L2}=0.5pu**
			X_L=0.5pu
IPFC parameters	**m_1=0.15**	**m_2=0.1**	**$\delta_1=28.1^0$**
			$\delta_2=-21.1^0$
Excitation System		**K_A=50**	**T_A=0.05s**
DC link		**V_{DC}=2.0pu**	**C_{DC}=1.0pu**

B: Constant for Lead- Lag Controller

IPFC Controller Input	**Lead-lag controller Parameters**			
	K_{DC}	**T_w (s)**	**T_1 (s)**	**T_2 (s)**
m_1	**308.1583**	**13.2799**	**0.198**	**0.0195**
m_2	**300.2638**	**9.6307**	**0.1993**	**0.0198**
δ_1	**312.4573**	**9.1681**	**0.1986**	**0.0192**
δ_2	**323.7909**	**12.2496**	**0.1931**	**0.0144**

C: Constant value of PH Model installed with IPFC

Constant	Value	Constant	Value
K_1	1.0586	K_{vm1}	0.044
K_2	0.7930	K_{cm1}	0.0327
K_3	1.9333	$K_{p\delta 1}$	0.0403
K_4	0.6549	$K_{q\delta 1}$	0.0532
K_5	-0.1210	$K_{v\delta 1}$	-0.0288
K_6	0.5251	$K_{c\delta 1}$	0.0188
K_7	-0.0514	K_{pm2}	0.5710
K_8	-0.1070	K_{qm2}	0.0041
K_9	0.0007385	K_{vm2}	-0.0926
K_{pv}	-0.0694	K_{cm2}	-0.0715
K_{qv}	-0.0226	$K_{p\delta 2}$	0.012
K_{vv}	-0.0013	$K_{q\delta 2}$	0.046
K_{pm1}	0.5344	$K_{v\delta 2}$	-0.017
K_{qm1}	-0.3035	$K_{c\delta 2}$	-0.0263

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