FOREX Publication
Open Access | Rapid and quality publishing

International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 12, Issue 2 | Pages 428-434| e-ISSN: 2347-470X

Modelling of IPFC with multifunctional VSC for low-frequency oscillations damping and system stability improvement

Alladi Sathish Kumar[1*] and G T Sundar Rajan[2]

[1]*Research Scholar, Department of Electrical & Electronics Engineering. Satyabama Institute of Science & Technology, Chennai, 600119, Tamilnadu, India; satishkumaralladi@gmail.com*
[2]*Professor, Department of Electrical & Electronics Engineering, Satyabama Institute of Science & Technology Chennai, 600119, Tamilnadu, India*

***Correspondence:** Alladi Sathish Kumar; *satishkumaralladi@gmail.com*

ABSTRACT- The unified power flow controller (UPFC) approach maximizes active power transfer with the least amount of losses by independently controlling both reactive and active power flow. This makes it possible to use individual transmission lines more effectively. The interline power flow controller (IPFC) utilizes the concept of UPFC for economic operation and control, management of multiline transmission systems. In its most basic form, the IPFC consists of many DC to AC converters such as voltage source inverters (VSCs), each of which performs the same purpose as the UPFC: providing series compensation for every line in multiline transmission system. A novel idea for the efficient power flow control management and compensation in multiline transmission system is the IPFC. This research proposed a backup controller for an effective modelling of IPFC in order to reduce low-frequency oscillations using four different damping controller options. The choice of an efficient damping control signal is discussed in this work in order to create a durable IPFC damping controller that can withstand changes in system loads and power supply problems. Using the proposed control approach, it is feasible to acquire both oscillation damping and independent interline power flow regulation. The results obtained in this research was improved the dynamic stability of the system using VSC based IPFC and proposed control strategy.

Keywords: UPFC, IPFC, System Stability, Damping of Oscillations, Reactive Power Compensation.

ARTICLE INFORMATION

Author(s): Alladi Sathish Kumar and G T Sundar Rajan.;

Received: 09/01/2024; **Accepted**: 05/04/2024; **Published**: 30/04/2024;
e-ISSN: 2347-470X;
Paper Id: IJEER 0901-06;
Citation: 10.37391/IJEER.120214
Webpage-link:
https://ijeer.forexjournal.co.in/archive/volume-12/ijeer-120214.html

crossref member
CROSSREF.ORG THE CITATION LINKING BACKBONE

Publisher's Note: FOREX Publication stays neutral with regard to Jurisdictional claims in Published maps and institutional affiliations.

1. INTRODUCTION

Power systems have begun to use Flexible AC Transmission Systems (FACTS) devices as a result of the quick development of power electronics [1]. It is possible to regulate power flow and improve system stability by using FACTS devices. The use of FACTS devices in the operation and control of power systems with new loading and power flow circumstances is becoming more popular, especially with the deregulation of the energy market. Installing FACTS devices will improve the current power systems' capacity and controllability, making better use of them essential. Given the current circumstances, two primary factors should be taken into account when utilizing FACTS devices: First, the power system may operate in a flexible manner based on the FACTS devices' capacity to manage power flow. The other component is the enhancement of power system transient and steady-state stability [2]. FACTS devices are the ideal solution to these problems.

The interconnection of substantial power networks is subject to low-frequency oscillations in the frequency range of 0.2 to 3.0 Hz. A power system stabilizer (PSS) is used to improve power system oscillation stability. It is inexpensive, efficient, and straightforward [3]. For consumers to obtain high-quality electricity, the power system's performance must be improved. The primary tool for minimizing system losses and maintaining power system stability is reactive power compensation. Devices known as FACTS have proven to be incredibly successful controllers for improving system performance. Power system stabilizers may not be as effective as FACTS controllers in suppressing oscillations brought on by severe disturbances, including 3-phase failures [4]. FACTS controllers such as Unified Power Flow Controllers (UPFC), Static VAR compensators (SVC), and Static Synchronous compensators (STATCOM) can also be used to improve the steady state, transient stability of the system and minimizes the damping oscillations through a backup signal in the primary control loop [5]. A novel FACTS controller idea for series compensation, the IPFC [6] has the special capacity to govern power flow among many lines. IPFC uses a shared DC connection between two or more voltage source converters (VSCs). Every VSC can exchange reactive power with its gearbox system and offer a range of compensation for the chosen line (slave or master line) in the transmission system. The damping controller of low

FOREX Publication
Open Access | Rapid and quality publishing
International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 12, Issue 2 | Pages 428-434| e-ISSN: 2347-470X

power frequency oscillations in the power system must be designed for a nonlinear dynamic model of the power system in order to achieve accuracy and desired performance at damping of oscillations. A system with one machine and two lines out can also employ an SSSC or STATCOM for budgetary reasons, however the linear system model with more than two installed IPFCs were very effective in stabilizing the system [7]. The reactive and active capacities of the transmission lines do not independently control. A linearized Phillips-Heffron model is used to construct an IPFC damping controller for the power system that is connected to a single machine with infinite bus by 3-IPFCs each for one line. Four different damping controllers are to be created in this [8-9]. Because IPFC compromises fewer converters than conventional active power filters like. UPFC and UPQC, the system arrangement in Figure 1 emphasizes IPFC's advantage over these filters. In 2010, R. Strzelecki and G. Benysek addressed this benefit [10]. The author of a 2011 study comparing the use of IPFC and UPFC in power transmission systems concluded that IPFC is a very effective FACTS device in the contemporary power system network [11]. As seen in *figure 2*, the DC-to-AC converters may be viewed as synchronous voltage sources injecting an essentially sinusoidal controlled voltage (magnitude and phase angle) in the steady-state analysis of power systems [12].

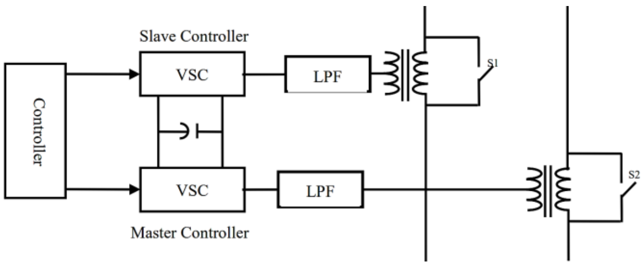


Figure 1. An Interline Power flow controller with VSCs

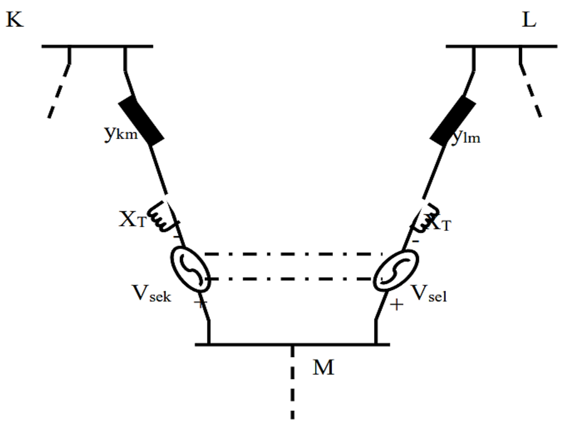


Figure 2. Single-line diagram of IPFC

This architecture allows each voltage source converter (VSC) to remove the reactive power from its line to the common DC link, in addition to offering individual series compensation. Because of this, the underutilized lines might supply an overall surplus of power that other lines can use to reduce the reactive power flow by using reactive power compensation through IPFC. For some converters, this implies that high-priority lines or lines with a high reactive power flow demand can have complete two-dimensional reactive and active power control capacities embedded in them, similar to what the UPFC performs [13]. To properly coordinate the control mechanisms of the converters and accomplish the aim of zero total active power exchange between the IPFC and all of the lines, it appears that this design demands rigorous control of the overall power balance at the common DC terminal.

2. MATHEMATICAL MODELLING OF A SINGLE MACHINE POWER SYSTEM WITH VSC-BASED IPFC

The operational characteristics of the IPFC provided in [14]. The conventional Interline power flow controller arrangement uses several DC to AC inverters, each of which offers series compensation for a different connection. The IPFC may provide a very effective power transmission regulation scheme for multiline substations. Nonetheless, the compensating inverters adhere to the basic IPFC by being connected at their DC terminals [15], as *figure 3* illustrates. With this, any inverter may be made to transmit actual power from its transmission line to a common DC connection, in addition to offering series reactive compensation. As a result, the underutilized lines might provide an overall surplus of power that other lines can use to make up for lost power. Similar to what UPFC offers, certain inverters that compensate for overloaded or heavily reactive power- laden lines can also be outfitted with complete two-dimensional, reactive, and real power flows and control capabilities [16]. The under loaded lines provide the overloaded lines with sufficient actual power transmission, which is the essential idea behind this configuration. To maintain the overall power balance between the two terminals at the common DC terminal, accurate monitoring control is therefore required.

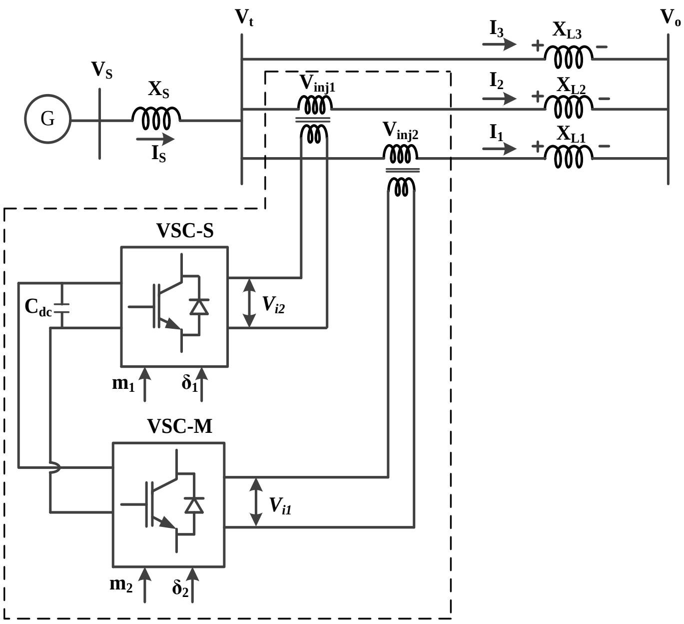


Figure 3. Line diagram of a single machine power system with VSC-based IPFC

The components of this IPFC are a common DC link capacitor (C_{dc}), as Slave Voltage Source Converter (VSC-S) and a Master Voltage Source Converter (VSC-M). The voltages of the transformers on lines 1 and 2,respectively, are V_{inj1} and V_{inj2} [17]. It is requiring to install Static Synchronous Series Compensator (SSSC) and Static Compensator (STACOM) for providing the control capacities while the system is using only two lines. The voltages of infinite bus and the terminals voltages are supplied by Slave VSC and Master VSC respectively denoted by V_B, V_S, V_{inj1}, and V_{inj2}. The IPFC inputsignals in *figure 3* are the control inputs for each VSC, represented by m_1, m_2, δ_1, and δ_2, which represent the amplitude modulation ratio and phase angle, respectively [18].

For the IGBT-based VSC, pulse width modulation, or PWM, is essential to produce the gating pulsed for the IGBT switches to control/regulate the voltage. By neglecting the resistance of the IPFC transformers the per unit values of three phase dynamic differential equations of UPFC and IPFC can be modelled using Park's Transformation as mentioned below.

$$\begin{bmatrix} V_{inj1d} \\ V_{inj1q} \end{bmatrix} = \begin{bmatrix} 0 & X_{t1} \\ -X_{t1} & 0 \end{bmatrix} \begin{bmatrix} I_{1d} \\ I_{1q} \end{bmatrix} + \begin{bmatrix} V_{i1d} \\ V_{i1q} \end{bmatrix} \quad (1)$$

$$V_{i1d} = \frac{m_1 V_{dc} cos\ \delta_1}{2} \quad (2)$$

$$V_{i1q} = \frac{m_1 V_{dc} Sin\ \delta_1}{2} \quad (3)$$

$$\begin{bmatrix} V_{inj2d} \\ V_{inj2q} \end{bmatrix} = \begin{bmatrix} 0 & X_{t2} \\ -X_{t2} & 0 \end{bmatrix} \begin{bmatrix} I_{2d} \\ I_{2q} \end{bmatrix} + \begin{bmatrix} V_{i2d} \\ V_{i2q} \end{bmatrix} \quad (4)$$

$$V_{i2d} = \frac{m_2 V_{dc} cos\ \delta_2}{2} \quad (5)$$

$$V_{i2q} = \frac{m_2 V_{dc} Sin\ \delta_2}{2} \quad (6)$$

$$\frac{dv_{dc}}{dt} = \frac{m_1}{2C_{dc}} [Cos\delta_1\ \ Sin\delta_1] \begin{bmatrix} I1d \\ I1q \end{bmatrix} + \frac{m_2}{2C_{dc}} [Cos\delta_2\ \ Sin\delta_2] \begin{bmatrix} I2d \\ I2q \end{bmatrix} \quad (7)$$

Here,
V_{dc} = DC link Voltage (Volts), X_{t1} = Reactance of the master injection transformer, X_{t2} = Reactance of the Slave injection transformer

$$\bar{I}_1 = I_{1d} + jI_{1q}\ , \bar{I}_2 = I_{2d} + jI_{2q} \quad (8)$$

The above equations are utilized to construct the dynamic model of a single-machine infinite bus power system with an IPFC.

$$\dot{\delta} = \omega_0 \omega \quad (9)$$

$$\dot{\omega} = \frac{P_m - P_e - D\omega}{2H} \quad (10)$$

$$\dot{E}'_q = \frac{-E_q + E_{fd}}{T'_{do}} \quad (11)$$

$$\dot{E}_{fd} = -\frac{1}{T_A} E_{fd} + \frac{K_A}{T_A}(V_{s0} - V_s) \quad (12)$$

Here, V_s refers the actual terminal voltage and V_{so} refers the reference value of the terminal voltage

T_e=$P_e = V_{sq} I_q + V_{sd} I_d$, $E_q = E'_q + (X_d - X'_d) I_d$, $V_s = \sqrt{V_{sd}^2 + V_{sq}^2}$, $V_{sd} = X_q I_q$

$$V_{sq} = E'_q - X'_d, I_d = I_{1d} + I_{2d} + I_{3d}, I_q = I_{1q} + I_{2q} + I_{3q} \quad (13)$$

Figure 1 allows us to have,

$$V_{sd} + jV_{sq} = X_q + (I_{1q} + I_{2q} + I_{3q}) + j[E'_q - X'_d(I_{1d} + I_{2d} + I_{3d})]$$

$$\text{j}(X_{L3})(I_{3d} + jI_{3q}) = j(X_{L1} + X_{t1})(I_{1d} + jI_{1q}) - V_{i1d} - jV_{i1q} \quad (14)$$

From the equations (10) to (14),

$$I_{1q} = V_{i1d}\, X_{q11} + V_{i2d}\, X_{q21} + V_b X_{qb1} \sin\delta \quad (15)$$

$$I_{1d} = V_{i1q}\, X_{d11} + V_{i2d}\, X_{d21} + V_b\, X_{db1} \cos\delta + E'_q\, X_{de1} \quad (16)$$

$$I_{2q} = V_{i1d}\, X_{q12} + V_{i2d}\, X_{q22} + v_b\, X_{qb2} \sin\delta \quad (17)$$

$$I_{2d} = V_{i1q}\, X_{d12} + V_{i2d}\, X_{d22} + V_b\, X_{db2} \cos\delta + E'_q\, X_{de2} \quad (18)$$

$$I_{3q} = V_{i1d}\, X_{q13} + V_{i2d}\, X_{q23} + v_b\, X_{qb3} \sin\delta \quad (19)$$

$$I_{3d} = V_{i1q}\, X_{d13} + V_{i2d}\, X_{d23} + V_b\, X_{db3} \cos\delta + E'_q\, X_{de3} \quad (20)$$

Where,

$$\Delta P_e = k_1\Delta\delta + K_2\Delta E'_q + K_{pd}\Delta V_{dc} + K_{p1}\Delta m_1 + K_{p\delta1}\Delta\delta_1 + K_{p2}\Delta m_2 + K_{p\delta2}\Delta\delta_2 \quad (11)$$

$$\Delta E'_q = k_4\Delta\delta + K_3\Delta E'_q + K_{qd}\Delta V_{dc} + K_{q1}\Delta m_1 + K_{q\delta1}\Delta\delta_1 + K_{q2}\Delta m_2 + K_{q\delta2}\Delta\delta_2 \quad (12)$$

$$\Delta V_s = k_5\Delta\delta + K_6\Delta E'_q + K_{vd}\Delta V_{dc} + K_{v1}\Delta m_1 + K_{v\delta1}\Delta\delta_1 + K_{v2}\Delta m_2 + K_{v\delta2}\Delta\delta_2 \quad (13)$$

$$\Delta V_{dc} = k_7\Delta\delta + K_8\Delta E'_q - K_9\Delta V_{dc} + K_{c1}\Delta m_1 + K_{c\delta1}\Delta\delta_1 + K_{c2}\Delta m_2 + K_{c\delta2}\Delta\delta_2 \quad (14)$$

Make a metrics form arrangement of the aforementioned equations as

$$\dot{X} = AX + BU$$

$$\text{U} = [\Delta m_1\ \Delta m_2\ \Delta\delta_1\ \Delta\delta_2]^T$$

Where, the parameters Δm_1, Δm_2, $\Delta\delta_1$, and $\Delta\delta_2$ indicate the linearization of the IPFC's input control signals. *Figure 4* displays the dynamic model that has been linearized.

Both the multi-converter IPFC configuration and the basic IPFC depicted in *figure 3* may be understood by using this logic. P_{S1} and Q_{S1} are typically exchanged between converter

VSC1 and the line upon V_{inj1} injection on system 1. Typically, the injection voltage $V_{inj1,2}$ is divided into d-q components using Park's transformation, making it easier to examine whole system. The V_{inj1q} is the quadrature component that has more effect on the real power the V_{inj1d} is the direct/in-phase component has more effect on the reactive power. Reactive power exchange (Q_{S1}) is provided by the converter itself. The DC terminals must, however, satisfy a demand imposed by the active power (P_{S1}). By using the $P_{S1}+P_{S2} = 0$ constraint, Converter VSC-2 is responsible for meeting this requirement.

3. DESIGN OF IPFC CONTROLLER

The synchronous machine Phillips-Heffron model is frequently used for off-line PSS design and tiny signal stability analysis. By dampening the oscillations of the generator rotor, oscillatory instability may be solved satisfactorily and economically. PSS design aims to offer supplementary damping torque at crucial oscillation frequencies without compromising the synchronising torque.

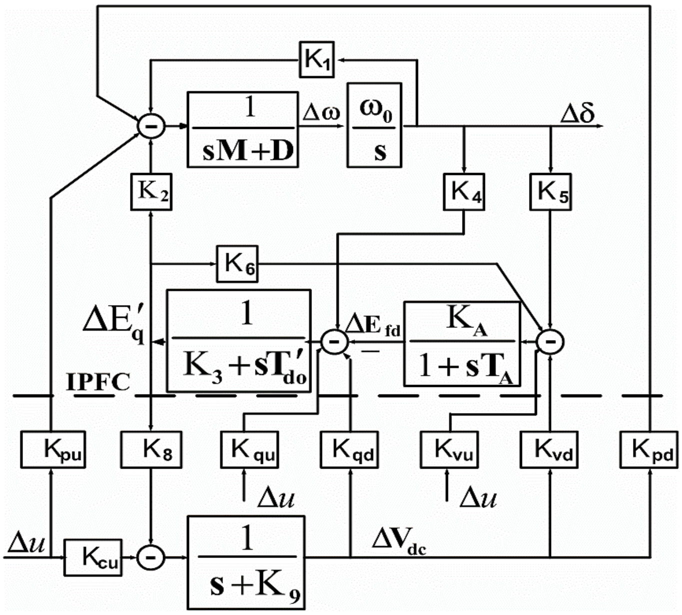


Figure 4. IPFC based Phillips Heffron Model

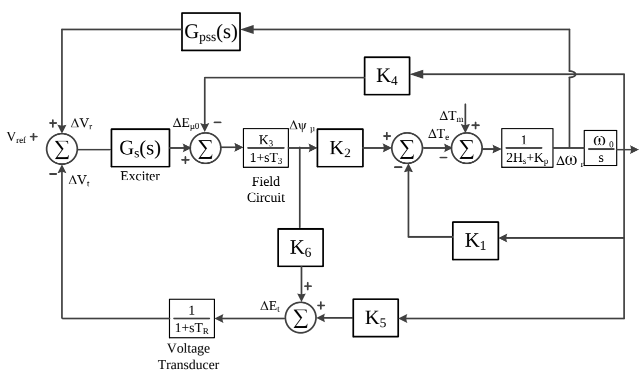


Figure 5. Power system stabilizer control diagram

A block diagram can be used to demonstrate the theoretical underpinnings of a power system stabiliser, as seen in *figure 5*, where the PSS's function is to add a damping torque component. The speed variation $\Delta\omega r$ is a functional output that should be utilized to regulate generator excitation. To account for the phase lag between the exciter input and electrical torque, the PSS transfer function, Gpss(s), needs suitable phase correction circuits.

4. DAMPING CONTROLLER DESIGN

In order to generate an electric torque in step with the speed variation, the damping controllers are built. To generate the damping torque, one can modify the four IPFC control parameters (m_1, m_2, δ_1, δ_2). The damping controllers use the speed deviation, Δw, as an input. In this paper, the four different IPFC-based damping controllers are analysed. Moving forward, a damping controller that utilises IPFC control parameter m_1 will be referred to as a damping controller (m_1). Likewise, damping controllers are determined by m_2, δ_1, and δ_2.

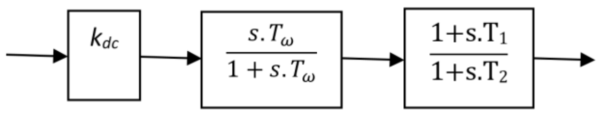
The process of finding the parameters of the damping controller with phase compensation is given in below steps:

1. The natural frequency of oscillation ω_n can be calculated by using the expression below

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

2. The Phase angle (γ) can be computed by $S = j\omega_n$. Where ω_n is natural frequency of oscillations found in step-1.

3. The transfer function (G_c) of the lead-lag compensator is then determined with the following block diagram.



4. The necessary level of phase adjustment is provided by the phase lead/lag compensator Gc. for a complete phase shift.

$$\angle G_c(j\omega_n) + \angle GEPA(j\omega_n) = 0$$

5. The transfer function of the phase compensator Gc(s) is found by assuming on lead-lag compensator ($T_1 = a\,T_2$).

$$G_c(s) = \frac{1+s.aT_2}{1+s.T_2}$$

6. Given that γ is the phase angle that the lead-lag network adjusts for, T_2 and the parameters can be found as follows

$$a = \frac{1+\sin(\gamma)}{1-\sin(\gamma)}$$

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

7. Computation of optimum gain K_{dc}.

FOREX Publication
Open Access | Rapid and quality publishing
International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 12, Issue 2 | Pages 428-434| e-ISSN: 2347-470X

To get the required quantity of damping torque, the IPFC damping controller can supply the value K_{dc} is setting. The high pass filter known as signal washout keeps the IPFC input parameter from changing when there are consistent variations in speed. In order for signals related to the speed oscillations in rotor is unaltered, the settling time constant value needs to be large enough. The value may be anything between 1 and 20 seconds, and from the perspective of the washout function, it is not significant. T_w equal to 10s is used as the Reference in this work.

5. RESULTS & DISCUSSIONS

When loads fluctuate and impact the transmission system, the power system is typically not in a stable state. Power system torque angle and speed deviations result from various load variations; as a result, power system power fluctuations may occur.

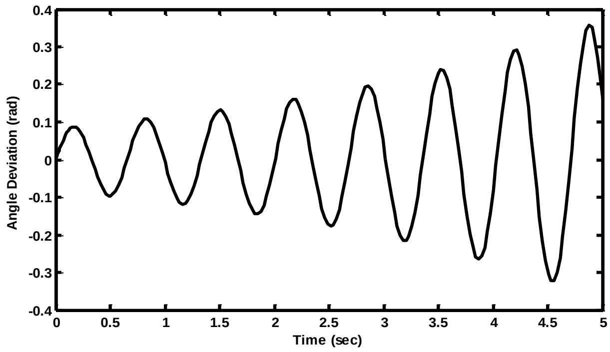


Figure 6. Angle deviation without using PSS and IPFC

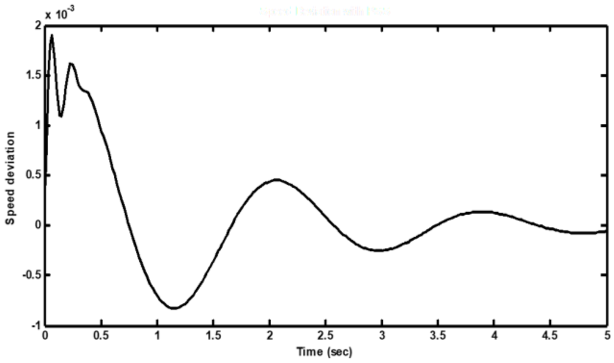


Figure 7. Speed change with time when PSS is in operating condition

Figure 6 illustrates how, in the absence of controllers, low-frequency oscillations and angle deviation rise with respect to time. As a result, the system becomes unstable. Consider the power system stabiliser, which was previously presented and is in working order, the waveforms in *figure 7*, and the speed deviation that can be controlled on the generator side in order to reduce these low frequency oscillations. Likewise, the low-frequency oscillations can be regulated in the transmission system and the angle deviations seen in *figure 8*, above by installing a power system stabilizer. We want to manage these low frequency oscillations to stabilize power system. An interline power flow controller fitted in series with the gearbox system regulates the phase angle and subsequently the speed deviations in the system, as illustrated in *figure 9*. In *figure 6*, the low-frequency oscillations are enhanced with varied loads in the power system.

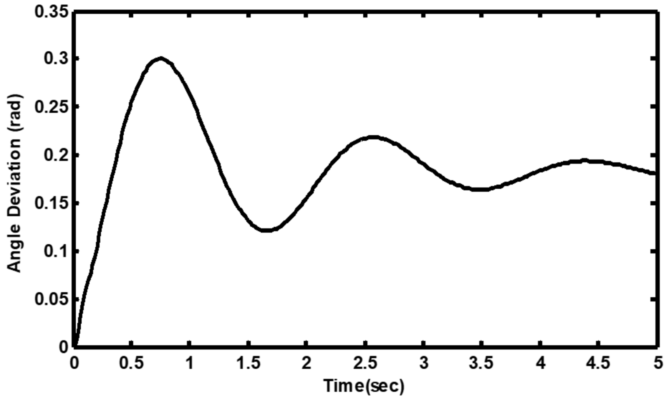


Figure 8. Angle deviation with PSS

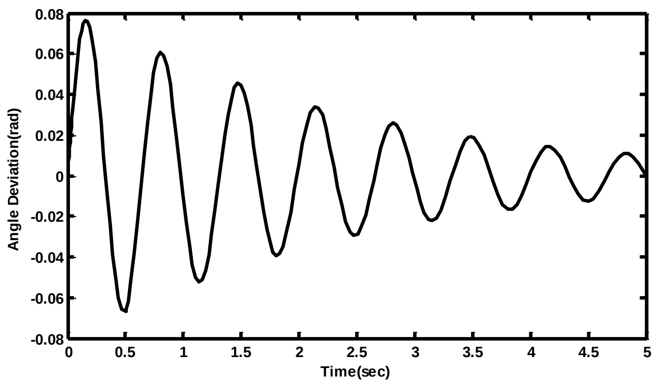


Figure 9. Phase angle speed deviation when IPFC in operating condition

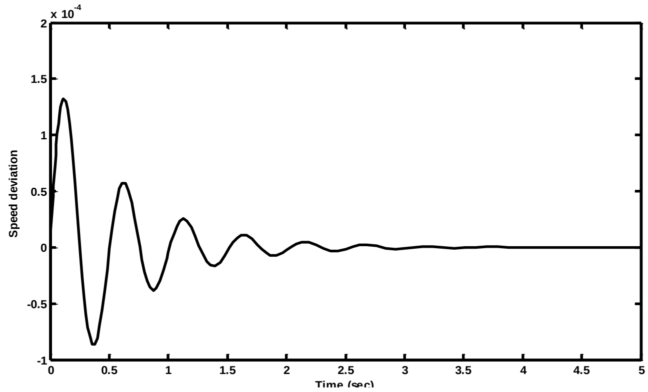


Figure 10. Variations in speed while operating the IPFC

Figure 6 illustrates how, in the absence of controllers, low-frequency oscillations and angle deviation rise with respect to time. As a result, the system becomes unstable. Consider the power system stabiliser, which was previously presented and is in working order, the waveforms in *figure 7*, and the speed deviation that can be controlled on the generator side in order to reduce these low frequency oscillations. Likewise, the low-

FOREX Publication
Open Access | Rapid and quality publishing
International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 12, Issue 2 | Pages 428-434| e-ISSN: 2347-470X

frequency oscillations can be regulated in the transmission system and the angle deviations seen in *figure 8*, above by installing a power system stabilizer. We want to manage these low frequency oscillations to stabilize power system. An interline power flow controller fitted in series with the gearbox system regulates the phase angle and subsequently the speed deviations in the system, as illustrated in *figure 9*. In *figure 6*, the low-frequency oscillations are enhanced with varied loads in the power system.

The IPFC, as shown in *figure 10*, will maintain system stability and rectify speed deviations faster than the power system stabilizer.

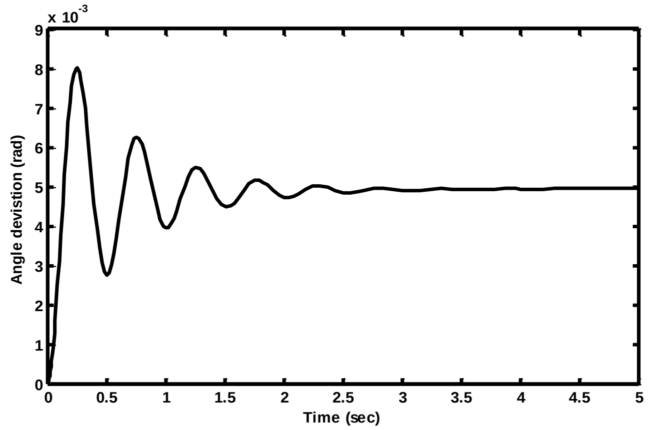


Figure 11. Angle deviation with IPFC in operation

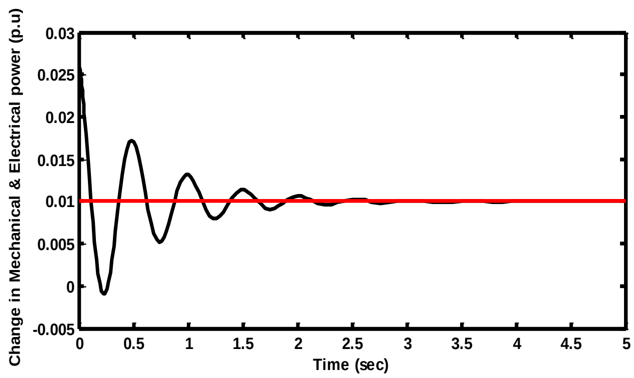


Figure 12. Mechanical & electrical power flow response

Specifically, as seen in *figure 11*, by controlling the interline power flow controller's angle deviation with respect to time, a parameter that has to be controlled in the shortest period of time relative to PSS. The transmission system would be more stable if IPFC was used to regulate both speed variation and angle variation in the power system. In addition, as *figure 12* shows, the power flow needs to be controlled. The waveform in the transmission system will control the power system's mechanical and electrical power. The comparative analysis for validation of this study with the published article is seen in *table.1*

Table 1. Comparative analysis of the results

Details of the Study	Angle of Deviation		Speed Deviation		Change in power (p.u)
	Without PSS & IPFC	With PSS & IPFC	Without PSS & IPFC	With PSS & IPFC	
A. V. N. Babu et al. (2010)	6.5	5.2	0.09	0.032	0.021
A. Murugan et al. (2013)	7.2	4.5	0.15	0.021	0.024
Mircea Eremia et al. (2016)	8.2	5.8	0.13	0.019	0.019
T. Kiran et al. (2020)	7.6	4.9	0.24	0.017	0.021
Muluneh Lemma et al. (2022)	7.1	5.2	0.15	0.021	0.016
Proposed	8.7	4.9	0.11	0.015	0.013

6. CONCLUSIONS

This study examines the effects of low-frequency oscillations on rapid variations in loads, torque angle, and speed in a single-machine infinite bus power system operating in a steady situation. As a result, the system becomes less stable and has a reduced capacity for electricity transmission. The power system, which is described in the simulation findings, uses controls for interline power flow and power system stabilisers to prevent these low-frequency oscillations. The resulting waveforms demonstrate how these controllers provide higher performance and stability with less time lapse. A power system stabiliser has a longer stabilisation time for low-frequency oscillations and speed deviations than an IPFC, which is lowered in the proposed work. By controlling the power flow in transmission line, the IPFC was able to provide system stability more quickly.

Future research on the topic of mitigating low-frequency oscillations in power systems could focus on several avenues to enhance the stability and efficiency of electricity transmission network, such as Integration of Renewable Energy Sources, Wide-Area Monitoring and Control, Optimal Allocation of Distributed Generation, Real-Time Simulation and Testing and Resilience to Extreme Events etc.

While the study demonstrates promising results in mitigating low-frequency oscillations and improving system stability using interline power flow controllers (IPFCs) and power system stabilizers (PSS), there are several limitations that should be considered such as, Limited Operating Conditions, Controller Tuning and Parameter Sensitivity, Validation and

Research Article | Volume 12, Issue 2 | Pages 428-434| e-ISSN: 2347-470X

Real-world Implementation, Reliability Concerns and Dynamic stability.

REFERENCES

[1] Li-Jun Cai and Istvan Erlich, "Simultaneous Coordinated Tuning of PSS and FACTS Damping Controllers in Large Power Systems", IEEE Transactions on Power Systems, Vol. 20, NO.1, pp. 294-300, February 2005.

[2] [2] H. F. Wang, "Selection of robust installing locations and feedback of FACTS-based stabilizers in multi-machine power systems," IEEE Trans. Power Syst., vol. 14, no. 2, pp. 569–574, May 1999.

[3] [3] L. Gyugyi, K. K. Sen and C. D. Schauder, "The interline power flow controller concept: a new approach to power flow management in transmission systems," in IEEE Transactions on Power Delivery, vol. 14, no. 3, pp. 1115-1123, July 1999, doi: 10.1109/61.772382.

[4] [4] X. Lei, E. N. Lerch, and D. Povh, "Optimization and coordination of damping controls for improving system dynamic performance," IEEE Trans. Power Syst., vol. 16, pp. 473–480, Aug. 2001.

[5] [5] Jianhong Chen, T. T. Lie and D. M. Vilathgamuwa, "Basic control of interline power flow controller," 2002 IEEE Power Engineering Society Winter Meeting. Conference Proceedings (Cat. No.02CH37309), New York, NY, USA, 2002, pp. 521-525 vol.1, doi: 10.1109/PESW.2002.985058.

[6] [6] A. M. Parimi, I. Elamvazuthi and N. Saad, "Interline Power Flow Controller (IPFC) based damping controllers for damping low frequency oscillations in a power system," 2008 IEEE International Conference on Sustainable Energy Technologies, Singapore, 2008, pp. 334-339, doi: 10.1109/ICSET.2008.4747027.

[7] [7] A. Murugan and S. Thamizmani, "A new approach for voltage control of IPFC and UPFC for power flow management," 2013 International Conference on Energy Efficient Technologies for Sustainability, Nagercoil, India, 2013, pp. 1376-1381, doi: 10.1109/ICEETS.2013.6533588.

[8] [8] A. V. N. Babu and S. Sivanagaraju, "Mathematical modelling, analysis and effects of interline power flow controller (IPFC) parameters in power flow studies," India International Conference on Power Electronics 2010 (IICPE2010), New Delhi, India, 2011, pp. 1-7, doi: 10.1109/IICPE.2011.5728060.

[9] [9] Mircea Eremia; Chen-Ching Liu; Abdel-Aty Edris, "Interline Power Flow Controller (IPFC)," in Advanced Solutions in Power Systems: HVDC, FACTS, and Artificial Intelligence, IEEE, 2016, pp.629-649, doi: 10.1002/9781119175391.ch11.

[10] [10] M. K. Liaqat, M. Safdar, H. Ahmad, S. Raza and A. Riaz, "Line Impedance Modulator Design For Load Flow Control In a Hybrid Power System," 2020 IEEE 23rd International Multitopic Conference (INMIC), Bahawalpur, Pakistan, 2020, pp. 1-6, doi: 10.1109/INMIC50486.2020.9318110.

[11] [11] Muluneh Lemma Woldesemayat, Ashenafi Tesfaye Tantu, "Security Enhancement of Power Systems through Interline Power Flow Controller (IPFC) under Contingency Condition: A Case Study and Analysis-EEP 400 kV System", Journal of Electrical & Computing Engineering, Volume. 2022, Article ID 5897285, https://doi.org/10.1155/2022/5897285

[12] [12] Y. Li, Y. Li, and Y. Sun, "Online static security assessment of power systems based on lasso algorithm," Applied Sciences, vol. 8, no. 9, pp. 1442–1465, 2018, https://doi.org/10.3390/app8091442

[13] [13] Y. Li and Y. Li, "Security-constrained multi-objective optimal power flow for a hybrid AC/VSC-MTDC system with lasso-based contingency filtering," IEEE Access, vol. 8, pp. 6801–6811, 2020.

[14] [14] A. Amarendra, S. Ravi, and S. Rao, "Security enhancement in power system using FACTS devices and atom search optimization algorithm," EAI Endorsed Transactions on Energy Web, pp. 1–15, 2021.

[15] [15] B. Desalegn, O. Ayodeji, and G. Yalew, "Load flow and contingency analysis for transmission line outage," Archives of Electrical Engineering, vol. 69, no. 3, pp. 581–594, 2020.

[16] [16] K. V. K. Kavuturu, P. V. R. L. Narasimham, and P. Narasimham, "Transmission security enhancement under (N−1) contingency conditions with optimal unified power flow controller and renewable energy sources generation," Journal of Electrical Engineering & Technology, vol. 15, no. 4, pp. 1617–1630, 2020.

[17] [17] G. Mostafa, J. Mohammad, S. Mostafa, A. Mahdi, and R. Mohammadreza, "Static security assessment of power systems: a review," International Trans Electr Energ Syst, vol. 30, 2020.

[18] T. Kiran and D. M. Vinod, "Power system security assessment and enhancement: a bibliographical survey," Journal of the Institution of Engineers, vol. 101, pp. 1–14, 2020.

© 2024 by the Alladi Sathish Kumar and G T Sundar Rajan Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).