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Damping Low-Frequency Oscillations in a Power System through Damping Controllers Utilizing Unified Power Flow Controller (UPFC)

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Abstract—*This study introduces a methodical strategy for formulating damping controllers that leverage the Unified Power Flow Controller (UPFC) to mitigate low-frequency oscillations within a power system. Thorough examination encompassing four distinct UPFC-based damping controllers have been conducted. The findings indicate that controllers relying on UPFC control parameters* δ_E *and* δ_B *exhibit resilient performance in the face of fluctuations in system loading and equivalent reactance* X_e*. The simulation is carried out in MATLAB/simulink which shows promising results*

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Keywords: *Unified Power flow controller (UPFC), FACTS, Power oscillation damping (POD) controller, Power system oscillations.*

INTRODUCTION

In an interconnected power system, the effective power transfer faces limitations imposed by transient stability, voltage stability, and small signal stability. These constraints curtail the optimal utilization of transmission corridors. Flexible AC transmission system (FACTS) technology serves as the solution to rectify transmission functionality, enabling the complete utilization of existing transmission facilities. Consequently, this minimizes the disparity between stability. A more efficient and effective power transfer The Unified Power Flow Controller (UPFC) falls under the category of Flexible AC Transmission System (FACTS) devices. It possesses the capability to manipulate power system parameters such as terminal voltage, line impedance, and phase angle. Consequently, the UPFC serves a dual purpose, functioning not only for power flow control but also as a means for stabilizing control within the power system.

The primary goals of the research outlined in this paper are as follows:

- To introduce a methodical strategy for the formulation of damping controllers utilizing the Unified Power Flow Controller (UPFC).
- To assess and compare the efficacy of varying UPFC control parameters (specifically m_B, m_E, δ_B, and δ_E) in modulating and damping oscillations within the Power Systems.

To assess the effectiveness of alternative damping controllers, investigation will be conducted under diverse loading conditions and varying system parameters. The aim is to identify the most efficient damping controller through comprehensive performance evaluations.

Unified Power flow controller:

The Unified Power Flow Controller (UPFC) serves as a combined series and shunt Flexible AC Transmission System (FACTS) device. It integrates a Static Synchronous Series Compensator (SSSC) in series and a Static Synchronous Compensator (STATCOM) in shunt with the transmission line. Both of these components, functioning as voltage source converters, are linked by a shared DC link capacitor. In the schematic diagram of the UPFC depicted in Fig.1, the series portion of the device injects a controllable magnitude voltage into the transmission line. This injection allows for the regulation of both real and reactive power in the power system. The overall design of the UPFC enhances the system's capability to control and optimize power flow within the transmission line. Each voltage source converter can control the magnitude and phase angle of the output voltages of series and shunt converters by controlling the amplitude of modulation index(m_B,m_E) and phase-angle(δ_B, δ_E)of series and shunt respectively.

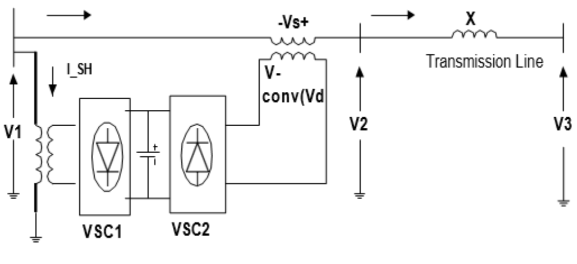

Fig. 1: schematic diagram of UPFC

Damping Power Oscillations

The primary control system of the Unified Power Flow Controller (UPFC) comprises both series and shunt controllers. However, these controllers may lack sufficient damping capabilities. To address this issue, an extra damping controller, referred to as the Power Oscillations Damping (POD) controller, is employed alongside the UPFC's main controller. The design of the POD controller closely resembles that of a Power System Stabilizer (PSS). Figure 2 illustrates the block diagram of the POD controller, which incorporates a gain block, a washout block, and two lead-lag blocks in the structure.

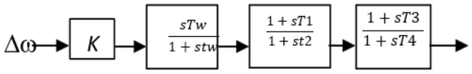

Fig. 2: Block Diagram of POD Controller

The input to the POD is the change in speed or change in real power and output is the damping signal X_{pod}.

System Study

Fig. 3 is a single-line diagram depicting the study system a two-area power system employed to examine the impact of the Unified Power Flow Controller (UPFC) in mitigating power system oscillations.

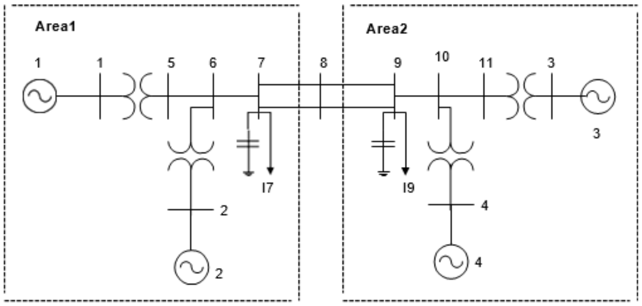

Fig. 3: Power System Area

The configured system comprises two distinct areas, area-1 and area-2, interconnected by a tie line with a voltage rating of 230kV and a length of 220km. Within each area, two generators are installed. The parameters of the generators share identical ratings, with the exception of the inertia Constant H is 6.5s for area-1 and 6.175s for area-2. Notably, area-1 transmits 400kW power to area-2. The choice of a two-area power system, as advocated by Graham Roger [16], facilitates the exploration of various oscillation types, including local oscillations, inter-area oscillations, inter-plant oscillations, and global oscillations. In the realm of local oscillations, generator-1 is specifically highlighted as undergoing oscillatory behaviour. In contrast, oscillations involving generator-2 in area-1 occur, or there is oscillatory behaviour between generator-3 and generator-4. Inter-plant oscillations manifest among generators that are closely interconnected. On the other hand, when generators in area-1 oscillate against generators in area-2, it is categorized as inter-area oscillations. Global oscillations typically involve extensive groups of generators. Therefore, the utilization of a two-area power system serves as a valuable framework for comprehensively studying and gaining insights into various oscillation phenomena, local, inter-plant, inter- area and global oscillations.

Simulated Results

In this segment, the analysis of the two-area power system under disturbance, considering the influence of the Unified Power Flow Controller (UPFC), its Power Oscillations Damping (POD) controller, and Power System Stabilizer (PSS). The simulations are conducted over a 12-second interval using the MATLAB/ Simulink platform. The disturbance introduced through a three-phase fault lasting 0.1s near bus-B7, occurring at 2.5s and clearing by 2.6s. The UPFC is connected in proximity to bus-B8. Fig.4 (a)-(d) illustrates the simulation outcomes for active power transfer in megawatts from area-1 to area-2 under different scenarios without any controller, with the combined application of UPFC, POD, and PSS. Additionally, Fig.4 (e) portrays results for the rotor angle of generator-1 (G1) relative to G4, maintaining the same.In Fig. 4(d) comparative analysis reveals the responses with Power System Stabilizer (PSS) alone, UPFC+PSS, and UPFC+PSS+Power Oscillations Damping (POD).This results indicate that the combination of UPFC+PSS+POD yields satisfactory outcomes in mitigating system oscillations. Similarly, Fig. 4(e), a comparison of results for the rotor angle of generator-1 (G1) relative to G4 is presented. Once again, the dynamic performance exhibited by the UPFC+PSS+POD combination stands out in effectively damping power system oscillations.

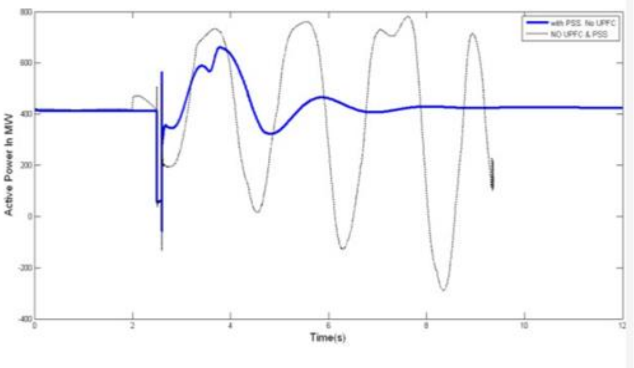

Fig. 4(a) Active power in MW with PSS alone

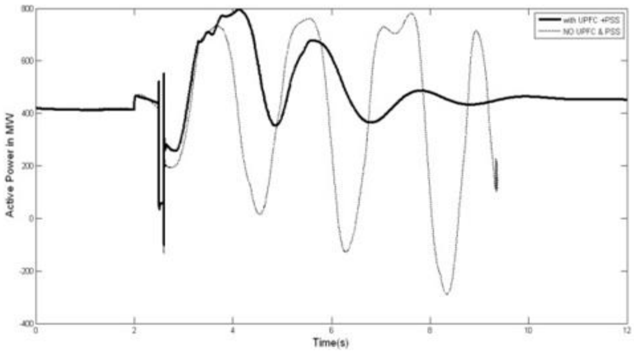

Fig.4(b)Active power in MW with and without PSS and UPFC

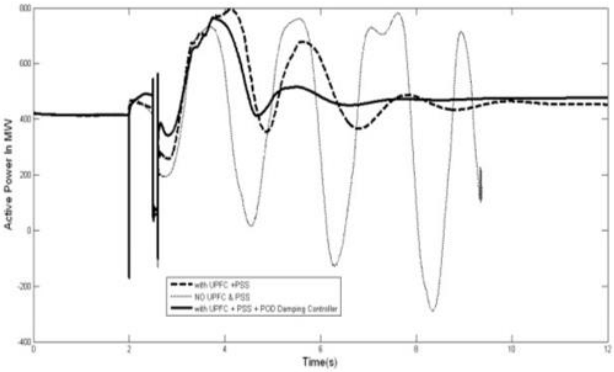

Fig. 4(c) Active power in MW with UPFC+POD+PSS and without PSS and UPFC.

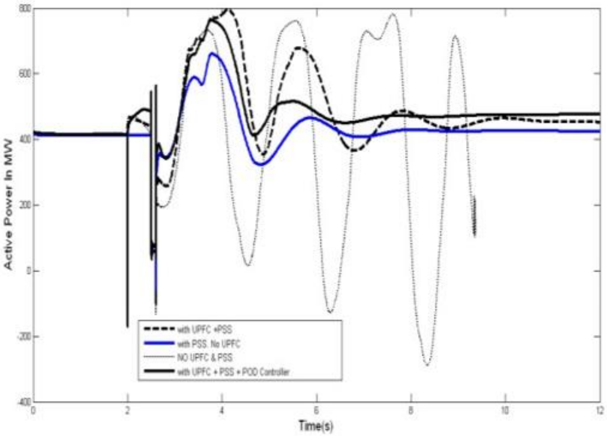

Fig. 4(d) Comparison between simulation response for UPFC+POD+PSS, UPFC+PSS+ No POD and only PSS for Active power in MW.

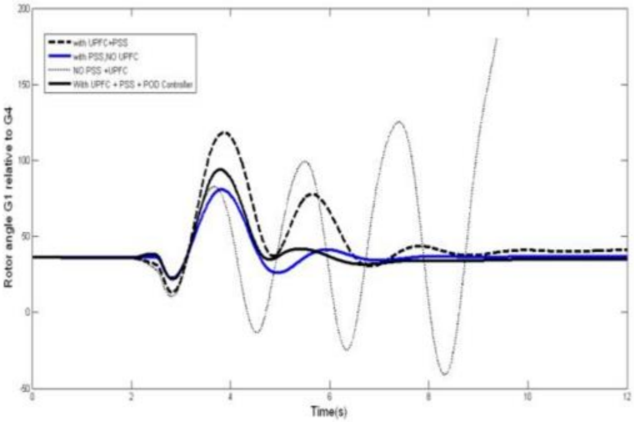

Fig. 4(e)Rotor angle G1relative to G4 in degrees

CONCLUSION

This paper provides an overview of the application of the Unified Power Flow Controller (UPFC) for damping power system oscillations, focusing particularly on a two-area power system analysis. The study underscores that the inclusion of Power Oscillations Damping (POD) and Power System Stabilizer (PSS) in conjunction with UPFC yields satisfactory performance compared to scenarios involving only UPFC or UPFC with PSS. Consequently, the findings suggest that, for the effective damping of power system oscillations, the integration of an additional Power Oscillations Damping (POD) controller is essential when employing UPFC.

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