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Damping of Power System Oscillations in Renewable Integrated Power System Using Unified Power Flow Controller

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Abstract: The deficiency of non-renewable energy sources makes the study of renewable energy sources, distributed generation and their operation in a power system network very much relevant to the current scenario. Power system network consisting of diesel generator set as a base power generating station, one wind farm as a source of renewable energy, five bus network, and a three-phase load is considered to study the damping of power system oscillations with the help of a prevalent flexible a.c. transmission system (FACTS) device named unified power flow controller (UPFC). The test system is simulated using MATLAB/Simulink. Simulation results verify the efficacy of unified power flow controller in damping out oscillations in the power system.

Key words: Power system, oscillation damping, diesel generator, renewable integration, wind farm, UPFC.

Introduction

The power system oscillations are the major concern when it comes to the stability of the system. The applications of UPFC on transmission system of Taiwan power system for redistribution of power flow over disproportionate parallel corridors and boost up the low voltage level are presented in Chang et al. (2002). A damping controller is also designed in order to enhance the damping for low-frequency oscillations.

A hybrid fuzzy logic controller is structured to show the efficacy of series FACTS devices for oscillation damping in Dash et al. (2000). This controller is very effective to damp out multi-mode power system oscillations. Effects of sub synchronous oscillations generated due to wind farm in a power grid are discussed and sub synchronous instability is also described in Du et al., 2019. A method to select the control signal of UPFC is proposed in Farsangi et al. (2004). In this paper, a comparison is done for achieving the best damping for inter-area oscillations between static var compensator (SVC), static synchronous series compensator (SSSC), and UPFC. A paper presents a control structure of UPFC as well as its comprehensive analysis in Fujita et al. (1999). The proposed scheme intended to damp out the power fluctuation in transient state. A novel control approach for UPFC in order to damp out the power system oscillations is focused by Guo et al. (2009). This control scheme is suitable for a wide range of operating conditions and found very effective even when multiple modes of oscillation are present.

A comparison for monitoring the real and reactive power between various FACTS devise like TCSC, TCPAR and UPFC is done by Gyugyi et al. (1995). In this condition, UPFC not only maintains the real and reactive power but also counteract power system oscillations. The suitable damping mechanism and

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Nomenclature

FACTS	Flexible a.c. transmission system
UPFC	Unified power flow controller
STATCOM	Static synchronous compensator
SSSC	Static synchronous series compensator
TCSC	Thyristor-controlled series compensator
SVC	Static var compensator
LMI	Linear matrix inequality
OWF	Offshore wind farm
SWF	Seashore wind farm
RES	Renewable energy sources
TCPAR	Thyristor-controlled phase angle regulator

control parameters to design UPFC controller are explained by HaiFeng et al. (2000). Applications of P-H model are also given. This linearized Phillips-Heffron model provides help in studying the effect on power system oscillation stability due to UPFC d.c. voltage regulator. A method for investigating the first swing stability is examined by Haque et al. (2008).

The improvement in damping of power swing of nonlinear power systems by using UPFC is done by Januszewski et al. (2004). In this paper, the state-variable control strategy is derived using the application of the direct Lyapunov method and implemented. Kumar et al. (2007) suggested a set of controllability catalogues to search the optimal placement of UPFC for improving the system stability by enhancing damping of small-signal oscillations. A paper analyzed the performance of distance relay under power swing condition for uncompensated and compensated line with UPFC installed (Moravej et al., 2008).

The main result achieved in this study is, the impendence seen by the distance relay for UPFC installed line under first power swing is analyzed. A controller built on H∞ diversified sensitivity in linear matrix inequality (LMI) structure for UPFC is designed for providing adequate damping of inter-area oscillations by Pal et al. (2002). The dynamic response of system exhibits the effectiveness of the controller to damp out the inter-area oscillations.

Shojaeian et al. (2012) focused on adaptive input-output feedback linearization control based approach to damp out the low-frequency oscillations for multi UPFCs in multi machine system. Shotorbani et al. (2013) states an algorithm that proves UPFC is able to instantaneously control the transmission line parameters.

This is proved by a study based on the direct Lyapunov stability theory for finite-time convergence and chattering-free characteristics in order to improve the damping of the power oscillation using UPFC. A Newton-type current injection-based model of UPFC is proposed by Son et al. (2004). This model is used to study the oscillation of low frequency.

A detailed designing of UPFC as power flow controller, d.c. voltage regulator and damping controller are done by Tambey et al. (2003). The impact of UPFC's control signal is examined to damp out the low-frequency oscillations. The results of improvement of stability and power fluctuation mitigation for an onshore power grid fed through a UPFC from an integrated farm (offshore wind farm OWF and seashore wind farm SWF) have been examined (Wang et al., 2013). Stability enhancement in power system connected to a wind farm using STATCOM is explained by Wang et al. (2017). Zarghami et al. (2010) states a multistage control approach using multiple UPFCs for damping the inter-area oscillations for a large power system. Zhou et al. (2018) explains the damping techniques for inter-area oscillations in wind farm integrated power system.

This paper is organized in the following manner: Model representation of renewable integrated power system network with and without UPFC is described in next section. The subsequent section examines the simulation results of the described model using MATLAB/Simulink with and without UPFC. Also comparative study of the results is explained with the help of waveforms captured at the time of simulation. At the last, the conclusion drawn about the work done is presented.

Representation of Renewable Integrated Power System Model

Power system oscillation is the major problem for the stability of the power system. A microgrid using a diesel generator set and a wind farm is considered for study.

Renewable Integrated Power System Model without UPFC

A power system network consisting of a diesel generator set with two machines (M1 and M2), a wind farm having two machines (M3 and M4), five buses, two transformers (T1 and T2), three-phase fault, three-phase source, three-phase load and two single circuit lines (L1 and L2) is considered to study the damping of power system oscillations.

Figure 1 shows the single line diagram of the renewable integrated power system network without UPFC.

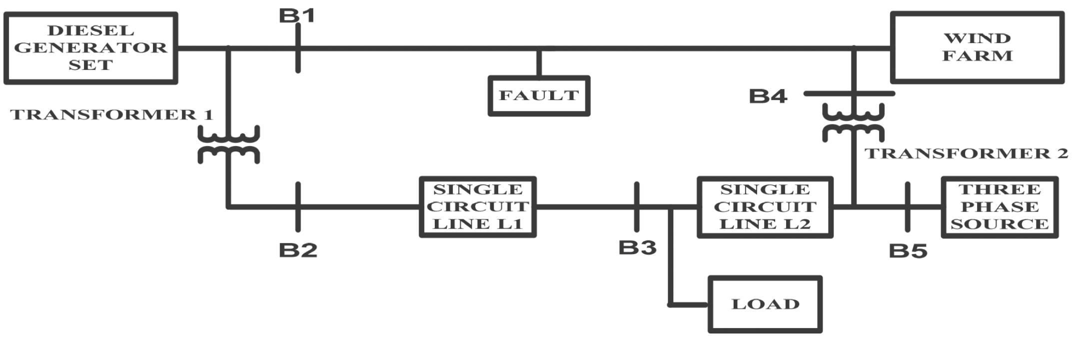

Figure 1: Single line diagram of the renewable integrated power system network without UPFC.

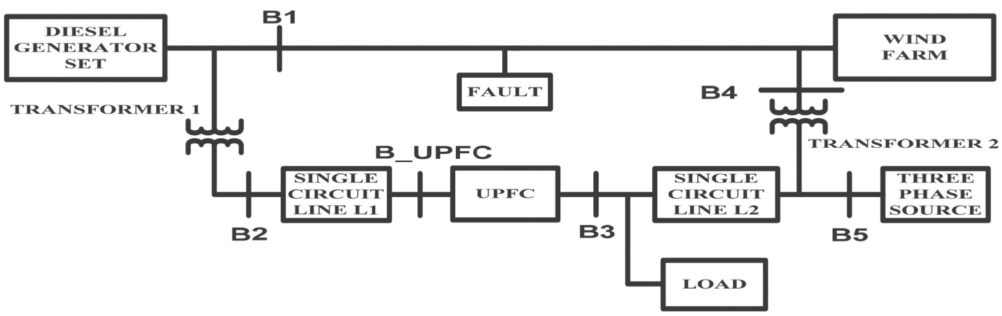

Figure 2: Single line diagram of the renewable integrated power system network with UPFC.

Renewable Integrated Power System Model with UPFC

In this case, one FACTS device named as unified power flow controller is used in the microgrid and also one extra bus B_UPFC is taken for study purposes (Figure 2). Unified power flow controller is chosen to check its suitability to damp out the oscillations in a renewable integrated power system network.

Result and Discussion

In this section, the results of the test system without (Figures 3-7) and with (Figures 8-12) UPFC are shown. A comparative study is explained by showing the graphical results of the system.

Results without UPFC

As presented in the figures one can observe the behaviour of renewable integrated power system network in absence of unified power flow controller. Results of positive sequence voltage (B1 and B2), real power (B1 to B2), angle variations of machines M1, M2 and M3 with respect to M4 and terminal voltage at machines M1, M2, M3 and M4 without UPFC are explained in Figures 3 to 7 respectively.

Results with UPFC

From Figures 8 to 12 the effect of unified power flow controller in damping out the oscillations can be seen.

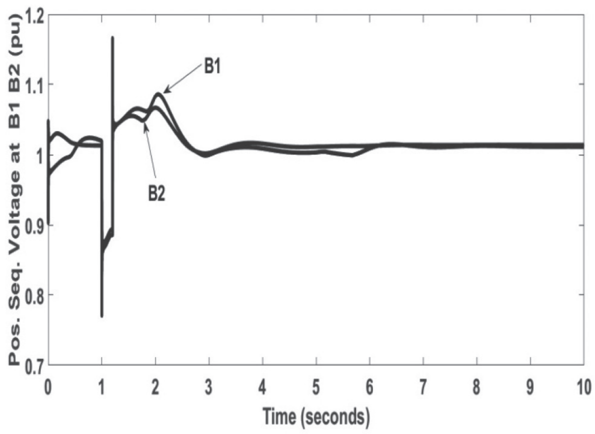

Figure 3: Positive sequence voltage at B1 and B2 without UPFC.

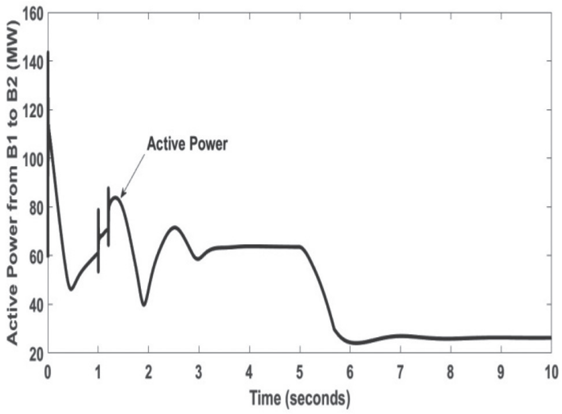

Figure 4: Real power (B1 to B2) without UPFC.

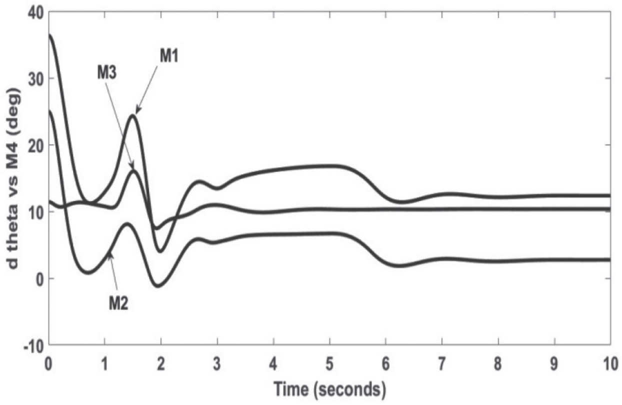

Figure 5: Angle variation of M1, M2 and M3 with respect to M4 without UPFC.

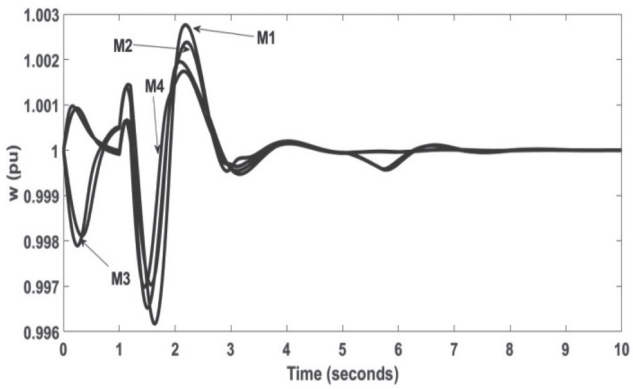

Figure 6: Speed at all machine M1, M2, M3 and M4 without UPFC.

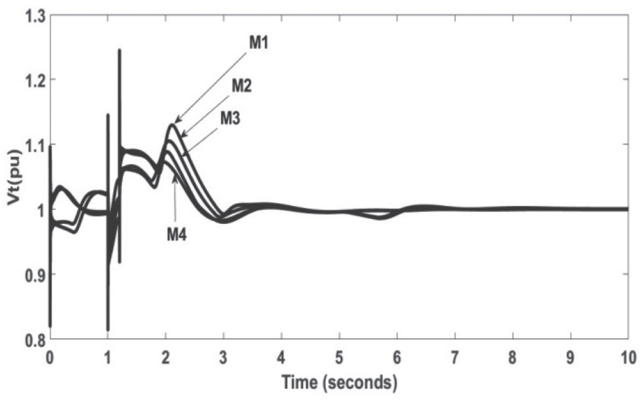

Figure 7: Terminal voltage at machines M1, M2, M3 and M4 without UPFC.

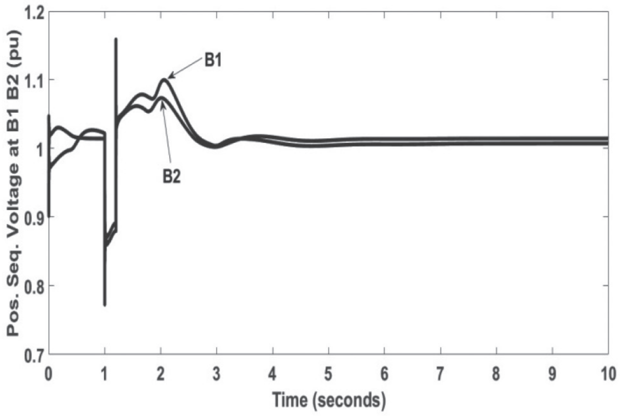

Figure 8: Positive sequence voltage at (B1 and B2) with UPFC.

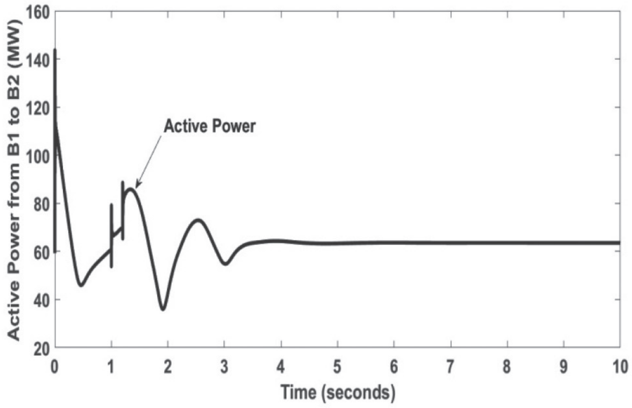

Figure 9: Real power (B1 to B2) with UPFC.

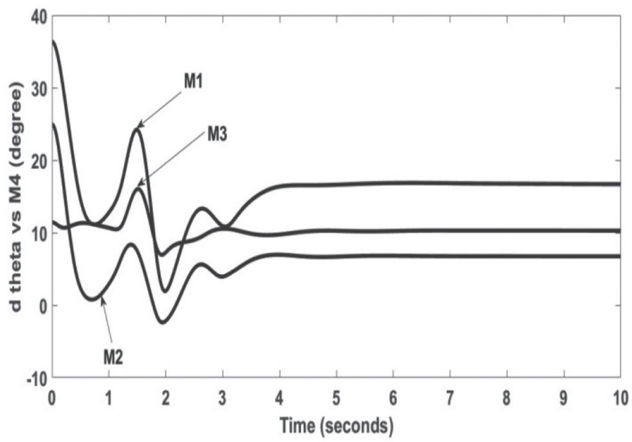

Figure 10: Angle variation of machine M1, M2, M3 with respect to M4 with UPFC.

In a renewable integrated power system when UPFC is installed it helps in damping out the oscillations in active power, voltage and angle variation of the given test system. UPFC also helps to make the power system more stable in comparison to a system when it was not installed. Results of the study are shown in Figures 3 to 12, with this discussion one can clearly observe the effect of UPFC on active power, voltage and angle variation waveforms that it has improved the system significantly.

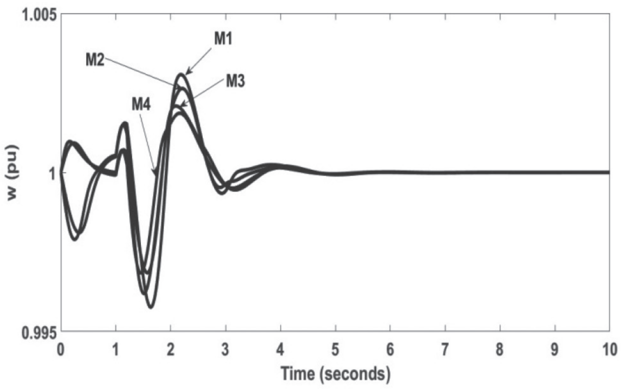

Figure 11: Speed at all machine M1, M2, M3 and M4 with UPFC.

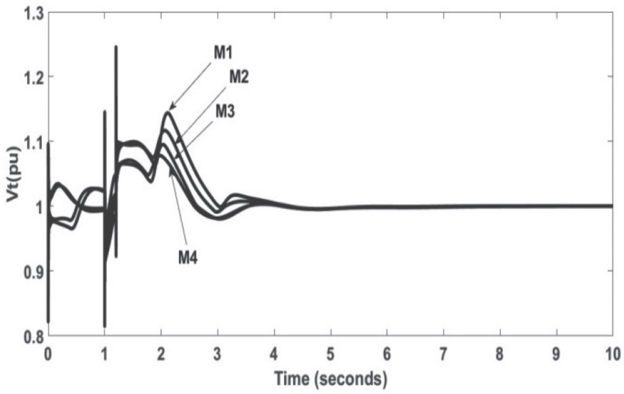

Figure 12: Terminal voltage at machines M1, M2, M3 and M4 with UPFC.

Comparison of Results

In this section, a comparative study is discussed about the results captured from the test system when this system was simulated with and without UPFC in MATLAB/Simulink. From Figures 13 to 15 one can easily understand the improvement in test system results after installation of UPFC.

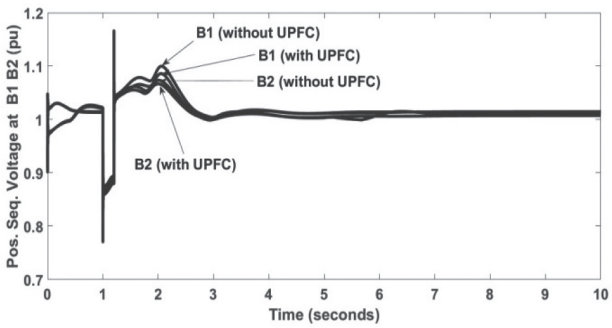

Figure 13: Comparison of positive sequence voltage at (B1 and B2) with and without UPFC.

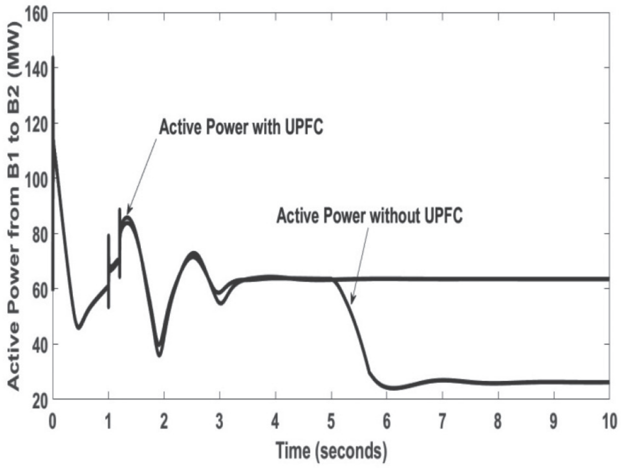

Figure 14: Comparison of real power (B1 to B2) with and without UPFC.

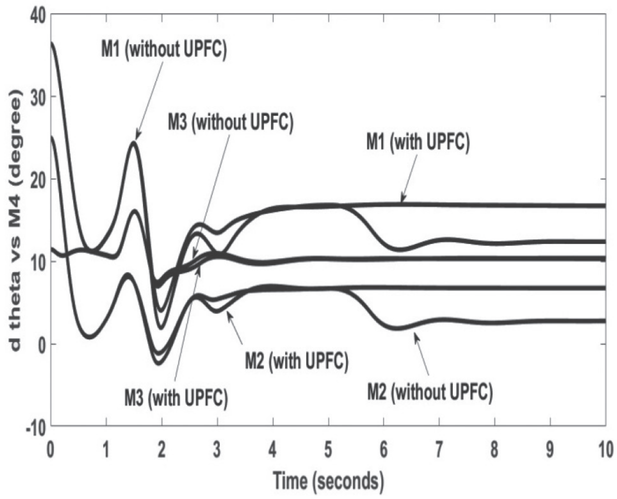

Figure 15: Comparison of Angle variation of machine M1, M2, M3 with respect to M4 with and without UPFC.

It is plainly visible from the comparison graphs shown that UPFC has done the virtuous job in damping out the oscillations in the power system in the presence of renewable energy sources as here wind farm is used as a source of renewable energy.

Conclusion

In this paper, the results of voltage magnitude, angle and speed for the four machine system is explained in detail in the presence of UPFC and in the absence of UPFC. Results of both the cases are shown in graphical simulation waveforms. The result shows that UPFC is very much effective in damping the multi-mode of oscillation.

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