Application of UPFC on Stabilizing Torsional Oscillations and Improving Transient Stability

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Abstract--**This paper investigates the application of Unified Power Flow Controller (UPFC) to stabilize multi-mode torsional oscillations of sub-synchronous resonance (SSR), and to improve the transient stability during a three phase short circuit fault that may result in oscillatory torques on the generator rotor shaft causing serious damages to the system and may call for the disconnection of a wind farm to avoid any possible damages. Simulation is carried out using MATLAB/Simulink software. Results show that the proposed UPFC controller is very effective in damping all SSR modes of the system under study and in minimizing the potential for the wind farm disconnection during the studied faults. The proposed controller is simple and easy to be implemented.**

Index Terms—**Sub-synchronous Resonance (SSR), UPFC, Stability, Wind Farms.**

I. INTRODUCTION

P OWER systems are becoming larger and more interconnected. As a consequence, transient stability problem has become more serious. If the stability is lost, network collapse may occur with annihilating economical losses and severe power grid damages that may lead to overall blackout [1-4]. Stability problem can occur due to the increase in the power demand with overloading the transmission lines, therefore, transmission line operators are required to increase the power transfer capability of the existing transmission lines. In this context, they have two options; the first one is to build an additional parallel transmission line which is not a cost effective option especially for long transmission lines. The second option is to use a series capacitor as a partial compensation reactance to the transmission line which has been extensively used as a very effective method to increase power transfer capability of transmission system, and improve the steady state and transient stability limits of a power system [5]. Series capacitor is however, not without a problem as it may cause subsynchronous resonance (SSR) when the mechanical frequency of the generator mechanical shaft and the electrical frequency of the transmission system are add up to the power frequency[6]. There are three ways in which a

system and generator can interact with subsynchronous effects: induction generator effect, torsional interaction and transient torques[6]. SSR due to transient torque can be developed if an electrical resonant frequency of the network is complementary to any one of the natural torsional oscillating frequencies of turbine-generator shaft during system disturbance events. The electric resonance of the transmission system and the torsional oscillations of the mass-spring system of the turbine generator will be mutually excited and might grow up causing serious shaft oscillations resulting in shaft fatigue and possibly damage and failure [7]. The first two shaft failures due to SSR occurred at the Mohave power station in 1970 and 1971 respectively [8-10]. It is important to investigate the subsynchronous resonance when planning to include series capacitors for new or existing transmission lines. Extensive research has been introduced in the literature to increase the damping of torsional mode and many countermeasures have been suggested to damp the SSR. Some suggested solutions include the use of synchronous-machine-based Energy Storage System (ESS) [11], static var compensator (SVC) [12, 13], superconducting magnetic energy storage (SMES) unit [14-17], Static Synchronous Compensator (STATCOM) [18], shunt reactor controller [19, 20], Thyristor-controlled dynamic resistance braking [9, 21], excitation control of synchronous generator [22, 23], and gate controlled series capacitors [24, 25].

Flexible AC Transmission Systems (FACTS) based power electronic converters are used extensively in power systems because of their ability to provide flexible active and reactive power flow control [26]. This paper investigates the use of Unified Power Flow Controller (UPFC) to enhance transient stability and to damp the SSR of a steam turbine-generator that is connected to a large interconnected AC grid via a series capacitor compensated transmission line.

II. SYSTEM UNDER STUDY

The system under study shown in Fig.1 consists of a synchronous generator and wind farm that includes 6 wind turbines of type D connected to the grid that is simulated as infinite bus via a Y/Δ step down transformer and two parallel transmission lines, one of which is series compensated. The UPFC is connected to bus-1 between the compensated transmission lines and the generators to provide adequate damping for the turbine generator set.
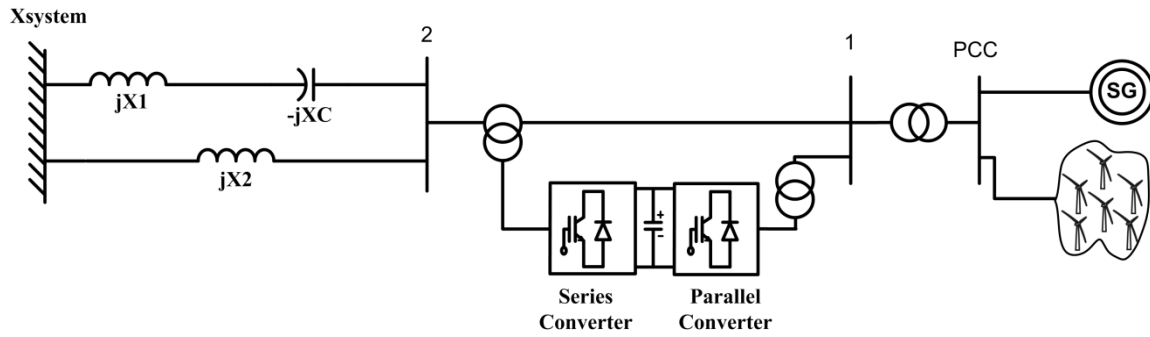
Fig. 1 System under study

III.   UPFC MODELING AND CONTROL

A UPFC is a complex power electronic device developed to control and to optimize the power flow in electrical power transmission systems. UPFC is a combination of a STATCOM and Static synchronous series Compensator (SSSC) coupled through a common DC link. The UPFC allows system to be more flexible by using high-speed response active and reactive power compensations. Therefore, installing UPFC at critical points of the transmission system will increase the power dispatch up to the power rating of generators and transformers and the thermal limits of transmission line conductors, by increasing the stability margin. The shunt and   series converters of the UPFC can control both active and reactive powers smoothly, rapidly and independently [26].

The series inverter is used to control the real and reactive line power flow by inserting a voltage of a controllable magnitude and phase in series with the transmission line. As shown in Fig.2. The active and reactive power error is used to generate the reference value of the V_{dref} and V_{qref} which is compared with the measured values of V_d and V_q. The error signal is fed to PID controller to calculate the required converter firing angle and modulation index. The Clarke-Park transformation is used to convert the a-b-c quantities to d-q reference frame [27].
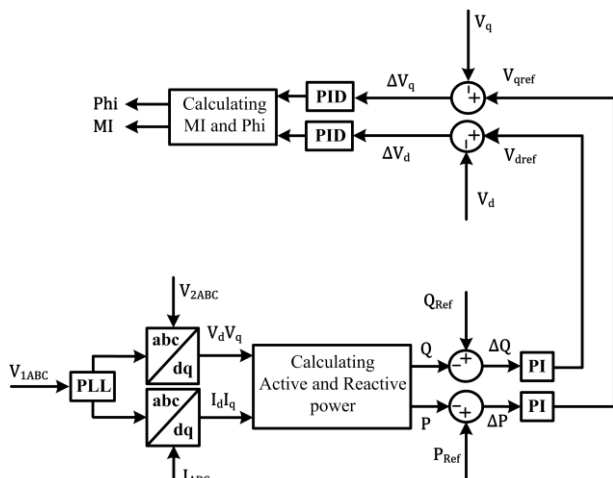
The shunt inverter is used for voltage regulation at the PCC by injecting reactive power into the transmission line and balancing the real power flow exchanged between the series inverter and the transmission line. The reference AC voltage and the DC converter voltage are compared with their measured bus values and the error is fed into a PI controller to create i_{qref} and i_{dref} which are compared with measured values i_q and i_d. The error signal is fed to a PID controller to create the firing angle and modulation index for the shunt converter.
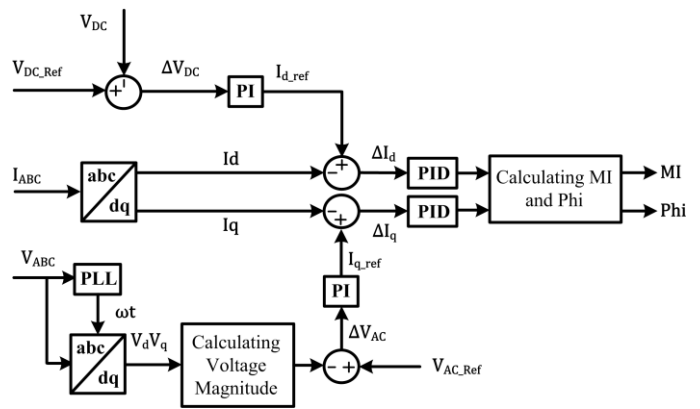

Fig. 3 Control system of the shunt converter

The robustness of the selected parameters is based on several runs that are conducted to the system, as shown in Fig.4. An $OF(K_I,K_P)$ is determined for the entire aggregate of runs, in which each run in the aggregate corresponds to one operating condition of the network.
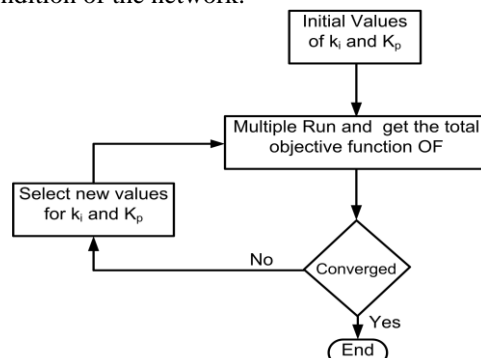

Fig. 2 Control system of the series converter

Fig. 4. Schematic diagram for selecting PI parameters

IV. DAMPING OF SSR

The shaft system of the turbine generator set consists of four masses; a high-pressure turbine (HP), a low-pressure turbine (LP), a generator rotor (Gen) and an exciter (Ex). To carry out the investigations, a non-linear model of the system is developed to incorporate the interaction between the electric network and the torsionally oscillating shaft system of the turbine-generator set. The system is simulated with the inclusion of all non-linearities such as exciter ceiling voltage limit and the limit of the PI parameters. A three phase short-circuit fault is simulated at bus-2 at t=12 s and is assumed to be cleared at t=12.035s.

Figs. 5 through 13 show the dynamic response of the studied system without and with the UPFC. The effect of the SSR and the UPFC controller is investigated through time domain waveforms of various system variables such as the synchronous generator speed deviation, torsional torque induced on the shaft sections between the high- pressure, low-pressure turbines (T_{HP-LP}) and the low-pressure turbine and generator (T_{Gen-LP}), the DFIG electromechanical torque, the point of common coupling (PCC) voltage the DFIG converter DC voltage and the DFIG speed. Without UPFC and due to the lack of system damping, the system is unstable as evident by the high torsional forces induced in the generator mechanical shafts and the significant increment in the shaft speeds.
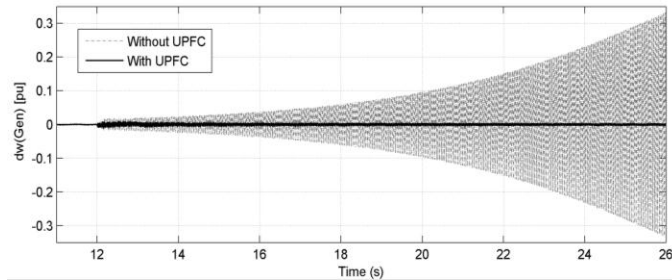

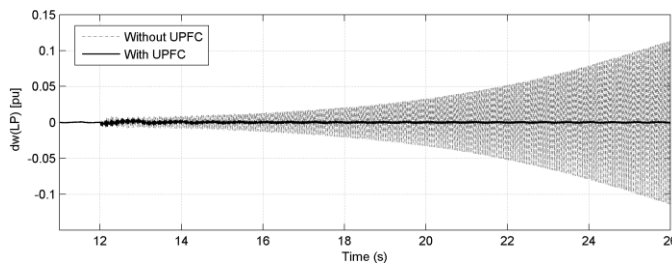Fig. 5. Generator speed deviation with and without UPFC

Fig. 6. LP speed deviation with and without UPFC
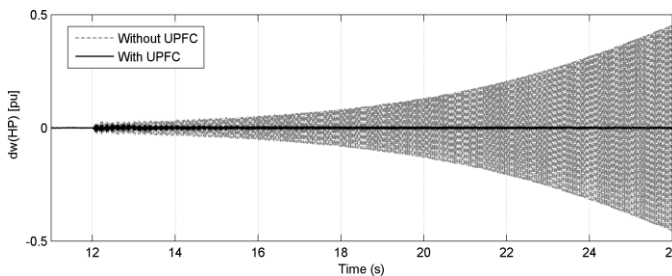

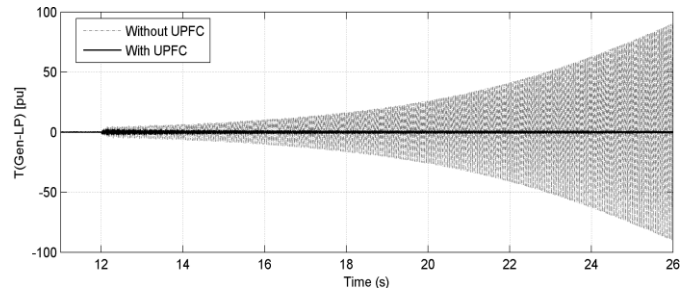Fig. 7. HP speed deviation with and without UPFC

Fig. 8. LP to Gen Torque with and without UPFC

When the UPFC is connected, the damping of the synchronous generator and the DFIG are greatly enhanced and the stability margin can be extended as shown in the Figures. It can also be shown that using a UPFC unit will reduce high torsional forces on the turbine-generator shaft sections to almost normal steady state values and decrease the settling time substantially. It will also reduce the generator shaft speed oscillations and maintain the speed at the nominal value. The effect of improving system damping and the overall performance using UPFC is very obvious as can be seen in the simulation results.
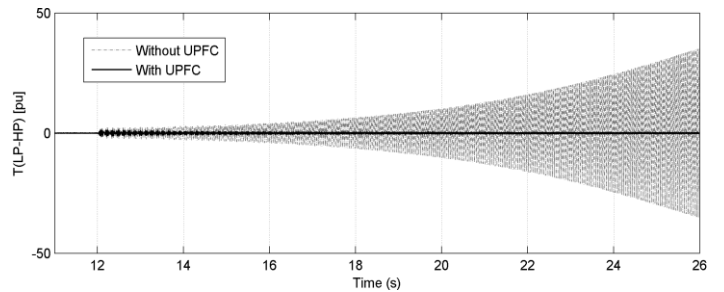

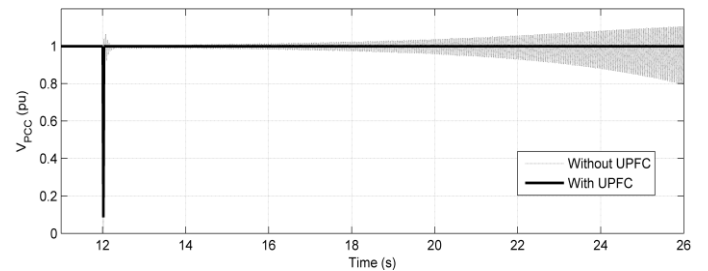Fig. 9. HP to LP Torque with and without UPFC

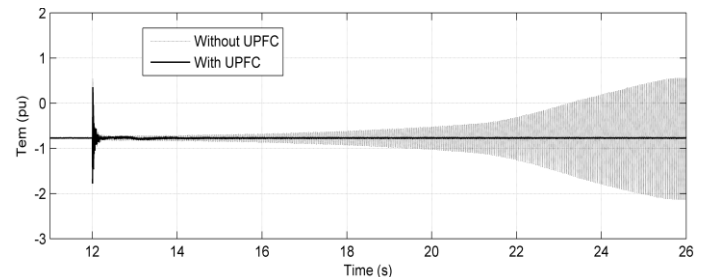Fig. 10. The PCC voltage with and without UPFC

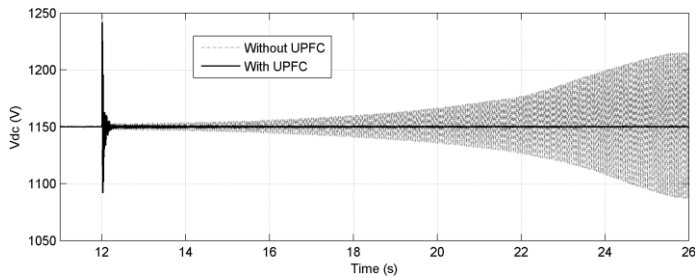Fig.11. DFIG Electromechanical Torque with and without UPFC
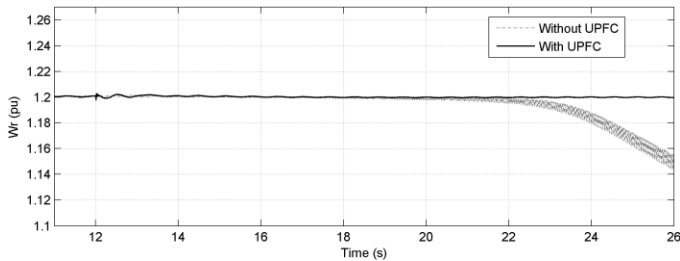
Fig.12. DFIG VDC response with and without UPFC

Fig.13. DFIG Speed with and without UPFC

V. Conclusions

Results show that the additional degree of freedom provided by the UPFC under the proposed controller significantly improves the system overall performance. The proposed control algorithm can effectively render active and reactive power support to damp system torsional oscillations and to enhance system transient stability during a three phase short circuit fault. This controller is simple in its structure and would require very little hardware to implement.

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