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Power Transfer Enhancement and Optimal Power System Security by use of Unified Power Flow Controller (UPFC)

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Abstract

This paper presents a discussion of the effect of Unified Power Flow Controller (UPFC) on Power Transfer Capability and Optimal Power System Security of a Nigerian 330kV network. By development and implementation of low frequency damping controller, UPFC is used to mitigate low frequency oscillations associated with inter-area. Mitigation of low frequency oscillation enhances the stability limits of the system, thereby improving power transfer through the system. For better studying of the capability of FACTS control, a power injection model of FACTS devices, which enables simulating the control of UPFC, is employed. Studies based on the 330kV network with UPFC demonstrate the effectiveness of FACTS control on ATC enhancement. The UPFC regulates bus voltages and enhances Power Transfer Capability of the power network over transmission lines of the Nigerian network.

1. Introduction

Electric power systems low frequency oscillations are known to constrain power transfer capabilities with resulting effect of reduced optimal power system security [1]. In order to enhance transfer capability of transmission lines, desired power flow can be achieved using proper control of FACTS devices. A modern solution to this problem is the placement with proper control of UPFC to the tie-line in the power system. This, of course, improves the stability of power systems by damping of low frequency oscillations present in the power system [2]. Low frequency oscillation damping results to increased tie-line power flows in the power system upon the implementation of the proposed control scheme. Damping of the low frequency oscillations improves the stability limits of the system; thereby translate to an enhancement in the transfer capabilities of the power system. The limitation of PSS in damping only the local modes over a broad range of operating points as mentioned in Ambafi's research work [3] can effectively be handled or eliminated with the use of the UPFC. The ability of interconnected power systems to transfer quality electrical power reliably and economically is mainly a function of three limitations: thermal, voltage and stability limits [4]. To gain maximum benefit of transmission facilities, power system stability margins must be maintained such that it does not constrain power transfer capability. Consequently, these requires the operations and planning of power systems in such a manner that the limits are not exceeded, hence transfer capabilities of transmission interface have to be computed thereby gaining the benefits of bulk power transfers.

Available transfer capability (ATC) is the measure of the ability of interconnected electric systems to reliably move or transfer power from one area (sending bus) to another area (receiving bus) over all physical paths connecting the areas under precise system conditions [5].

Knowledge of transfer capability plays a vital role in planning and operation of the power systems with regards to system security. One benefit of interconnected power systems is the potential for increased reliability. In an interconnected system, the loss of generation in one area can be replaced by generation from other areas. Thus, several systems interconnected can survive contingencies that the individual systems could not. Transfer capability computations are useful for evaluating the ability of the interconnected system to remain secured following generation and transmission outages [6]. The purpose of the transfer capability computation which takes into accounts the capacity benefit margin (CBM) is to determine the quantity of lost generation that can be replaced by the potential reserves and the limiting constraints in each circumstance. Transfer capability enhancement can thus be obtained through improvement in any one of the three limitations. Specifically, the ability of UPFC to regulate system voltage through reactive power compensation improves transfer capability constrained by voltage limitation.

On the other hand, however, power system is said to be secured if the flow of electrical power from the generating stations to load centers is maintained, particularly under planned or unplanned contingency conditions. In view of the fact that contingencies (disturbances) can be transients or severe, localized or widespread, power systems must be planned, designed and operated to meet desired level of security. Additional investment is required to account for unplanned and severe disturbances in the design of power system to achieve certain level of security. In developed countries, the customer is often willing to pay more for minimizing the interruption of power, whereas in the less developed countries the scarcity of capital and other reasons keep the level of power system security lower [7].

In this paper, the focus is to damp low frequency oscillations which are functions of power transfer with the aid of UPFC thereby improving the system security.

2. Control Principles of UPFC

Unified Power Flow Controllers (UPFC) is often used to control power flows in transmission lines. It has the ability to direct real and reactive power flows through a transmission path and regulate the system voltage through reactive power compensation. UPFC in its basic structure consist of two voltage source converters (an exciter and a booster both of which are ac/dc voltage source converters). The UPFC can be viewed as a combination of STATCOM and SSSC with a shared dc bus. A common dc capacitor is connected to the dc sides of both converters thereby provides a dc voltage support for the converter operation and equally functions as energy storage (See Figure 1). At the ac side of the booster a synchronous ac voltage of controllable magnitude and phase angle is injected in series with the transmission line through a series booster transformer. While the ac side of the exciter makes a parallel connection to the transmission line through a transformer where a current of controllable magnitude and power factor angle is injected to or absorbed from the power system, having several operating modes [8, 9].

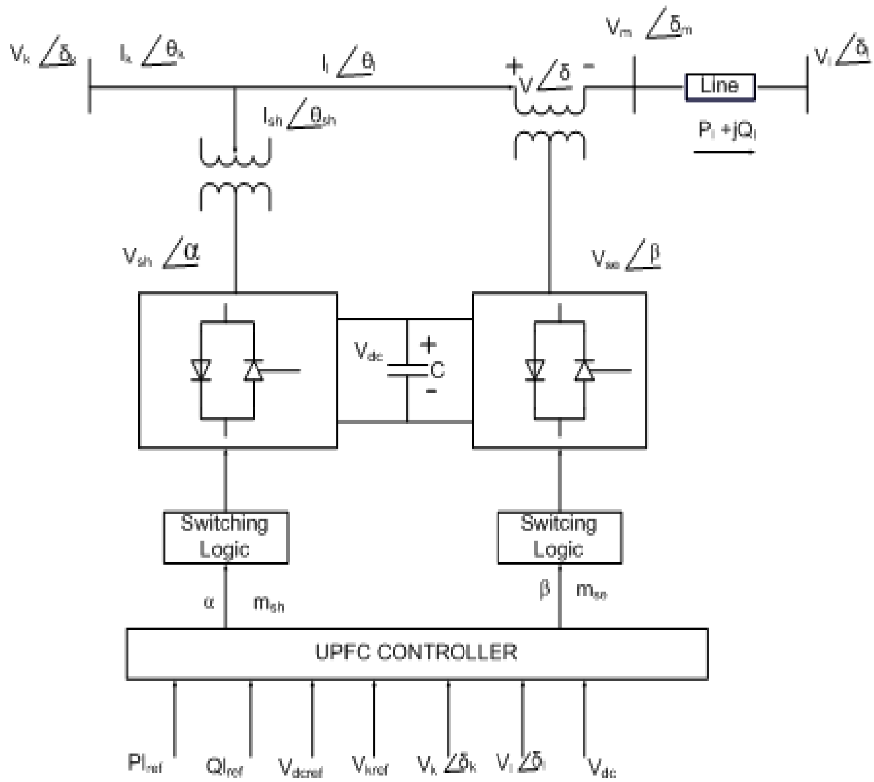

Figure 1. Block Diagram of a UPFC

3. Transient Stability Improvement Using UPFC – Case Study

The tendency of a power system to develop restoring forces equal to or greater than the disturbing forces in other to maintain equilibrium (synchronism) after a severe transient disturbance is termed transient stability [10]. Basically, transient instability occurs when the kinetic energy accumulated in the generator rotors during system fault are not released during initial power swing if the system fault is not cleared within a required time (critical clearing time). As a result, the excessive kinetic energy makes a group of generators going out of step from the main grid after the fault is cleared. This phenomenon is clearly explained by equal area criterion (EAC) [11]. Transient stability is important from the view point of maintaining system security; that is the incidence of a fault should not lead to tripping of generating unit due to loss of synchronism and the possibility of a cascaded outage leading to system black out. Transient stability studies deals with the effects of large, sudden disturbances such as the occurrence of a fault, the sudden outage of a line or the sudden application or removal of loads. Stability depends on both the initial operating state of the system and the severity of the disturbance. Factors that affect the transient stability of a generator in a practical power system includes: the system reactance after fault, duration of fault-clearing time, generator inertia, the generator internal voltage (determined by excitation system) and infinite bus voltage (system voltage), the generator loading before the disturbance, the generator internal reactance, and the generator output during the fault. Hence, an enhancement in any of these factors to preferred level means improved system stability. Specifically, UPFC implements reactive power damping control to achieve stability improvement [12]

3.1 An Example System

The Nigerian 330kV transmission network (grid system) is used in this research work. Herein, the grid system is conveniently zoned into four geographical areas in conformity with operational structure of the electric utility (PHCN). The three hydro power stations are situated in Area 1 while Area 2 has thermal power station located in it and areas 3 and 4 have gas power stations located in them as shown in Figure 2.

3.2 Case Study Simulation to verify the performance of UPFC at its optimal location

To validate the performance of the FACTS controller with respect to ATC, the Nigerian Grid System was modeled and simulated in PSAT environment as shown in Figure 3. A three-phase fault through impedance is applied to the transmission line at Bus 10 at 250ms and subsequently, the fault is cleared in 265ms. The UPFC is located between Bus 20 and Bus 22 to control the power flow on the line between the two buses and the voltage at bus 20. The generator is operating at its rated power level. The system responses are simulated using PSAT. It is observed that the UPFC with coordinated controller can greatly improve the voltage profile of the system. Moreover, the optimal placement of UPFC allows minimizing the system losses and improves real power flow in transmission lines as depicted from the values obtained in Table 1.

Table 1. Specific values obtained for voltage at Ikeja West bus, real power loss and real power flow on Ikeja West-Egbin transmission line.

	Voltage at Ikeja West bus in kV	**Real power loss in MW along Ikeja West-Egbin line**	**Real power flow in MW for a 3-Ø fault @ Bus10**
Without UPFC	278.069	3.602	70.02
With UPFC	330.0	2.447	88.33

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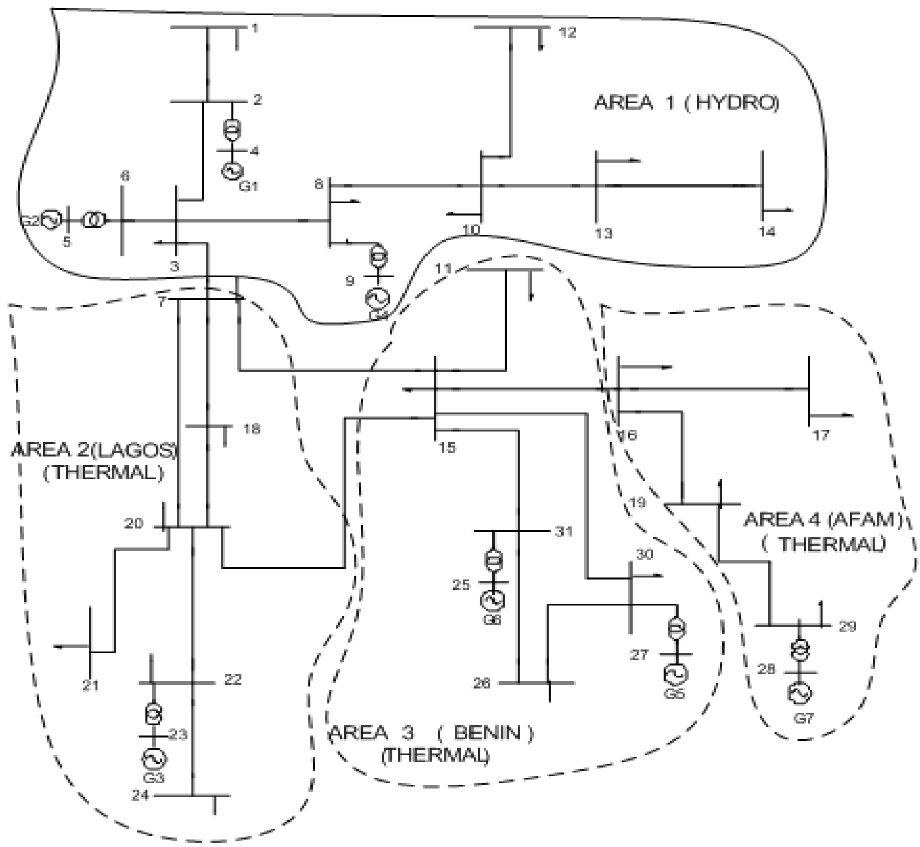

Figure 2. Nigerian Grid system for case study

By definition, ATC determination in this paper can be obtained in terms of the transmission line power flows which can be limited by thermal, voltage and stability limits. Suppose, a line between buses i,j encountered a thermal load limit, then ATC in this paper is obtained using (1)

$$ATC_{mn,TL} = P_{ij} - P_{ij}^{0}(inMW) \tag{1}$$

where, , mn TL ATC is the calculated ATC for transaction between sending bus/area m and receiving bus/area n constrained by thermal limit violation. P_{ij} is power flow in the line connecting buses i and j. P_{ij}^{0} is the base case line flow between buses i and j.
Also, if a PQ bus violates the voltage limit (i.e., ±10% from nominal value of 1.0 p.u.) then, the ATC is obtained using (2)

$$ATC_{mn,VL} = P_{ij} - P_{ij}^{0}(inMW) \tag{2}$$

where, , mn VL ATC is the calculated ATC for transaction between seller bus/area m and buyer bus/area n due to voltage limit violation.
Similarly, Suppose, if a load (PQ) bus encountered maximum loadability limit which translate to stability concerns then, the ATC is obtained using (3).

$$ATC_{mn,VSL} = P_{ij} - P_{ij}^{0}(inMW) \tag{3}$$

where, , mn VSL ATC is the calculated ATC for transaction between sending bus/area m and receiving bus/area n due to voltage stability limit. [13]
Generally, the additional line power flow above base case (without UPFC) gives the improvement in the transfer capability as shown in Table 1.

4. Inter-Area Low Frequency Oscillations Improvement by UPFC

For many years, one key concern for large for large inter-connected power systems such as the Nigerian grid is the issue of low frequency oscillations. The limitation of Power system stabilizer in reducing local mode oscillations invigorates the use of FACTS controllers for inter-area oscillations [14]. Hence, UPFC having fast active and reactive power controlling capability is used in damping the oscillations in the grid through power modulation (active or reactive).

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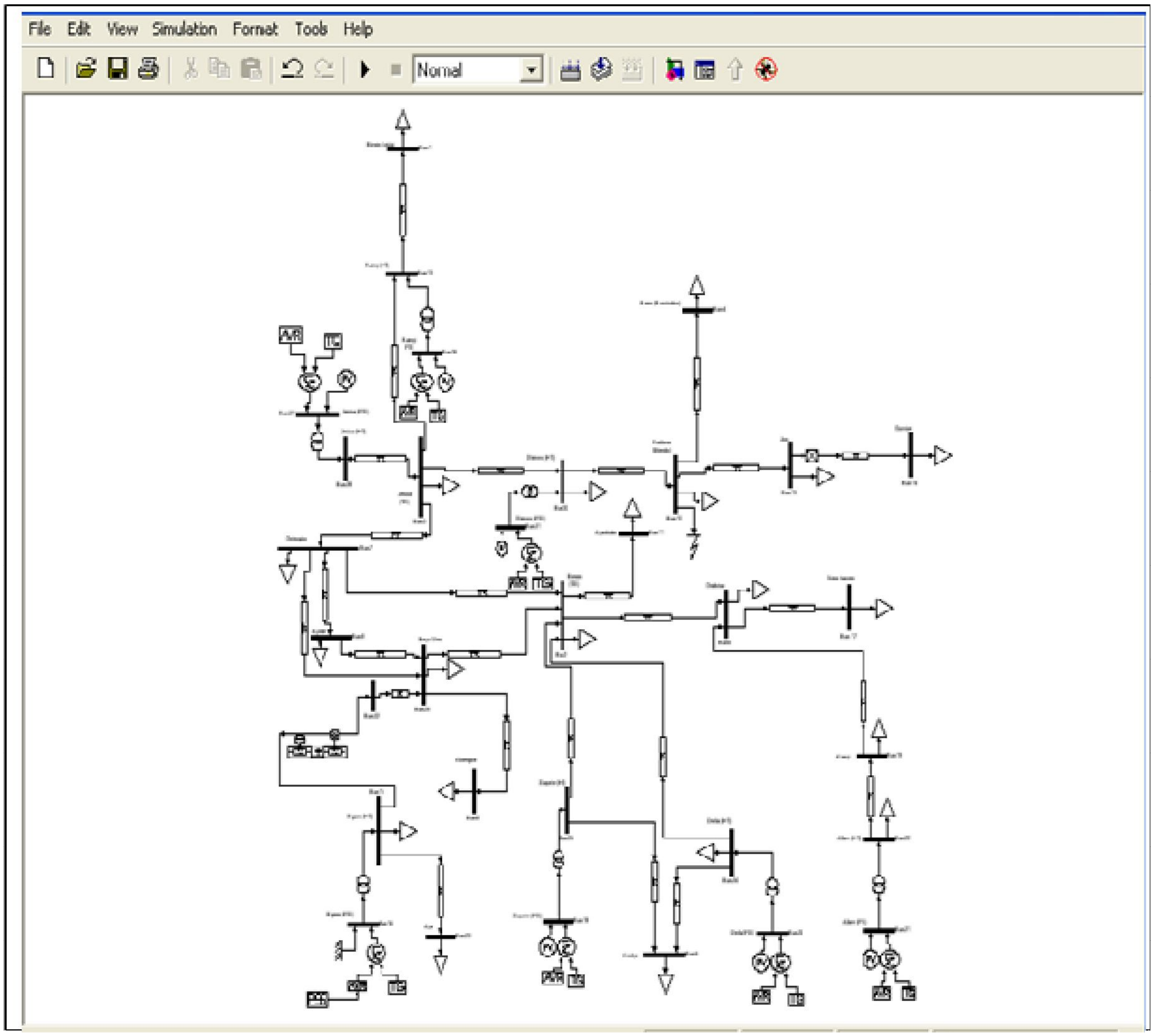

Figure 3. PSAT Representation of Nigerian Grid System.

4.1 Damping Control by Active Power Modulation

In the studied scenario, UPFC is used to provide damping effect when the system experiences oscillation mode. The damping effect is prominent at the electrical proximity of UPFC to the oscillating generator. This is depicted in the Figures 4 and 5 below by implementing an active power damping controller.

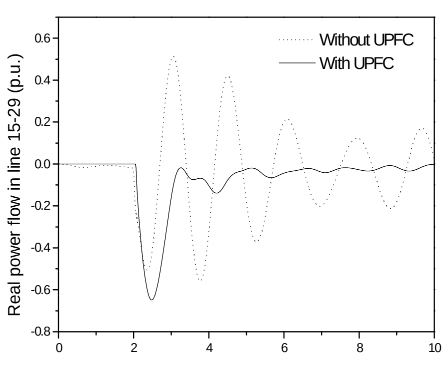

Figure 4. The damping effect of UPFC on the power flow in line 15-29.

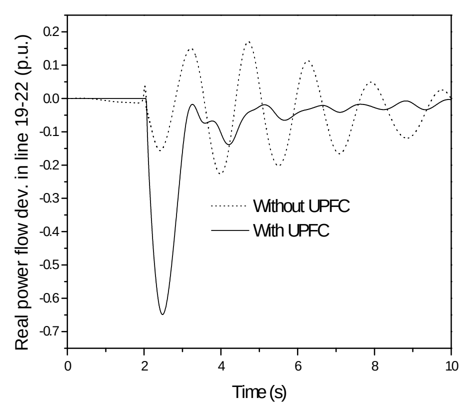

Figure 5. Real power flow in line 22-19 of Nigerian grid system.

4.2 Damping Control by Reactive Power Modulation

By implementing reactive power damping control, UPFC provides damping effect to inter-area oscillation. Hence, a lead-lag type damping

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5. Voltage Stability Improvement Using UPFC

Instability of voltage and its subsequent collapse is a major concern in the design and operation of power system. Voltage collapse results from Inadequacy of reactive power support both from generators and transmission lines, which has manifested in major system failures in recent years [15]. As ac loads are continuously varied, UPFC stabilizes the ac voltage. UPFC when connected initially consumes reactive power to maintain the ac voltage since the ac transmission line generates reactive power as it is lightly loaded. At a point when the system added load is equal to the "natural load", the ac transmission line can neither generates nor consumes reactive power. As the connected loads are further increased, UPFC starts to generate reactive power to support the ac system. These continuous reactive power supports from UPFC, an improvement in the voltage stability margin is noticed.

6. Conclusion

It is generally observed that low frequency oscillation distort the normalcy of power system security and stability that consequently affect the power transfer. However, the use of UPFC in damping these oscillations has tremendously improved the power transfer and optimal power system security. By simulation using PSAT in MATLAB environment, the damping effect of UPFC controllers on power transfer enhancement is validated.

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