

# **DESIGN AND SIMULATION OF UPFC AND IPFC FOR VOLTAGE STABILITY UNDER A SINGLE LINE CONTINGENCY: A COMPARATIVE STUDY**

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## **Abstract**

Reactive power imbalances lead to voltage instability and these are major problem in power systems. This study presents a comparative analysis of the performance of Unified Power Flow Controller (UPFC) and Interline Power Flow Controller (IPFC) for the enhancement of voltage stability and improvement of the transmission system. The two devices under review are two of the most advanced classes of Flexible Alternating Current Transmission System (FACTS) devices. An IEEE 30-bus transmission line system is modelled with MATLAB/Simulink software. The novelty of the study is the design of a new model of IPFC using the Sim-block of Static Synchronous Series Compensator (SSSC) in MATLAB Simulink. Three scenarios were investigated to evaluate the developed system. In scenario one, the 30-bus network system is modelled and simulated without any compensating device. For scenario two, the system is modelled with UPFC incorporated while scenario three has IPFC modelled. The system models are design to have a single line to ground fault of resistance  $0.010\Omega$  and ground resistance of  $0.001\Omega$  occur at bus 1. The fault is expected to cause instability in the system and be cleared after 0.05sec in all cases. The simulated results of the three cases were compared to determine the device with a better performance in improving the voltage stability of the system. The results show that both devices stabilized the system voltages with UPFC having a slightly better improvement of voltage magnitude while IPFC on the other hand had the advantage of stabilizing voltages on double lines. The study has thus, increased insight on the use of both devices in the transmission system.

## **Keywords**

MATLAB, Simulink, FACTS, UPFC, IPFC, Compensator/Controller

## 1. Introduction

The demand for quality, reliable and stable electrical power is always on the increase thus putting pressure on the power system. Pressure such as overloading of the system could lead to reactive power imbalances which in turn lead to voltage instability. Voltage instability is a major problem in power system networks. It results in recurrent voltage collapses which are usually seen as outages and blackouts. This problem reflects unreliability of the system which requires serious attention (Anulekha et al. 2012).

In trying to meet the increasing demand for power, new power transmission lines could be built or the existing ones can be restructured. Both options are expensive and time consuming. “A better and effective option for tackling these problems is by the introduction of high power electronic controllers that can absorb or inject reactive power as required by a particular power system. FACTS (Flexible Alternative Current Transmission System) devices are one of the most effective sources of reactive power. These devices enhance operational flexibility yet do not stress the system” (Bisen and Shrivastava 2013).

According to Bindeswar et al. (2011), the following are other benefits of employing FACTS:

- Reduction of system losses, voltage stability and security improvement
- Improvement of dynamic and transient stability to improve line capacity
- Control of real and reactive power for power profile and quality improvement
- Flexibility in operation

This study investigates the performance of UPFC and IPFC connected to a 132KV transmission line. The aim is to determine the best device to be used in the particular network under consideration. The remainder of this paper is organized thus: Section II presents an overview of FACTS devices, Section III details the research methodology used in this work, section IV analyses the results and section V is the conclusion.

## 2. Overview of Facts Devices

Advancements in power electronics have shown considerable improvement in satisfying the need for voltage stability and power quality improvement via the introduction of FACTS devices (Bhanu et al. 2003). The main functions of these devices are reactive power compensation, voltage control and power flow control to enhance better power quality in modern power systems (Seifi et al. 2010).

Before the advent of FACTS devices were mechanically controlled capacitors, inductors and phase shifting transformers with mechanical on-load tap changers. The first generation were developed such that thyristor valves replace the mechanical switches. This gave a significant improvement in the speed of the devices. The second generation were designed using voltage source converter based devices. These devices provide multiple and total control of the power system parameters (Acha et al. 2004).

According to Hingorani and Gyugyi (2000), FACTS controllers can be divided in four categories as follows:

### 2.1 Series Controllers

Series Controllers inject voltage in series with the line. They are used to reduce the transfer reactance of a power line and hence increase transmission line capacity and improve system stability. Example of series controllers are Thyristor Controlled Series Compensator (TCSC) and SSSC (Zhang et al. 2006).

### 2.2 Shunt Controllers

Shunt controllers are mainly used in high voltage systems to improve voltage profile, by supplying reactive power as they inject current into the system at the point of connection. Static Var Compensator (SVC) and Static Synchronous Compensator (STATCOM) are such controllers (Mithu 20013).

### 2.3 Combined Series-Series Controllers

This is a series combination of separate series controllers, which are coordinately controlled, in more than one transmission line system. The IPFC belongs to this category (Pramod et al. 2012).

## 2.4 Combined Series-Shunt Controllers

These are controllers that have combined shunt and series controllers, which have sophisticated control. When the shunt and series controllers are jointly used, there can be a real power exchange between them through their shared DC link. The UPFC is a series-shunt controller (Pramod et al. 2012).

The two FACTS devices used in this work are described in the subsequent subsections:

## 2.5 Interline Power Flow Controller (IPFC)

IPFC has two series converters connected to two different transmission lines as shown in Figure 1. It provides a very good power flow control for more than one transmission lines with each of the two SSSC giving series power addition for its own transmission line. The two converters are joined through a DC capacitor and attached to the AC network through transformers directly connected. By this, it does not only provide reactive power addition but furthermore, any of the converters can be manipulated to inject real power to the DC joint from its own transmission line. And also any of the IPFC converters can move real power to the other and by implication real power exchange between the lines may be carried out in order to create a balance between overloaded and under loaded lines controlling reactive series compensation of each individual line (Mohamed, 2002).

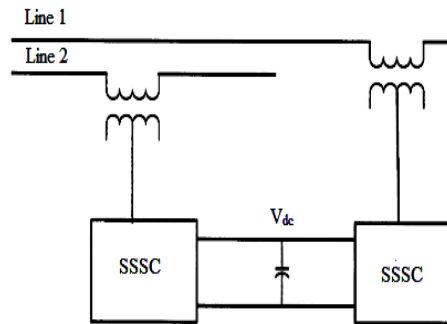


Figure 1. Schematic diagram of IPFC (Mohamed, 2002)

The IPFC concept applied for two lines can be generalized for multiple lines, thus, under-loaded lines can share the power from overloaded lines in order to optimize the transmission system utilization. The net real power exchanged by all the converters must be zero.

## 2.6 Unified Power Flow Controller (UPFC)

The UPFC is considered as one of the most versatile and powerful FACTS devices in power system today. "It is primarily used for flexible control of powers for better voltage stability. The UPFC allows concurrent or independent control of these parameters with transfer from one control scheme to another in real time". (Pramod et al. 2012)

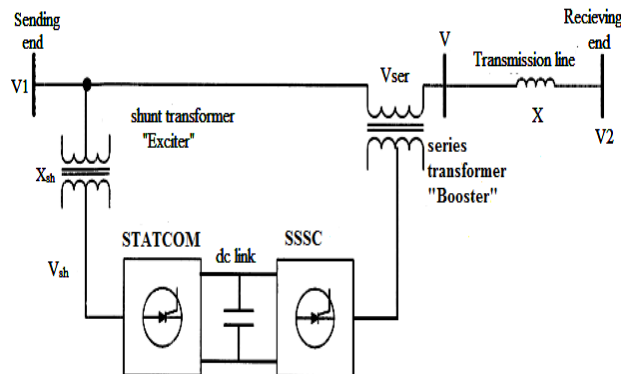


Figure 2. Schematic diagram of UPFC (Mohamed, 2002)

UPFC as shown in Figure 2 is design using STATCOM and SSSC linked together with a DC. The converters are connected to the line with transformers. The unique combination of this device allows for flexibility of operation when connected to the power system network.

This paper limits its scope to UPFC and IPFC. Since there are many FACTS devices that perform similar functions, there is a need for comparative study to determine which of the FACTS devices is best for a particular system. Due to the hybrid structure of the UPFC and the IPFC, it is obvious that they are constructed for better performance than the other FACTS devices as they combine the functions of the other devices. But what is not very obvious is the relative performance of these two advanced FACTS devices under contingency, thus the need for their comparative study. The study will explore the advantages of these devices (UPFC and IPFC) and suggest which is more adequate for a particular power system considering cost effectiveness and efficiency of the devices in improving voltage stability in the system.

### 3. Research Methodology

An IEEE 30-bus transmission line system is model with MATLAB/SIMULINK software in three scenarios:

- In scenario one, the original transmission line system is model and simulated without any compensating device.
- The system is modelled with UPFC incorporated in scenario 2 while
- Scenario 3 has IPFC incorporated.

For each scenario, the system is designed to have a single line to ground fault of resistance  $0.010\Omega$  and ground resistance of  $0.001\Omega$  occur at bus 1. The fault is expected to cause instability in the system and be cleared after 0.05sec in the three scenarios. The system had bus 1 as the reference bus, 6 generator buses and 23 load buses with flat data values of nominal voltage of 132KV (1.0pu).

Figure 3 below shows the IEEE 30-bus system to be considered for modelling and simulation.

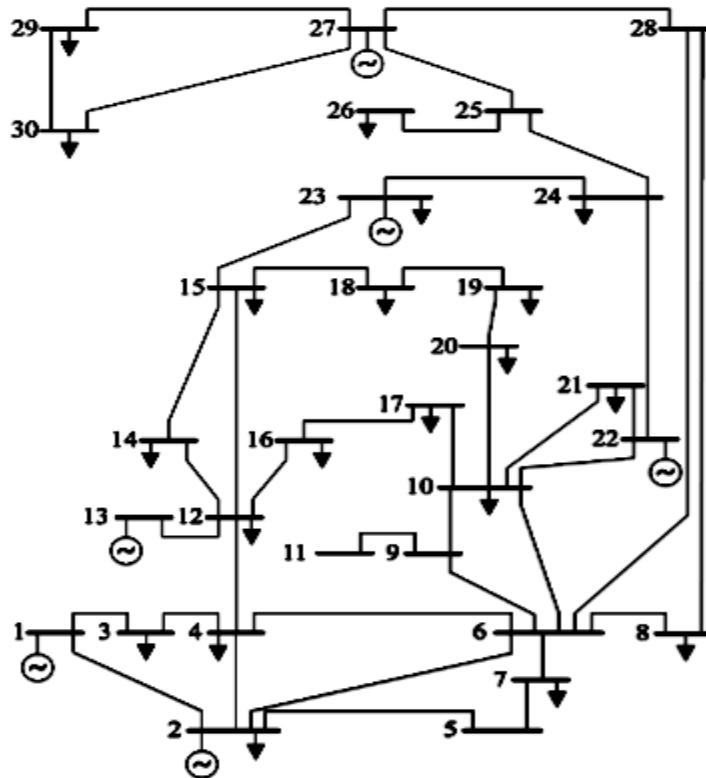


Figure 3 IEEE 30-bus power transmission line network

There is a measurement and control unit as the subsystem of both UPFC and IPFC. These units are designed separately and configured together to form the overall model of both the UPFC and IPFC.

Figure 4 is a model of pack transformation which enables the transformation of three phase (abc) natural input variables such as voltages to direct-quadrature-zero (dq0) rotating reference frame.

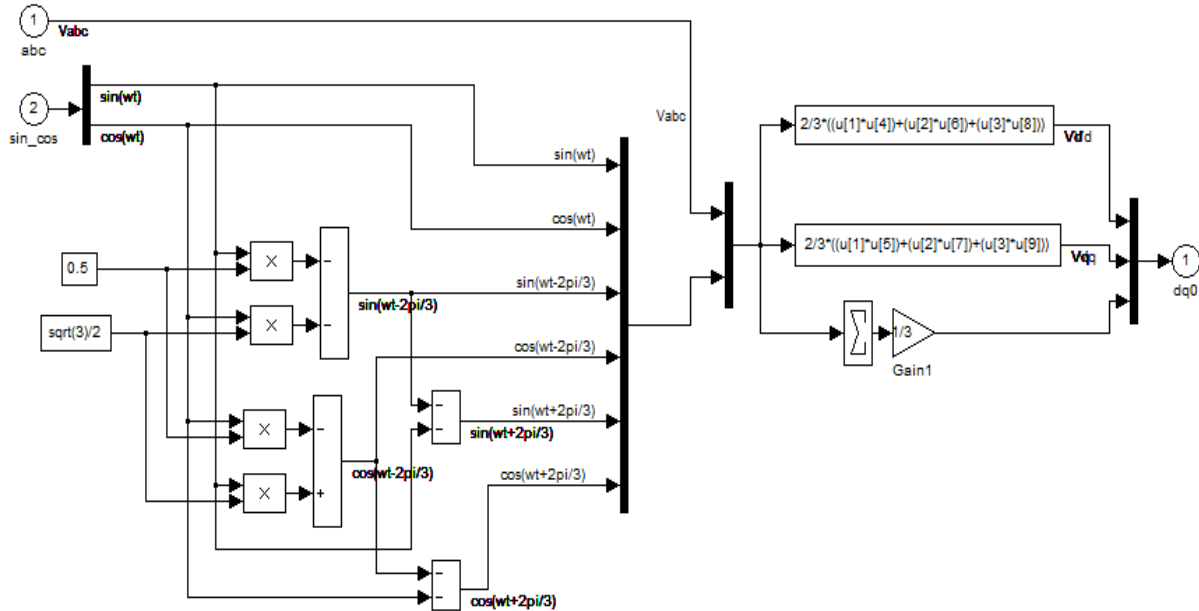


Figure 4. Model of abc to dq0 transformation

In transforming abc to dq0 signal the following equations are used:

$$V_d = \frac{2}{3} * [V_a * \sin(\omega t) + V_b * \sin(\omega t - \frac{2\pi}{3}) + V_c * \sin(\omega t + 2\pi)] \quad (1)$$

$$V_q = \frac{2}{3} * [V_a * \cos(\omega t) + V_b * \cos(\omega t - \frac{2\pi}{3}) + V_c * \cos(\omega t + \frac{2\pi}{3})] \quad (2)$$

$$V_o = \frac{1}{3} * [V_a + V_b + V_c] \quad (3)$$

Where  $w$  = rotation speed (rad/s) of the rotating frame.

Figure 5 is the power computation model.

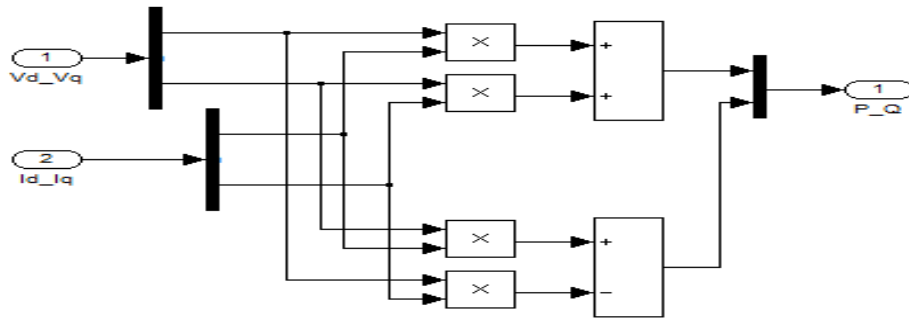


Figure 5. Real and reactive power computation model

Equation (4) and (5) are for the computation of real and reactive power respectively.

$$P = V_d * I_d + V_q * I_q \quad (4)$$

$$Q = V_q * I_d - V_d * I_q \quad (5)$$

Figure 6 is the model of the control unit of both the UPFC and the IPFC.

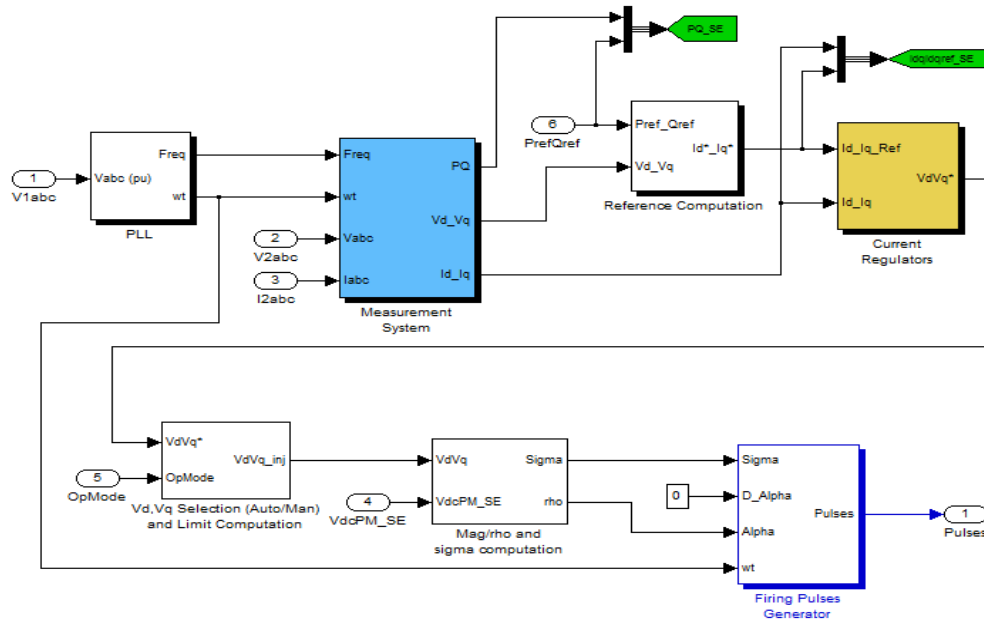


Figure 6. UPFC and IPFC control subsystem

The STATCOM and SSSC are configured together with the control unit in Figure 6 to form the UPFC model in Figure 8, while two SSSC models are combined with the control unit to form the IPFC in Figure 10. Figure 7 is the Simulink model of the 30-bus system under consideration without any compensating device.

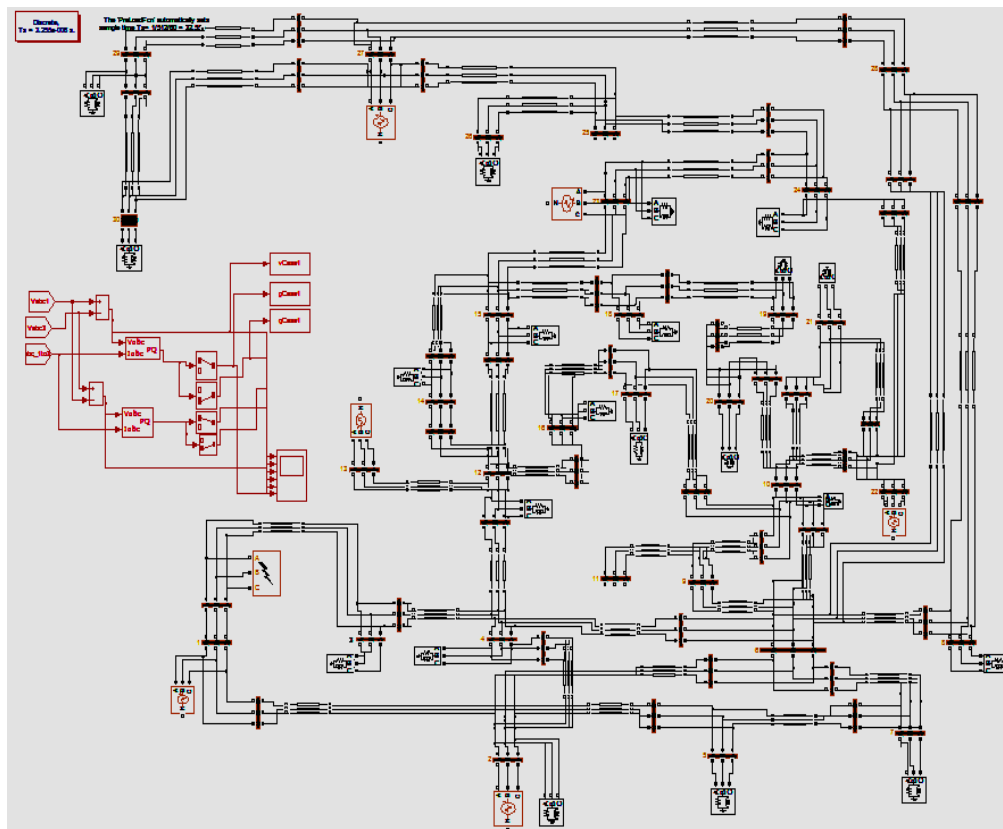


Figure 7. Scenario 1: Simulink model of original 30-bus system without compensating devices

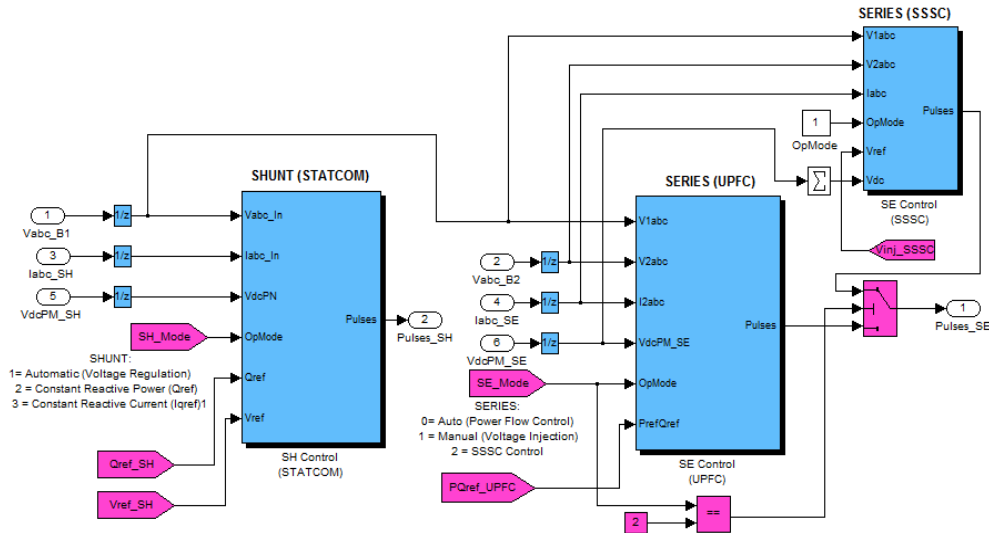


Figure 8. UPFC subsystem configuration

The UPFC subsystem is configured to consist Simulink blocks of two different converters (STATCOM and SSSC) sharing a common capacitor on their DC side and a unified control system as shown in Figure 8. It provides concurrent control of power system parameters such as active power, reactive power and voltage magnitude. It can also be set to control one or more of these parameters in any combination or none of them. In figure 9, the system is model with UPFC incorporated between bus1 and bus3 (i.e. line 1-3). The shunt converter draws the real power needed by the series converter from the AC network and supply through the DC link. The voltage inverted from the series converter is added to the bus voltage, at bus 1 to boost the nodal voltage at bus 3

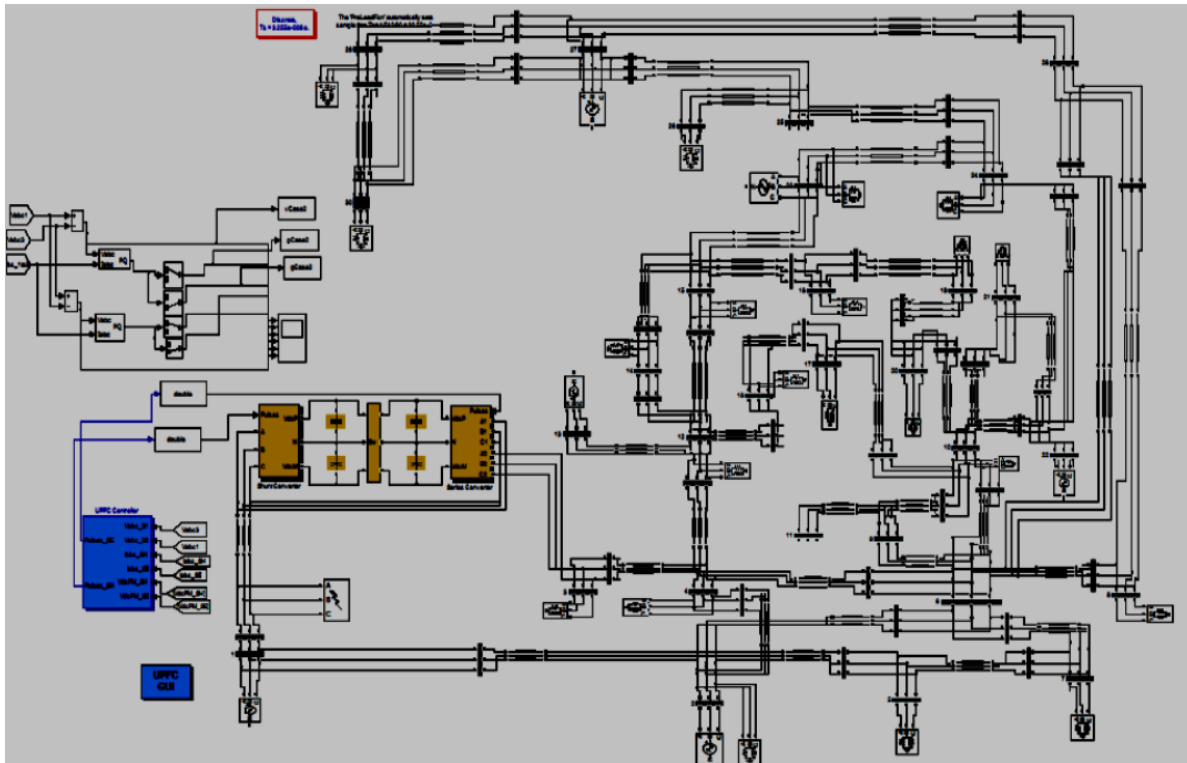


Figure 9. Scenario 2: Simulink model of 30-bus system with UPFC

The IPFC model is configured to consist Simulink blocks of two SSSCs connected back-to-back through the DC link as shown in Figure 10. The converters produce a controllable AC output voltage. The real power taken from one line must be given to the other line. Therefore, the IPFC is capable to control both real and reactive power flow between the lines (1-3 and 3-4); thus transfer power from the overloaded line to under-loaded line. The voltage component is controlled in such a way to compensate against resistive line voltage drop or to increase the effectiveness of the compensating system for dynamic disturbances.

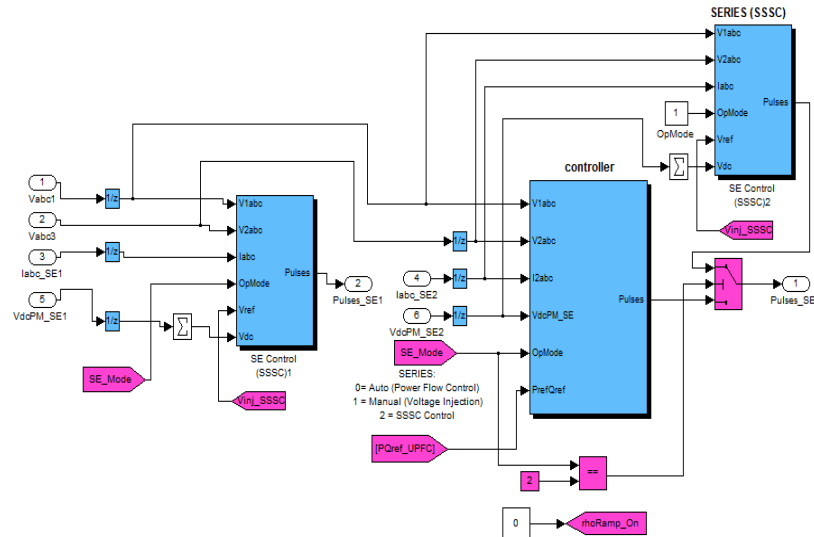


Figure 10. IPFC configuration

In figure 11, the system is model with IPFC having one of its SSSC converter connected to line 1-3 and another connected to line 3-4.

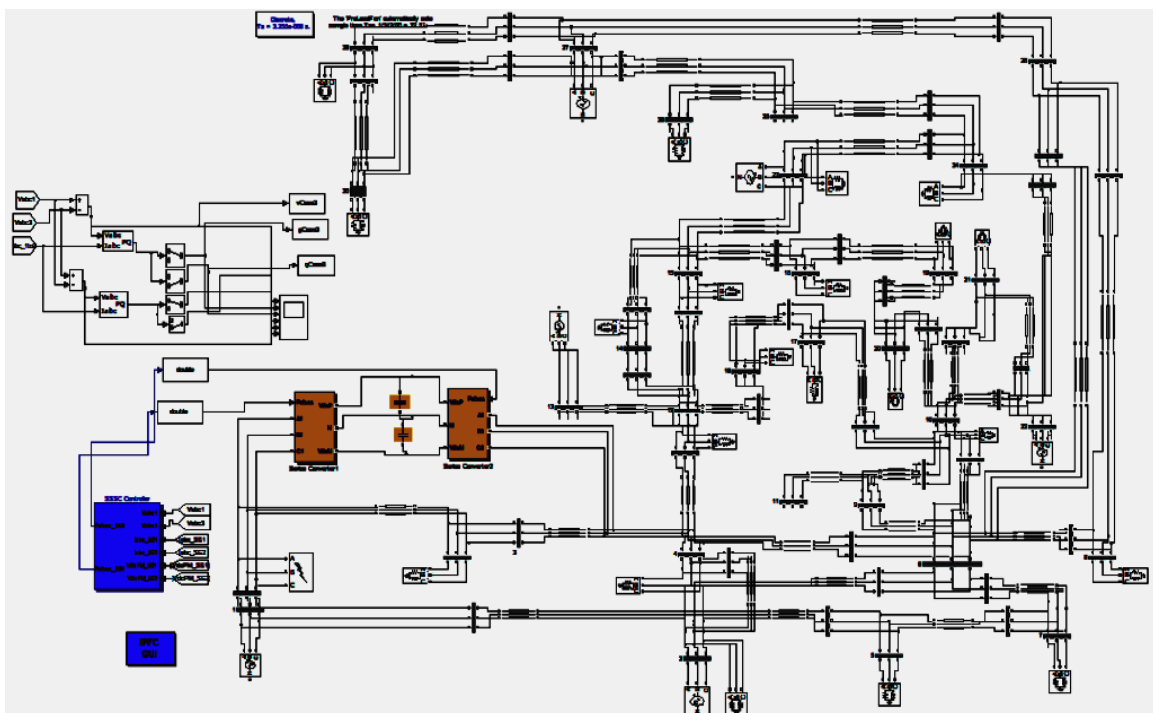


Figure 11.Scenario 3: Simulink model of 30-bus system with IPFC



## 4. Results and Analysis of Results

### 4.1 Simulated Result of Scenario 1

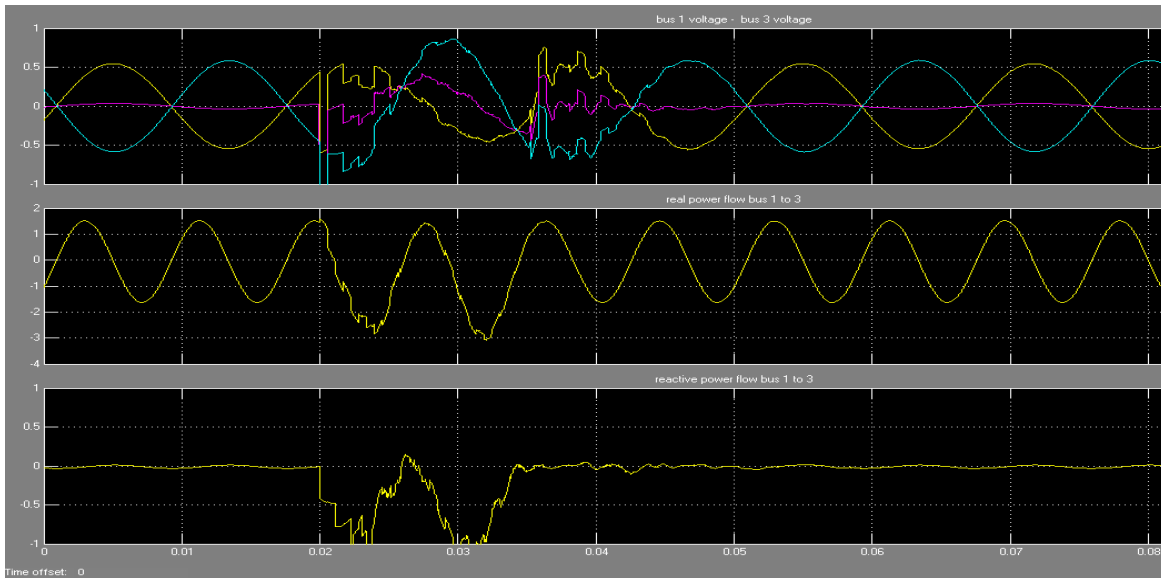


Figure 12. Simulation result of Case 1 (the original system)

Figure 12 shows the simulation result of voltages, real power and reactive power flow from bus 1 to bus 3 respectively in Scenario 1. It is observed that fault occur at 0.02sec and lasted until 0.05sec when the system again regains stability.

### 4.2 Simulated Result of Scenario 2

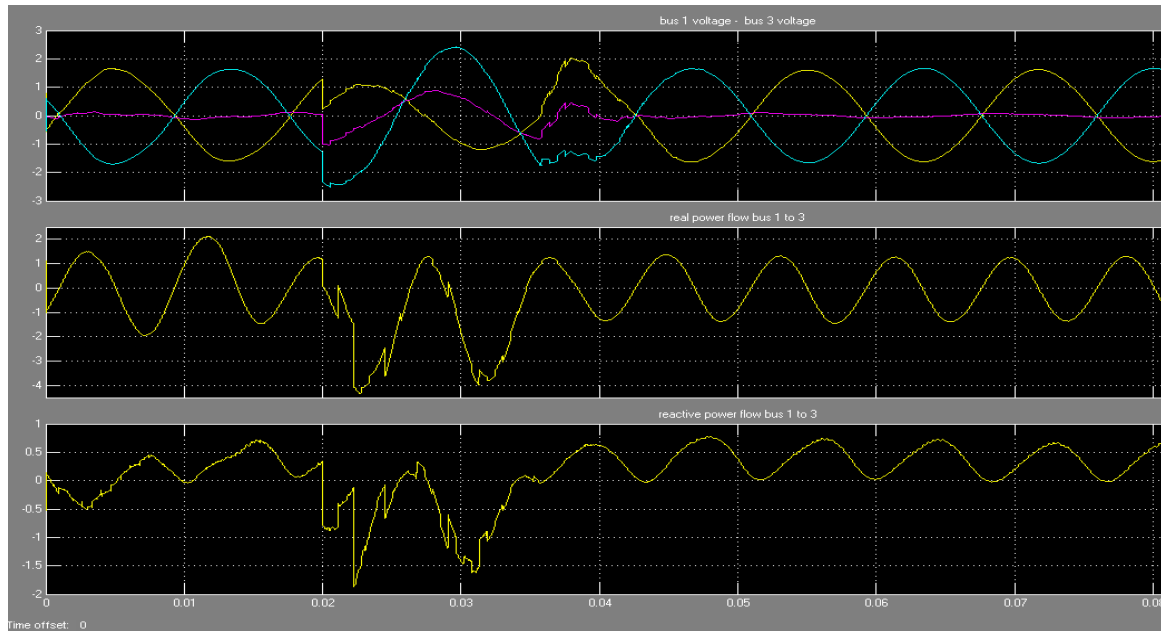


Figure 13. Simulation result of Case 2 (with UPFC)

Figure 13 is the simulation result of voltages, real power and reactive power flow from bus 1 to bus 3 respectively in Scenario 2. It is observed that fault occur at 0.02sec and lasted until 0.042sec when the system start regains stability.

### 4.3 Simulated result of Scenario 3

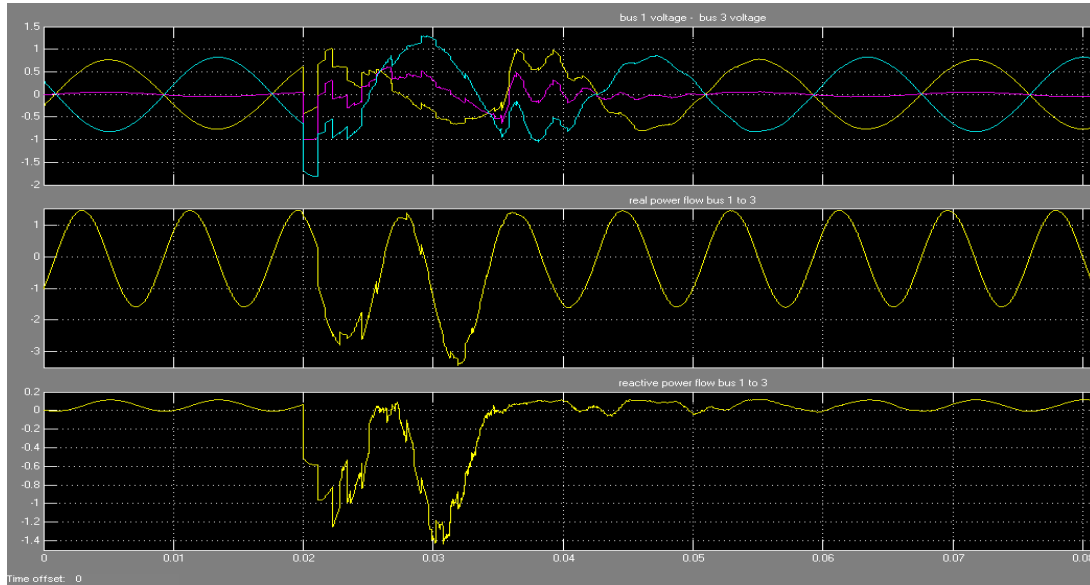


Figure 14. Simulation result of Case 3 (with IPFC)

Figure 14 is the simulated result of scenario 3 showing voltages, real and reactive power flow from bus 1 to bus 3 respectively. It is observed that fault occurred at 0.02sec and lasted until 0.05sec before the system regains stability.

### 4.5 Graphical Representation of Comparative Results

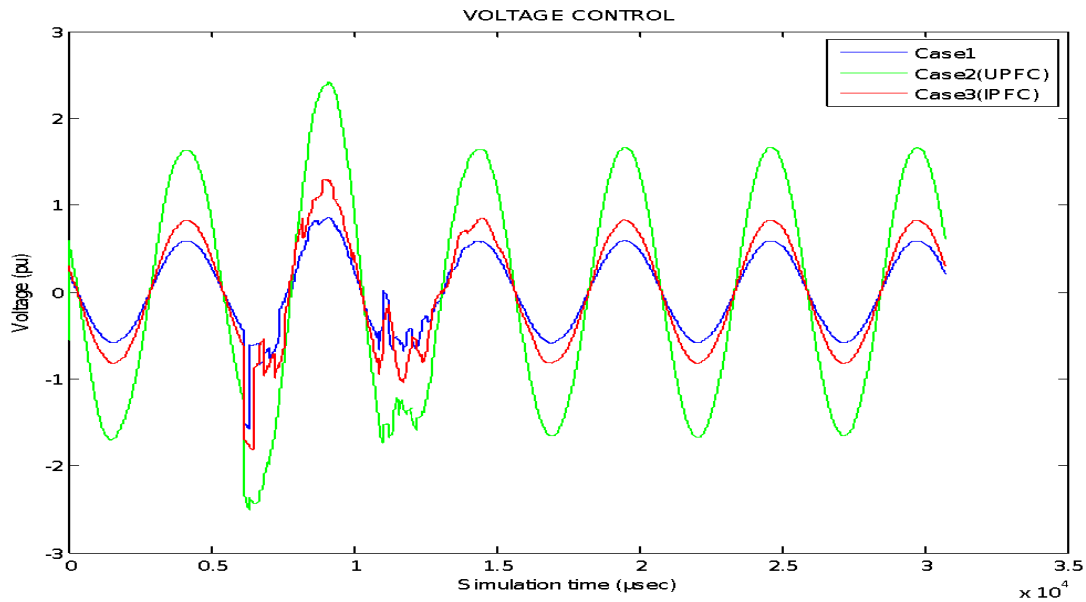


Figure 15. Voltage variations against time of simulation

Figure 15 is the voltage variation of the three scenarios drawn from the simulation results shown in figures 12, 13 and 14 to show in closer and clearer view the difference in the three scenarios. It was observed that, Scenario 2 has more voltage improvement and a faster stability enhancement than Scenario 1 and Scenario 3. Scenario 3 has a better improvement than Scenario 1.

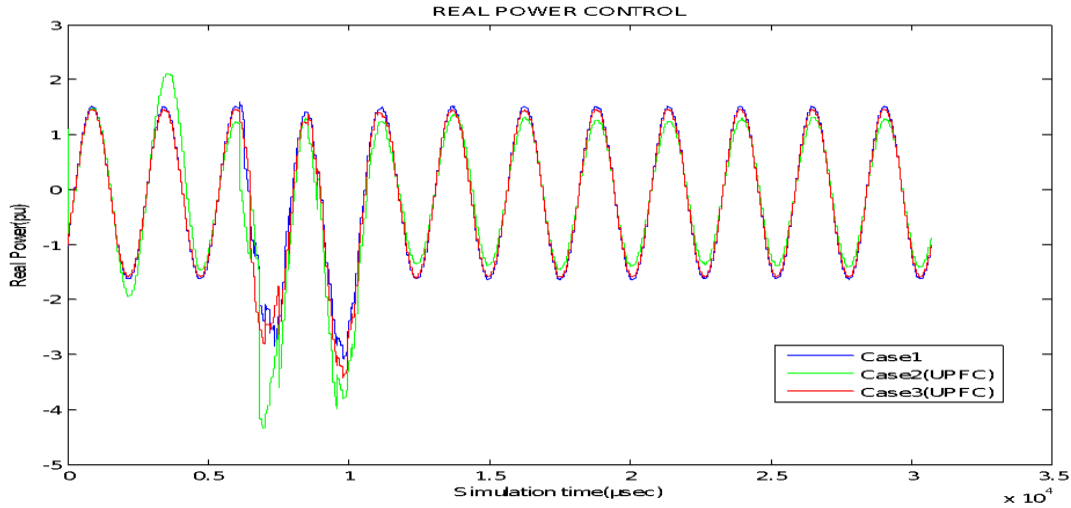


Figure 16. Real power variations against simulation time

Figure 16 is the real power variation of the three Scenarios. It is observed that, the three Scenarios have almost the same level of real power flow after point of fault. Scenario 2 has more stable power flow after occurrence of fault than even its initial state. This indicates the effective power control of UPFC.

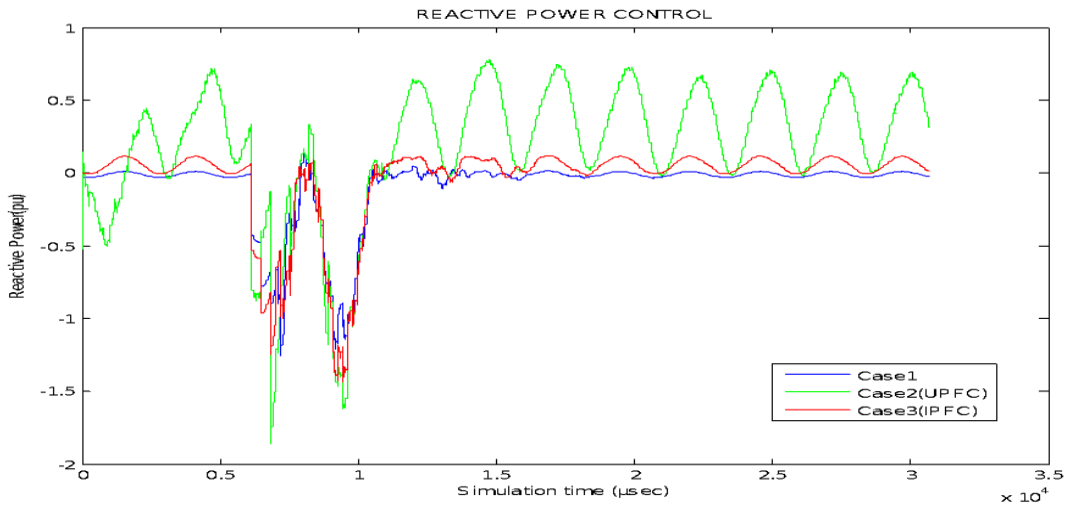


Figure 17. Reactive power variations against simulation time

Figure 17 represent the reactive power variation of the three scenarios. It is also observed that, all three scenarios got balance reactive power flow at different time after fault occurrence. Scenario 2 achieved stability first at  $1.3 \times 10^4 \mu\text{sec}$  with more reactive power injection which is also reflected in its increase voltage magnitude. Scenario 1 and 2 have almost the same recovery time of about  $1.75 \times 10^4 \mu\text{sec}$ . This also reflected in the result of their voltage magnitude as compare in figure 14.

## 5. CONCLUSION

Comparative study of UPFC and IPFC on transmission line for voltage stability enhancement is presented in this work. Simulink models of IEEE 30-bus test systems were developed such that; Scenario 1 is without any compensating device, Scenario 2, has UPFC incorporated and Scenario 3 has IPFC incorporated. The three model systems were simulated and the results compared. It was observed that the voltage profile of the system was

improved both in magnitude and in stability time in Scenario 2 with UPFC incorporated. In Scenario 3 with IPFC incorporation, the voltage magnitude was also improved but not as much as in Scenario 2 and its stability time was slightly delayed after point of fault as compared to Scenario 2.

The results show that both devices stabilized the system voltages with UPFC having a slightly better improvement of voltage magnitude while IPFC on the other hand have the advantage of stabilizing voltages on double lines. In conclusion, the UPFC has a better and faster voltage stability enhancement than the IPFC.

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