Fault Clearance and Transmission System Stability Enhancement using Unified Power Flow Controller

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***Abstract*— Fault current introduces voltage and reactive power imbalances which are major problems in power systems. This study shows the ability of Unified Power Flow Controller (UPFC) to clear a single line to ground fault and improves transmission system stability. The device under review is one of the most advanced classes of Flexible Alternating Current Transmission System (FACTS) devices. A 30-bus transmission line system is modelled with MATLAB/Simulink software. Two cases were simulated to evaluate the performance of UPFC. In Case 1, the 30-bus network system is modelled and simulated without a compensating device whilst Case 2, the system is modelled with UPFC. The system models are designed to have a single line to ground fault with resistance 0.010Ω and ground resistance of 0.001Ω occurring at bus 1. The fault is expected to cause instability in the system and be cleared after 0.04s in both cases. The simulated results of the two cases were compared to determine the performance of UPFC in improving the voltage stability and power profile of the system. The results show that UPFC has the ability of stabilizing voltage and power profile of transmission system. The study has thus, increased insight on the use of the device in transmission system stability and control.**

Keywords— MATLAB, Simulink, FACTS, UPFC, Compensator/Controller

Introduction

There is constant demand for reliable electrical power and as a result, steady state power system analysis is of high importance. Power system faults destabilize steady state power flow and could lead to reactive power imbalances which in turn lead to voltage instability and hence, unreliability of the system [1].

In trying to meet up with reliable power demands, quick response to fault clearance is paramount as fault Location and clearing could be time consuming. Hence, an effective option to mitigate this problem is by the introduction of high power electronic controllers that can absorb or inject reactive power as required by the power system network. FACTS (Flexible Alternative Current Transmission System) devices are one of the most effective sources of reactive power. These devices enable operational flexibility without stressing the system [2].

According to [3], FACTS devices enhance power system security with flexibility and automatic control of the system parameters. Prominent among the FACTS devices is the Unified Power Flow Controller (UPFC).

This study investigates the performance of UPFC on transmission line. The aim is to determine how effective UPFC can be used for fault clearance and hence, improves voltage stability. The remainder of this paper is organized thus: Section I presents UPFC, Section II is the research methodology used in this work, Section III detailed the obtained results whilst Section IV concludes the work**.**

I. UNIFIED POWER FLOW CONTROLLER (UPFC)

The UPFC is considered as one of the most versatile and powerful FACTS device in power system today [4]. It is one of the second generation of FACTS devices designed with voltage source converters which replace thyristor valves used in the first generation, hence providing a better performance in controlling power system parameters [5]. Comparative analyses of UPFC performance on transmission network as against other FACTS devices such as, Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Static Var Compensator (SVC) and Interline power Flow Controller (IPFC) shows that UPFC is more efficient in enhancing power system stability[6, 7].

UPFC as shown in Figure 1 is designed 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 [8].

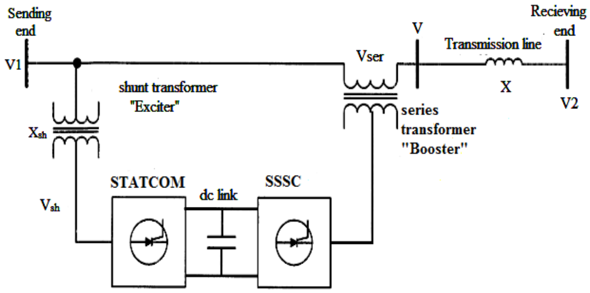

Fig. 1. Schematic diagram of UPFC [8]

II. MODELLING METHODOLOGY

A 30-bus transmission line system is modelled with MATLAB/SIMULINK software in two cases; Case 1, the original transmission line system is modelled and simulated without a compensating device while in Case 2, the system is modelled with UPFC incorporated.

For each case, the system is designed to have a single line to ground fault with resistance 0.010Ω and ground resistance of 0.001Ω occurring at bus 1. The fault is expected to cause instability in the system and be cleared before 0.04sec in the two Cases. 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).

Fig. 2, shows the IEEE 30-bus system to be considered for modelling and simulation.

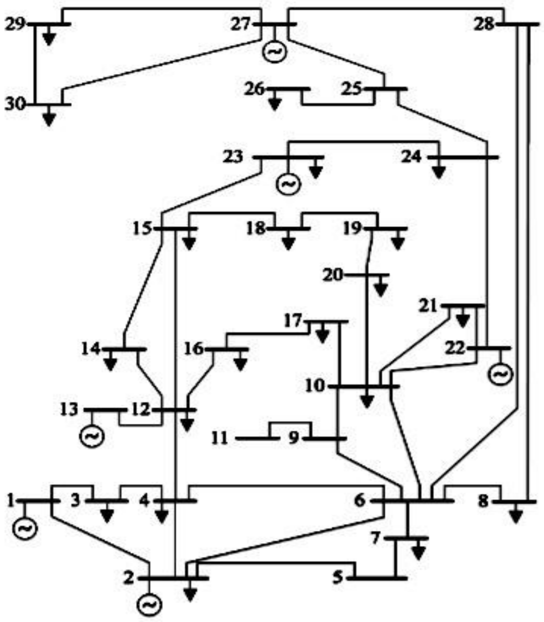

Fig. 2. IEEE 30-bus power transmission line network

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

Fig. 3, 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.

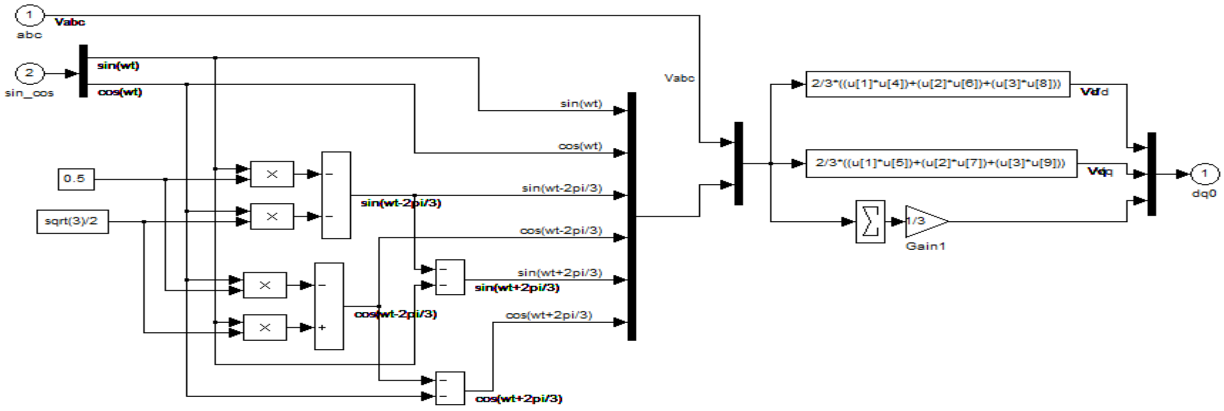

Fig. 3. Model of abc to dq0 transformation [10]

In transforming abc to dq0 signal the following (1), (2) and (3) are used:

$$Vd = \frac{2}{3} * [Va * \sin(wt) + Vb * \sin\left(wt - \frac{2\pi}{3}\right) + Vc * \sin(wt + 2\pi)] \quad (1)$$

$$Vq = \frac{2}{3} * [Va * \cos(wt) + Vb * \cos\left(wt - \frac{2\pi}{3}\right) + Vc * \cos\left(wt + \frac{2\pi}{3}\right)] \quad (2)$$

$$Vo = \frac{1}{3} * [Va + Vb + Vc] \quad (3)$$

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

Fig. 4, is the power computation model

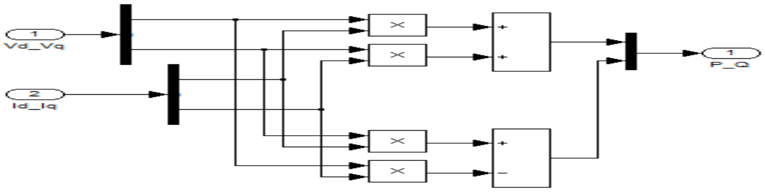

Fig. 4. Real and reactive power computation model

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

$$P = Vd * Id + Vq * Iq \tag{4}$$

$$Q = Vq * Id - Vd * Iq \tag{5}$$

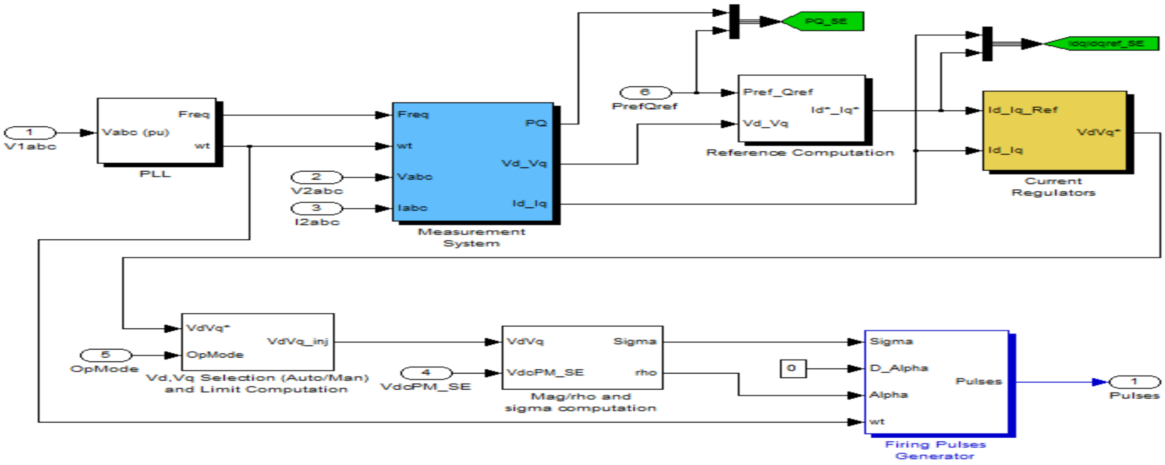

Fig. 5. UPFC control subsystem

The STATCOM and SSSC are configured together with the control unit in Figure 5 to form the UPFC model in Fig 6.

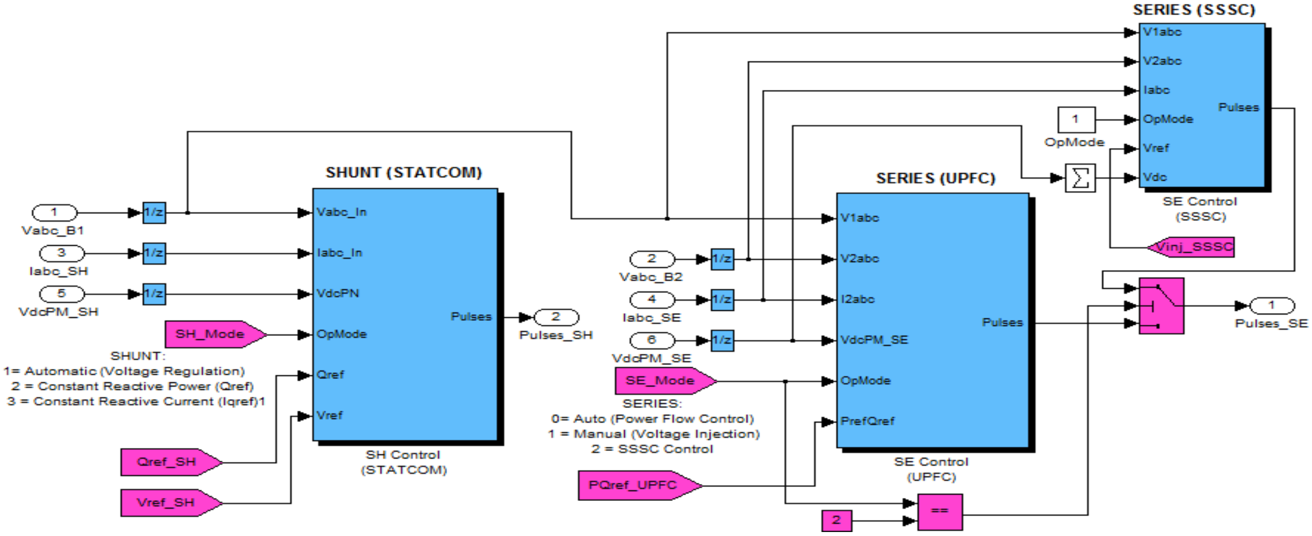

Fig. 6. UPFC subsystem configuration

Fig. 7, is the Simulink model of the 30-bus system under consideration without any compensating device.

In Fig.8, the system is model with UPFC incorporated between bus 1and bus 3 (i.e. line 1-3). The UPFC consist of two converters, STATCOM and SSSC sharing a common capacitor on their DC side and a unified control system. 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. 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.

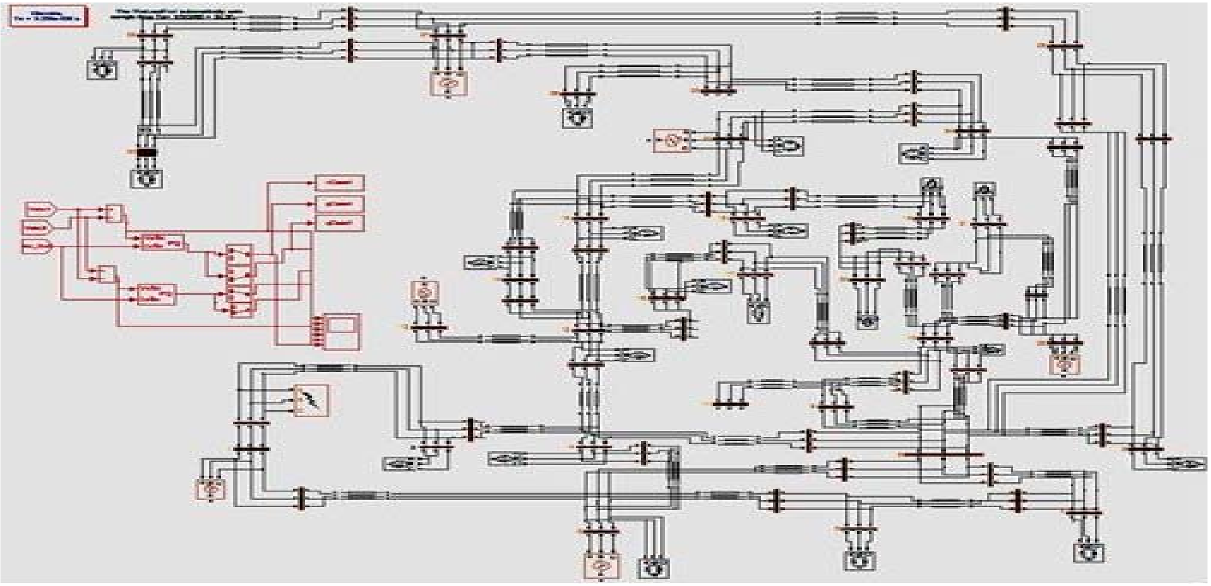

Fig. 7. Case 1: Simulink model of original 30-bus system without compensating devices

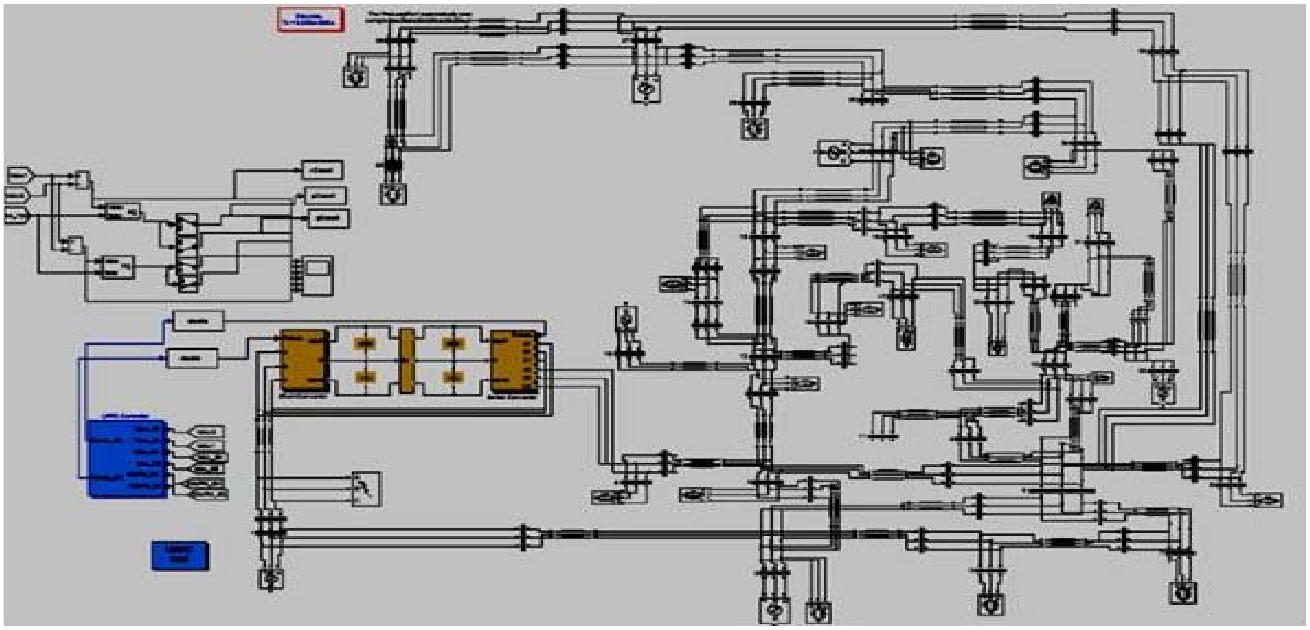

Fig. 8. Case 2: Simulink model of 30-bus system with UPFC

III. RESULTS AND ANALYSIS

A. *Simulated Result of Case 1*

Fig. 9, shows the simulation result of voltages, real power and reactive power flow from bus 1 to bus 3 respectively in Case 1. It is observed that fault occurs briefly and the system again regains stability.

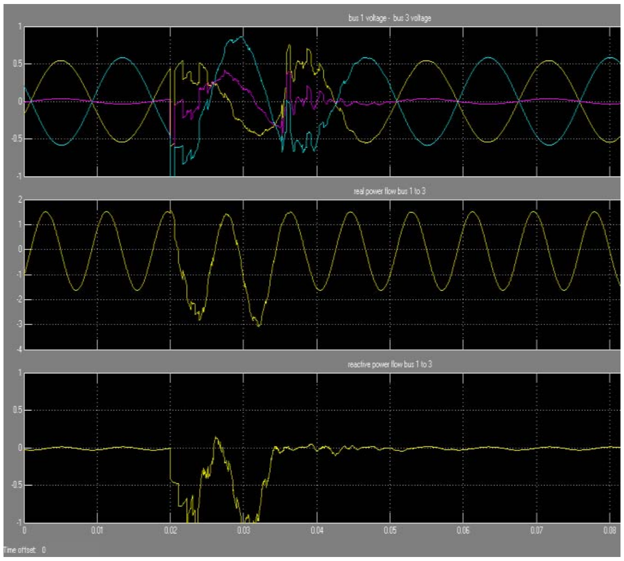

Fig. 9. Simulation result of Case 1 (the original system)

B. *Simulated Result of Case 2*

Fig. 10, is the simulation result of voltages, real power and reactive power flow from bus 1 to bus 3 respectively in Case 2.

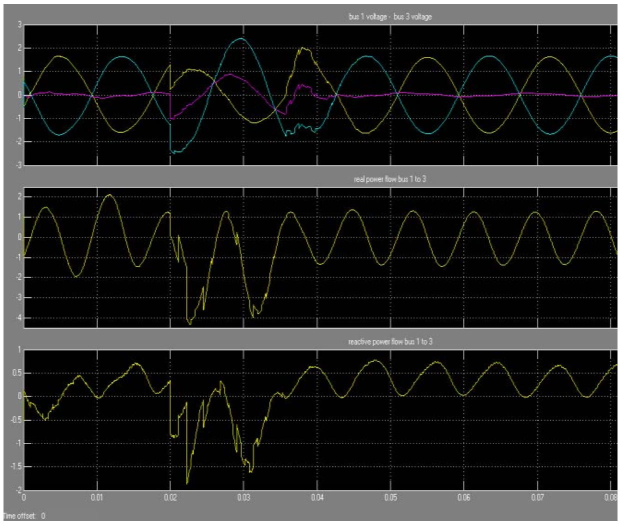

Fig. 10. Simulation result of Case 2 (with UPFC)

C. *Graphical Representation of Comparative Results*

Fig. 11, is the voltage variation of the two scenarios drawn from the simulation results shown in Fig. 9 and 10 to show in closer and clearer view the difference in the two Cases. It was observed that, Case 2 has more voltage improvement with average voltage value of 0.9pu as against 0.49pu of Case 1. Also, Case 2 has faster fault clearance and voltage stability recovery time (0.025s) as against 0.029s of Case 1.

Fig. 12, is the real power variation of the two Cases. It was observed that, the two Cases have almost the same level of real power flow after point of fault indicating that active power was restored in either Cases after 0.2s.

Fig. 13, represent the reactive power variation of the two Cases. It is also observed that, both Cases got balance reactive power flow at different times after fault occurrence.
Case 2 achieved stability first at 0.026s with more reactive power injection which is also reflected in its increase voltage magnitude as compared with Case 1 in fig. 11. Case 1 have recovery time of about 0.032s.

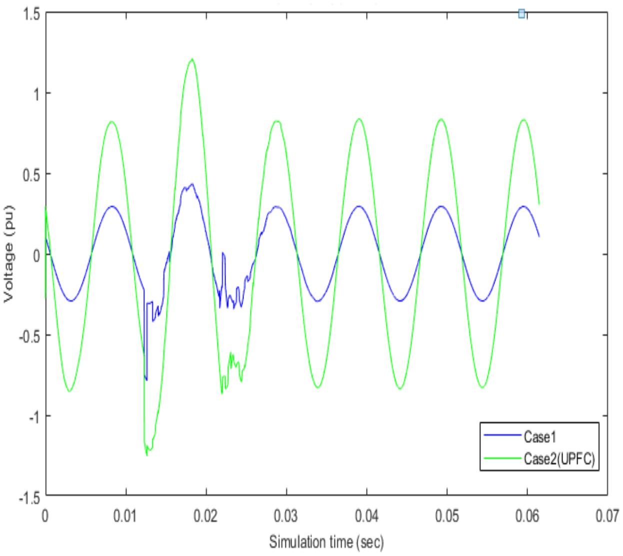

Fig. 11. Voltage variations against time of simulation

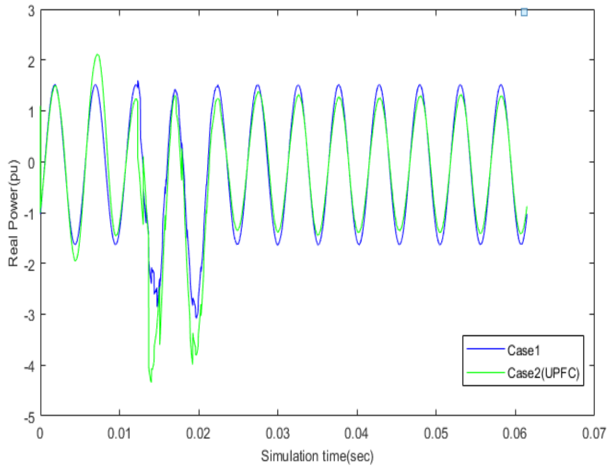

Fig. 12. Real power variations against simulation time

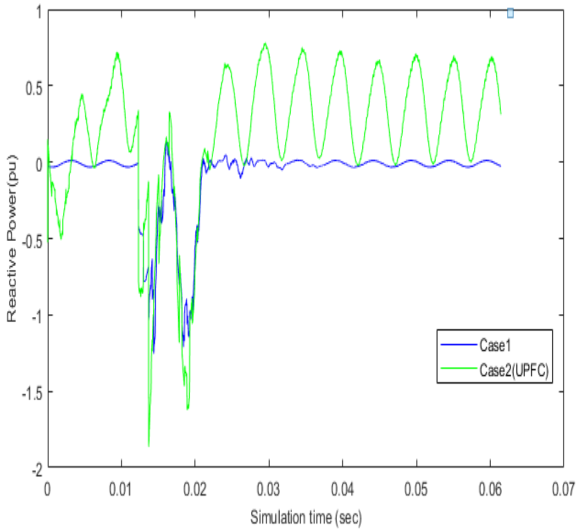

Fig. 13. Reactive power variations against simulation time

IV. CONCULSION

Fault clearance and transmission system stability enhancement using UPFC is presented in this work. Simulink models of IEEE 30-bus test systems were developed such that; Case 1 is without a compensating device whilst Case 2 has UPFC incorporated. The two modelled systems were simulated and the results compared. It was observed that transmission parameters such as voltage and power profile of the system were improved both in magnitude and in stability time in Case 2 using UPFC.

The results show that UPFC has the capacity to clear fault and stabilize transmission system by improving voltage magnitude and power profile of the system.

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