Performance Comparison of UPFC for Smooth Power Flow in Coordination with Dispersed Generator

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ABSTRACT
In this paper the performance of Synchronous Generator which is act as a Dispersed Generator is examined in controlling the flow of power over the transmission line. This project presents real and reactive power flow control through a transmission line by placing Synchronous Generator at the load end along with UPFC at the midpoint of a power system. The real and reactive powers can be easily controlled in a power system using a Synchronous Generator and UPFC in the system. The Matlab simulation results are presented to verify the model. The result of network with and without using Synchronous Generator and UPFC are compared in terms of active and reactive power flows in the line and active and reactive power flows at the load end to analyze the performance of generator. After using UPFC the power transfer capacity has increased. Hence consumer will be benefited. The studies are performed based on well known software package MATLAB/Simpower tool box.

General Terms
FACTS, Distributed Generation, MATLAB/Simulink tool box.

Keywords
Power Flow, Dispersed Generation, Load bus, Utility Supply, FACTS, UPFC, MATLAB/Simulink tool box.

1. INTRODUCTION
The demand of efficient and high quality power is escalating in the world of electricity. Today's power systems are highly complex and require suitable design of new effective and reliable devices in deregulated electric power industry for flexible power flow control. In the late 1980s, the Electric Power Research Institute (EPRI) introduces a new approach to solve the problem of designing, controlling and operating power systems: the proposed concept is known as Flexible AC Transmission Systems (FACTS) [1]. It is reckoned conceptually a target for long term development to offer new opportunities for controlling power in addition to enhance the capacity of present as well as new lines [2] in the coming decades. Its main objectives are to increase power transmission capability, voltage control, voltage stability enhancement and power system stability improvement. Its first concept was introduced by N.G.Hingorani in April 19, 1988. Since then different kind of FACTS controllers have been recommended. FACTS controllers are based on voltage source converters and includes devices such as Static Var Compensators (SVCs), static Synchronous Compensators (STATCOMs), Thyristor Controlled Series Compensators (TCSCs), Static Synchronous Series Compensators (SSSCs) and Unified Power Flow Controllers (UPFCs).Among them UPFC is the most versatile and efficient device which was introduced in 1991. In UPFC, the transmitted power can be controlled by changing three parameters namely transmission magnitude voltage, impedence and phase angle. Unified Power Flow Controller (UPFC) is the most promising version of FACTS devices as it serves to control simultaneously all three parameters (voltage, impedence and phase angle) at the same time.

Many researchers have proposed different approaches of installing UPFC in power systems [3, 4, 5]. The concepts of characteristics have been broadly reported in the literature [5].The UPFC has been researched broadly and many research articles dealing with UPFC modeling, analysis, control and application have been published in the recent years. Mathematical models of UPFC has been developed to study steady state characteristics using state space calculations without considering the effects of converters and the dynamics of generator [6,7]. The performance of UPFC has been reported by designing a series converter with conventional controllers [8,9]. Many power converter topologies have been planned for the implementation of FACTS devices such as multipulse converter like 24 pulses and 48 pulses and multi level inverters [10,11,12].The advantages and limitations of high power converters have been discussed [13]. In [14] the dynamic control of UPFC has been analyzed with six pulse converter using switching level model. Their proposed technique aims at to control the real and reactive power flow in the transmission lines, by effectively changing the firing angle of shunt converter and modulation index of the series converter. Limyingcharoen et al investigated the mechanism of three control strategy of a UPFC in enhancing power system damping [15].A current injected UPFC model for improving power system dynamic performance was developed by Meng and So [16] where a UPFC was represented by an equivalent circuit with a shunt current source and a series voltage source [17]. Fujita et al. [18] investigated the high frequency power fluctuations induced by a UPFC. Different algorithms have been proposed to increase the power flow control with UPFC in power transmission systems [19]. Different case studies have been carried on standard bus network. Baskar et. al. proposes a technique to control the real and reactive power in the transmission line by the two leg three phase converters based on UPFC. In this paper dynamic control of UPFC has analyzed with two leg three phase converters by switching level model with linear and nonlinear loads. They suggests that the UPFC with their proposed controller successfully increase the real as well as reactive power flow and improves voltage profile for the duration of the transient conditions in the power transmission systems [20]. Some results of network with and without UPFC are also been compared in terms of active and reactive power flows in the line and reactive power flow at the bus to compare the performance of UPFC. A number of simulation results have compared when UPFC is connected between different buses in a specified transmission system. We found from different papers that a system performs better when the UPFC is connected to a bus which has low voltage profile [21]. In our paper we have investigate the performance of UPFC with synchronous generator which is act as a Dispersed Generator in controlling power flow over the transmission line. We also proposes a model which can

improve and control the active as well as reactive power by placing Synchronous Generator which is act as a Dispersed Generator, at the load end along with UPFC at midpoint of a power system. A comparative performance evaluation with and without Dispersed generator and UPFC has been studied. Our proposed technique successfully improves the voltage and power profile in the power transmission systems.
This paper is organized as follows: After this introduction, section II describes Dispersed Generator and illustrates the main reasons of wide spread use of DGs, section III explains the principle of operation of UPFC and the mathematical model of UPFC, section IV provides the Simulation results and analysis and finally, section V Concludes this paper.

2. DISPERSED GENERATOR

For the trend of deregulating electric power industry, the demand for distributed generation is becoming an important and reliable corridor today. Distributed Generation (DG) is defined as standalone small to medium size power generation. IEEE defines the generation of electricity by facilities sufficiently smaller than central plants, usually 10 MW or less, so as to allow interconnection at nearly any point in the power system, as Distributed Resources. DGs are modular electric generation technologies which provide electric capacity and/or energy when and where needed. It reduces the amount of energy lost in transmitting electricity because the electricity is generated very near where it is used, perhaps even in the same building. This also reduces the size and number of power lines that must be constructed [22]. They are usually retained by a customer, utility and connected to the grid at a distribution voltage level [23, 24]. DG has an important role in the electric power distribution system, power quality improvements and upgradations. It can partially replace the need to set up new generating stations in order to meet the increasing load demand and gives us a global flexibility for the future load growth [24]. DG can also be installed within the end users service area. The main reasons of wide spread uses of DG are [25]:

- Overfill of existing networks with low ratings and continuous load growth demands.
- DG has small size and flexible in their operation. So, we can install it very easily near the load.
- Necessity of new generation technologies with low ratings, economic and ecological advantages. Also it can regulate the voltage when the loads are separated from the supply.
- Cogeneration, Premium power, uninterrupted power supply and high power quality.
- Little or no transmission and distribution (T&D) expansion costs. Improvement of system reliability, voltage support and power transfer capacity as well as loss reduction in power system.
- Utilities can meet energy demand incrementally with a lower cost and lower risk investment.
- DG reduces the overloading of the existing equipment and hence increases their life. It also reduces network upgrading.

There are mainly two conventional procedure of sharing DG power with utility supply at load bus-DG can be used as a standalone device and secondly it can be used in a grid with traditional utility service [25]. In grid connected mode, DG is used to supply regulated real and reactive power to the grid. Whereas, in standalone mode the objective is to provide power supply, with controlled voltage, to the customers/local loads. We have used in this paper a Power system with synchronous generator based DG.

3. OPERATING PRINCIPLE OF UPFC

The UPFC is the most versatile and complex of the FACTS devices, combining the features of the STATCOM and the SSSC. The main reasons behind the wide spreads of UPFC are: its ability to pass the real power flow bi-directionally, maintaining well regulated DC voltage, workability in the wide range of operating conditions etc [19].The basic components of the UPFC are two voltage source inverters (VSIs) sharing a common dc storage capacitor, and connected to the power system through coupling transformers. One VSI is connected to in shunt to the transmission system via a shunt transformer, while the other one is connected in series through a series transformer. The DC terminals of the two VSCs are coupled and this creates a path for active power exchange between the converters. Thus the active supplied to the line by the series converter can be supplied by the shunt converter as shown in fig. 1 [26]. Therefore, a different range of control options is available compared to STATCOM or SSSC. The UPFC can be used to control the flow of active and reactive power through the transmission line and to control the amount of reactive power supplied to the transmission line at the point of installation [27]. The series inverter is controlled to inject a symmetrical three phase voltage system of controllable magnitude and phase angle in series with the line to control active and reactive power flows on the transmission line. So, this inverter will exchange active and reactive power with the line. The reactive power is electronically provided by the series inverter, and the active power is transmitted to the dc terminals. The shunt inverter is operated in such a way as to demand this dc terminal power (positive or negative) from the line keeping the voltage across the storage capacitor Vdc constant. So, the net real power absorbed from the line by the UPFC is equal only to the losses of the inverters and their transformers. The remaining capacity of the shunt inverter can be used to exchange reactive power with the line so to provide a voltage regulation at the connection point.
The two VSI's can work independently of each other by separating the dc side. So in that case, the shunt inverter is operating as a STATCOM that generates or absorbs reactive power to regulate the voltage magnitude at the connection point. Instead, the series inverter is operating as SSSC that generates or absorbs reactive power to regulate the current flow, and hence the power flows on the transmission line. The UPFC can also provide simultaneous control of all basic power system parameters, viz., transmission voltage, impedance and phase angle. The UPFC has many possible operating modes: Var Control mode, automatic voltage control mode, direct voltage injection mode, phase angle shifter emulation mode, line impedance emulation mode and automatic power flow control mode [28].

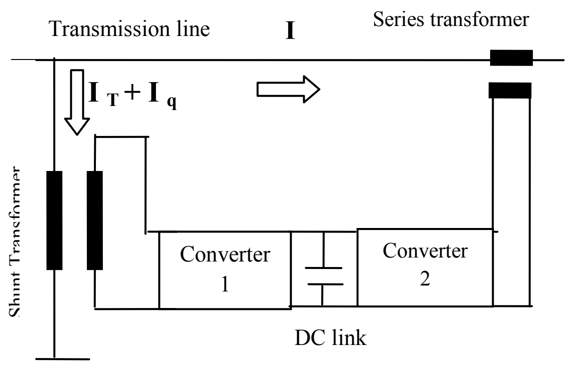

Figure 1: Basic Circuit arrangement of UPFC

3.1 Mathematical Model Of UPFC

In this model, we have considered the UPFC is placed at the centre of a 300km transmission line. This model was derived with to study the relationship between electrical transmission system and UPFC in steady state conditions. The basic scheme is shown in fig.2 [29]

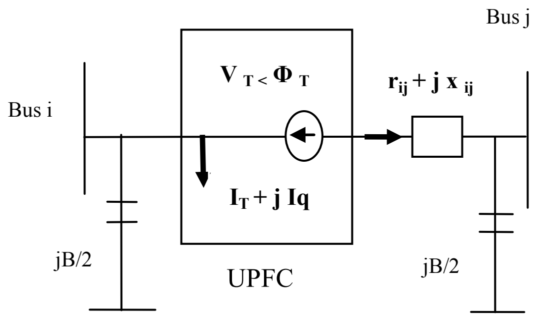

Figure 2: Equivalent circuit of UPFC

Based on the basic principle of UPFC and network theory, the active and reactive power flows in the line, from bus-i to bus-j, having UPFC can be written as [30],

$$P_{ij} = (V_i^2 + V_T^2)g_{ij} + 2V_iV_Tg_{ij}\cos(\phi_T - \delta_j)$$
$$-V_jV_T\ [g_{ij}\cos(\phi_T - \delta_j) + b_{ij}(\sin(\phi_T - \delta_j)]$$
$$-V_iV_j(g_{ij}\cos\delta_{ij} + b_{ij}\sin\delta_{ij}).......................(1)$$
$$Q_{ij} = -V_iI - V_i^2(b_{ij} + B/2)$$
$$-V_iV_T[g_{ij}\sin(\phi_T - \delta_i) + b_{ij}\cos(\phi_T - \delta_i)]$$
$$-V_iV_j(g_{ij}\sin\delta_{ij} - b_{ij}\cos\delta_{ij}).......................(2)$$

where $g_{ij} + jb_{ij} = \dfrac{1}{r_{ij} + jx_{ij}}$ and I_q is the reactive current flowing in the shunt transformer to improve the voltage of the shunt connected bus of UPFC.

Similarly, the active and reactive power flows in the line, from bus-j to bus-i, having UPFC can be written as,

$$P_{ji} = v_j^2g_{ij} - V_jV_T[g_{ij}\cos(\phi_T - \delta_j)$$
$$-b_{ij}g\sin(\phi_T - \delta_j)] - V_iV_j(g_{ij}\cos\delta_{ij} - b_{ij}\sin\delta_{ij})....(3)$$
$$Q_{ji} = -V_j^2(b_{ij} + B/2) - V_jV_T(g_{ij}\sin(\phi_T - \delta_j)$$
$$-b_{ij}\cos(\phi_T - \delta_j)) + V_iV_j(g_{ij}\sin\delta_{ij} + b_{ij}\cos\delta_{ij})....(4)$$

The real power and reactive power injections at bus-i with the system loading (λ) can be written as [29],

$$p_i = P_{Gi} - P_{Di}^0(1+\lambda) = \sum_{j\in N_b} P_{ij}.................(5)$$
$$Q_i = Q_{Gi} - Q_{Di}^0(1+\lambda) = \sum_{j\in N_b} Q_{ij}...............(6)$$

4. SIMULATION RESULTS AND DISCUSSIONS

Figure 3 shows DG working parallel to the load side in MATLAB/Simulink Environment. The Simulink model/diagram for test system developed is shown in the Fig. 4. The control of power flow from utility supply and DG source to common load bus will be such that load will not sense any kind of disturbances. The test system consists of the upper transmission system of 132 KV and the distribution system of 11KV. B3 is load bus at 11 KV, which consumes the active power of 17.8 MW. DG source is installed at bus B3 and is having capacity of 6.5 MVA at 11KV. We assume that DG is a synchronous Generator used at common load bus. Overhead line is 11 KV, 300 Km in length having, Resistance= 0.01273 (Ω/Km), Inductance =0.9337 (mH/Km), Capacitance=12.74 (µF/Km). In this paper we have investigated three different case studies: when there is no synchronous generator which is act as a Dispersed generator in the system, when DG is connected at the load end and finally when both DG and UPFC are connected in the system. The respective waveforms are given in the figure below. A comparative performance evaluation with and without Dispersed generator and UPFC has been studied. The waveform of mechanical power, field voltage, termimal voltage, speed, stator current, load angle, output active power, output reactive power, electric power, rotor speed, electro magnetic torque, rotor angle deviation, active and reactive power at the load end with synchronous generator is shown in figure 5-11. Figure 12 shows the waveform of active and reactive power at the load end without synchronous generator. Fig 13 is the waveform of electrical power,rotor speed,electromagnetic torque and rotor angle deviation with synchronous generator and UPFC. Fig 14 shows the waveform of Stator current,load angle,output active and reactive power,field current and stator voltage with synchronous generator and UPFC.Fig 15 shows the waveform of Stator current,load angle,output active and reactive power,field current and stator voltage with synchronous generator and UPFC.Also waveform of mechanical power,field voltage,terminal voltage and speed of synchronous generator when connected with an UPFC is investigated. These waveforms are obtained by simulating the Simulink diagram for test system in the environment of Simpower toolbox of MATLAB. DG source terminal voltage output waveform is also shown. Simulation stop time is set from 0 to 6 to completely analyze the stabilization time for the active power outputs of both DG source and utility supply along with load active power drawn from both DGs source and utility supply. Ode 23tb [stiff/TR-BDF2] Simulink solver is used as developed Simulink model involves nonlinear elements.

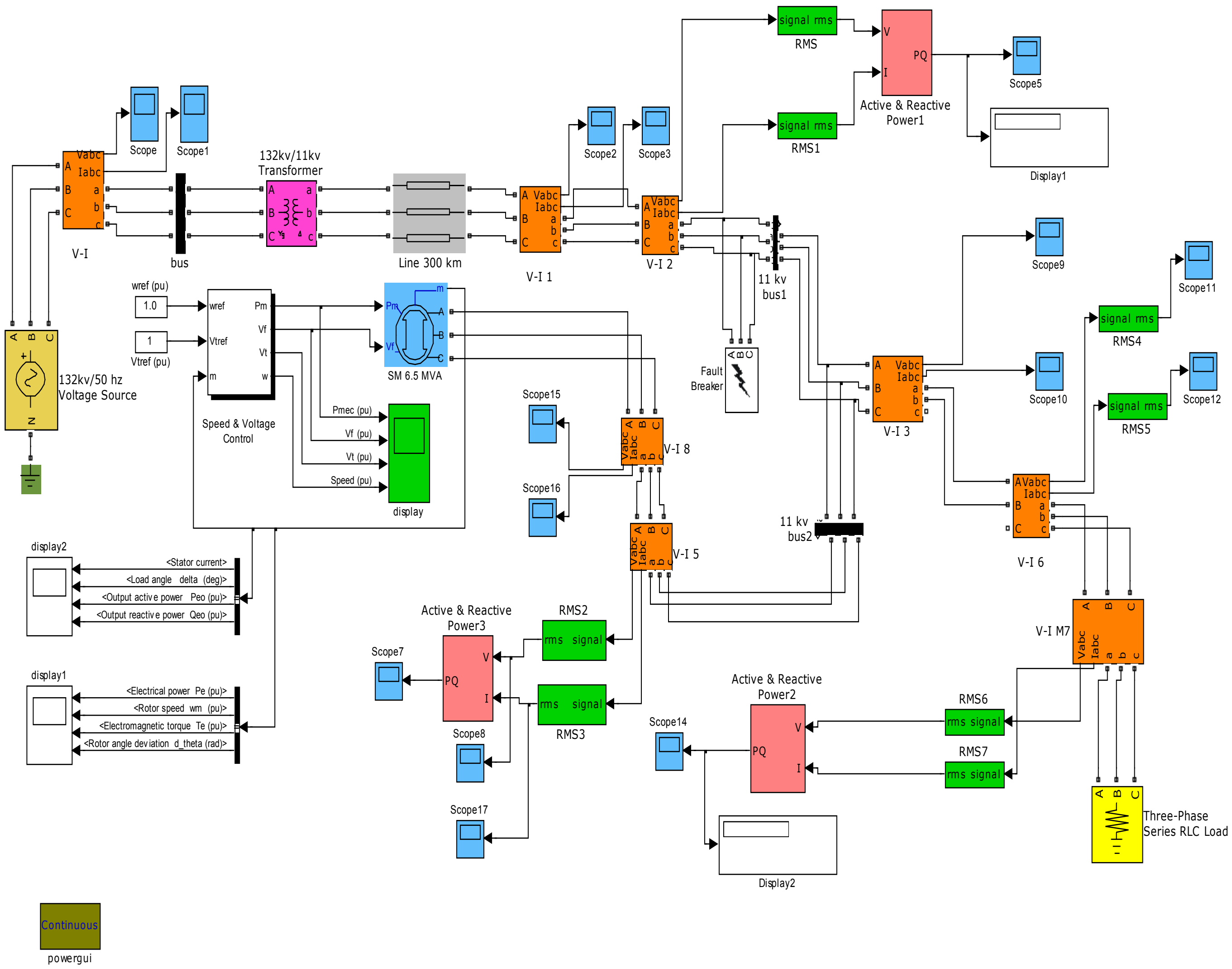

Figure 3: DG working parallel to the load side in MATLAB/Simulink Environment.

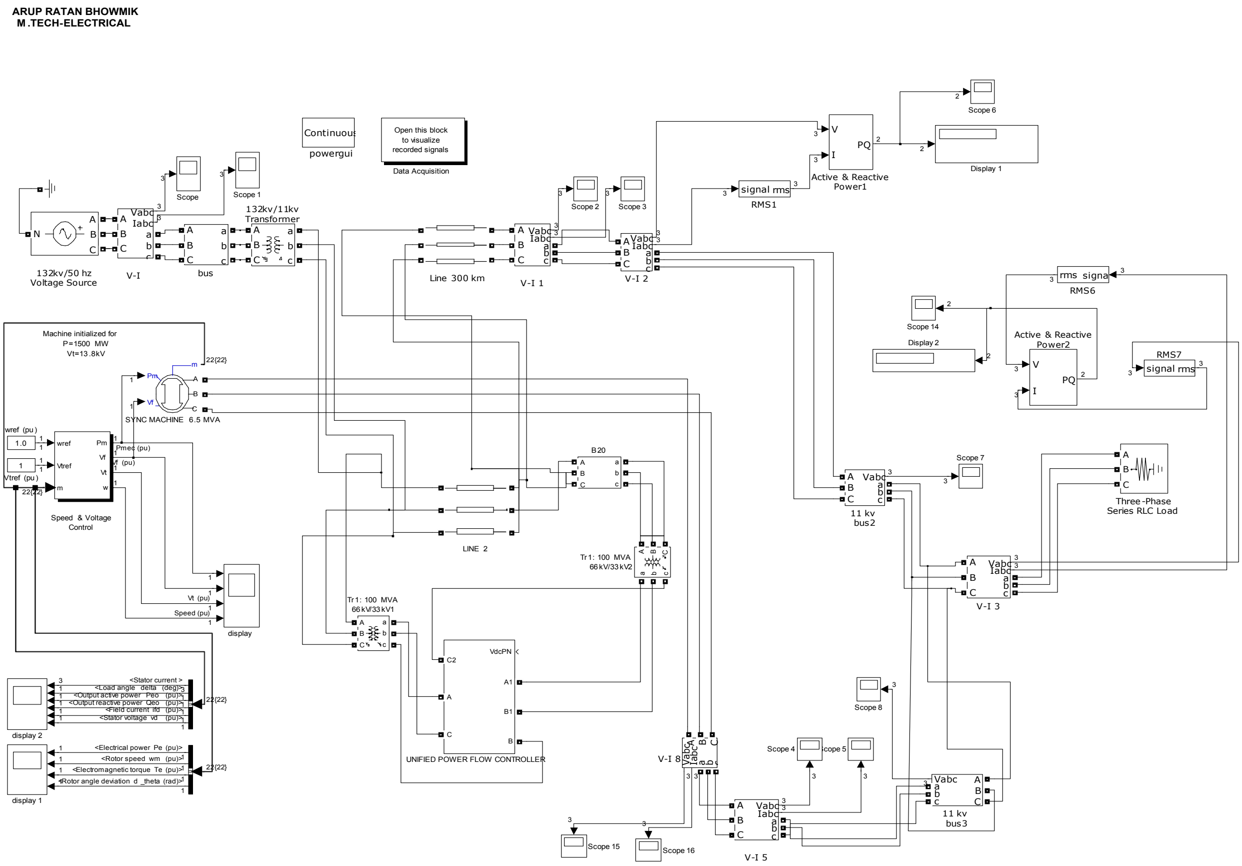

Figure 4: DG and UPFC working parallel to the load side in MATLAB / Simulink Environment.

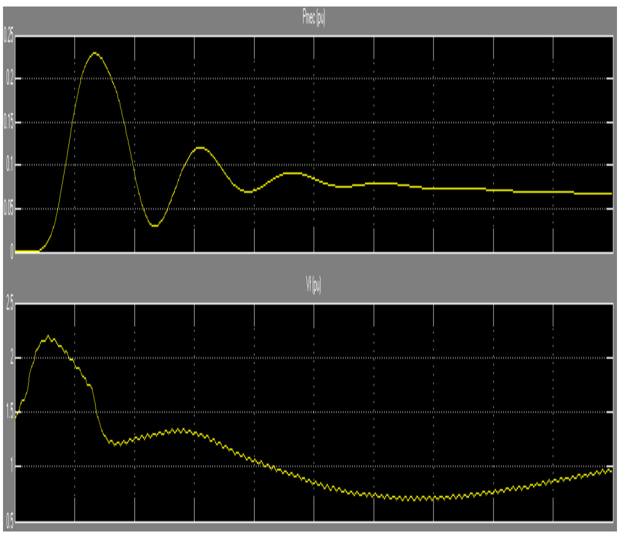

Figure 5: waveform of mechanical power in pu and field voltage in p.u.

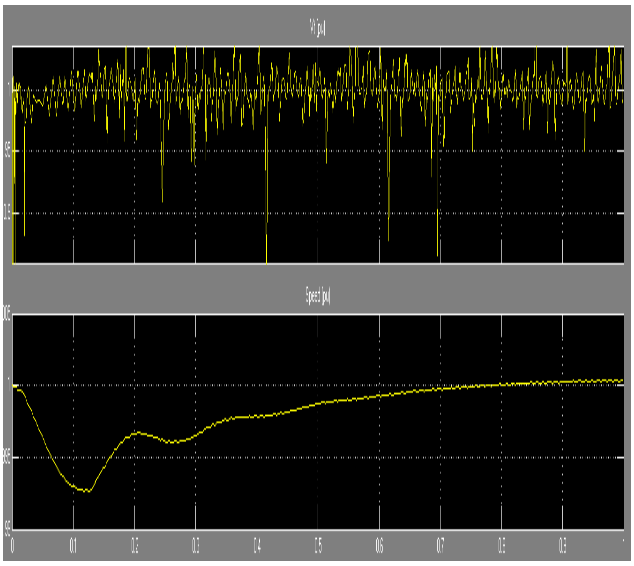

Figure 6: waveform of termimal voltage in p.u. and speed in p.u. of a synchronous generator.

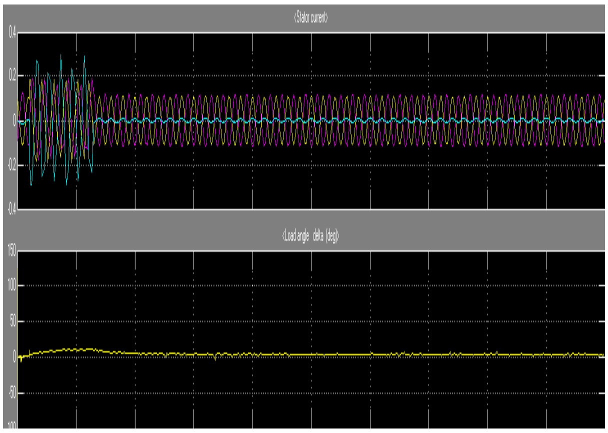

Figure 7: waveform of stator current and load angle of synchronous generator

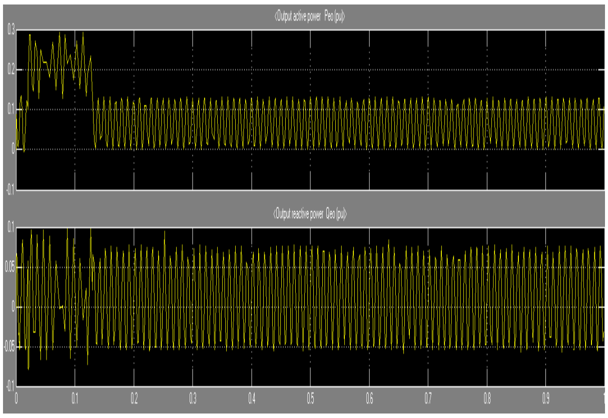

Figure 8 : waveform of output active power and output reactive power of synchronous generator

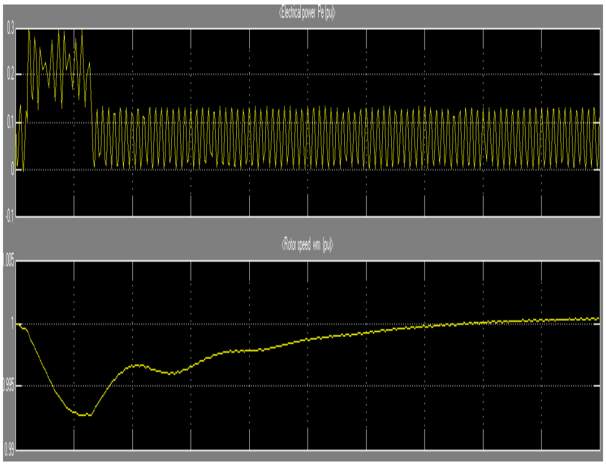

Figure 9: waveform of electric power and rotor speed of synchronous generator

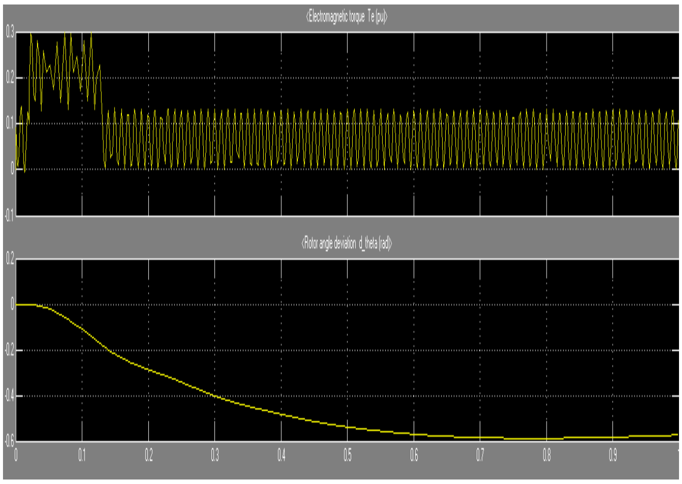

Figure 10: waveform of electro magnetic torque and rotor angle deviation of synchronous generator.

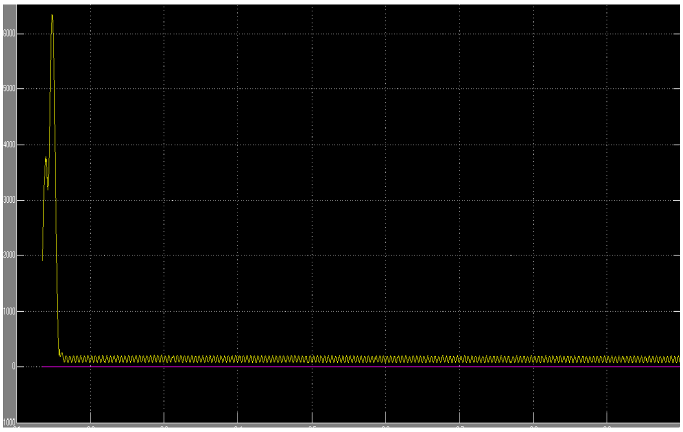

Figure 11: waveform of active and reactive power at the load end with synchronous generator

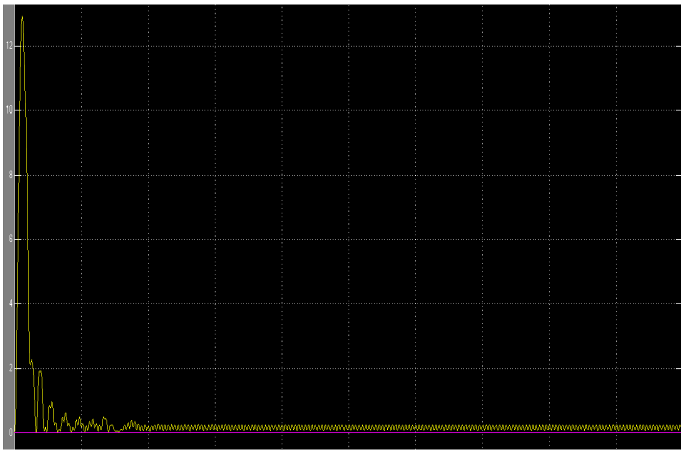

Figure 12: waveform of active and reactive power at the load end without synchronous generator.

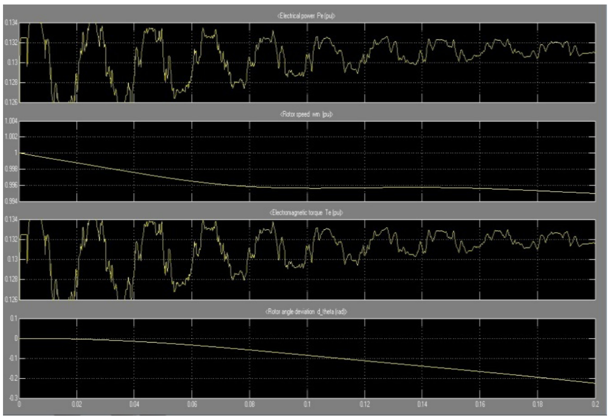

Figure 13: waveform of electrical power,rotor speed,electromagnetic torque and rotor angle deviation with synchronous generator and UPFC.

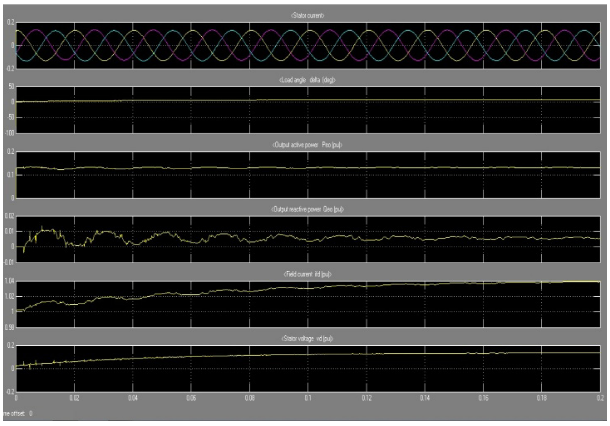

Figure 14: waveform of Stator current,load angle,output active and reactive power,field current and stator voltage with synchronous generator and UPFC.

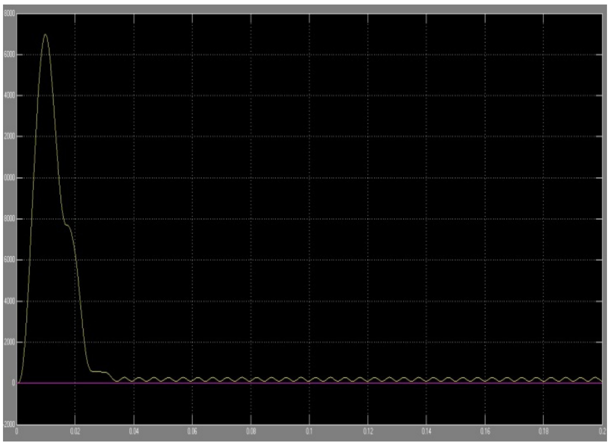

Figure 15: waveform of Stator current,load angle,output active and reactive power,field current and stator voltage with synchronous generator and UPFC.

Table 1. Comparative performance of different case studies

Case study	Real power(KW)
Without DG	23.07
With DG	81.72
With DG and UPFC	108.4

5. CONCLUSION

In this paper the performance of Synchronous Generator which is act as a Dispersed Generator is investigated in controlling the flow of power over the transmission line. A comparative performance evaluation with and without Dispersed generator and UPFC has been studied. This paper presents real and reactive power flow control through a transmission line by placing Synchronous Generator at the load end using computer simulation. In the absence of Synchronous Generator, real and reactive power through the transmission line cannot be controlled and it is about $2.307e^{-005}$ watt. When Synchronous Generator is installed in the load side the real power is 81.72 watt and when UPFC is installed in the midpoint the maximum power transfer capacity is increased and now real power is about 108.4 Kilowatt. Hence power is increased by the DG and UPFC.

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