Enhancement of Power Transfer Capability by using IGBT based Unified Power Flow Controller

Sujata Tandon
M.Tech Scholar
Electrical Engg. Department
BBSBEC, Fatehgarh Sahib

Lakhwinder Singh
Professor
Electrical Engg. Department
BBSBEC, Fatehgarh Sahib

Manpreet Singh
Assistant Professor
Electrical Engg. Department
BBSBEC, Fatehgarh Sahib

***Abstract*: Global demand for electrical power consumer has been drastically increased but the generation has not been increased proportionally. Due to this huge gap between generation capacity and consumer load demand, transmission lines are forced to operate at their maximum limits. To satisfy this condition, Flexible AC Transmission System (FACTS) controllers are widely used. In this paper, Unified Power Flow Controller (UPFC) is applied to enhance the power transfer capability of transmission line. UPFC is a combination of series and shunt Voltage Source Converter (VSC) and both the converters are coupled to each other through a DC link. UPFC controls the power flow in the transmission line by controlling line impedance, magnitude of voltage and phase angle of injected voltage or current in line. Methodology to improve power transfer capability of system has been tested in MATLAB simulation software.**

Keywords: Unified Power Flow Controller (UPFC), Flexible AC Transmission System (FACTS), Series Converter, Shunt Converter, Voltage Source Converter (VSC).

1. INTRODUCTION:

Since last two decades load has been increased at higher rate than generation capacity. As a result, transmission lines are overloaded and are more prone to severe outages. To cope this situation several methods are implemented to improve power transfer capability of transmission lines and one of them is FACTS controllers. FACTS are most acceptable devices in the world to solve the problem of power stability and voltage stability. Flexible AC transmission system controller (FACTS) is a power electronic static device which provides control over several lines simultaneously. FACTS controllers are divided as, First Generation FACTS Controllers; It is the earliest generation of FACTS controllers in which manual switching technology is used. In first generation SVC and TCSC are included. Second generation of FACTS Controllers; It is Thyristorised FACTS controllers generation, which includes STATCOM, SSSC, UPFC and IPFC. Third generation of FACTS controllers, it includes generalized unified power flow controller (GUPFC), Hybrid power flow controller(HPFC) Fourth generation of FACTS controllers, includes APFC. In power system, FACTS controllers are divided in four types.

a) Series Controllers.
b) Shunt Controllers.
c) Combined series -series controllers
d) Combined series-shunt controllers

Series Controllers: Series controllers are connected in series with the transmission line. It could be variable impedance type. For example TCSC, TCVL, SSSC and IPC.

Shunt Controllers: These controllers are connected in parallel with transmission line. Shunts controllers includes variable impedance, variable source or a combination of variable impedance and source. For example SVC, TSC, TCR, TCBR, STATCOM, BESS, SMES.

Combined Series-Series Controllers: It is a unified series-series controller which provides independent control of reactive power flow in each line. For example IPFC.

Combined Series-Shunt Controllers: In this type of controller both series and shunt controllers are connected to each other in coordinated manner. For example UPFC.

2. UNIFIED POWER FLOW CONTROLLER:

Unified power flow controller is second generation family of FACTS controller which is used to control power flow over transmission line. It is a combination of two, back to back series shunt converters which is coupled through a DC link. Series converter injects voltage of controlled magnitude and phase angle in series to transmission line through series coupling transformer, similarly shunt converter injects current of controlled magnitude and phase angle to parallel with line through shunt transformer. Reactive power is a function of voltage, therefore by controlling voltage of transmission line, reactive power can be controlled and if reactive power in transmission line is limited, then active power flow in line will rise. Typical schematic diagram of UPFC controlled power system has been shown in Fig. 1.

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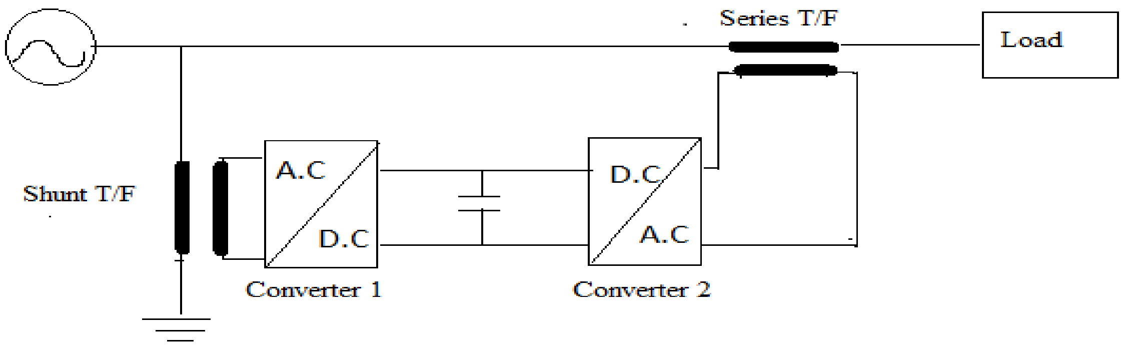

Figure. 1: UPFC controlled transmission line

3. METHODOLOGY:

There are many techniques available to solve the problem of power transfer capability and voltage sag like STATCOM, SSSC etc but in this paper UPFC scheme is used to solve the problem of power transfer capability. UPFC are more reliable and can control active and reactive power over transmission line, as shown in Fig. 2.

4. MODELING OF FACTS CONTROLLER:

The model of power flow study of UPFC is known as power injection model. Series converter is a main component which controls, phase angle, voltage magnitude and power injection in series with line. Therefore, only series voltage converter is described in Fig. 3.

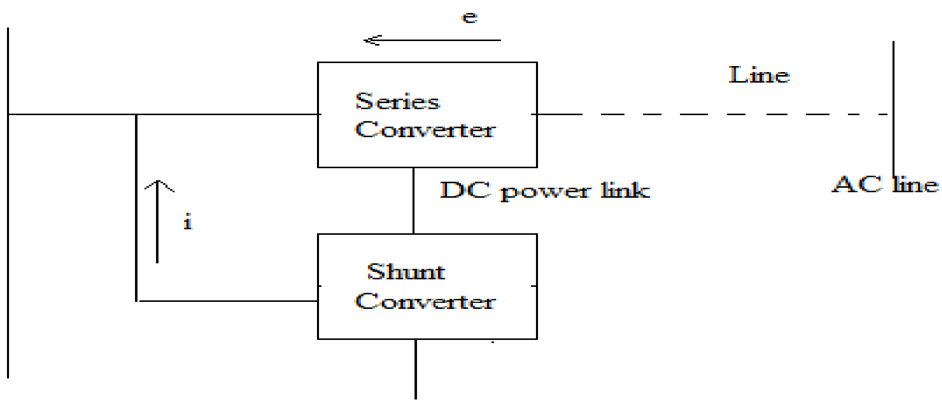

Figure. 2: Internal structure of UPFC

For injection modeling following points are considered.

- Consider transmission line as line series reactance *jx*. It is reactance taken from terminal voltage and is equal to
  .$x_s = x_k r^2_{max}(S_B/S_s)$ 3.1
  Where, x_k resembles transformer series reactance, r_{max} denotes maximum per unit injected voltage magnitude, S_B denotes base power of system and S_s denotes nominal rating power of series converter.
- Replace the voltage source $\bar{V}$se by a current source $\bar{I}_{inj}$= -jbs$\bar{V}$se in parallel with xs $\bar{V}$se = r$\bar{V}_K e^{-j\gamma}$where 0≤ r ≤ $r_{max}$and 0 ≤ γ ≤ 2 3.2

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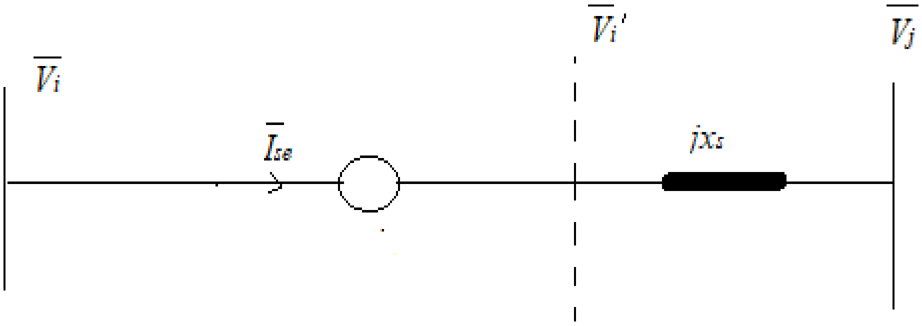

Figure. 3 Injection model of series converter

The current source $\bar{I}_{inj}$ corresponds to injection powers $\bar{S}_i$ and $\bar{S}j$ which are defined by

$\bar{S}i = \bar{V}i\,(-\bar{I}_{inj}) = -rb_sV_i^2Sin(\gamma) - jrb_sV_i^2cos(\gamma)$ 3.3

$\bar{S}j = \bar{V}_j\,(\bar{I}_{inj}) = rb_sV_iV_jsin(\theta_{ij} - \gamma) + jrb_sV_iV_jcos(\theta_{ij} - \gamma)$ 3.4

Where $\theta_{ij}=\theta_i - \theta_j$, and $b_s = 1/\,x_s$.

Fig 3 shows injection model of the series converter part of upfc, in this

$P_i = -real(\bar{S}i\,)$, $Q_i = -imag(\bar{S}i\,)$

$P_j = -real(\bar{S}j)$, $Q_j = -imag(\bar{S}j)$

If we neglect UPFC loss then,

$P_{conv\,1} = P_{conv\,2}$ 3.5

Apparent power generated by the series voltage source converter is:

$\bar{S}_{CONV\,2} = \bar{V}_{se}\bar{I}_{se} = re^{j\gamma}\bar{V}i(\frac{\bar{V}i - \bar{V}j}{jXe})$ 3.6

Equations of active and reactive power supplied by series converter are:

$P_{conv2} = rb_sV_iV_jsin(\theta_i - \theta_j + \gamma\,) - rb_sV_i^2sin\gamma$ 3 .7

$Q_{conv2} = -\,rb_sV_iV_jcos(\theta_i - \theta_j + \gamma\,) - rb_sV_i^2cos\gamma + r^2b_sV_i^2$ 3.8

At the UPFC shunt side, the active and reactive power flows are given as

$Pi1 = -\,rb_sV_iV_jsin(\theta_{ij} + \gamma\,) - b_sV_i^2sin\theta_{ij}$ 3.9

$Q_{i1} = -\,rb_sV_iV_jcos\gamma + Q_{conv1} + b_sV_i^2cos\theta_{ij} - b_sV_i^2$ 3.10

Where at series side they are

$Pj2 = rb_sV_iV_jsin(\theta_{ij} + \gamma\,) + b_sViV_jsin\theta ij$ 3.11

$Q_{j2} = rb_sV_iV_jcos\gamma + Q_{conv1} + b_sV_i^2cos\theta_{ij} - b_sV_i^2$ 3.12

The UPFC injection model is thereby defined by the constant series branch susceptance bs which is included in the system bus admittance matrix, and the bus power injections P_{si}, Q_{si}, P_{si}, and Q_{sj}

5. MATLAB SIMULATIONS:

Simulation model of both compensated and uncompensated transmission line has been shown in Fig. 4, Fig. 5 and Fig. 6, respectively. In compensated model UPFC controller is used to compensate line. Load 2 (4KW) is connected with transmission line through circuit breaker at 0.3 sec. After the connection in transmission line voltage sag is present in uncompensated line which can be observed from Fig. 8 and also active and reactive power transfer is low, which is shown in Fig. 7. But in case of compensated line voltage profile is improved as well as power transfer capability is also increased as compared to uncompensated line shown in Fig. 9 and Fig. 10.

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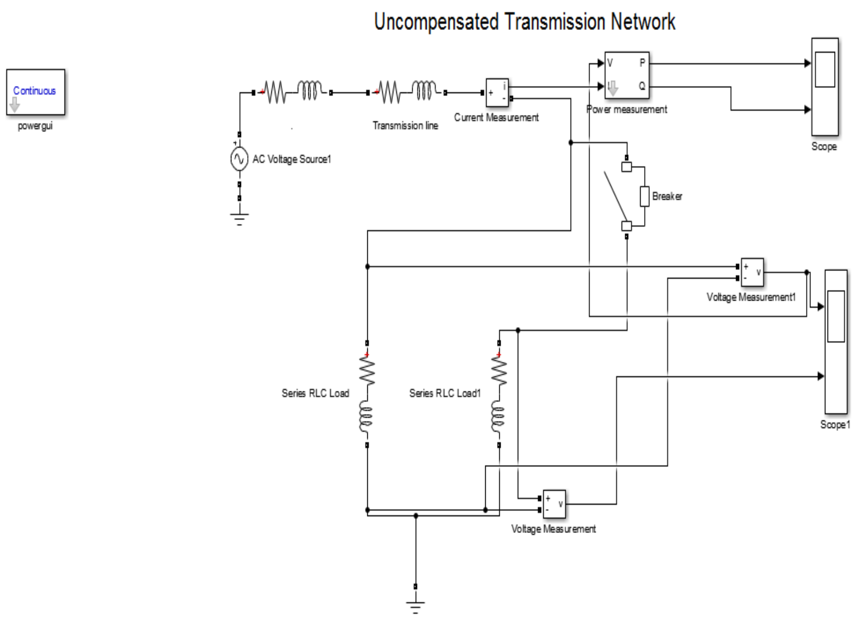

Figure.4: Model of Uncompensated Line

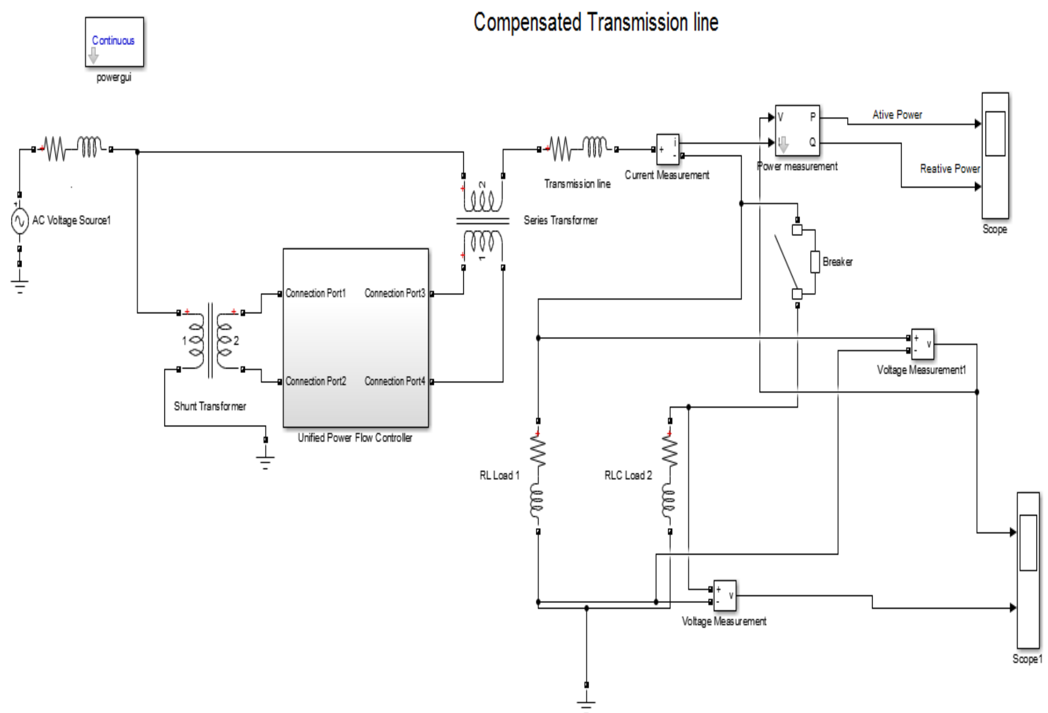

Figure. 5: Model of Compensated line

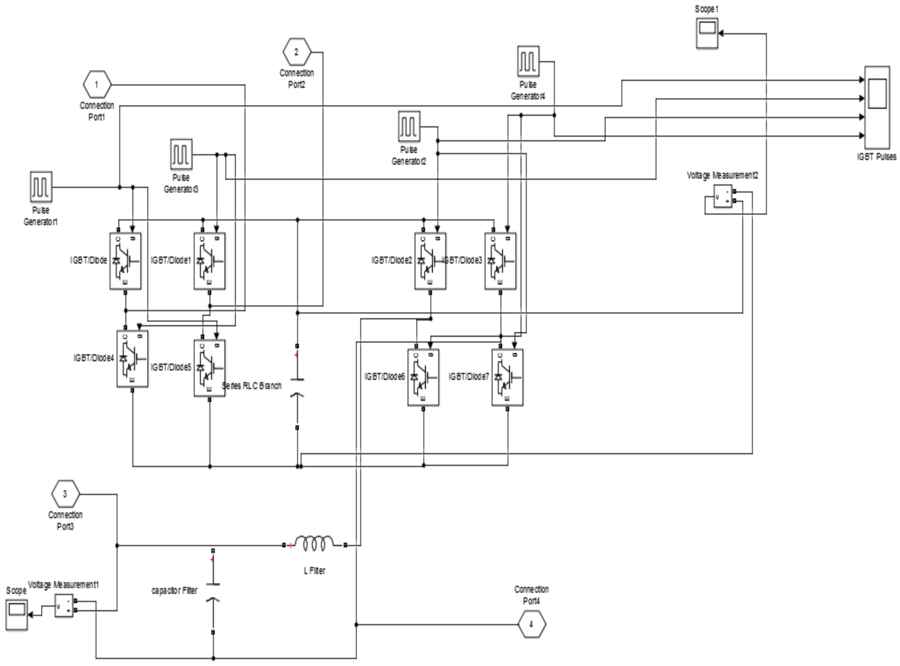

Figure. 6: Open loop model of UPFC

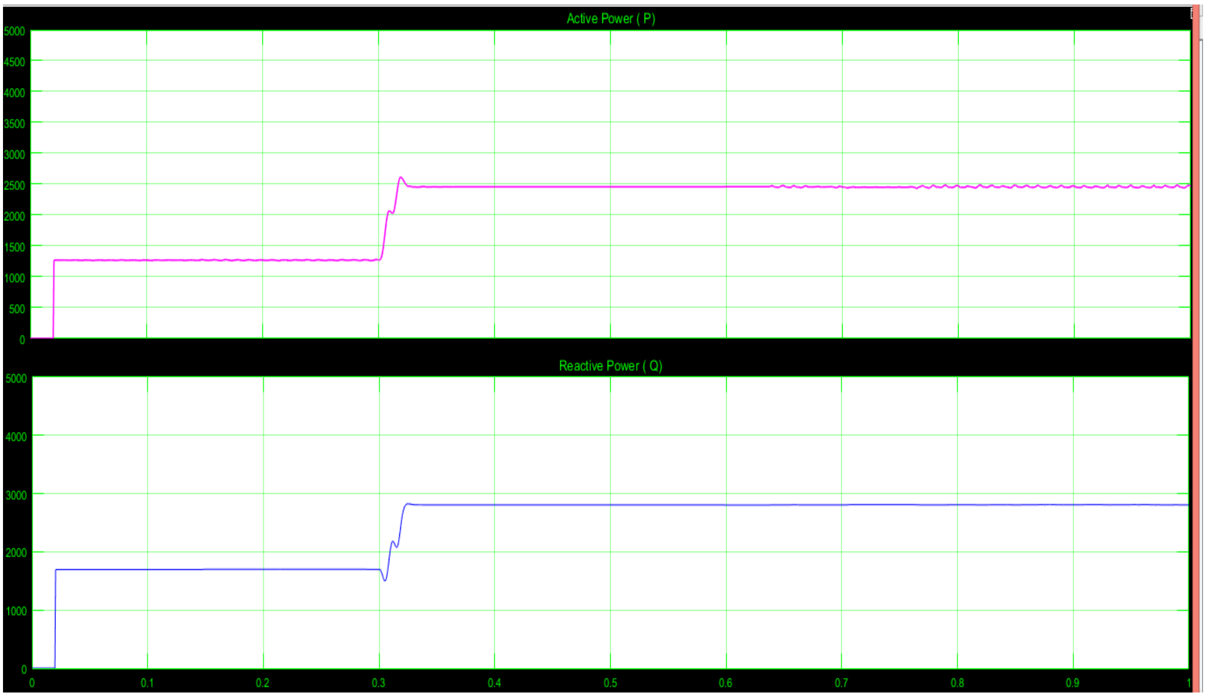

Figure. 7: Power flow graph of uncompensated line

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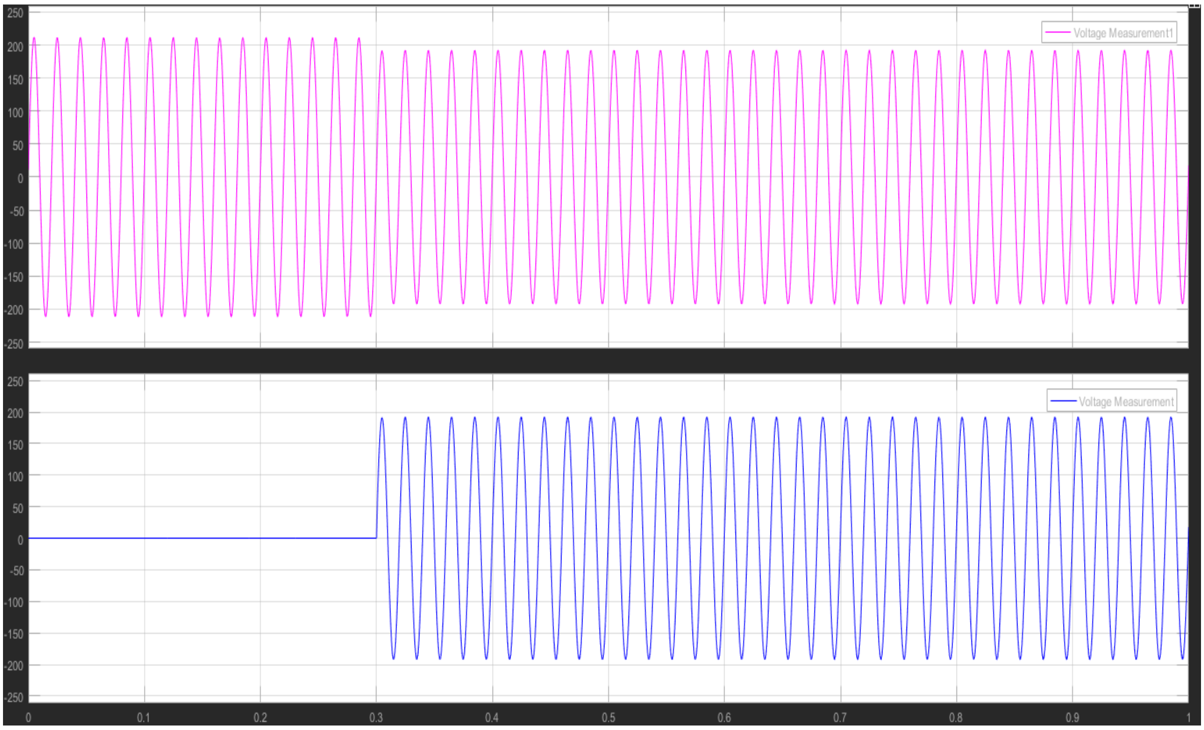

Figure.8: Voltage sag across load in uncompensated line

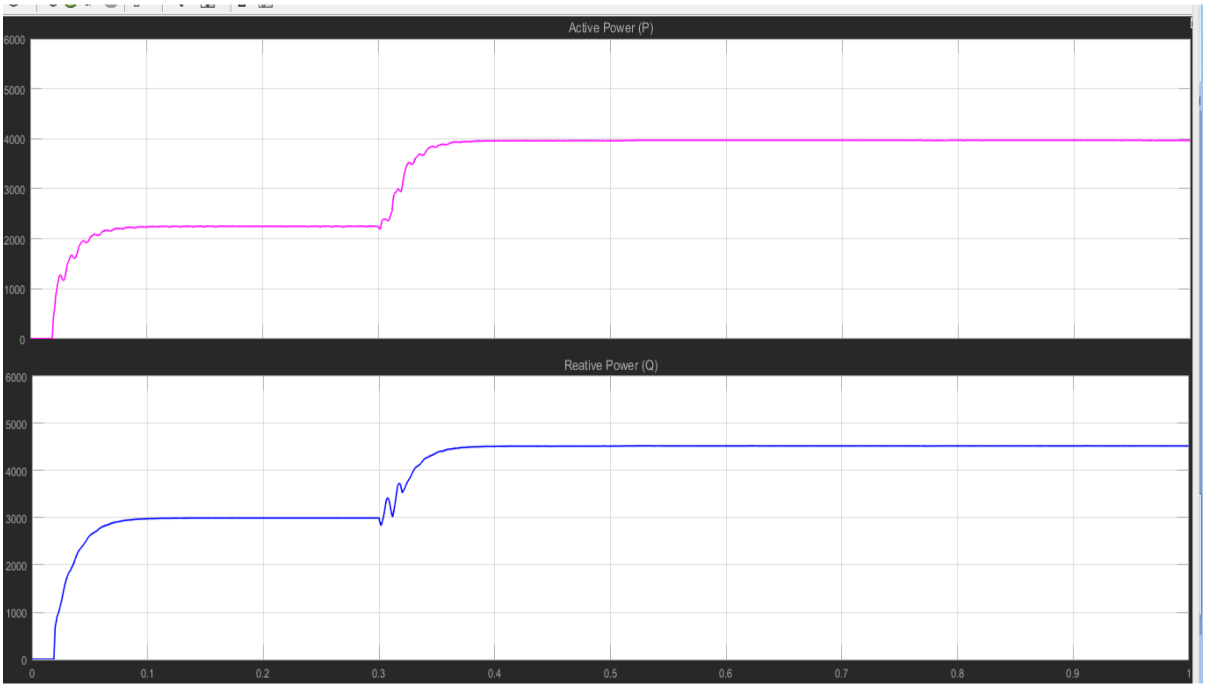

Figure.9: Power flow graph in compensated line

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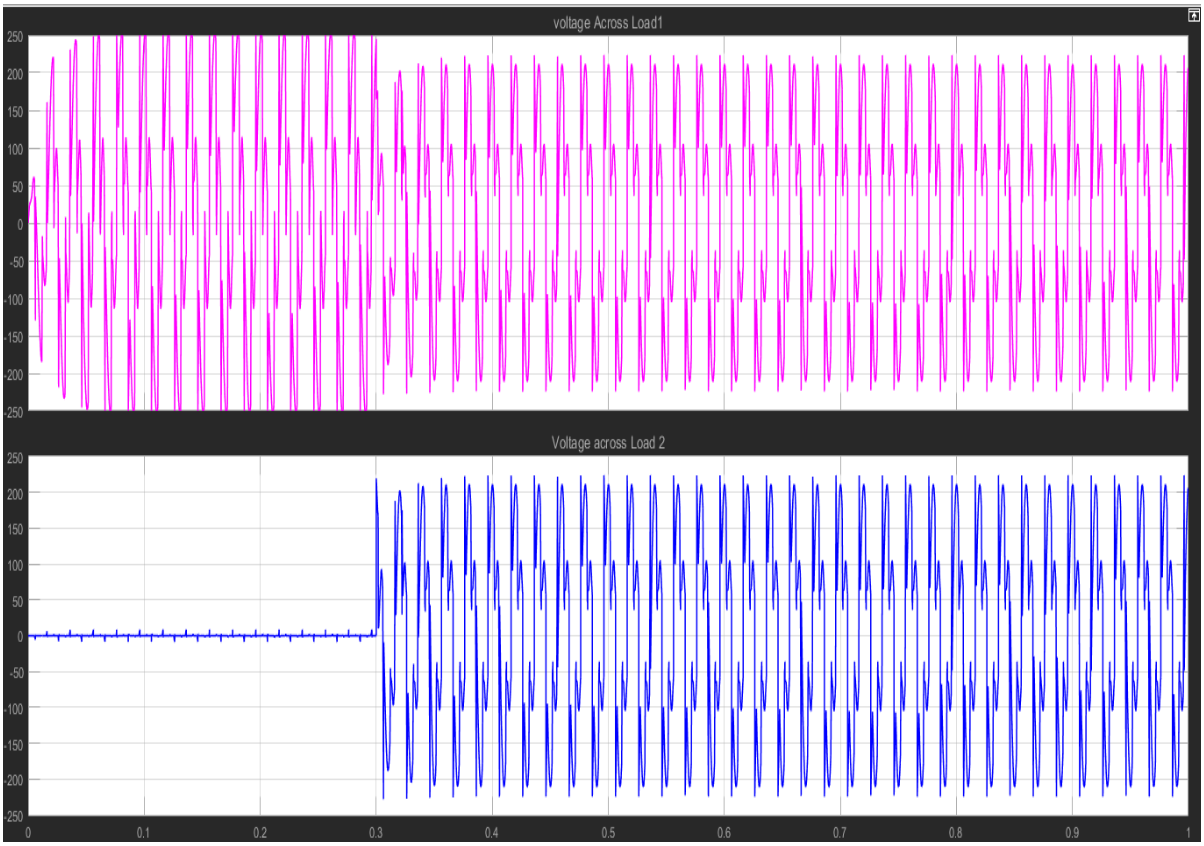

Figure.10: Voltage graph in Compensated line

6. RESULTS:

To enhance the power transfer capability of transmission line, UPFC controller has been used. Simulation results of both the uncompensated and compensated line have been obtained and are summarized in Table 1 given below.

Table 1: Comparison of uncompensated and compensated line response.

Sr. No	Condition	Load Voltage	Active Power	Reactive Power
1	Uncompensated line (Without (UPFC)	185 V	2422 W	2830 VAR
2	Compensated Line (With UPFC)	220 V	4000 W	4500 VAR

CONCLUSIONS:

In this paper, Unified Power Flow Controller (UPFC) has been successfully implemented on transmission line having non linear load. By the output response of simulation, it can be observed that the UPFC improves voltage profile as well as power transfer capability of transmission line.

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