Real and Reactive Power Flow Analysis & Simulation with UPFC Connected to a Transmission Line

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Abstract: ***The UPFC is a member of the FACTS family with very attractive features and it is a solid state controller which can be used to control active and reactive power flow in a transmission line. In this paper the performance of Unified Power Flow Controller (UPFC) is investigated in controlling the flow of power over the transmission line. This research deals with simulation of transmission line using UPFC to improve the real and reactive power flow control through a transmission line. In this research paper a Simulink Model is considered with UPFC model to evaluate the performance of single and double transmission line systems (33/22) kV. In the simulation study, the UPFC models ease the real time control and dynamic compensation of AC transmission system. It should be consider as real and reactive power compensation, capable of independently controlling voltage profile as well as the real and reactive powers in the line. The simulation model is tested for single and double transmission line systems with and without UPFC model in MATLAB/SIMULINK environment. By using a UPFC the oscillation introduced by the faults, the rotor angle and speed deviations can be damped out quickly than a system without a UPFC. It is also shown that a UPFC can control independently the real and reactive power flow in a transmission line.***

Keywords: FACTS, OPF, Power system, UPFC, N-R method, power flow controller.

1. Introduction

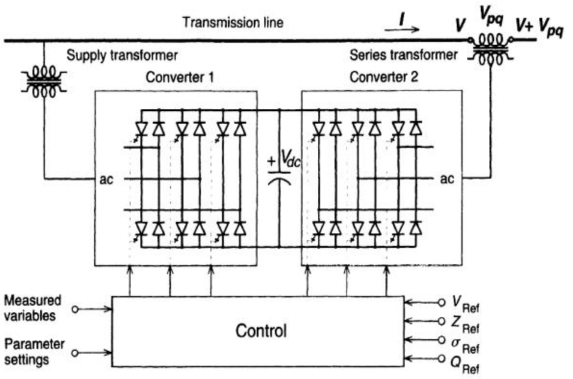
As the load increases, demand of power utilities is increases due to this the utilization of their existing transmission system increases. Continuous and fast improvement of power electronics technology has made Flexible AC Transmission System (FACTS) a good concept for power system development. Among a variety of FACTS controllers, UPFC have attractive feature so it is discussed in detail. UPFC is an advanced power systems device capable of providing simultaneous control of voltage magnitude and active and reactive power flows. UPFC was proposed for real time and dynamic compensation of AC transmission systems, providing the necessary functional flexibility required to solve many problems which are faced by the utility industry. The UPFC is an advanced power system device capable of providing simultaneous control of voltage magnitude, active and reactive power flows in an adaptive fashion. It has

- Extended functionality
- Capability to control voltage, line impedance and phase angle in the power system network
- Enhanced power transfer capability
- Ability to decrease generation cost
- Ability to improve security and stability
- Applicability for power flow control, loop flow control

In this paper, a comprehensive method is developed for power flow analysis of a transmission system with UPFC Simulink Model to evaluate the performance of a single and double transmission line system has been focused. A mathematical model of UPFC has been developed to study the characteristics using state space calculations without considering the effects of converters and the dynamics of generator. The aim of this technique is 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 the two leg three phase converters based on UPFC. They suggests that the UPFC with their 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. Some results of network with and without UPFC are also been compared in terms of active and reactive power flows in the line. A number of simulation results have compared when UPFC is connected between two transmission line with a transmission line without UPFC. The performance of UPFC in controlling power flow over the transmission line is investigated

2. Modeling of UPFC

The UPFC consists of two switching converters, which are considered as voltage sourced inverters using gate turn-off (GTO) thyristor valves (as shown in fig.1). These inverters labelled “Inverter 1” and “Inverter 2” in the figure is operated from a common dc link provided by a dc storage capacitor. The function of this arrangement as an ideal ac to ac power converter in which the real power can freely flow in either directions between the ac terminals of two inverters and each inverter can independently generate (or absorb) reactive power at its own ac output terminals. Inverter 2 provides the main function of UPFC by injecting an ac voltage Vpq , in line via a series transformer with controllable magnitude Vpq ($0 \leq Vpq \leq Vpq$) and phase angle ρ ($0 \leq \rho \leq 2\pi$), at the power frequency. This injected voltage can be considered essentially as a synchronous ac voltage source. The real power exchanged at the ac terminal is converted by the inverter into dc power which appears at the dc link as positive or negative real power demand. The reactive power exchanged at the ac terminal is generated internally by the inverter. The basic function of Inverter 1 is to supply or absorb the real power demanded by Inverter 2 at the common dc link. This dc link power is converted back to ac and coupled to the transmission line via a shunt-connected transformer. Inverter 1 can also generate or absorb controllable reactive power, if it is desired, and thereby it can provide independent shunt reactive compensation for the line. The reactive power exchanged is supplied or absorbed locally by inverter 2 and therefore it does not flow through the line. Thus, inverter 1 can be operated at a unity power factor or be controlled to have a reactive power exchange with the line independently of the reactive power exchanged by Inverter 2.



Basic circuit arrangement of the Unified Power Flow Controller

The following equations of voltage, Real Power, Reactive Power are given as.

$V= Vej\ \partial/2 = V\ (\cos\partial/2+j\sin\partial/2)$

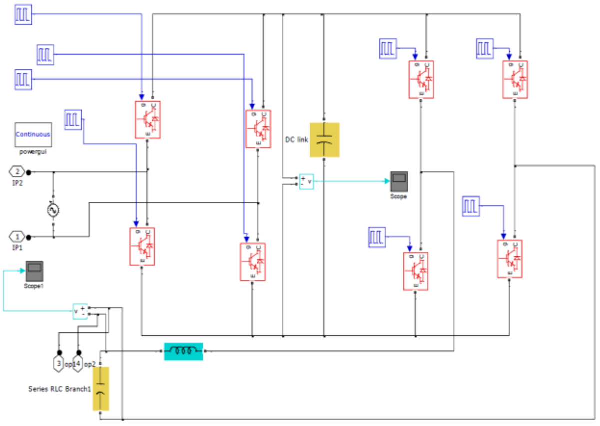
$V= Ve\text{-}j\ \partial/2 = V\ (\cos\partial/2+j\sin\partial/2)$

$Vpq = Vpqej\ (\partial/2+p) = Vpq\ \{\cos(\partial/2+\rho) +j \sin(\partial/2+\rho)\}$

$P\ (\partial, \rho) = P0\ (\partial) + Ppq\ (\rho) = V2/X \sin\partial - VVpq/X \cos(\partial/2+\rho)$

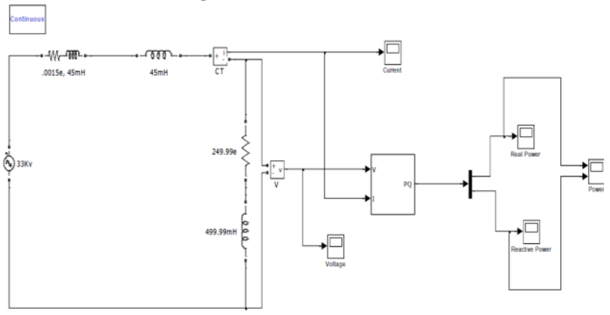
$Q\ (\partial, \rho) = Q0\ (\partial) + Qpq\ (\rho) = V2/X\ (1- \cos\partial) - VVpq/X \sin(\partial/2+\rho)$

This means that there is no continuous reactive power flow through the UPFC. When viewed the operation of the UPFC, it can perform the functions of reactive shunt compensation, series compensation and phase shifting simultaneously; thereby can meet multiple control objectives by adding the injected voltage Vpq, with appropriate amplitude and phase angle, to the terminal voltageV0. With these assumptions the series voltage source, together with the real power coupling to the sending end generator is an accurate representation of the basic UPFC.



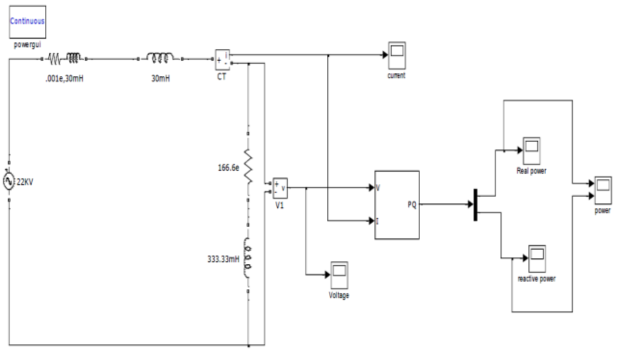
Simulink model of UPFC

The simulation model of Single Transmission line of 33kV, Line-I is shown in Fig.



Line Model of 33kV Line

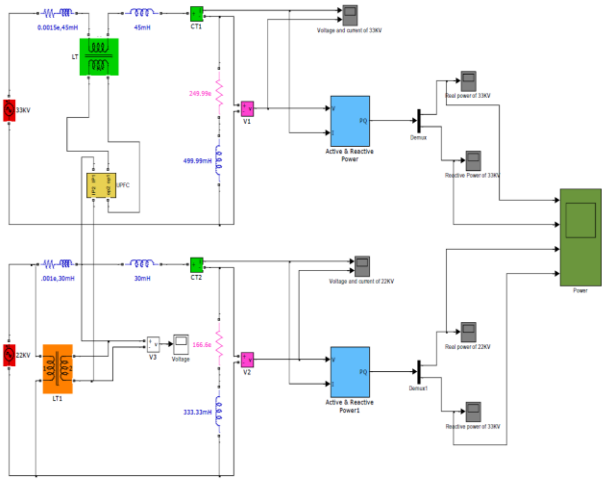
In this model of transmission line, there is a 33kV kV voltage source is feeding to an RL load. For measurement of current a current measurement block named CT is connected in the circuit, whose output can be taken from the scope 'current' connected to this block. A block for voltage measurement named V1 is connected across the load. The output of this voltage measurement block is fed to the scope named voltage for voltage waveform. Further a block for power measurement is connected the circuit to calculate the power consumed by the load. This power measurement block is further connected to the demux, for obtaining the power in terms of real and reactive power. The power outputs of this demux can be obtained from the two scopes connected to it. All the blocks used in this transmission line model are taken from the SimPowerSystem toolbox of Matlab Simulink.



Line Model of 22 kV Line

In this model of transmission line, there is a 22 kV voltage source is feeding to an RL load. For measurement of current a current measurement block named CT is connected in the circuit, whose output can be taken from the scope 'current' connected to this block. A block for voltage measurement named V1 is connected across the load. The output of this voltage measurement block is fed to the scope named voltage for voltage waveform. Further a block for power measurement is connected the circuit to calculate the power consumed by the load. This power measurement block is further connected to the demux, for obtaining the power in terms of real and reactive power. The power outputs of this demux can be obtained from the two scopes connected to it. All the blocks used in this transmission line model are taken from the SimPower System toolbox of Matlab Simulink

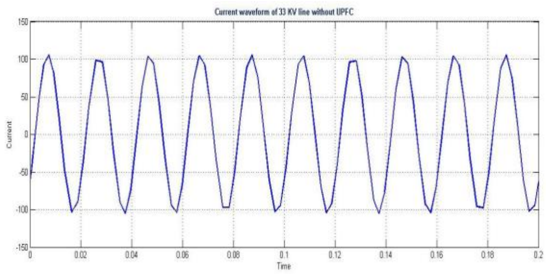
Simulink Model of 33 kV/22kV Transmission Lines With UPFC



Simulink model of 33Kv/22Kv with UPFC

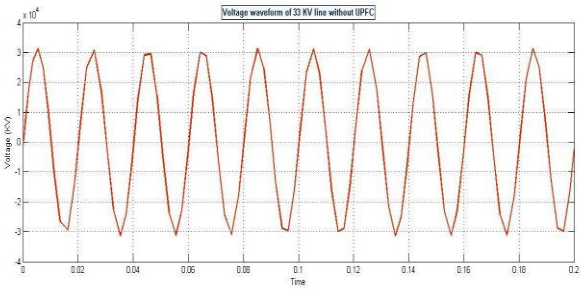
The Simulink Model is shown in Fig.4.4 represents the double line transmission model which consists of normal circuit and compensation circuit with an UPFC device. The compensation circuit, Line-I i.e. 33kV can absorb real power to the DC link through the converter or rectifier present in the UPFC system. From the DC link, in normal period, the normal circuit, Line-2 that is 22kV can give real power from DC link through converter or inverter. The real power needed by the compensation circuit to mitigate the compensation is exactly equal to the real power delivered by the normal circuit which includes both line and converter switching losses. Results of 33kV line without and without UPFC

The following fig shows the current waveform of 33kV transmission line without UPFC (Simulink model of 33kV transmission line is developed in Chapter-4 in section 43). At the steady state time t=0.02sec the current is 98.55Amp.



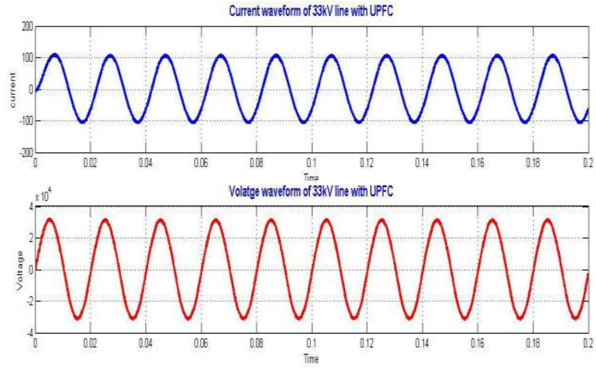
Current waveform of 33kV line without UPFC

The following fig shows the voltage waveform of 33kV transmission line without UPFC (Simulink model of 33kV transmission line is developed in Chapter-4 in section 4.3). At the steady state time t=0.02sec the voltage is 30.78 kV.



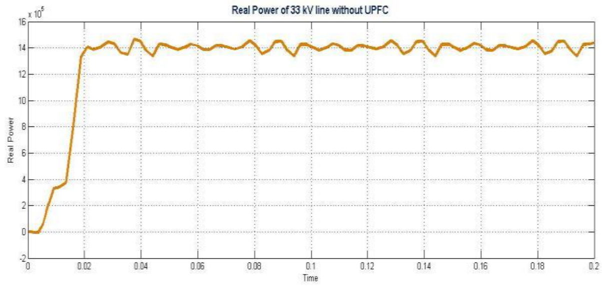
Voltage waveform of 33kV line without UPFC

The following fig. shows the current and voltage waveform of 33kV transmission line with UPFC (Simulink model of 33kV/22kV transmission line is developed in Chapter-4 in section 4.5). At the steady state time t=0.02sec the current and the voltage are 105Amp and 31.25kV.



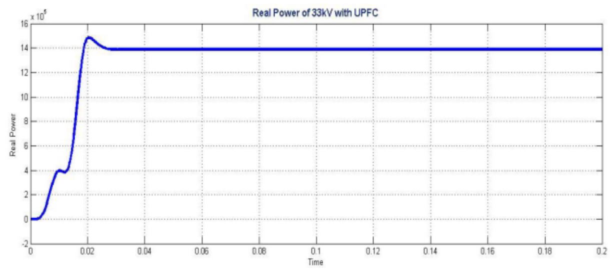
Current and Voltage waveform of 33kV line with UPFC

The following fig. shows the real power waveform of 33kV transmission line without UPFC (Simulink model of 33kV transmission line is developed in Chapter-4 section 4.3). At the steady state time t=0.02sec the Real Power is 1.405MW.



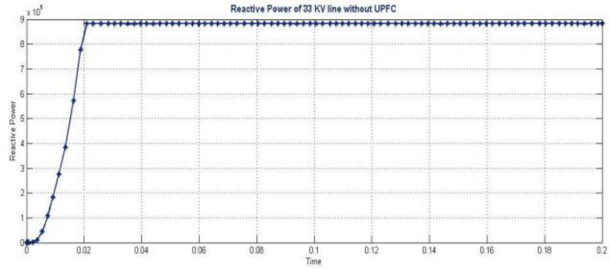
Real Power waveform of 33kV line without UPFC

The following fig. shows the Real Power waveform of 33kV transmission line with UPFC (Simulink model of 33kV/22kV transmission line is developed in Chapter-4 section 4.5). At the steady state time t=0.02sec the Real Power is 1.4816MW.



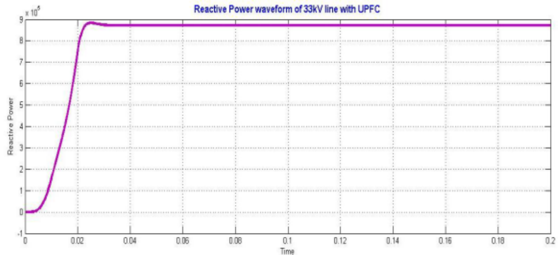
Real power waveform of 33kV line with UPFC

The following fig. shows the Reactive waveform of 33kV transmission line without UPFC (Simulink model of 33kV transmission line is developed in Chapter-4 section 4.3). At the steady state time t=0.02sec the Reactive Power is 85MVAr.



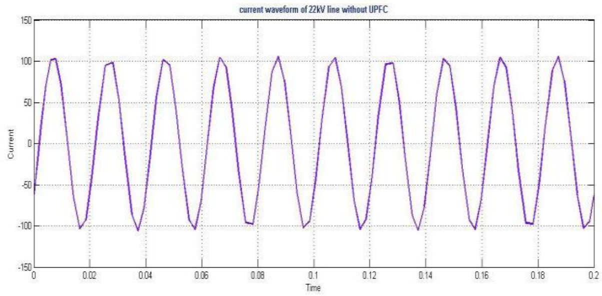
Reactive Power waveform of 33kV line without UPFC

The following fig. shows the Reactive Power waveform of 33kV transmission line with UPFC (Simulink model of 33kV/22kV transmission line is developed in Chapter-4 section 4.5). At the steady state time t=0.02sec the Reactive Power is 88MVAr.



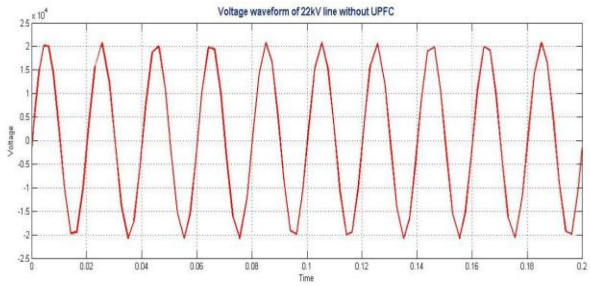
Reactive power waveform of 33kV line with UPFC

The following fig. shows the current waveform of 22kV transmission line without UPFC (Simulink model of 22kV transmission line is developed in Chapter-4 section 4.4). At the steady state time t=0.02sec the current is 98.3743Amp.



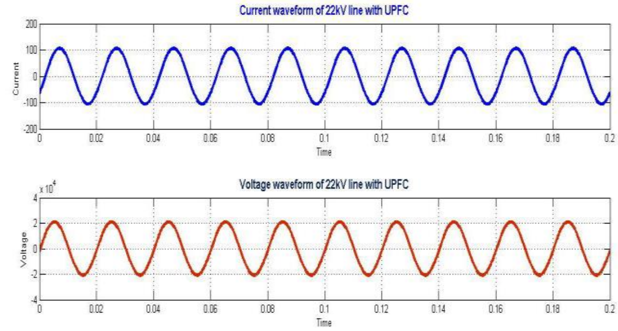
Current waveform of 22kV line without UPFC

The following fig. shows the voltage waveform of 22kV transmission line without UPFC (Simulink model of 22kV transmission line is developed in Chapter-4 section 4.4). At the steady state time t=0.02sec the voltage is 20.76kV.



Voltage waveform of 22kV line without UPFC

The following fig. shows the current and voltage waveform of 22kV transmission line with UPFC (Simulink model of 22kV/33kV transmission line is developed in Chapter-4 section 4.5). At the steady state time t=0.0sec the current and voltage are 106Amp and 21kV.

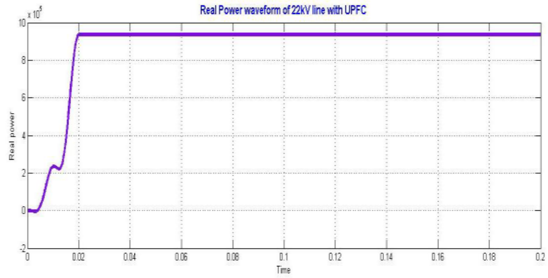


Current and Voltage waveform of 22kV line with UPFC

The following fig. shows the Real Power waveform of 22kV transmission line without UPFC (Simulink model of 22kV transmission line is developed in Chapter-4 section 4.4). At the steady state time t=0.02sec the Real Power is 91.50MW.

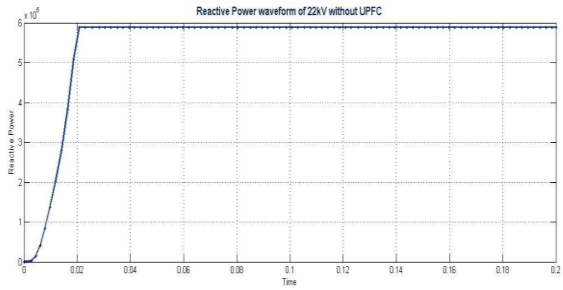
Real Power waveform of 22kV line without UPFC

The following fig. shows the Real Power waveform of 22kV transmission line with UPFC (Simulink model of 33kV/22kV transmission line is developed in Chapter-4 section 4.5). At the steady state time t=0.02sec the Real Power is 93.70MW.



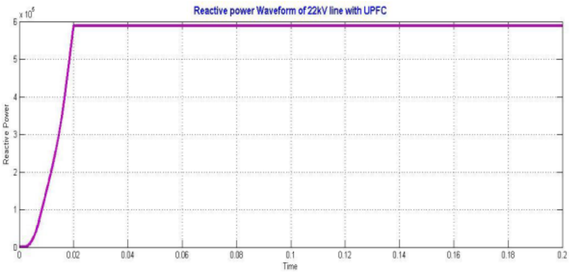
Real power waveform of 22kV line with UPFC

The following fig. shows the reactive power waveform of 22kV transmission line without UPFC (Simulink model of 22kV transmission line is developed in Chapter-4 section 4.4). At the steady state time t=0.02sec the Reactive Power is 56 MVAr.



Reactive Power waveform of 22kV line without UPFC

The following fig. shows the Reactive Power waveform of 22kV transmission line with UPFC (Simulink model of 33kV/22kV transmission line is developed in Chapter-4 section 4.5). At the steady state time t=0.02sec the Reactive Power is 58.90MVAr.



Reactive power waveform of 22kV line with UPFC

3. Conclusion

In this presented work, MATLAB/ SIMULINK model is used to simulate the model of rectifier and inverter based UPFC connected with transmission lines i.e. 22kV and 33kV. This dissertation gives control and performance of the UPFC used for power quality improvement and to obtain the steady state time, objectives are achievable by control settings of the UPFC controllers. Simulation results show the effectiveness of UPFC to control the real and reactive powers as well as voltage magnitude and current magnitude. It is found that there is an improvement in the real power and reactive power and voltage & current magnitude through the transmission line when UPFC is connected. The UPFC concept provides a powerful tool for the cost effective utilization of double transmission lines by facilitating the independent control of both the real and reactive power flow. There is an improvement in both voltage and power profiles, through the transmission line when UPFC is combined in the system. The UPFC model can be reduce the harmonics and ability to control and improve real and reactive powers, voltage and current magnitudes. The heating in the transformers is reducing by using multilevel response. This is due to the education in the harmonics. So, that the simulation results are in line with the predictions.

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