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Control Reactive Power Flow with UPFC Connected Using Different Distance Transmission Line

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ABSTRACT: The proposed researches are based on compensation of reactive power in transmission lines using Unified Power Flow Controller (UPFC). A Flexible Alternating Current Transmission System (FACTS) is defined by the IEEE as a power electronic based system and additional static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer Ability. A Unified Power Flow Controller (UPFC) is an electrical device for providing fast acting reactive power compensation on high voltage electricity transmission networks. In this proposed work measure the reactive power for STATCOM, SSSC and UPFC and showing the comparison of reactive and active power using equal load connected at different distance of transmission line. These proposed works are done in Matlab/Simulink 8.1 to make the design and performance.

The objectives of the study are to 1) the proposed research on compensation of reactive power in transmission line using UPFC. 2) Measure the reactive power for STATCOM, SSSC and UPFC. 3) Showing the reactive and active power comparison using equal load connected at different distance of transmission line.

KEYWORD: POWER SYSTEM, FACTS, STATCOM, SSSC, UPFC.

I. INTRODUCTION

The proposed researches are based on compensation of reactive power in transmission lines using Unified Power Flow Controller (UPFC). A Unified Power Flow Controller (UPFC) is a FACTS device for providing fast acting reactive power compensation on high voltage electricity transmission networks. It utilizes a pair of three-phase controllable bridges to produce current that is inserted into a transmission line using a series transformer. The controller can control real and reactive power flows in a transmission line. The UPFC utilizes solid state devices, which provide functional adaptability, generally not achievable by ordinary thyristor controlled systems. The UPFC is a combination of a STATCOM and SSSC coupled through a common DC voltage link. The controllable parameters of the UPFC are impedance, phase angle and voltage.

The UPFC could be providing Instantaneous control of all fundamental power system parameters i.e. transmission voltage, impedance and phase angle. The controller can be fulfilling functions of reactive shunt compensation, series compensation and phase shifting meeting multiple control objects. From a functional perspective, the objectives are met by applying a boosting transformer injected voltage also an exciting transformer reactive current. The injected voltage is inserted through a series transformer. Further transformers, the general structure of Unified Power Flow Controller (UPFC) contains besides a "back to back" AC to DC voltage source converters operated from a shared DC Link capacitor.

In recent years, better demands have been placed on the transmission network, and these demands will continue to development because of the increasing number of nonutility generators and delicate competition between utilities themselves. Increasing request on transmission, nonexistence of long–term organization and the necessity to provide open access to generating companies and consumers all together have produced tendencies toward less security and reduced quality of supply. The FACTS technology is necessary to improve some but not all of these difficulties by enabling utilities to get the most services from their transmission conveniences and enhance grid dependability.

Due to expand in power demand modern power system networks are being operated under importantly stressed conditions. This has resulted into the difficulty in conference reactive power necessity, especially under contingencies and hence maintaining the bus voltage within acceptable limits [1]. Voltage instability in the system normally occurs in the form of a progressive decay in voltage magnitude at some of the buses a possible result of voltage instability is loss of burden in an area or tripping of transmission lines and additional component by their protective system leading to cascaded outages and voltage collapse in the system [2, 3].

Power flow among two buses of the lossless transmission line is specified by:

$$P_{ij} = \frac{V_i \; V_j}{X_{ij}} \sin \delta_{ij}$$

Where V_i and δ_i are the i^{th} bus voltage magnitude and angle, Vj and δj are the j^{th} bus voltage magnitude and angle, Xij is the line reactance. Thus, from the equation it is clear that the power flow is a utility of transmission line impedance, the magnitude of sending end and receiving end voltage and the phase angle between voltages. Control the real and reactive power flow in the transmission line is likely by controlling one or a blend of the power flow arrangements. The bus voltage, line impedance as well as phase angle in the power system can be controlled quickly and flexibly with FACTS technology such as Static Var Compensator, Static Synchronous Condenser, Static Synchronous Series Compensator and Unified Power Flow Controller etc.

II. UNIFIED POWER FLOW CONTROLLER (UPFC)

The Unified Power Flow Controller (UPFC) concept was suggested by Gyugyi in 1991. The Unified Power Flow Controller (UPFC) was invented for the real time control and dynamic compensation of AC transmission systems, providing multifunctional adaptability required to solve many of the difficulties facing the power delivery industry. The Unified Power Flow Controller (UPFC) is capable to control, simultaneously or individually, all the parameters (i.e. voltage, impedance and phase angle) affecting power flow in the transmission line.

The main reason for the wide spreads of UPFC are its capability to power flow bidirectional maintaining well regulated DC voltage, workability in the wide range of effective conditions. This FACTs implement consolidates the two factors of two different FACTS devices static synchronous compensator and static synchronous series compensator. Essentially these devices are voltage source converters (VSC's). The UPFC is the most important part of synchronous voltage source (SVS). The SVS normally exchange both reactive and active power with the transmission system. Honestly speaking an SVS is capable to generate only the reactive power exchanged, the active power must be supplied to it, or absorbed from it, by an acceptable power supply or link.

A Unified Power Flow Controller (UPFC) is an electrical device for provide quick acting reactive power recompense on high voltage electricity transmission networks. The Unified Power Flow Controller (UPFC) is a versatile flexible alternating current transmission system (FACTS) device which can be used to control active and reactive power flows in a transmission line. It utilizes a pair of three-phase controllable bridges to create current that is inserted into a transmission line using a series transformer. The UPFC utilises solid state devices, which provide functional flexibility, generally not achievable by conventional thyristor controlled systems. The UPFC is a blend of a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) coupled through a common DC voltage link. The UPFC concept was defined in 1995 by L. Gyugyi of Westinghouse [4].

III. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

A static synchronous compensator (STATCOM) is also known as "static synchronous condenser" (STATCON) is a regulating device utilized on alternating current electricity transmission networks. It is based on a power electronics voltage source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide real AC power. It is a member from the FACTS controller of devices. Generally a STATCOM is installed to support electricity networks that require a poor power factor and

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frequently poor voltage regulation. There are nevertheless, additional uses, the most well-known utilization is for voltage stability. STATCOM is a Static synchronous generator operated as a shunt-connected static var compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage. A STATCOM is a voltage source converter (VSC) based device, with the voltage source behind a reactor. The voltage source is generated from a DC capacitor and consequently a STATCOM has very little active power ability. However its active power ability can be increased if a suitable energy storage device is connected across the DC capacitor [5, 6].

IV. STATIC SYNCHRONOUS SERIES COMPENSATOR (SSSC)

Static synchronous series compensator (SSSC) is a series compensator of FACTS family. It injects an almost sinusoidal voltage with variable amplitude. It is equivalent to an inductive or a capacitive reactance in series with the transmission line. The heart of SSSC is a voltage source inverter (VSI) that is supplied by a DC storage capacitor. With no outside DC link, the inserted voltage has two parts: the fundamental part is in quadrature with the line current and emulates an inductive or capacitive reactance in series with the transmission line, and a small part of the injected voltage is in phase with the line current to cover the losses of the inverter. When the inserted voltage is leading the line current, it will emulate a capacitive reactance in series with the line, producing the line current as well as power flow through the line to increase. When the immunized voltage is lagging the line current, it will emulate an inductive reactance in series with the line, generating the line current as well as power flow through the line to reduce [7].

The SSSC is a solid-state voltage source inverter coupled with a transformer, is connected in series with a transmission line. An SSSC injects an almost sinusoidal voltage, of variable magnitude, in series with a transmission line. This injected voltage is almost in quadrature with the line current, thereby emulating an inductive or a capacitive reactance in series with the transmission line. The emulated variable reactance, inserted by the injected voltage source, influences the electric power flow in the transmission line [8].

V. LITERATURE REVIEW

The Unified Power Flow Controller (UPFC) is a original power transmission controller. The UPFC provides a full dynamic controller of transmission parameters voltage, line impedance and phase angle. This paper presents a useful tool for power functions engineers to evaluate the application of the UPFC, its effect on their power system and what would be the shunt and series ratings. This paper provides sets of equations for a system including the UPFC and an equal two bus power system [9].

The development and procedure of interlinked large power systems is becoming difficult. The power transfer proficiency of long transmission lines is usually limited by large signals capability. Economic factors such as the high cost of long lines and income from the delivery of additional power give strong intensive to explore all economically and technically reasonable means of raising the stability limit. The development of effective methods is to use transmission systems at their maximum thermal capability. In this paper a Simulink Model is considered with UPFC model to assess the performance of a single and double transmission line systems (6.6/22) kV. The UPFC model is a member of the FACTS controller with very attractive features and it is a solid state controller which can be used to control real and reactive power flow in a transmission line. In the simulation study, the UPFC model facilitates the real time control and active compensation of AC transmission system. It provides the necessary functional flexibility required for solving the difficulties faced by the utility industry. It should be considered as real and reactive power compensation, capable of individually controlling voltage profile as well as the real and reactive powers in the line. The simulation model is verified for single and double transmission line systems with and without UPFC model in MATLAB / SIMULINK environment [10].

The unified power flow controller (UPFC) is one of the most favorable Flexible AC Transmission Systems (FACTS) devices used for the load flow control. Real-time optimization of location and parameters for UPFCs is an important subject when the given number of UPFCs is applied to the power system with the purpose of increasing system load ability. This paper presents a mathematical model about optimal location and parameters of UPFCs to maximize the system load ability subject to the transmission line capacity limits and specified voltage level. An improved computational intelligence methodology: self-adaptive evolutionary programming (SAEP) is used to solve the nonlinear programming problem offered above for improved accuracy. Case studies of the IEEE 30- and 118-bus systems using the proposed model and technique prove that the proposed mathematical model is corrective and efficient. Moreover, steady-state performance of power system can be successfully enhanced due to the optimal location and parameters of UPFCs [11].

Many researchers have proposed different methodologies of installing UPFC in power systems [11, 12, and 13]. The concepts of characteristics have been broadly reported in the writings [13].The UPFC has been researched broadly and many research objects dealing with UPFC modeling, analysis, control and request have been published in the modern years. A mathematical model of UPFC has been industrialized to study steady state characteristics using state space calculations without considering the effects of converters including the dynamics of generator [14, 15]. The execution of UPFC has been reported by planning a series converter with conventional controllers [16, 17].The real and reactive power flow in transmission lines can be control by pair of back to back power electronics inverters. This configuration is calling UPFC. The operation of a UPFC using a control strategy, which is based on D-Q access theory is presented by simulation and observed result [17].

Numerous power converter topologies have been suggested for the implementation of FACTS devices such as multi pulse converter like 24 pulses and 48 pulses and multilevel inverters [18, 19, 20].The benefits and limits of high power converters have been debated [21].In [22] the dynamic control of UPFC has been analyzed with six pulse converter utilizing switching level model. Their proposed technique objectives at to control the real and reactive power flow in the transmission lines, by successfully fluctuating the firing angle of shunt converter and modulation index of the series converter.[Limyingcharoen et al] examined the mechanism of three control plan of a UPFC in enhancing power system damping [23]. A current inserted UPFC model for improving power system dynamic performance was industrialized by Meng [24] where a UPFC was represented by an equivalent circuit using a shunt current source and a series voltage source [25].
Fujita et al [26] investigated the high frequency power fluctuations convinced by a UPFC. Different algorithms have been suggested to increase the power flow controller with UPFC in power transmission systems [27].Different situation studies have been supported on normal bus network. Baskar et. al. advises a technique to control the real as well as reactive power in the transmission line by the two legs three phase converters built on UPFC. In this paper dynamic control of UPFC has considered with two leg three stage converters by switching level model with linear and nonlinear burden. They propose that the UPFC with their suggested controller effectively increase the real as well as reactive power flow and develop voltage profile for the duration of the transient situations in the power transmission systems [28].

VI. RESULT ANALYSIS

The comparison of reactive power in transmission lines using UPFC research done in Matlab (Simulink 8.1). Here we have used power system library tool to design our research. After making the design the models simulated the model and generate all the necessary result. In this section, showing the Simulink block diagram and generated graph of the proposed research.

i. A Static Synchronous Compensator (STATCOM)

A STATCOM is a voltage source converter (VSC)-based device, with the voltage source behind a reactor. The voltage source is created from a DC capacitor and therefore a STATCOM has very little active power capability. However, its active power capability can be increased if a suitable energy storage device is connected across the DC capacitor. The STATCOM are complete with all these model and every block have an own role of functionality. The measurement block gives the value of basic parameter of voltage and current. Voltage regulator regulated the voltage and makes it efficient use for the complete model. The current regulator used for current regulation and each and every model are connected to each other. The STATCOM are the part of the UPFC Controller.

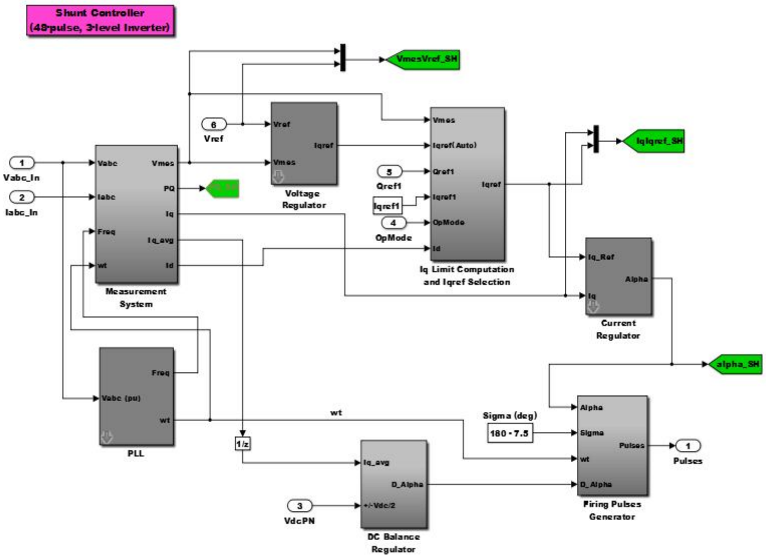

Figure 1: A complete model of static synchronous compensator (STATCOM)

ii. Static Synchronous Series Compensator (SSSC)

Static Synchronous Series Compensator (SSSC) is a series compensator of FACTS family. It injects an almost sinusoidal voltage with variable amplitude. It is equivalent to an inductive or a capacitive reactance in series with the transmission line. The heart of SSSC is a VSI (voltage source inverter) that is supplied by a DC storage capacitor.

The SSSC is also the part of the UPFC Controller and it's completed using such small-small block diagrams. These block make SSSC controller working complete here measurement works same a STATCOM. The complete block diagrams of SSSC are mention in (Figure. 2).

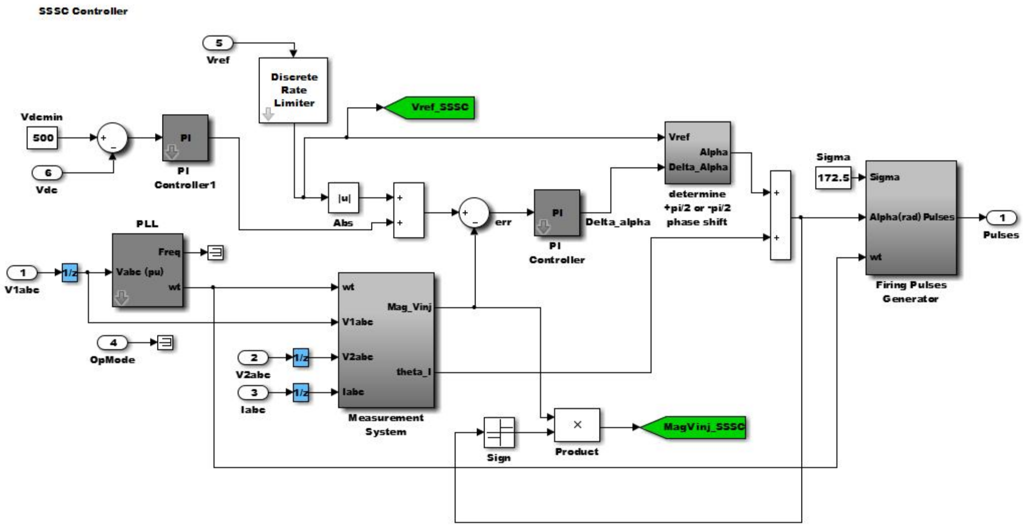

Figure 2: A complete model of Static Synchronous Series Compensator (SSSC).

iii. Series Controller

A series controller in the UPFC, in this Simulink model we have used 48 pulse with 3 level inverter. The mathematical models of inverter are given in methodology. The workings of the inverter are used here for conversion of DC to AC. The Series UPFC Controller are used the PLL, measurement system, current regulator and firing pulse generator etc in (Figure. 3). All block are connected to each other and performing the combine output. In the Simulink all input and output are connected to each other. After using the output of these blocks we plot the output graphs.

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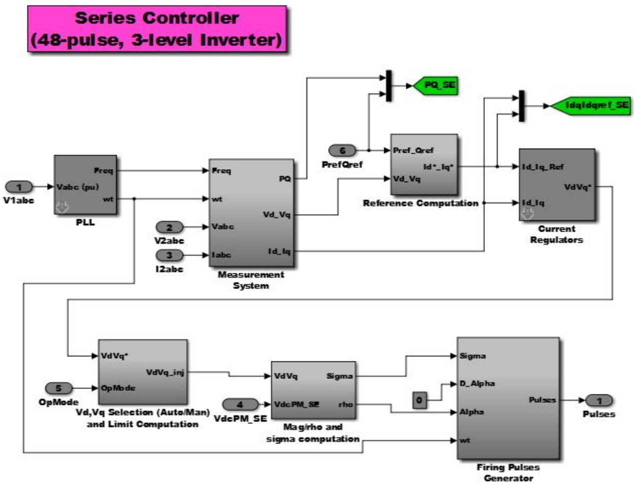

Figure 3: A complete model of Series Controller

iv. Unified Power Flow Controller (UPFC)

A Unified Power Flow Controller (UPFC) is used to control the power flow in a 500 kV transmission system. The UPFC located at the left end of the 239-km line L2, between the 500 kV Buses B1 and B2, is used to control the active and reactive powers flowing through bus B2 while controlling voltage at bus B1. It consists of two 100-MVA, three-level, 48-pulse GTO-based converters, one connected in shunt at bus B1 and one connected in series between buses B1 and B2. The shunt and series converters can exchange power through a DC bus. The series converter can inject a maximum of 10% of nominal line-to-ground voltage (28.87kV) in series with line L2 (Figure. 4) & (figure. 5).

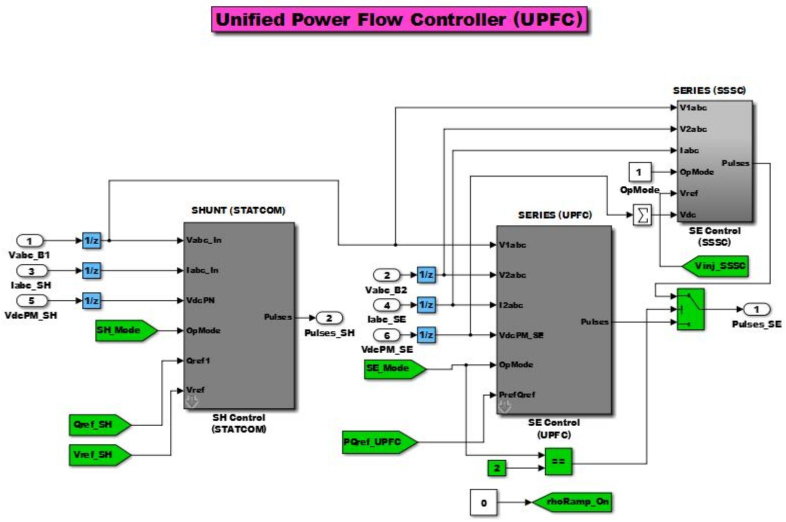

Figure 4: A complete model of Unified Power Flow Controller (UPFC)

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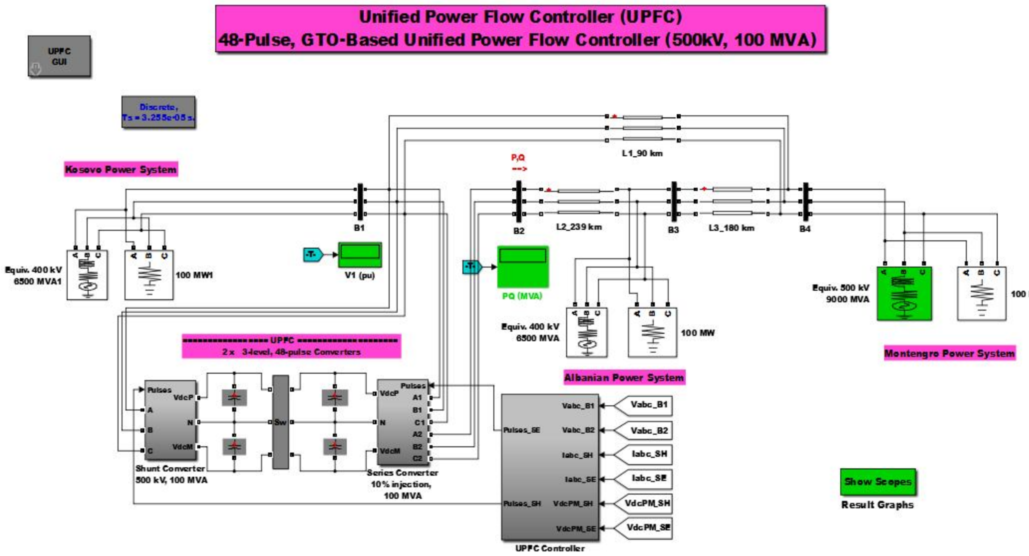

Figure 5: A complete model of proposed research of Unified Power Flow Controller (UPFC).

This pair of converters can be operated in three modes:-

Unified Power Flow Controller (UPFC) mode, when the shunt and series converters are interconnected through the DC bus, When the disconnect switches between the DC buses of the shunt and series converter are opened, two additional modes are available: Shunt converter operating as a Static Synchronous Compensator (STATCOM) controlling voltage at bus B1 Series converter operating as a Static Synchronous Series Capacitor (SSSC) controlling injected voltage, while keeping injected voltage in quadrature with current. The mode of operation as well as the reference voltage and reference power values can be changed by means of the “UPFC GUI” block. The principle of operation of the harmonic neutralized converters is explained in another demo entitled “Three-phase 48-pulse GTO converter”.

When the two converters are operated in UPFC mode, the shunt converter operates as a STATCOM. It controls the bus B1 voltage by controlling the absorbed or generated reactive power while also allowing active power transfer to the series converter through the DC bus. The reactive power variation is obtained by varying the DC bus voltage. The four three-level shunt converters operate at a constant conduction angle (Sigma= 180-7.5 = 172.5 degrees), thus generating a quasi-sinusoidal 48-step voltage waveform. When operating in UPFC mode, the magnitude of the series injected voltage is varied by varying the Sigma conduction angle, therefore generating higher harmonic contents than the shunt converter.

When the series converter operates in SSSC mode it generates a “true” 48-pulse waveform. The natural power flow through bus B2 when zero voltage is generated by the series converter (zero voltage on converter side of the four converter transformers) is P=+870 MW and Q=-70 Mvar. In UPFC mode, both the magnitude and phase angle and the series injected voltage can be varied, thus allowing control of P and Q. The UPFC controllable region is obtained by keeping the injected voltage to its maximum value (0.1 pu) and varying its phase angle from zero to 360 degrees

Power control in UPFC mode

Open the UPFC GUI Block Menu (figure 6). The GUI allows you to choose the operation mode (UPFC, STATCOM or SSSC) as well as the Pref/Qref reference powers and/or Vref reference voltage settings. Also, in order to observe the active response of the control system, the GUI allows you to specify a step change of any reference value at a specific time. Make sure that the operation mode is set to “UPFC (Power Flow Control)”. The reference active and reactive powers are specified in the last two lines of the GUI menu. Initially, Pref= +8.7 pu/100MVA (+870 MW) and Qref=-0.6 pu/100MVA (-60 Mvar). At t=0.25 sec Pref is changed to +10pu (+1000MW). Then, at t=0.5 sec, Qref is changed to +0.7 pu (+70 Mvar).

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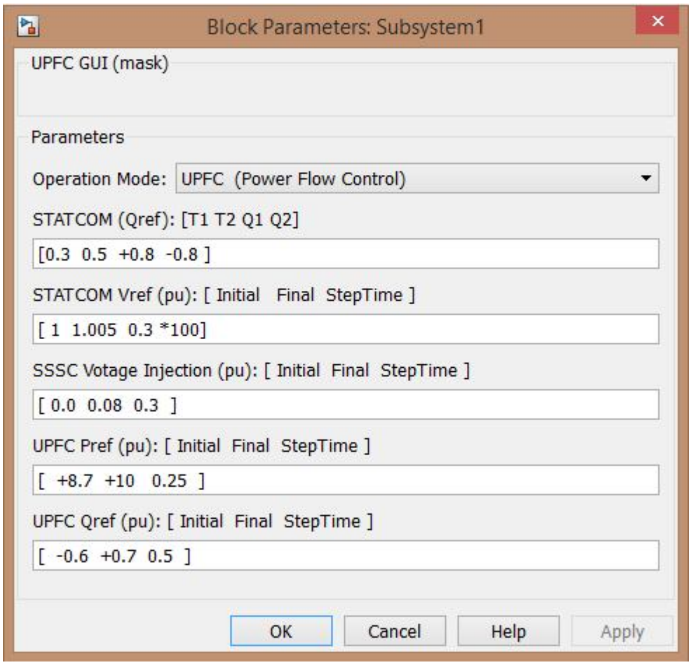

Figure 6: UPFC GUI(Mask) Block Parameters

Run the simulation for 0.8 sec. Open the "Show Scopes" subsystem. Observe on traces 1 and 2 of the UPFC scope the variations of P and Q. After a transient period lasting approximately 0.15 sec, the steady state is reached (P=+8.7 pu; Q=-0.6 pu). Then P and Q are ramped to the new settings (P=+10pu Q=+0.7pu). Observe on traces 3 and 4 the resulting changes in P Q on the three transmission lines. The performance of the shunt and series converters can be observed respectively on the STATCOM and SSSC scopes. If you zoom on the first trace of the STATCOM scope, you can observe the 48-step voltage waveform Vs generated on the secondary side of the shunt converter transformers (yellow trace) superimposed with the primary voltage Vp (magenta) and the primary current Ip (cyan). The dc bus voltage (trace 2) varies in the 19kV-21kV range. If you zoom on the first trace of the SSSC scope, you can observe the injected voltage waveforms Vinj measured between buses B1 and B2.

Var control in STATCOM mode

In the GUI block menu, change the operation mode to "STATCOM (Var Control)". Make sure that the STATCOM references values (1st line of parameters, [T1 T2 Q1 Q2]) are set to [0.3 0.5 +0.8 -0.8]. In this mode, the STATCOM is operated as a variable source of reactive power. Initially, Q is set to zero, then at T1=0.3 sec Q is increased to +0.8 pu (STATCOM absorbing reactive power) and at T2=0.5 sec, Q is reversed to -0.8 pu (STATCOM generating reactive power).

Run the simulation and observe on the STATCOM scope the active response of the STATCOM. Zoom on the first trace around t=0.5 sec when Q is changed from +0.8pu to -0.8pu. When Q=+0.8pu, the current flowing into the STATCOM (cyan trace) is lagging voltage (magenta trace), indicating that STATCOM is absorbing reactive power. When Qref is changed from +0.8 to -0.8, the current phase shift with respect to voltage changes from 90 degrees lagging to 90 degrees leading within one cycle. This control of reactive power is obtained by varying the magnitude of the secondary voltage Vs generated by the shunt converter while keeping it in phase with the bus B1 voltage Vp. This change of Vs magnitude is performed by controlling the dc bus voltage. When Q is changing from +0.8pu to -0.8pu, Vdc (trace 3) increases from 17.5 kV to 21 kV.

Series voltage injection in SSSC mode

In the GUI block menu change the operation mode to "SSSC (Voltage injection)". Make sure that the SSSC references values (3rd line of parameters) [Vinj_Initial Vinj_Final StepTime] are set to [0.0 0.08 0.3]. The initial voltage is set to 0 pu, then at t=0.3 sec it will be ramped to 0.8pu.

Run the simulation and observe on the SSSC scope the impact of injected voltage on P and Q flowing in the 3 transmission lines. Contrary to the UPFC mode, in SSCC mode the series inverter operates with a constant conduction angle (Sigma= 172.5 degrees). The magnitude of the injected voltage is controlled by varying the dc voltage which is proportional to Vinj (3rd trace). Also, observe the waveforms of injected voltages (1st trace) and currents flowing through the SSSC (2nd trace). Voltages and currents stay in quadrature so that the SSSC operates as a variable inductance or capacitance in (Figure 7).

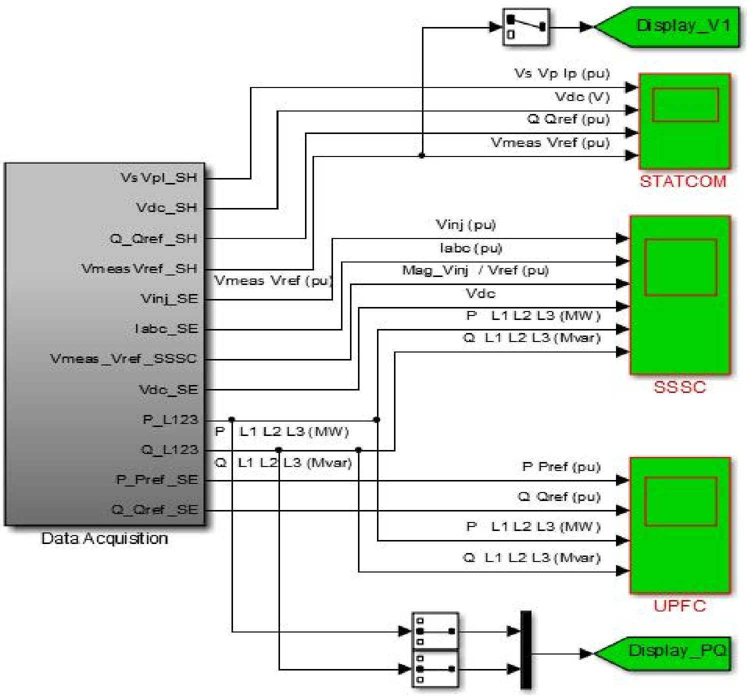

Figure 7: A complete model of Data Acquisition for SSSC, STATCOM, and UPFC.

Every block has four waveform and these results are showing:-

1. In the given block we have taken a base voltage 400 kV with a load power 100 MW. The active powers are given by the load which is connected with a different power and different distance transmission line.
2. We have run this model at the initial time 10 (this time we can choose 0.001 to infinite). The simulation time is depending on the user, which time you want to run your simulation. The simulation time was depending on the model size, no of the scope and time graph.
3. After simulate the model we can see the graphs of UPFC, STATCOM, SSSC. All graph models we have declare inside the scopes model, open the scope and see all the connection which one we have made.
4. The Voltage Vs is generated on the secondary side of the shunt converter transformers in the (yellow trace) superimposed with the primary voltage Vp (magenta) and the primary current Ip (cyan).
5. The V_{dc} bus voltage (trace 2) varies in the 19kV-21kV range. If you zoom on the first trace of the SSSC scope, you can observe the injected voltage waveforms Vinj measured between buses B1 and B2.
6. When Q=+0.8pu, the current flowing into the STATCOM (cyan trace) is lagging voltage (magenta trace), indicating that STATCOM is absorbing reactive power. When Qref is changed from +0.8 to -0.8, the current phase shift with respect to voltage changes from 90 degrees lagging to 90 degrees leading within one cycle.
7. This control of reactive power is obtained by varying the magnitude of the secondary voltage Vs generated by the shunt converter while keeping it in phase with the bus B1 voltage Vp. This change of Vs magnitude is performed by controlling the dc bus voltage. When Q is changing from +0.8pu to -0.8pu, Vdc (trace 3) increases from 17.5 kV to 21 kV.

After completing the block diagram of compensation of reactive power in transmission line using UPFC. We generate the result of this model. Here we generate the result for STATCOM (Figure 8), SSSC (Figure 9) and UPFC (Figure 10).

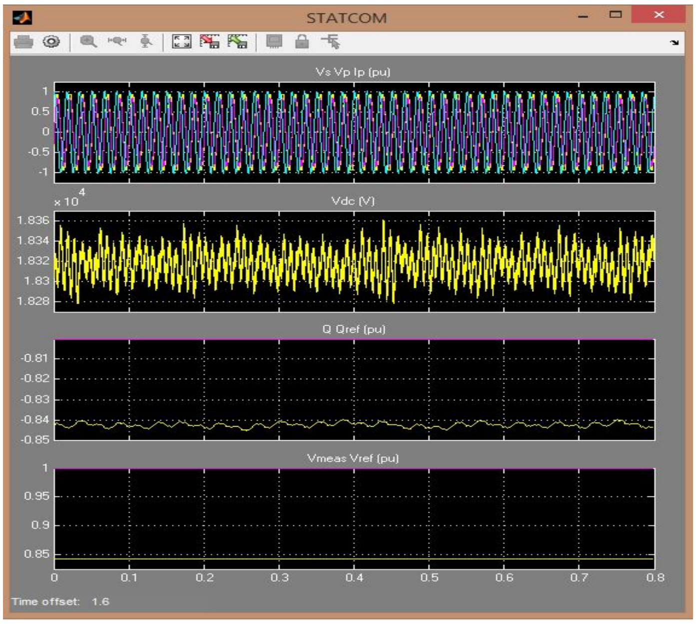

Figure 8: An Output waveform for STATCOM

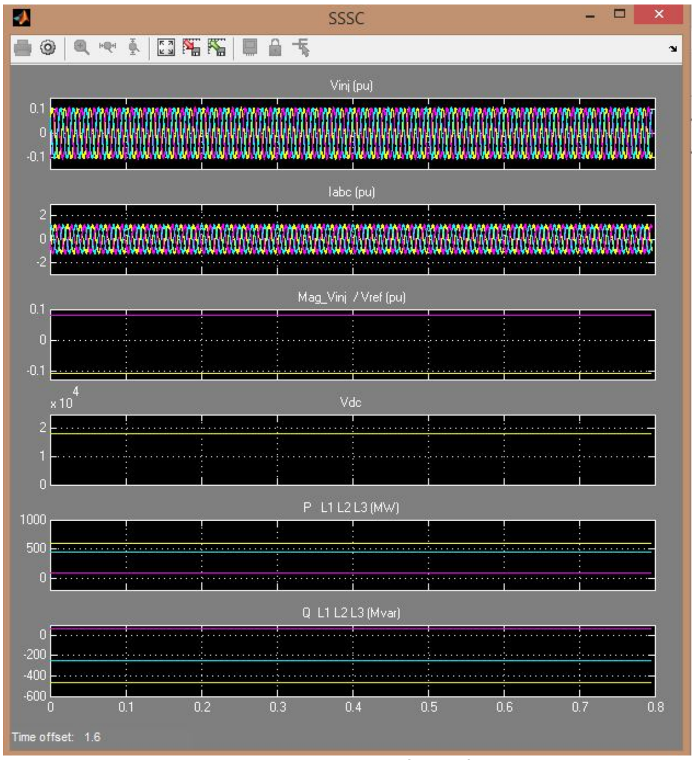

Figure 9: An output waveform for SSSC.

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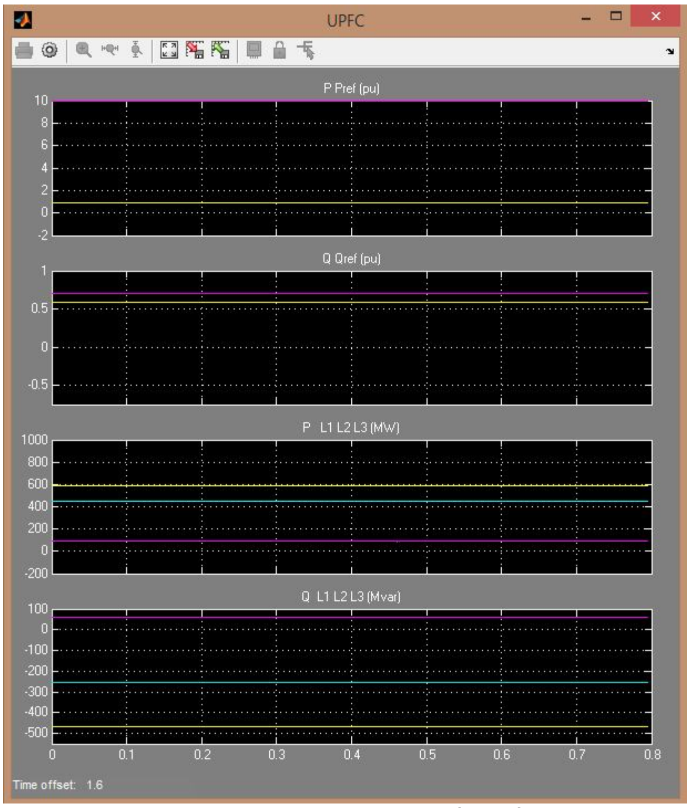

Figure 10: A complete output waveform for UPFC

VII.CONCLUSION

These proposed research paper presents a platform here that can be used for FACTS controller studies. This paper presents the performance analysis of UPFC for improving the power quality in the conventional system and PI controller system. Simulation results show the effectiveness of the UPFC to control active and reactive powers. It has been found that there is reduction in the switching period and reduction in the value of the peak voltage during the switching period. The platform can be extended to study the advance controller with UPFC for improving power quality.

The three main aspect of this proposed research STATCOM, SSSC and UPFC. These three aspects are interconnected and performing well. UPFC are linked with STATCOM & SSSC and these are interlinked with the transmission line. The transmission lines are having a different distance, same load with two same base voltages and one upgraded base voltage, different load power (reactive power) with different voltage source. These permutations have generated the active and reactive power value; the reactive powers are greater than as the active power, it depend on the load and load voltage.

The comparison on between the STATCOM, SSSC and UPFC, have noticed the UPFC take much time to show the output like active and reactive power on the transmission line L1, L2 & L3 as compared to STATCOM & SSSC. The UPFC has shown the active and reactive powers are almost similar on transmission line L1, L2 and L3 but UPFC has shown the smooth and sharpen change in all three active and reactive powers, the main difference is time offset. Here concluded the UPFC is better for comparison between the active and reactive power depends on the transmission line. The transmission line parameters are affected the power and its change in values.

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