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ADAPTIVE CONTROL FOR INCREASING POWER TRANSMISSION IN HIGH VOLTAGE OVERHEAD TRANSMISSION LINES

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ABSTRACT

Due to ever increasing demand of electricity throughout the world, new ways of extracting and harvesting energy through clean sources is becoming more mainstream than ever before. After the industrial revolution, the need of electrical energy has been increased drastically. Today, electrical energy has become an essential requirement for every individual and the quest for its generation to fulfill its exponentially increasing demand without affecting the ecosystem and environment has become a challenge which is being addressed through research and innovation. The major causes of power losses in transmission lines and provide a viable solution regarding the reduction of these losses through an adaptive controller. The power losses in transmission lines can vary due to several reasons such as environmental conditions and load profile, which is why an adaptive compensator that is able to alter its parameters to cater for the inductive and capacitive losses.
This research would aim to reduce the losses in overhead power transmission lines by implementing adaptive control of the compensators and filters which would be able to readjust themselves as per the compensation requirements. This would include the use of FACTS devices, harmonic filters and adaptive controllers. The reactive part of the power flow would thus be controlled by these devices in transmission lines and the losses will be reduced significantly.

INTRODUCTION

It is worth mentioning that the power losses during the transmission from generation point till the consumer end is of essential importance. The power losses in the transmission systems, if controlled and managed properly, can enhance the power transfer and can therefore mitigate the gap between supply and demand of electrical energy without the need of new power generation plants. The device that is widely used for this purpose is commonly referred to as the Flexible AC Transmission Systems or FACTS devices or controllers.
FACTS devices thus provide a viable solution to the power losses in the transmission systems through regulating the alternating current flowing through the power lines. These devices have the capability to control the flow of current through in the power lines and can respond almost instantaneously to the changes occurring in the system due to load change and other factors and address the stability issues encountered in the system. FACTS devices are mainly static electronics devices connected with eh transmission system for power flow control. The FACTS devices are mainly categorized on the basis of the switching technology used. In this context, there are three main types or categories of FACTS devices namely the mechanically switched FACTS, thyristor switched FACTS and IGBT based FACTS devices. The most commonly used FACTS devices include Phase Shifting Transformer (PST) and Static

Variable Compensator (SVC) which have been widely used throughout the world. Aside from PST and SVC, new developments in power electronics have enhanced the applications of FACTS devices in recent years. Besides, the utilization and synchronization of multiple electrical generation sources such as renewable energy and demand for higher power flow have created new applications for FACTS devices.

Due to this distant placement of generation plants, the whole electrical system is divided into three main stages before reaching the consumer end which are;

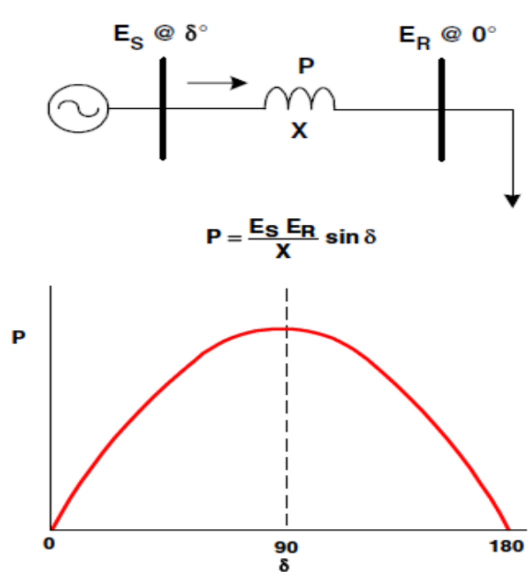
1) Generation
2) Transmission
3) Distribution

The same stages or areas provide the basis on which the power companies are organized. In the first stage, the power is being generated through conversion of some naturally available source to electrical form. A hydro-electrical power plant converts the mechanical energy generated through flow of water. Similarly, a nuclear power plant converts nuclear energy to mechanical energy which is further converted into electrical energy. The generated energy is then transported to the grid stations which requires a voltage increase to hundreds and thousands of volts. This super high voltage is then transmitted over thousands of kilometers long transmission lines. The grid stations at the other end are responsible of decreasing the voltage and bring it back to an optimum voltage level which can then be distributed amongst towns and areas.

Electrical System organization

The FACTS devices used for the purpose are mostly operate under dynamic conditions however the curve shown below only sheds light on the fact that three variables should be controlled to regulate the transmission. The entities are:

- Voltage
- Angle
- Impedance



Controllability of power systems

The first one is conventional methodologies such as increasing the number of transmission lines, enhancing the transmission network or utilize expensive material with low resistance. The other solution is to use FACTS controllers to manage reactive power and through angle, voltage and impedance control.

Research Methodology

The method to acquire expected results would include various techniques which would be implemented in a step wise manner to achieve the objectives effective and efficiently. Theoretical studies and recently conducted research work on the subject would be the primary source to design the adaptive controller.

A brief step wise approach for achieving the desired results is appended below.

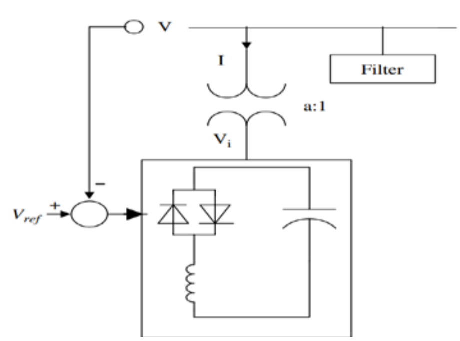
- Gathering all the relevant information regarding transmission lines and loss mitigation techniques recently published in authentic journals with high impact factor.
- Modeling the system and controller on a test bed.
- Tuning and optimization of the controller to obtain the desired results.
- Comparing the results with other papers and concluding them.

POWER ENHANCEMENT IN TRANSMISSION LINE THROUGH (FACTS)

The advanced models of FACTS devices have been used in many power system networks in today's world. These devices not only provide a viable solution to the power losses compensation but also increases their ability to adapt to the changing conditions without any external interference. The FACTS devices have been used since a long time to compensate and reduce losses in transmission networks. These devices can either be connected in series or in shunt with the transmission networks. In some cases, a combination of both shunt and series is also used. Some of the most commonly known shunt compensation devices include SVC and STATCOM whereas in series configuration, TCSC and SSSC are most renowned and widely used devices.

i) Shunt FACTS Devices

The SVC is a well-known shunt FACTS device. In order to maintain some specified variables related to the power systems, the capacitive and inductive current of the system can be controlled by controlling the output of this devices. SVCs are used to either absorb or inject reactive power into the system for compensation.



SVC equivalent circuit

By including the SVC equations with power flow equations, a DC equivalent of the device can be included into static voltage stability study. The corresponding differential equations governing the SVC model can be expressed as

$$\begin{bmatrix} \dot{x}_c \\ \dot{\alpha} \end{bmatrix} = f\,(x_c, \alpha, V, V_{\text{ref}})$$

$$0 = \underbrace{\begin{bmatrix} B_e - \frac{2\alpha - \sin 2\alpha - \pi(2 - X_L/X_C)}{\pi X_L} \\ I - V_i B_e \\ Q - V_i^2 B_e \end{bmatrix}}_{g(\alpha, V, V_i, I, Q, B_e)}$$

In the equations above, B_e represents accumulative susceptance, α represents angle of fire of thyristor whereas X_L and X_C represent inductance and capacitance respectively. Alongside with this, the current injected into the system and terminal voltage of the device are represented as I and V_i respectively. The same equation can also be included into the power flow equation through CPF procedure.

II) Shunt FACTS Devices

Series FACTS devices are regarded as the FACTS devices which are installed or connected in series with the power system networks. Among the series FACTS, TCSC are most common and well known. These devices use TCRs connected in parallel with the capacitor banks. The combination and configuration of capacitors with the thyristors enable the system to control capacitive reactance very smoothly with a large window of control.

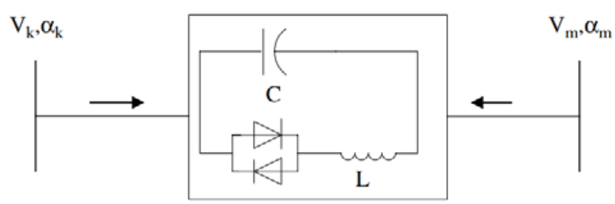


Figure TCSC Equivalent Circuit

The corresponding differential equation governing the device is shown through the equations below where *k* and *m* in the equations below represent the buses between which the device is connected:

$$\begin{bmatrix} \dot{x}_c \\ \dot{\alpha} \end{bmatrix} = f\,(x_c, \alpha, V, V_{\text{ref}})$$

$$0 = \underbrace{\begin{bmatrix} P + V_k V_m B_e \sin(\delta_k - \delta_m) \\ -V_k^2 B_e + V_k V_m B_e \cos(\delta_k - \delta_m) - Q_k \\ -V_m^2 B_e + V_k V_m B_e \cos(\delta_k - \delta_m) - Q_m \\ B_e - B_e(\alpha) \\ \sqrt{P^2 + Q_k^2} - I V_k \end{bmatrix}}_{g(\alpha, V_k, V_m, \delta_k, \delta_m, I, P, Q_k, Q_m, B_e)}$$

The steady state equation for TCSC can thus be expressed as

$$0 = \begin{bmatrix} B_e - B_{e,\text{ref}} \\ g\,(\alpha, V_k, V_m, \delta_k, \delta_m, I, P, Q_k, Q_m, B_e) \end{bmatrix}$$

The same steady state equation can be incorporated into the power flow equation whereas from the above equation, it can be seen that the entire susceptance of the device can be controlled through controlling a single value.

III) MIX FACTS DEVICES

Mixed FACTS refer to the FACTS devices that can are used in both shunt and series in a power system network. The most common and universally recognized mixed FACTS device is UPFC or Universal Power Flow Controller.
The fact that both power flow through transmission lines and amplitude of the voltage can be controlled by UPFC makes it a very important FACTS device.

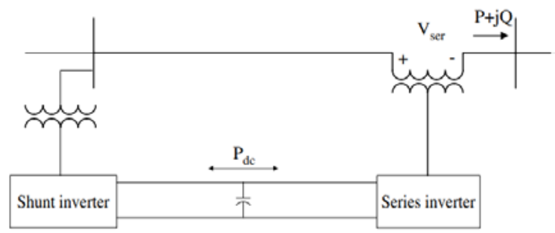


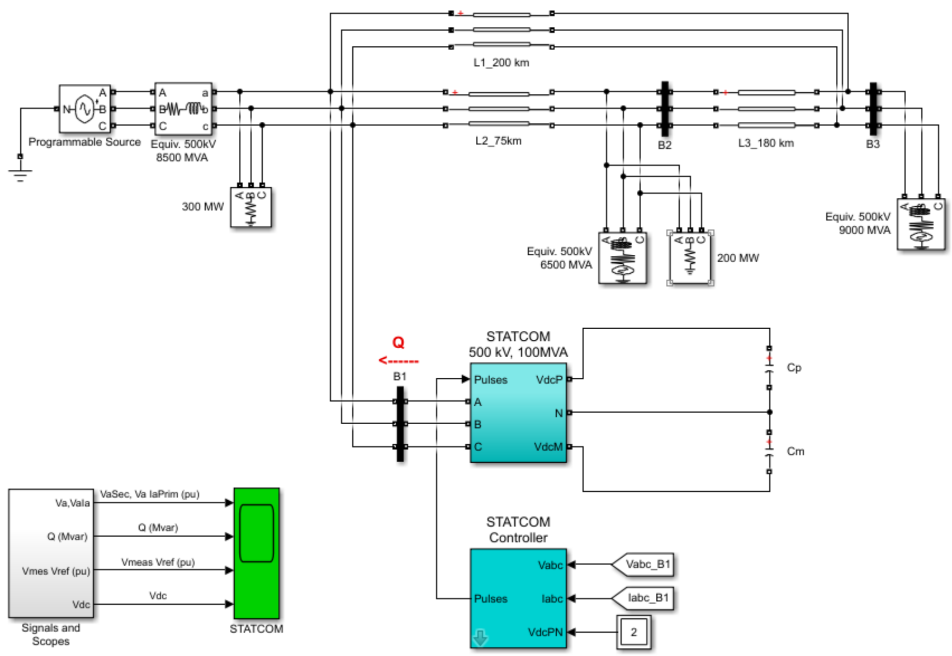
Figure UPFC Equivalent Circuit

The steady state model of UPFC can thus be written as follows which also can be incorporated into the power flow equations.

$$0 = \begin{bmatrix} V_k - V_{k,\mathrm{ref}} \\ V_{\mathrm{dc}} - V_{\mathrm{dc,ref}} \\ P_{\mathrm{se}} - P_{\mathrm{se,ref}} \\ Q_{\mathrm{se}} - Q_{\mathrm{se,ref}} \\ P_{\mathrm{sh}} - P_{\mathrm{se}} - G_C V_{\mathrm{dc}}^2 - R_{\mathrm{sh}} I_{\mathrm{sh}}^2 - R_{\mathrm{se}} I_l^2 \\ g_{\mathrm{sh}}(\alpha, k_{\mathrm{sh}}, V_k, V_{\mathrm{dc}}, \delta_k, I_{\mathrm{sh}}, \theta_{\mathrm{sh}}, P_{\mathrm{sh}}, Q_{\mathrm{sh}}) \\ g_{\mathrm{se}}(\beta, k_{\mathrm{se}}, V_{\mathrm{dc}}, V_k, V_l, V, \delta_k, \delta_l, \delta, I_l, \theta_l, P_k, P_l, \\ P_{\mathrm{sh}}, P_{\mathrm{se}}, Q_k, Q_l, Q_{\mathrm{sh}}, Q_{\mathrm{se}}) \\ g_{\mathrm{con}}(V_k, \delta_k, I_k, I_{\mathrm{sh}}, I_l, \theta_k, \theta_{\mathrm{sh}}, \theta_l, P_k, Q_k) \end{bmatrix}$$

SIMULATION & RESULTS

The simulation carried out for the STATCOM shows a 100 MVAR STATCOM device. The device used in the simulation is a 48 pulse STATCOM that uses a voltage source inverter which is made up of four Gate Turn Off Switches or GTOs. Each of the GTOs used in the system is operates on 12 pulses making it 48 pulses for four GTOs. As a result, four sets of three phase voltages are obtained at the output of STATCOM. These sets of three phase voltage are applied at the secondary windings of the transformer. The transformer used here is a four-phase shifting transformer with -15, -7.5, +7.5 and +15 degrees of phase shifting capability. The fundamental component of the voltage thus obtained at the secondary windings of the transformer, which is 500kV, is then added in phase through serial connection of primary windings of the transformer.



STATCOM Simulation overview

Dynamic reaction of the STATCOM:

Upon running the simulation, the scope block of the STATCOM can be checked to see the resulting graphs. During this operation, the STATCOM device is configured to operate in the voltage control mode where the reference voltage provided to the system is set at 1 pu. In this setting, the voltage droop of the system is set at 0.03 pu /100 VA. For the very same reason, when the operating point of the STATCOM device is switched from entirely capacitive at +100 MVAR to entirely inductive at -100 MVAR, the resulting voltage of the STATCOM would vary between 1.0 – 0.03 = 0.97 pu and 1.0 + 0.03 = 1.03 pu.

In order to check the system response, the programmable voltage source in the simulation is set to deliver to provide 1. 0491 pu initially. This consequently results in 1 pu voltage at the output terminals of the SVC and thusly the STATCOM remains unengaged due to the reason that the reference voltage is set at 1 pu and no current is being introduced into the system by STATCOM and under these conditions, the DC voltage is at 19.3 kV. To check the system response to sudden changes, the voltage is decreased by 4.5% i.e., to 0.955 pu at 0.1 seconds of the simulation. In order to compensate for this decrease in system voltage, the SVC engages and injects reactive power of +70 MVAR into the system and taking the voltage level to 0.979 pu. The system takes about 47 milli seconds to track the change and stabilize the system. The DC voltage at this point where the reactive power is being introduced into the system is increased to 20.4 kV. To check the system for the inductive point operation, at 0.2 seconds of the simulation, the nominal power of the system is changed to 1.045 pu of its nominal value. At this point, the SVC again reacts accordingly by shifting its operating point from capacitive to inductive and starts to absorb reactive power out of the system to maintain the voltage level at 1.021 pu. As the system starts to absorb reactive power, the power absorbed by SVC is 72 MVAR and its corresponding DC voltage is reduced to 18.2 kV. By observing the initial trace of that is representing the primary voltage of the STATCOM, it can be deducted that current and voltage of the system almost takes one complete cycle to go from entirely capacitive to inductive. In the end, at about 0.3 seconds, the simulation settings tend to bring the source voltage back to its original value and at this point STATCOM is again disengaged and returns to 0 MVAR.

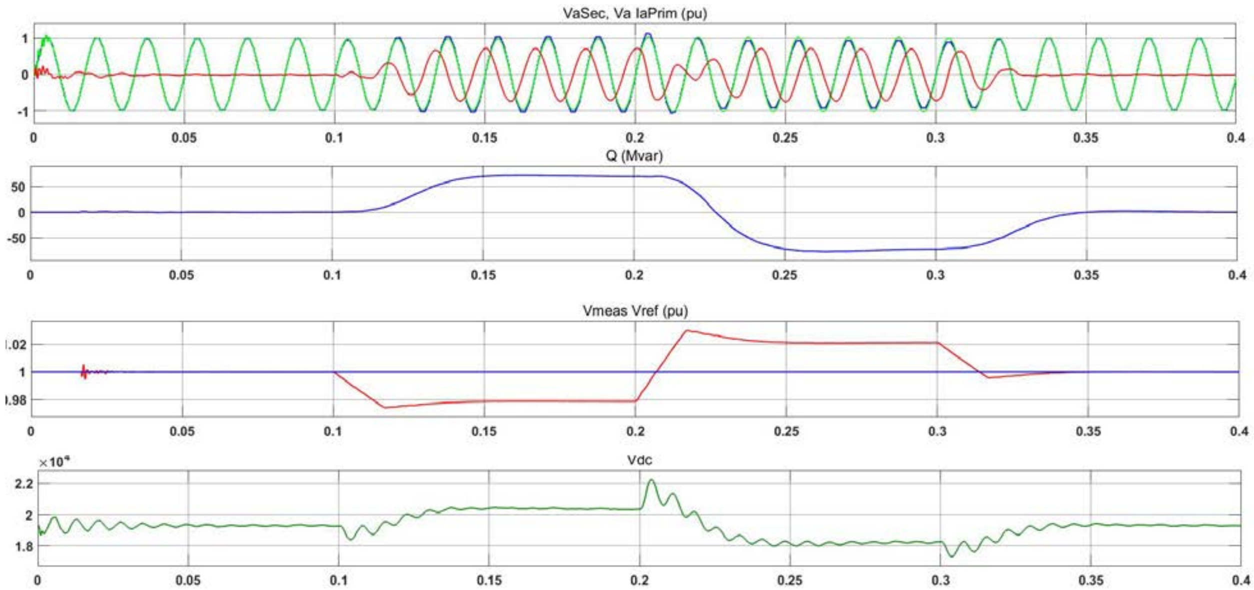


Figure STATCOM Output

SVC and TCR Simulation:

A 300-Mvar Static Var Compensator (SVC) manages voltage on a 6000-MVA 735-kV framework. The SVC comprises of a 735kV/16-kV 333-MVA coupling transformer, one 109-Mvar thyristor-controlled reactor bank (TCR) and three 94-Mvar thyristor-exchanged capacitor banks (TSC1 TSC2 TSC3) associated on the optional side of the transformer. Exchanging the TSCs in and out permits a discrete variety of the optional reactive power from zero to 282 Mvar capacitive (at 16 kV) by steps of 94 Mvar, while phase control of the TCR permits a consistent variety from zero to 109 Mvar inductive. Considering the spillage reactance of the transformer (15%), the SVC identical susceptance seen from the essential side can be shifted ceaselessly from -1.04 pu/100 MVA (completely inductive) to +3.23 pu/100 Mvar (completely capacitive).

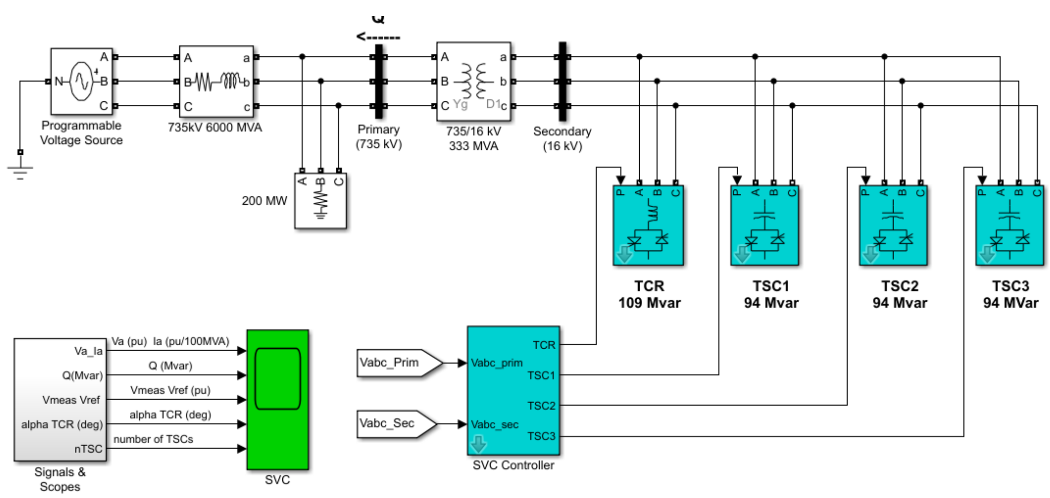
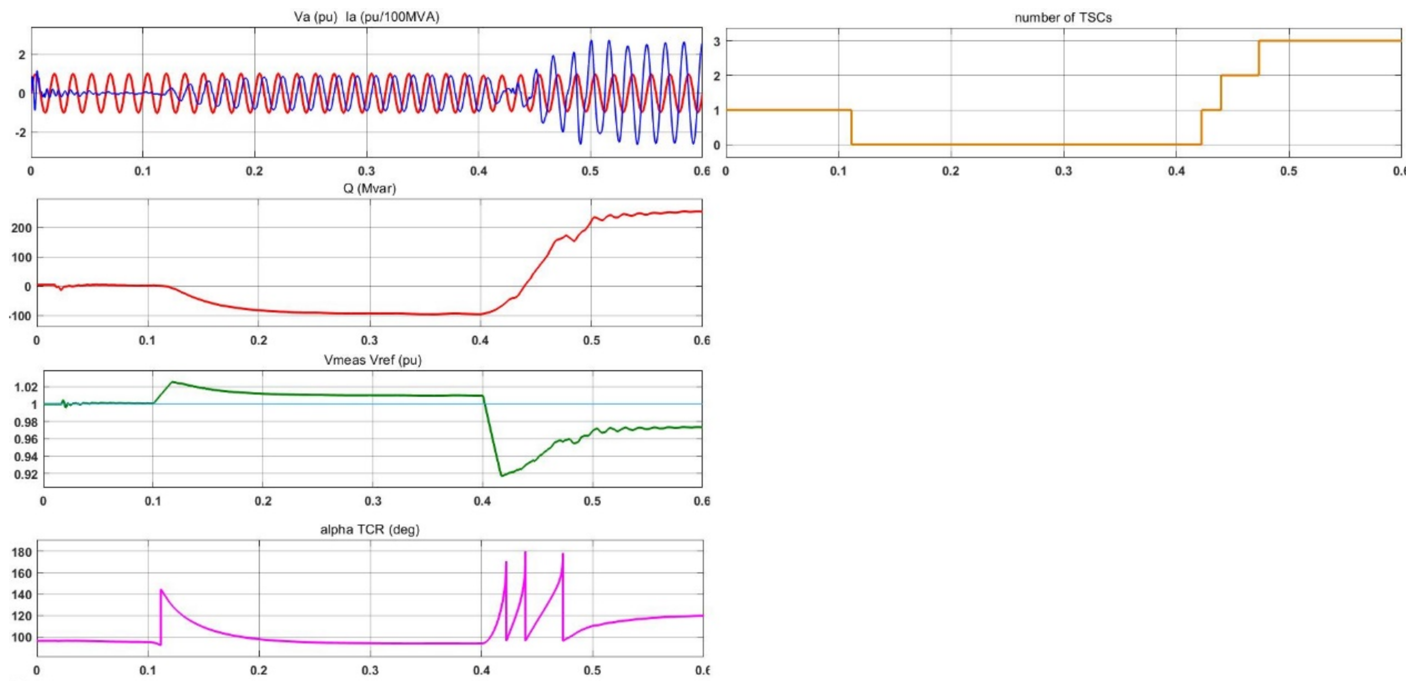


Figure SVC Simulation overview

The voltage drop of the regulator is 0.03 pu/300MVA. Therefore, when the SVC operating point changes from fully capacitive (+300 Mvar) to fully inductive (-100 Mvar) the SVC voltage varies between 1-0.03=0.97 pu and 1+0.01=1.01 pu.

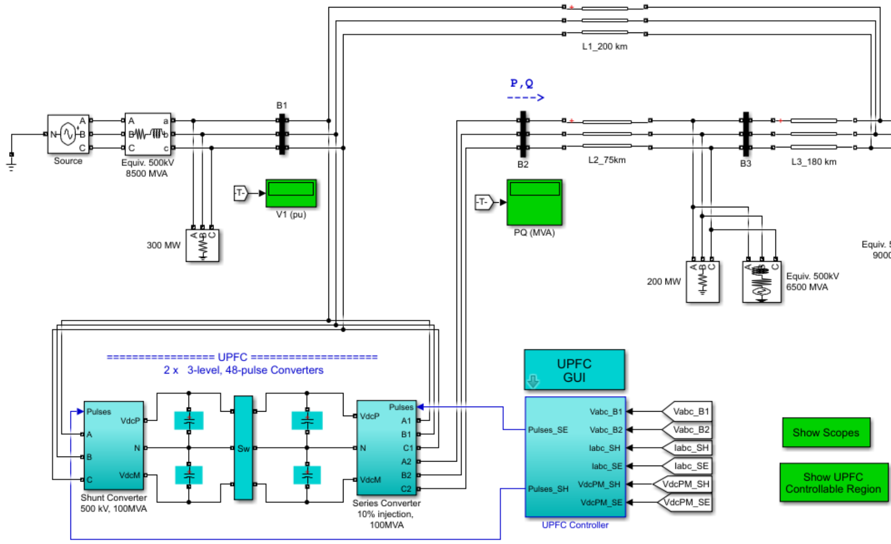
Initially the source voltage is set at 1.004 pu due to which, the voltage across the output terminals of SVC remains 1.0 pu. At this point, the SVC is disengaged. Due to the same reason, SVC does not float any current into the system. This point where no current is flowing into the system is obtained when one of the TSCs i.e., TSC 1 is ON and TCR is operating at full conduction mode where its alpha angle is 96 degrees. The operating voltage is of the system is changed from 1.0 to 1.025 pu. The SVC due to this sudden change starts to absorb reactive power of about -95 Mvar which brings the voltage back to about 1.01 pu. The time required by the system to bring the voltage back to its nominal level is about 135 milliseconds. At this point, all TSCs are turned off whereas the TCR is operating at almost full conduction mode with an alpha angle to 94 degrees. At t=0.4 s the source voltage is suddenly lowered to 0.93 pu. The SVC reacts by generating 256 Mvar of reactive power, thus increasing the voltage to 0.974 pu. At this point the three TSCs are in service and the operates at an alpha angle of 120 degrees. TSC switching can be checked on the scope by looking at the alpha angle variation. Whenever the alpha angle changes from 180 to 90 degrees, it means that the TSC has been switched on. Finally, at t=0.7 s the voltage is increased to 1.0 pu and the SVC reactive power is reduced to zero.



Reactive Power compensation using TSC and TCR with SVC

UPFC Simulation:

The GUI block allows the user to choose between different modes of UPFC in the simulation. The available modes include, UPFC, STATCOM and SSSC mode of operation. Moreover, the GUI block also allows to control the reference active power, reactive power and reference voltage. Moreover, the block allows for including a step time into the simulation to change these reference values during while the simulation is running to check the dynamic response of the system.



UPFC Simulation overview

Initially, the UPFC mode of operation is selected. The last two lines of the GUI menu represent the specified active and reactive power values. In this mode, initially the reference active power, Pref is set at +8.7 pu and reference reactive power at -0.6 pu. At 0.25 seconds, the reference active power is changed to +10 pu and at 0.5 seconds the reference reactive power is changed to +0.7 pu whereas the reference voltage in this case is kept at 1.0 pu. The 1st and 3rd line in the GUI representing the reference values for STATCOM and SSSC remain unused when UPFC operation mode is selected

When the simulation is started, the system takes about 0.15 seconds to stabilize and reach a steady state. Once the system is stabilized, at 0.25 seconds, the active reference power is changed from +8.7 pu to +10 pu whereas at 0.35 seconds the reactive power is changed from -0.6 pu to +0.7 pu. In both the cases, the system changes the power accordingly and slowly ramps up to reach both +10 pu active power and +0.7 pu reactive power.

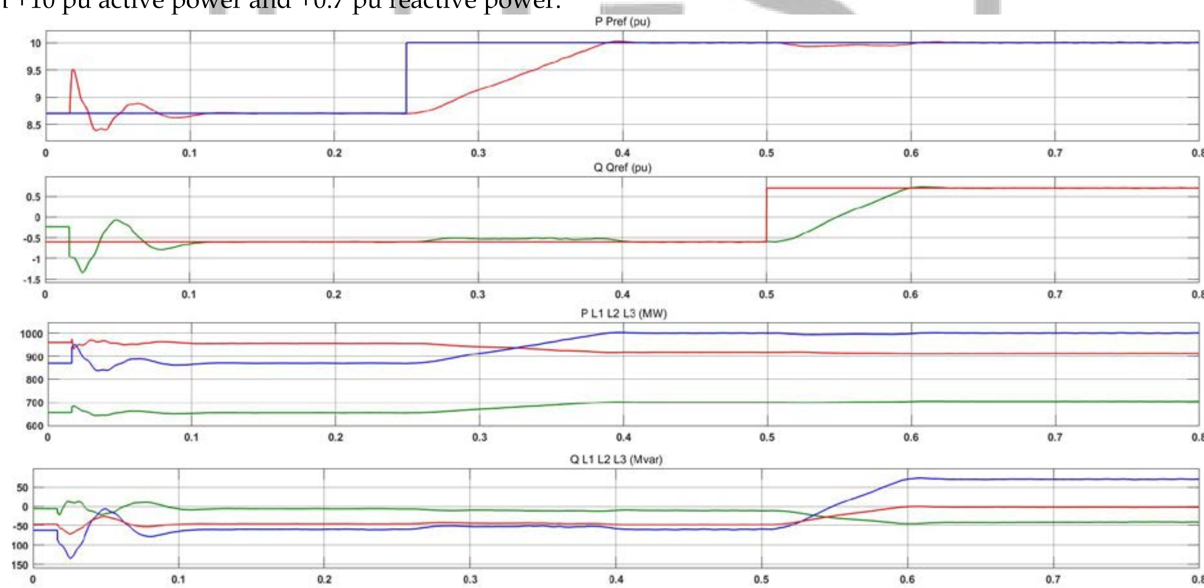


Figure Active and Reactive power tracing in UPFC mode

Conclusion & Future Works:

Electricity demand is continuously increasing due to rapid industrialization and population growth. Keeping in mind the given situation, the increase of power flow through the transmission lines can help mitigate power demand up to a viable extent. In this regard, FACTS devices are widely known and utilized to increase power system stability and power transfer over long distanced transmission lines. The system proposed in this work is able to work in STATCOM SSC and other relevant types of FACTS devices. The power transfer capability of the system was tested under different conditions. The results obtained from the simulation reveal that UPFC device has the maximum ability to mitigate the power losses which was measured to be 34% percent.

If the quality of the semiconductors used in these core components are upgraded, it can add more stability to the system and enhance its controllability. The current efficiency as per the simulation results is estimated to be around 65 to 70% for practical applications. Thusly, the efficiency of the device can be further increased by proper placing of the devices on transmission lines and the quality of components used.

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