Flexible Alternating Current Transmission System (FACTS) Applications

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Abstract

With the developing technology, most of the loads used in industrial applications consist of inductive loads. Due to their nature, inductive loads use inductive reactive energy. The reactive energy used degrades the system's quality and efficiency, as well as causing power factor issues. Flexible alternating current transmission systems (FACTS) are vital for increasing the power system's performance and quality. The FACTS system makes it faster and easier to regulate a power system. The most popular FACTS device used to enhance power quality is the Distribution Static Synchronous Compensator (D-STATCOM). According to apply FACTS applications, we are talking about FACTS devices their applications. After the comparing of the FACTS devices, discuss the differences and apply the simulation model using MATLAB/SIMULINK. After the preparing simulation, results will be discuss and researching about future applications.

Keywords: *DC,AC,FACT,MW,VA,VAr.*

1. Introduction

All of the world's electrical power supply systems are linked, including intra-utility connections, cross-grid connections from outside their own areas, inter-regional connections from multinational firms, and finally worldwide connections. This is done for financial reasons to save money. To increase the electricity and power supply's dependability. To reduce overall power producing capacity and fuel costs, we require links at pool power plants and load centers. Transmission line interconnections guarantee that power is delivered to loads reliably and at a low cost. Transmissions have incorporated FACTS Technology to increase network reliability and address practical challenges in mechanics and devices used as controllers in transmission networks. FACTS Technology has provided the transmission planner with a new opportunity to control power and increase existing capacity as well as transmission line upgrades the current through the line may be managed at a reasonable cost, allowing existing lines with huge conductors to be expanded significantly, while the use of FACTS controllers maintains the power flow steady. FACTS controllers regulate factors that influence transmission system functioning, such as At frequencies below the normal frequency, series impedance, shunt impedance, current, voltage, phase angle, and oscillation damping are all important. In an AC power flow, electricity generation and load must always be balanced. Since the electrical system is self-regulating, if one of the generators supplies less power than the load, the voltage, and frequency drop, hence the transmission losses, and the load continues to decrease to equalize the power produced. But self-regulation has a small margin. If the voltage drops due to reactive power, the load will increase and the frequency will continue to decrease, resulting in the system crashing. These situations can be prevented with FACTS Devices.

In the energy transmission of today's world, problems such as voltage fluctuation and power limitation are constantly increasing due to high reactive power consumption. The power factor of the system drops as reactive power consumption rises, the power quality deteriorates, and the system's efficiency is decreasing. Furthermore, higher transmission losses result in overheating, voltage decrease, and high operating expenses. "The consumed reactive power should be regulated to eliminate all of these issues. Reactive power control has become more important especially in transmission and distribution systems due to difficulties in the construction of new transmission lines. Therefore, in order to control the reactive power, the reactive power drawn by the industrial and lighting loads should be fed from the point where these loads are located or from the closest place to them." [1] The fact that the reactive power demanded by the loads from the network is met by the electrical elements producing reactive power at the load point or close to the load is called compensation. In other words, compensation is the process of balancing the inductive reactive power they have created on the network and bringing the phase current back to the required position due to the magnetization effect of inductive loads in the electrical system, due to the shifting of the phase current of the devices that convert the electrical energy back to electrical energy or different energy.

2. Problem Defınıtıon

In alternative energy systems, criteria such as the current and voltage having a pure sine wave shape, the constant frequency at the nominal value (50Hz or 60Hz), and the voltage on the load being at the nominal value or within acceptable limits are the desired quality conditions. Energy quality is proportional to the fulfillment of these criteria under all conditions. Power quality problems include disturbances that will disrupt the operation of sensitive industrial loads and cause production losses. Although there are different classifications for power quality problems, the IEEE 1159:2019 standard collects power quality problems under 7 headings.

- Transients
- Short-Term Voltage Changes
- Long Term Changes
- Voltage Imbalance
- Power Frequency Changes 9
- Waveform Distortion
- Voltage Fluctuations

Table 1.1 shows the energy quality problems, durations, and sizes according to the IEEE 1159:2019 standard.

Table 1. 1. Energy quality problems according to IEEE 1159:2019 Energy quality problems according to IEEE 1159:2019 according to IEEE 1159:2019 standard [1]

<table>
<tr><th colspan="3">Category</th><th>Typical Spectral</th><th>Duration</th><th>Amplitude</th></tr>
<tr><td rowspan="6">Transient Events</td><td rowspan="3">percussive</td><td>ns</td><td>5 ns incrase</td><td><50ns</td><td></td></tr>
<tr><td>µs</td><td>1 µs incrase</td><td>50ns-1ms</td><td></td></tr>
<tr><td>ms</td><td>0.1 ms incrase</td><td>>1 ms</td><td></td></tr>
<tr><td rowspan="3">oscillating</td><td>Low</td><td>< 5 kHz</td><td>0.3-50 ms</td><td>0-4 pu</td></tr>
<tr><td>Medium</td><td>5-500 kHz</td><td>20 µs</td><td>0-8 pu</td></tr>
<tr><td>High</td><td>0.5-5 MHz</td><td>5 µs</td><td>0-4 pu</td></tr>
<tr><td rowspan="8">Short temprary Changes</td><td rowspan="2">Sudden Changes</td><td>Collapse</td><td></td><td>0.5 – 30</td><td>0.1-0.9 pu</td></tr>
<tr><td>Rise</td><td></td><td>0.5 - 30</td><td>1.1-1.8 pu</td></tr>
<tr><td rowspan="4">Temporary Changes</td><td>Interruption</td><td></td><td>0.5 - 3 s</td><td>< 0.1 pu</td></tr>
<tr><td>Collapse</td><td></td><td>30 - 3 s</td><td>0.1-0.9 pu</td></tr>
<tr><td>Rise</td><td></td><td>30 - 3 s</td><td>1.1-1.4 pu</td></tr>
<tr><td>Voltage Imbalance</td><td></td><td>30 - 3 s</td><td>2-15 %</td></tr>
<tr><td rowspan="2">Long Temporary Changes</td><td>Interruption</td><td></td><td>>3 s - 1min</td><td>< 0.1pu</td></tr>
<tr><td>Collapse</td><td></td><td>>3 s - 1min</td><td>0.1-0.9pu</td></tr>
</table>

		Rise		>3 s - 1min	1.1-1.2pu
		Voltage Imbalance		>3 s - 1min	2-15 %
Long Temporary Changes		Collapse		> 1min	0.0 pu
		Voltage Drop		> 1min	0.8-0.9 pu
		Gerilim Yükselmesi		> 1min	1.1-1.2 pu
		Over Current		> 1min	
Voltage Imbalance Current Imbalance				Stable	0.5-5 %
				Stable	1.0-3.0 %
Waveform Distortion		DC Ofset		Stable	0-0.1 %
		Harmonic	0-9 kHz	Stable	0-20 %
		Hidden Harmonics	0-9 kHz	Stable	0-2 %
		notches		Stable	

Transient Events

It is defined as changes in any system variable as a result of switching from one steady-state activity to another. Pulsed and oscillating transients are two types of alterations. The energizing of transformers and capacitors creates oscillating transients, while the action of lightning on the power system causes pulsing transients.

Short Term Voltage Changes

Changes in the source voltage for periods longer than half a period and not exceeding one minute are defined as short-term. These changes are classified as sudden, instantaneous and temporary voltage sag, voltage spike and momentary voltage interruption as seen in Figure 1.1. Voltage sag refers to voltages lower than 90% of line voltage nominal value, while voltage spike refers to high values exceeding 110% of nominal value. [2]

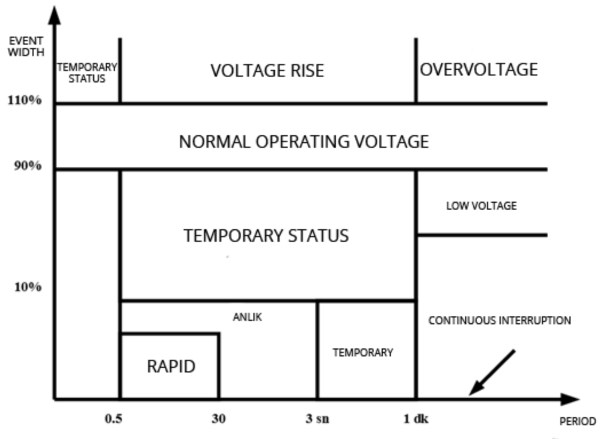

Figure 1. IEEE Std. Strain relief standard according to 1159-2019 [1]

Voltage Imbalance

It is defined as the situation where the three-phase voltage magnitudes of the source are not equal. The main reason is single-phase loads. The greatest deviation derived from the average of the three phase voltages is also determined. Undervoltage imbalances are caused by single-phase loads in three-phase systems. Furthermore, when three-phase loads are left on a single phase, a massive voltage imbalance arises, causing considerably more serious issues.

Power Frequency Changes

It is a power quality problem caused by rapid changes in the loads connected to the system. It is defined as the difference between the nominal value of the power system's fundamental frequency and the actual value. The frequency of the electricity system is determined by the rotation speed of the generators that feed it. Small frequency variations may occur as the dynamic balance between generation and load shifts. The generation control system's reactivity to load changes and the load characteristics affect the frequency shift's length and breadth. A huge generation resource outside the system, a heavy load leaving the system, or issues in the loaded power transmission networks all cause frequency variations that exceed the limits for ordinary steady functioning in the power system.

Waveform Distortion

It is defined as the variation of the power frequency in steady state from an ideal sine wave. Direct current component, harmonics, interharmonics, notches, and noise are all types of distortions. Harmonics are defined as deviations from the pure sinusoidal condition of a voltage or current waveform in a power system. Interharmonics are entire multiples of the power frequency (for example, 100 Hz, 150 Hz) as well as fractional multiples (125 Hz, 175 Hz). The waveform containing harmonics is also periodic. All harmonic components except the 50 Hz component, which is the basic component, cause increased power losses, voltage drops and reduced efficiency of the electrical system. The negative effects of harmonics can be reduced by using harmonic filters. Unbalanced power converters or half-wave rectifiers in power systems cause DC component. The DC component in the system can saturate the power transformers. In addition, current commutating rectifier circuits in DC and AC motor drivers, uninterruptible power supplies (UPS) cause notches in power systems. Increasing the duration and depth of voltage notches may damage other loads fed from the same voltage source.[4]

Voltage Fluctuations

They are defined as rapid and systematic changes in the source voltage with amplitudes between 90% and 110% of the rated voltage. These are also known as voltage flicker. They are caused by rapid and large changes in the amplitude of the current caused by low power factor loads. Large and rapid changes in the load current cause sudden drops in the source voltage. With the developing technology, the loads are mostly inductive and the use of semiconductor power elements has increased, resulting in different phase and non-linear currents drawn from the network. Therefore, the power quality problems described above arise in the system. On the contrary, in the power system; frequency and voltage are expected to be constant, no harmonics, current and voltage to be in the same phase. For this, the control of reactive power is very important in increasing the system's electrical quality Reactive power compensation is used for voltage and load balance in this case. The recognized institutes have established many criteria. of the state for the solution of power quality problems. Changes in the source voltage at the fundamental frequency for periods exceeding one minute, such as overvoltage, undervoltage, and prolonged interruption. For periods exceeding one minute, the effective value (rms) of the rated voltage is defined as an overvoltage increase of more than 110%, undervoltage when it falls below 90%, and long-term interruption when it is zero. Switching on and off of a large load with a low power factor causes overvoltage or undervoltage. Reactive energy limitations according to installed power for consumers directly connected to the transmission line in accordance with the "Electricity Transmission Systems Supply Safety and Quality Regulation" by the Turkish Energy Market Regulatory Authority (EPDK) Table It is shown in 2.2. The majority of the power quality issues stated above may be mitigated by proper Reactive power control, also known as reactive power compensation, is a technique for reducing reactive power. In transmission and distribution systems, reactive power compensation is utilized for voltage management and load adjustment.

Table 1. 2. Reactive energy limitations put into effect by EPDK [3]

<table>
<tr><th rowspan="3">Installed Power of the Business</th><th colspan="3">Energy Demand/Month</th></tr>
<tr><th rowspan="2">Active Energy (%)</th><th colspan="2">Reactive Energy (%)</th></tr>
<tr><td>inductive</td><td>capacitive</td></tr>
</table>

<50kVA	100	≤33	≤20
>50kVA	100	≤20	≤15

Load compensation is used to decrease current harmonics caused by high non-linear loads, correct the system's power factor, and balance the active power extracted from the network. Voltage regulation's goal is to decrease voltage variations at the regulated point. To increase power quality and adjust voltage, proper reactive power compensation is required. FACTS and Special Power devices are excellent choices for controlling reactive power quickly.[5]

Reactive Power Compensation

If a circuit contains an inductor, capacitor, or both, some of the energy introduced during a period is stored and then returned to the source. When AC voltage is applied to an inductor, The inductor stores energy in its magnetic field during the positive phase of the voltage. This stored energy is returned to the source during the negative phase of the voltage. This period will continue as long as the source is present in the circuit. In an AC circuit with just a capacitor, the energy received from the source is stored in the electric field between the plates of the capacitor during a half-period time period. In the second half-period, the stored energy is restored to the source.[6] Two circuit components that work together are the inductor and the capacitor. The phase difference between these two circuit elements is 180 degrees when they are linked in series. As a result, the capacitor releases the energy it has stored while the inductor gets power from the source. The inductor then returns the power it has saved while the capacitor draws power. During a period, the signs of the current and voltage values may be the same or different. Where the voltage and current signs differ, the power is negative and the power flow is from the user to the grid. This energy withdrawn from the grid is given back to the grid without being used. This situation causes unnecessary loading of transmission lines and increases losses. This power, which is withdrawn from the network and given back to the network without being used, is known as reactive power and is represented by the letter Q.

$$Q = V.I.sin\Phi \ (1)$$

is expressed as. In the above equation, the sinΦ factor is called the reactive power factor.[7] Reactive power does not show energy loss, but shows the peak value of the instantaneous power received and delivered by the inductor or capacitor. Since reactive power will cause voltage decrease and losses by loading the transmission line and transmission devices unnecessarily, it is desirable to minimize the reactive power drawn from the network. In AC circuits, active power is drawn by resistors, reactive power

by inductors and capacitors. In an AC circuit with resistance and reactance, there will be active and reactive power, which combined produce the perceived power. (S).

Apparent power phasor for an inductive load;

$$S = P + jQL \ (2)$$

Apparent power phasor for a capacitive load;

$$S = P - jQC \ (3)$$

is defined as apparent power S;

$$S = \sqrt{P^2 + Q^2} \ (4)$$

The scalar quantities of active power P, reactive power Q, and apparent power S created by the two powers may be represented geometrically as the horizontal side, vertical side [6], and hypotenuse of a right triangle, respectively, as illustrated in Figure 1.2. This triangle is referred to as the power triangle. The power triangle is the Z impedance triangle scaled by the factor I.2, as seen in Figure 1.2.

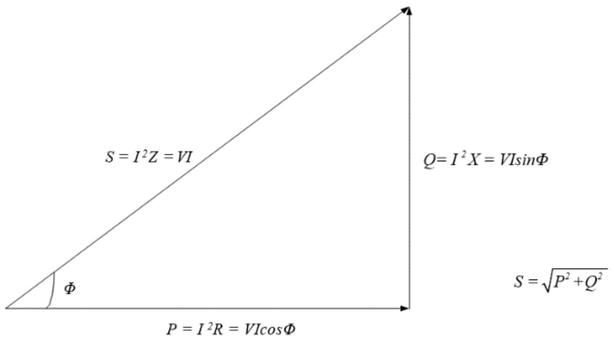

Figure 2. Power Triangle[8]

3. Results and Discussion

In this chapter we are talking to methods and their applications to FACTS system. We need to understand the topics and the application type of FACTS. Applied FACTS system has many ways. That will be a simple circuit breaker or complex UPFC devices. FACTS systems have many types and table 1.3.

Table 3. 1 FACTS device types [9]

FACTS Name	Connection Type	Control Parameters
Thyristor Controlled FACTS Devices		
SVC	Parallel	Voltage control, VAr compensation, Transient and dynamic stability, Voltage stability, Damping oscillations
TCSC	serial	Current control, Transient and dynamic stability, Voltage stability, Oscillation damping, Fault current limitation
Voltage Source Switching Inverter FACTS Devices		
STATCOM	Parallel	Voltage control, VAr compensation, Transient and dynamic stability, Voltage stability, Damping oscillations
SSSC	serial	Current control, Transient and dynamic stability, Voltage stability, Oscillation damping, Fault current limitation

UPFC	Combined Structured Series-Parallel	Active and reactive power control, Voltage control, VAr compensation, Transient and dynamic stability, Voltage stability, Oscillation damping, Fault current limitation
IPFC	Combined Structure Series-Series	Voltage control, Reactive power control, Transient and dynamic stability, Voltage stability, Damping oscillations

According to table we have many types of FACTS devices. In this study planning to do something similar to UPFC systems. Our FACTS system has a distinctive feature. According to this UPFC device. Determine the parameters in simulation. In that condition, device topology is need to be explain.

4. Developed Or Applied Approach

Due to the nature of FACTS devices, different methods have been developed day by day. As discussing at the simulation, The UPFC, which is situated between the 500 kV buses B1 and B2 at the left end of the 75 km line L2, is used to regulate the voltage at bus B1 and the active and reactive energy flowing via bus B2. It consists of two 100-MVA, three-level, 48-pulse GTO-based converters, one linked in series between buses B1 and B2, the other in shunt at bus B1. Through a DC bus, the shunt and series converters can trade power. The series converter may connect line L2 in series with a maximum of 10% of the nominal line-to-ground voltage (28.87 kV). When the shunt and series converters are coupled together through the DC bus, this is known as the Unified Power Flow Controller (UPFC) mode. Two more modes are accessible when the disconnect switches between the DC buses of the shunt and series converter are opened. The shunt converter functions as a STATCOM when the two converters are used in UPFC mode. It permits active power transmission to the series converter through the DC bus while also regulating the absorbed or produced reactive power, which regulates the bus B1 voltage. By changing the DC bus voltage, the reactive power fluctuation may be produced. A quasi-sinusoidal 48-step voltage waveform is produced by the four three-level shunt converters operating at a constant conduction angle (Sigma=180-7.5 = 172.5 degrees). The 47th and 49th harmonics are the first important harmonics.

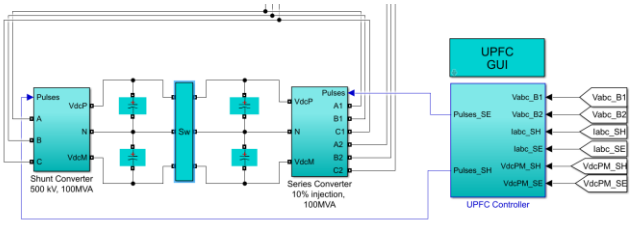

Figure 3. UPFC device

As you see in figure 4.1 you can clearly see the UPFC device working principle if want to explain detailly each part:

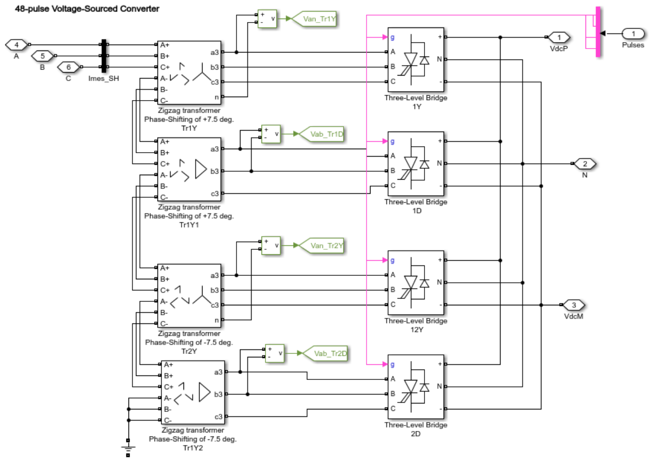

Figure 4. Shunt Converter

Shunt and series converter control the circuit configuration of two connected converters allows for many UPFC control modes, series voltage injection, and separately adjustable reactive power exchange. The alternatives to the method used for power flow control are reactive shunt compensation and free control of series voltage injection. The shunt inverter runs on a closed-loop current control architecture that allows for independent control of the actual and reactive power components. While shunt real power is determined by a different control loop that works to maintain a specific voltage level at the dc connection, shunt reactive power reacts immediately to input demand. Shunt and series converter control the circuit configuration of two connected converters allows for many UPFC control modes, series voltage injection, and separately adjustable reactive power exchange. The alternatives to the method used for power flow control are reactive shunt compensation and free control of series voltage injection. The shunt inverter runs on a closed-loop current control architecture that allows for independent control of the actual and reactive power components. While shunt real power is determined by a different control loop that works to maintain a specific voltage level at the dc connection, shunt reactive power reacts immediately to input demand. In order for series insertion to simulate reactive impedance as viewed from the line, the main purpose of series compensation is to adjust the magnitude of the injected voltage in proportion to the line current. In order to phase shift the output bus voltage with regard to the input voltage by the amount determined by the reference input, the injected voltage is regulated with respect to the input bus voltage.

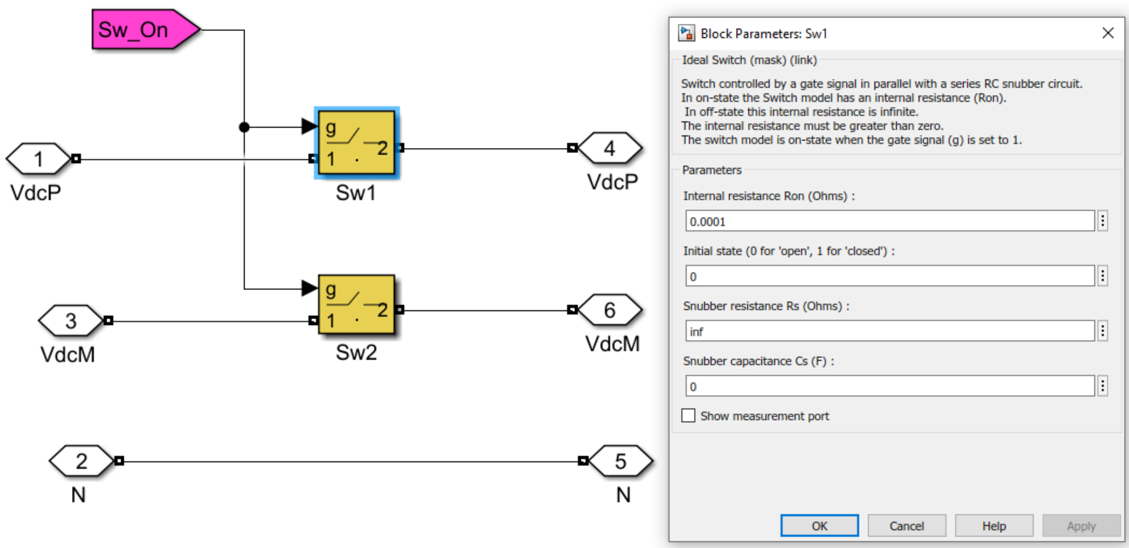

Figure 5. Switching

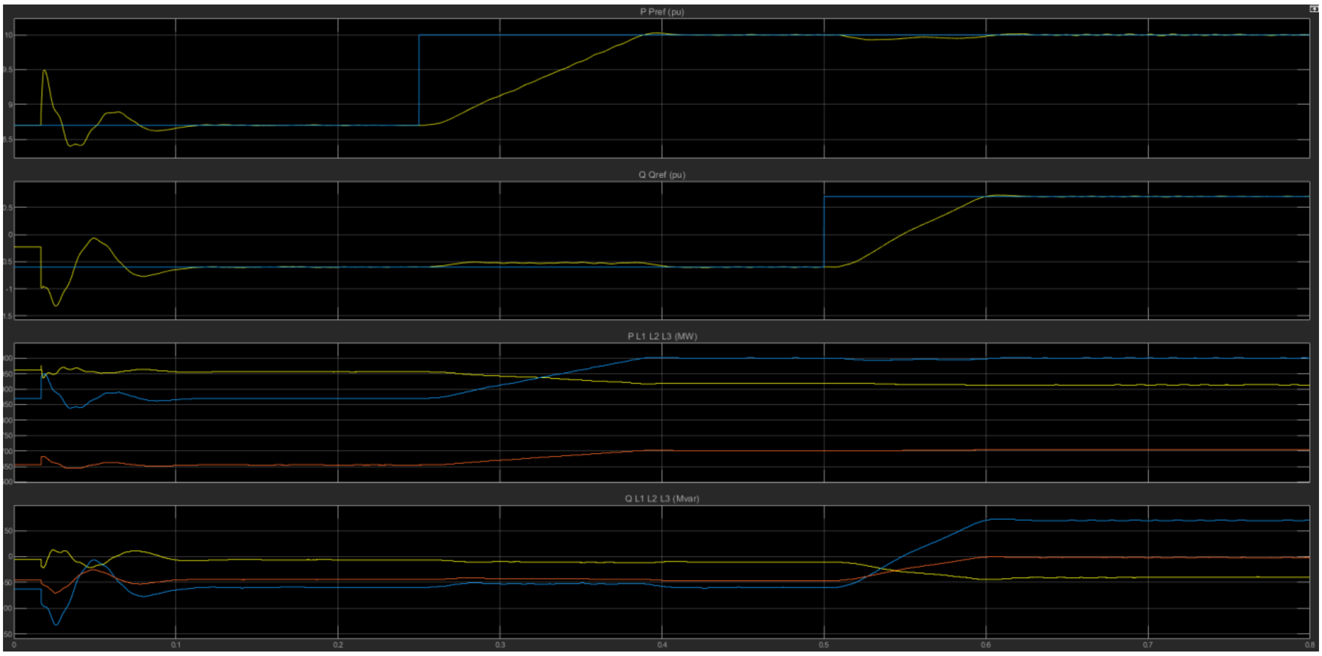

Figure 6. Simulation output-1

In the figure 6 you can clearly see the P and Q graphs in whole circuit. This figure is help us to compare reference and real time values.

5. Conculsions

FACTS in general: in the energy transmission system, it is a collection of power electronics-based controllers and systems designed to provide quicker and more effective control, boost the transmission system's power carrying capability, and mitigate abnormal operating circumstances. Its application to transmission systems is referred to as flexible alternating current transmission systems (FACTS), power electronics-based circuit architectures act. The word flexible here refers to the ability of these controllers to comfortably control the variables of the power transmission system, such as current or voltage. Thanks to FACTS structures (devices, controllers or controllers): Power flows in the network can be controlled, and the power carrying capacity of the lines can be increased. [10] In addition, solutions can be found for problems such as sub synchronous resonance, voltage instability, power oscillations and transient stability in the network. Rapid events that may occur in the network can be intervened in a very short time. FACTS controllers are structures based on power electronics and their operation is generally based on the on and off of semiconductor switches.

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