International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Design Simulation And Analysis of A Unified Power Flow Conditioner for Transmission Line

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Abstract*: The reactive power compensation in power system is done by using different Flexible AC Transmission Controllers (FACTS). Unified Power Flow Controller (UPFC) is simulated and analyzed to observe its overall functions when integrated into a transmission line. It is installed in electric transmission lines hence assisting in the controlling and manipulating of the power flowing in the lines to give out reliable, controlled and efficient electricity to an ordinary consumer. The modelling of this device UPFC was done based on the theory of line models which are short, medium and a long line models. Conclusion on which model to use was based on two factors. The first one is model voltage level and length of the transmission line. The simulation of the designed circuit models was carried out using MATLAB and the results were then analyzed.

Keywords: *Reactive Power, FACTS, UPFC, Transmission Line.*

I. INTRODUCTION

In this modern day era, the world's technology is growing rapidly and hence this accelerates the demand of electrical power from companies which generate electricity and also from transmission lines [1]. Due to unforeseen events which have occurred from the past to the present, but some generation stations cannot fully handle the electrical power demand brought about by increase in population and also migration of consumers, town/city developments etc. This leads to most consumers having complaints about poor electrical supply i.e. being power cuts and also zeros electrical supply. Flexible AC Transmission System (FACTS) devices can manage to solve some of these by increasing transmission lines productivity rate and enhancing their reliability [2]. Electrical Power Transmission expansion/growth in the power system can lead to the power system being more difficult to operate. Due to large power flows with less control and also excessive reactive power. Due to this high power demand these new power systems are being operated under high pressure conditions. As a result, there is difficulty in reaching requirements of reactive power more especially under contingencies and maintaining the bus voltage with acceptable limits [3]. Voltage instability happens in the form of decay in voltage magnitude which is also progressive at some points of the bus and it can result in a certain area losing load or the transmission lines tripping and also due to other elements by their protective system leading to cascaded outages and voltage collapse in the system.

Cascaded outages are a process in a system of interconnected parts in which the failure of one or few parts can trigger the failure of the other parts [4]. The voltage collapse occurs when the reactive power demand at the load is not met due to shortage in reactive power production. Most of the challenges mentioned above have been overcome with the use of FACTS technologies. These technologies comprises of Power Electronic Devices (PED's). FACTS devices where created mainly to overcome limitations of power flow in the transmission line.

The Power flow is usually limited by system stability, loop flows and voltage limits. In system stability the ability of the system is to return its operation to steady state after being subjected to a form of a disturbance. The physical flows resulting from energy transfer. They are hard to control and can lead to transmission equipment damage. Voltage Limits is known as voltage tolerance, defined as the allowed voltage of transmission [5-6].

The electrical parameters such as voltage, current, impedance, phase angle, reactive and active power lack high speed control hence power transfer is limited during transmission. The value of AC system transmission assets improved by controlling these parameters with the help of the FACTS devices. One of the FACTS devices that can be used to control some of these parameters i.e. either individually or simultaneously is a Unified Power Flow Controller [7-8].

Manuscript published on 30 September 2019
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II. UNIFIED POWER FLOW CONTROLLER

A. Introduction

The static compensator and static series compensation is combined together and forming the UPFC. The UPFC device can work as shunt compensation device and phase shifting device simultaneously. Shunt and series transformer are the devices used in the UPFC. These two devices connected by using two voltage source converters and DC link capacitor are connected as common source. The configuration of an UPFC is shown in Fig.1. The Thyristor bridge is and series converter is to be protected. The high efforts for the voltage source converters and the protection because of that the UPFC is becoming costly. Due to the high cost the UPFC it limits the practical applications.

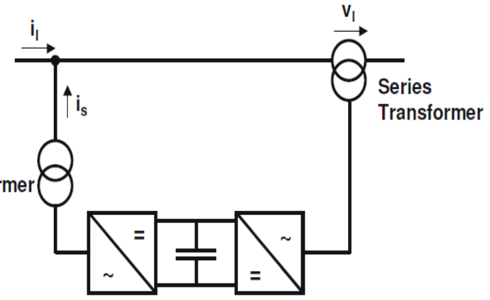

Fig.1. Principle configuration of an UPFC

B. Theoretical Analysis

The imaginary power is not used for any useful work. The imaginary power exists at the time of voltage and current are out of phase. Denoted by Q and measured in Volt-Ampere-Reactive. The amount of power that is actually consumed in an AC circuit is called as active power. It is denoted by P and measured in Watts (W). In most transmission lines the power generated at the source cannot deliver the entire apparent power to the load and this is due to the non-linear impedance of the line. The UPFC is able to solve this by acting as a Synchronous Voltage Source (SVS) connected to the transmission line. The dc voltage from the dc link of the UPFC is switched in a predetermined manner to control the angle of the SVS. The Fig.2 shows the UPFC phasor analyzer.

$$\theta_1 = Angle\ made\ by\ Vs\ w.r.t\ Ref$$

$$\theta_2 = Angle\ made\ by\ Vr\ w.r.t\ Ref$$

$$Vs > Vr\ due\ to\ the\ line\ resistance$$

$$V'_s = V_s + V_{svs} \quad (1)$$

The presence of the SVS will yield a new voltage on the transmission line called V's which is a combination of the Voltage from the source and that of the SVS.

$\emptyset_1 = Angle\ made\ by\ V_{svs}\ w.r.t\ V_s$

$V's = the\ vector\ summation\ of\ V_{svs}\ and\ V_s$

Using KVL:

$$V'_s = V_L + V_r \quad (2)$$

$$V_L = V'_s - V_r \quad (3)$$

Using the amplitude of V_{SVS} and angle Ø the position of V_L can be varied. Adjusting of V_{SVS}, the current can be shifted anywhere in the 360 degrees. Change in V_{SVS} and Ø will result in current phasor coinciding with V_S leading to a power factor being 1 and the angle of the power factor being 0. This in turn will result in the power being generated being fully delivered to the load. Neglecting the resistive voltage in the transmission line we result in similar magnitude of Vs and Vr

$$V_s = V_s e^{j\theta_1} \quad (4)$$

$$V_r = V_r e^{j\theta_2} \quad (5)$$

$$V_{svs} = V_{svs} e^{j(\theta_1+\emptyset)} \quad (6)$$

Since

$$P = VI \quad (7)$$

For

$$V = V_r\ and\ I = I^* \quad (8)$$

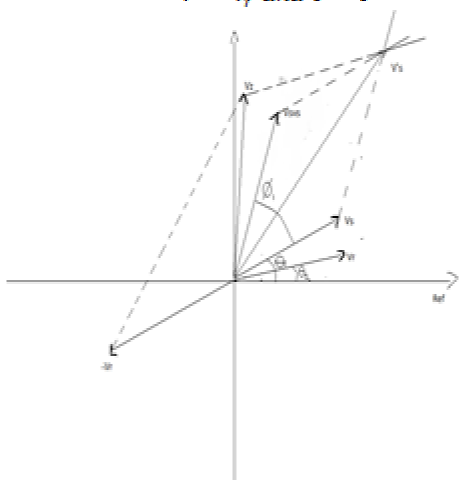

Fig.2. Phasor analysis of the UPFC controller

Where I^* defines the complex conjugate of the current and V_r is the voltage at the receiver.

Power at the receiving end will be:

$$P - jQ = V_r * I^* \quad (9)$$

Where jQ is the imaginary or reactive power.

Using KVL:

$$I^* = \frac{V_S + V_{SVS} - V_r}{Z^*} \quad (10)$$

Z^* is the transmission line impedance .

$$P - jQ = V_r * \left(\frac{V_S + V_{SVS} - V_r}{Z^*}\right) \quad (11)$$

III. PROPOSED SYSTEM

A. Simulation for UPFC Controller

UPFC provides flexibility in many ways to solve the problems of power transmitting industries. UPFC control the voltage, phase angle and the impedances which affect the power flow of the overall network of the system.

Real and reactive power can be exchanged by using UPFC in the transmission system like SVS. The SVC can generate the reactive power but the real power is observed by suitable power supply. Two back to back inverters used i.e. shunt and series inverter connected at a dc link which is having a dc storage capacitor.

Retrieval Number: B1641078219/19©BEIESP
DOI:10.35940/ijrte.B1641.098319
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
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The Fig.3 shows the functional block diagram of the UPFC system. The Fig.4 shows the simulation diagram of the UPFC controller.

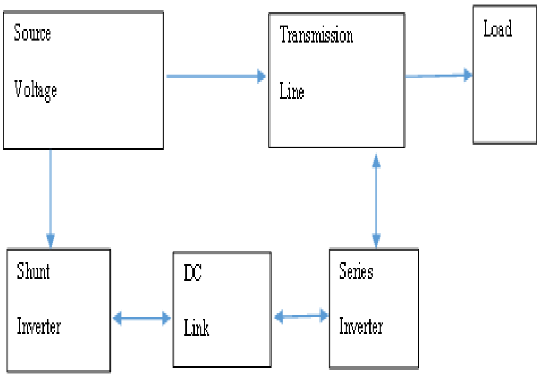

Fig.3. Functional block diagram of the UPFC system

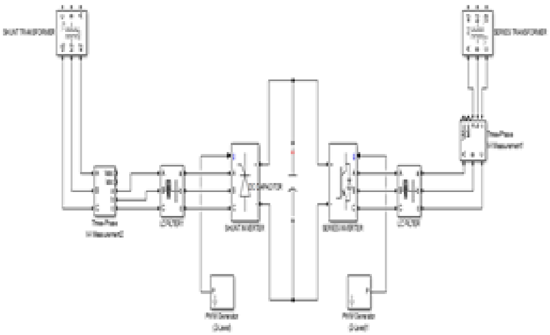

Fig.4. Simulation diagram of the UPFC controller

Voltage is injected with a controllable magnitude and phase angle in the transmission system done by the two inverters. With the presence of the synchronous voltage source, the current which flows in the line will pass through this voltage source and this will produce a reactive and active power transfer between the line and the ac voltage source.

B. Shunt Inverter

The Fig.5 shows the shunt inverter. After stepping down of the AC voltage by the shunt transformer, the voltage is converted from AC to DC through a process called rectification and this is done for easier manipulation of the DC waveform. A rectifier consists of diodes (an electrical device which allows electric current to flow in one direction) arranged in a circuit in a predetermined manner to produce a desired output or voltage hence in this case being a DC voltage. The shunt device will comprise of a full wave rectifier to a produce a desired and smooth DC output waveform from the AC input. The AC/DC conversion and voltage rectification is done at shunt inverter.

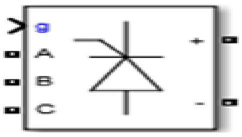

Fig.5. Shunt inverter

C. Shunt Inverter

Connected to the transmission line through a series transformer, the series inverter is responsible for the conversion of ac to dc voltage and also generating real and reactive power. The series inverter is shown in Fig.6. The real power is controlled by varying the ac voltage which is being injected to the transmission line through the series transformer whilst the reactive power is controlled by the varying the phase angle of the injected ac voltage. The series converter that will be used will be the Insulated-gate bipolar transistor. DC/AC conversion and real and reactive power is done by the series inverter.

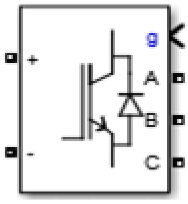

Fig.6. Series inverter

D. DC Link Circuit

The Fig.7 shows the DC link circuit. Made up of a predetermined configuration of a capacitor, diodes and transistors, the DC link performs the most important function in the UPFC circuit as it links the rectifier, capacitor and the inverter to form a single component which does different functions but also works as one entity. The capacitor in the dc link is used to store dc power fed to it by the rectifier i.e. it filters out the variations in the DC voltage. After filtering, the DC power is injected on to the inverter which is comprised of Insulated gate bipolar transistor and this inverter will convert the stable dc into ac power.

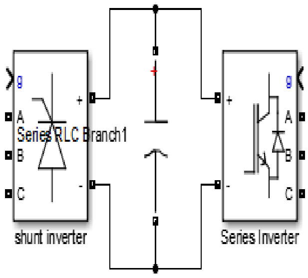

Fig.7. DC link circuit

E. Shunt Transformer

A transformer is used to increase or decrease voltage during transmission i.e. it is able to change the value of the current by increasing and reducing the voltage. The main reason why the UPFC will require a transformer is because of the transformer's ability to exchange or transfer electric power from one circuit (transmission line) to the other (UPFC) without tempering with its frequency. This will be achieved through mutual induction i.e. the two circuits will be joined magnetically and still exists electrically separate. Two transformers will be incorporated into our circuits i.e. the shunt transformer which link rectifier to the transmission line and the series transformer which will link the transmission line to the inverter.

IV. TRANSMISSION LINE MODELLING

A transmission line model relies mostly on the length of the line and the voltage level subjected to the line. The transmission line can be a short model for a distance of the line being approximately less than 80km and voltage level less than 69kV. The medium model with the line length(x) is approximately between 80km<x<250km. the long lone is with the length greater than 250Km. For the proposed transmission line, the short model will be implemented because its parameters are lumped hence it is easier to analyze the simplified model and also, the results are of some accurate degree. Only inductance and resistance will be used in the transmission line. The short model of the transmission line is shown in Fig.8. The UPFC connected short model transmission line is shown in Fig.9.

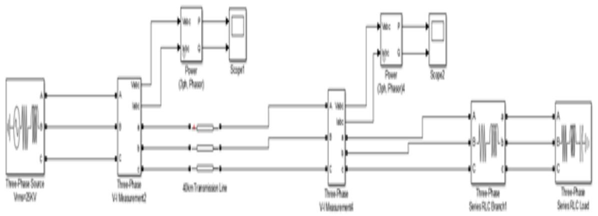

Fig.8. Short model transmission line

The model is observed having a sending and Receiving voltage (V_S,V_R) , Sending and Receiving current(I_S,I_R respectively), inductance(L) and resistance(R). The path from the load to generator is assumed to be imaginary neutral.

Applying KVL:

$$V_S = V_r + ZI_r \quad (11)$$

Where:

$$Z = R + jX_L \quad (12)$$

X_L -Total Line Inductance

R- Total Line Resistance

Using a two port network analysis representation of supply voltage and current with receiving voltage and current

$$V_S = AV_r + BI_r \quad (13)$$

$$I_S = CV_r + DI_r \quad (14)$$

In the above equations, A and D are considered dimensionless whilst B and C have their dimensions being Ohm and Siemens respectively.

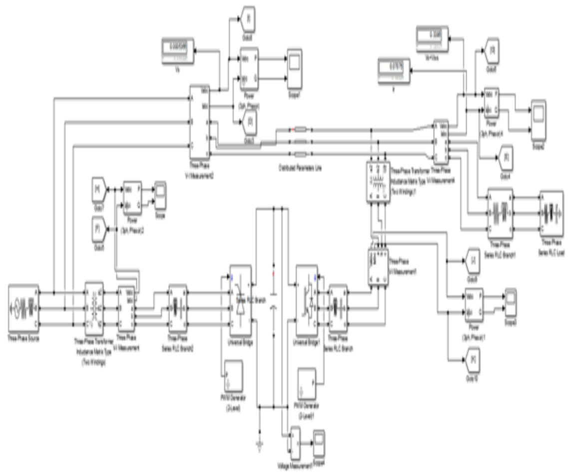

Fig.9. UPFC connected to a short model transmission line

V. SIMULATION ANALYSIS

From the TABLE.I the active and reactive power is given. An active power of 0.03237p.u is present in the transmission line with a 0 p.u reactive power. The UPFC generates an active power of 0.2086 p.u but due to the low voltage of the network, the active power is not supplied. The 0.3615 p.u reactive power generated by the UPFC gives rise to the transmission line active power i.e. it changes from 0.03237 p.u to 0.08633p.u. The Fig.10 shows the reactive power compensation analysis. Fig.11 shows the fault occurred at transmission system. The Fig.12 presents the current, voltage and powers at the start of the simulation i.e. before the fault occurs in the transmission line. Fig.13 shows a fault occurrence causes a disturbance to the smooth running of the system. This results in no current flow in the transmission line. The Fig.14 shows the disturbance in the transmission line is then resolved by the UPFC after some time while the simulation is running. The Fig.15 shows the system returns to its full operational state after the fault is dealt with by the UPFC

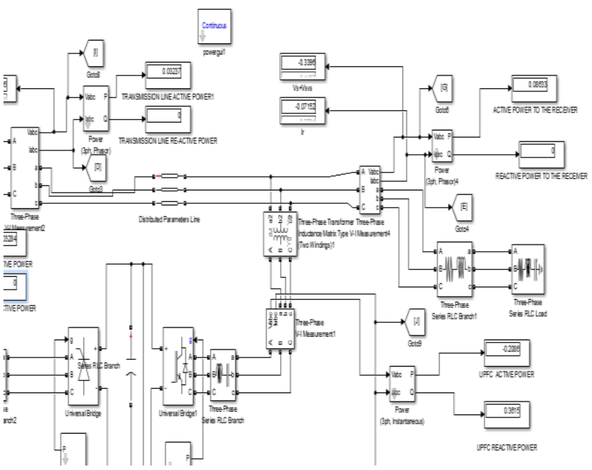

Fig.10. Reactive power compensation analysis

TABLE I. REACTIVE AND ACTIVE POWER DETAILS

Transmission Line		UPFC		Load	
Active	Reactive	Active	Reactive	Active	Reactive
0.03237	0	-0.2086	0.3615	0.08633	0

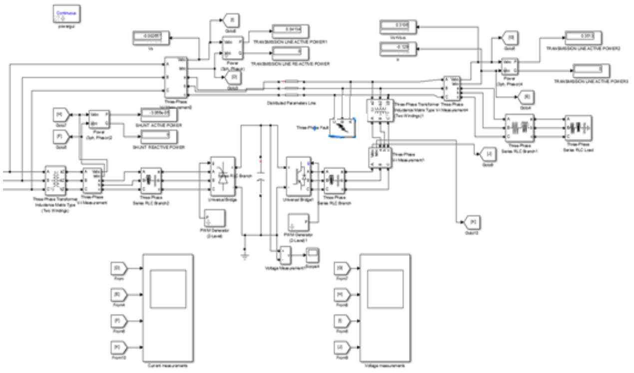

Fig.11.Transmission line fault

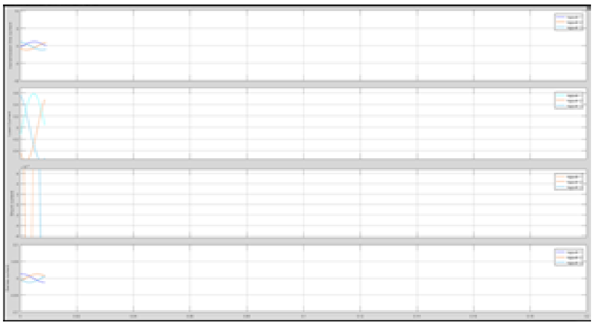

Fig.12.Output before the fault occurrence
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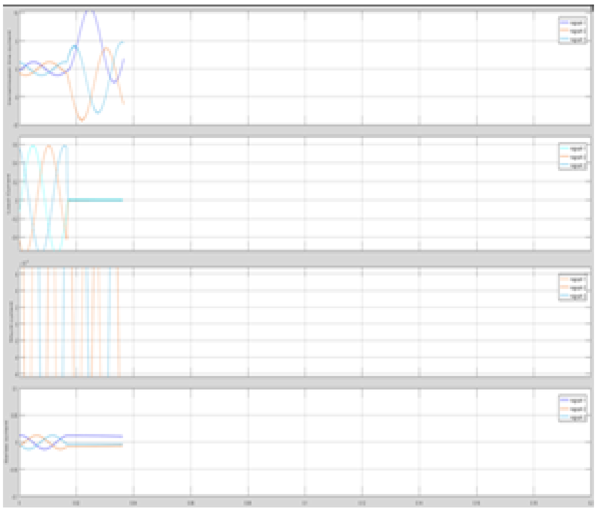

Fig.13.Output current after fault

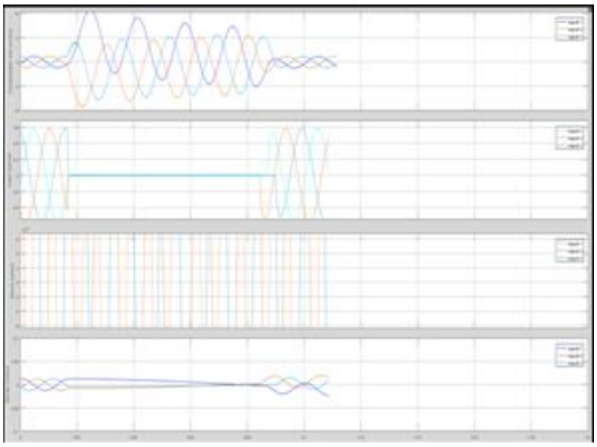

Fig.14. System recovery after fault

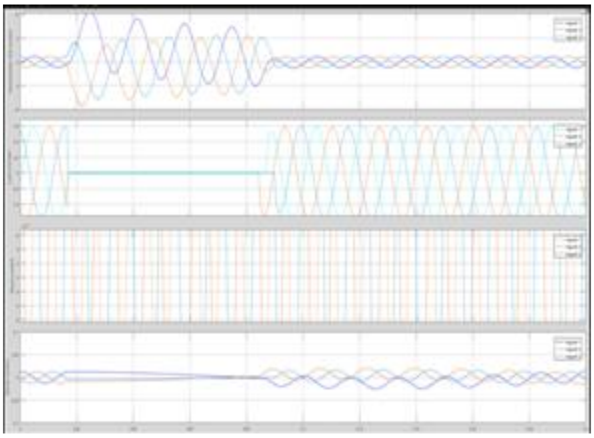

Fig.15. Transmission line in operation after the fault

VI. CONCLUSION

This proposal studies the Unified power flow controller through its simulation and analysis. The UPFC connected to a transmission line was tested on the basis of how it's able to overcome an electrical fault and return to its normal state of operation. The UPFC was able to do so by generating reactive power for compensation i.e. it performed it's proposing function.

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