International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 10, October - 2013

Comparison of Performance of Distance Relay In a Transmission system with & without UPFC

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Abstract - The analytical and simulation results of the application of distance relays for the protection of transmission systems employing flexible alternating current transmission controllers such as the unified power flow controller (UPFC) are described. Firstly a detailed model of the UPFC and its control is proposed and then it is integrated into the transmission system for the purposes of accurately simulating the fault transients. An apparent impedance calculation procedure for a transmission line with and with out UPFC based on the power frequency sequence component is then investigated. The simulation results show the impact of UPFC on the performance of a distance protection relay for different fault conditions and various control schemes.
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Index Terms-Distance relay, flexible alternating current transmission(FACTS)controllers, power system protection ,UPFC.

I .INTRODUCTION

FACTS technology is based on the use of reliable high-speed power electronics, advanced control technology, high-power microcomputers and powerful analytical tools. The key feature is the availability of power electronic switching devices that can switch electricity at megawatt levels (kV and kA levels). The impact of FACTS controllers on transmission systems is thus likely to have a significant impact on power system networks worldwide. Amongst the different types of FACTS controllers, UPFC is considered to be one of the most effective in the control of power flow. It comprises two back-to-back gate-turn-off thyristor (GTO) based voltage source converters (VSCs) connected by a dc -link capacitor. An exciting transformer connecting one VSC is arranged in shunt and a boosting transformer linking the second VSC is inserted into the transmission line. By virtue of its ability to control freely and independently three major parameters in power transmission *viz.* the line impedance and the magnitude and phase of the voltage, it provides both voltage regulation and improvement in stability. Because of the presence of FACTS controllers in a fault loop, the voltage and current signals at the relay point will be affected in both the steady state and the transient state. This in turn will affect the performance of existing protection schemes, such as the distance relay which is one of the very widely used methods in transmission line protection [3], [4]. The main principle of this technique is to calculate the impedance between the relay and fault points; the apparent impedance is then compared with the relay trip characteristic to ascertain whether it is an internal or external fault. A common method of calculating this impedance is to use symmetrical component transformation using power frequency components of voltage and current signals measured at the relay point.

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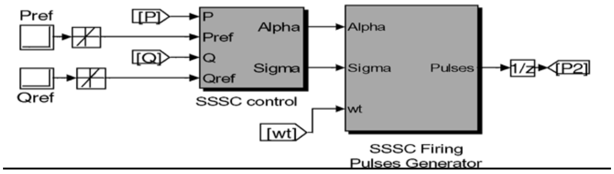
II. CLASSIFICATION OF FACTS CONTROLLERS

Power electronics devices have had a revolutionary impact on the electric power systems around the world. The availability and application of thyristors has resulted in a new breed of thyristors -based fast operating devices devised for control and switching operations. Flexible AC transmission system (FACTS) devices are new comings, which have found a wide spread application in the power industry for active and reactive power control.FACTS controllers can be broadly divided into four categories, which include series controllers, shunt controllers, combined series-series controllers and combined series-shunt controllers. Their operation and usage are described next.

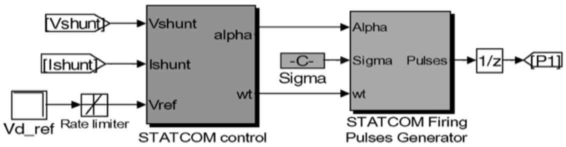
A. Series Controllers

A series controller may be regarded as variable or capacitive impedance whose value is adjusted to damp various oscillations that can take place in the system. This is achieved by injecting an appropriate voltage phasor in series with the line. This voltage phasor can be viewed as the voltage across impedance in series with the line. if the line voltage is in phase with the line current, the series controller absorbs or produces reactive power, while if it is not, the controller absorbs or produces real and reactive power .Examples of such controllers are SSSC,TSSC and TCSR to cite a few. Theycan be effectively used to control current and power flow in the system and to damp system’s oscillations.



B. Shunt Controllers

Shunt controllers are similar to the series controllers with the difference being that they inject current into the system at the points where they are connected. The variable shunt impedance connected to a line causes a variable current flow by injecting a current into the system. If the injected current is in phase with the line voltage, the controller adjust reactive power while if the current is not in phase quadrature, the controller adjusts real power. Examples of such systems are static synchronous generator (SSG),SVC. They can be used as a good way to control the voltage in and around the point of connection by injecting active or reactive current into the system.



C. Series-Series Controllers

A combined series –series controller may have two configurations; one configuration consists of series controller operating in a coordinated manner in a multi line transmission system. The other configurations provides independent reactive power control for each line of a multi line transmission system and at the same time, facilities real power transfer through the power link. An example of this type of controller is the interline power flow controller (IPFC), which helps in balancing both the real and reactive power flows on the line

D. Series-Shunt Controllers

A combined series –shunt controller may have two configurations; one being two separate series and shunt controller that operate in a coordinated manner and the other one being an interconnected series and shunt components. In each configuration, the shunt component injects a current into the system while the series component injects a series voltage. When these two elements are unified, a real power can be exchanged between them via the power link. Examples of such controllers are UPFC and Thyristor controlled phase Shifting transformer (TCPST).These make use of the advantages of both series and shunt controller and, hence, facilities effective and independent power/ current flow and line voltage control.

III .UPFC AND TRANSMISSION SYSTEM MODEL

A. Transmission System Employing A UPFC Model

In this study, SimPowerSystem 3.1 toolbox in Matlab 7 is used to model the 138-kV parallel transmission system with UPFC installed in the middle of one transmission line. Two 200-km parallel 138-kV transmission lines terminated in two 6500-MVA Short-Circuit Levels (SCLs) sources and the angle difference is 20. The 160-MVA UPFC is installed in the middle of the second transmission line. The simulation time step length is 0.02 ms. The UPFC consists of two 48-pulse voltage source inverters which are connected through two 2000 common dc capacitors. The first inverter known as STATCOM connects into the transmission system through a 15 kV/138 kV /Y shunt transformer, and injects or consumes reactive power to the transmission system to regulate the voltage at the connecting point; another inverter known as static synchronous series compensator (SSSC) connects into the system through a 15 kV/22 kV Y/Y series transformer to inject an almost sinusoidal voltage of variable magnitude and angle, in series with the transmission line to regulate the power flow through the transmission line.

B. Voltage Source Inverter Model

The voltage source inverter employed herein is based on the 48-pulse quasi harmonic neutralized GTO inverter and the structure is shown in Fig:1 .It consists of four 3-phase, 3-level GTO inverters and four phase-shifting transformers. Each inverter uses a 3-level GTO bridge block to generate three square wave voltages. These voltage are fed to the secondary windings of four phase-shifting transformers whose primary windings are connected in series to produce an almost sinusoidal voltage output. A dc capacitor is connected to the four 3-level inverters, the magnitude of square-wave voltage can be, 0,. The duration of zero voltage in each quarter cycle is defined as “dead angle”

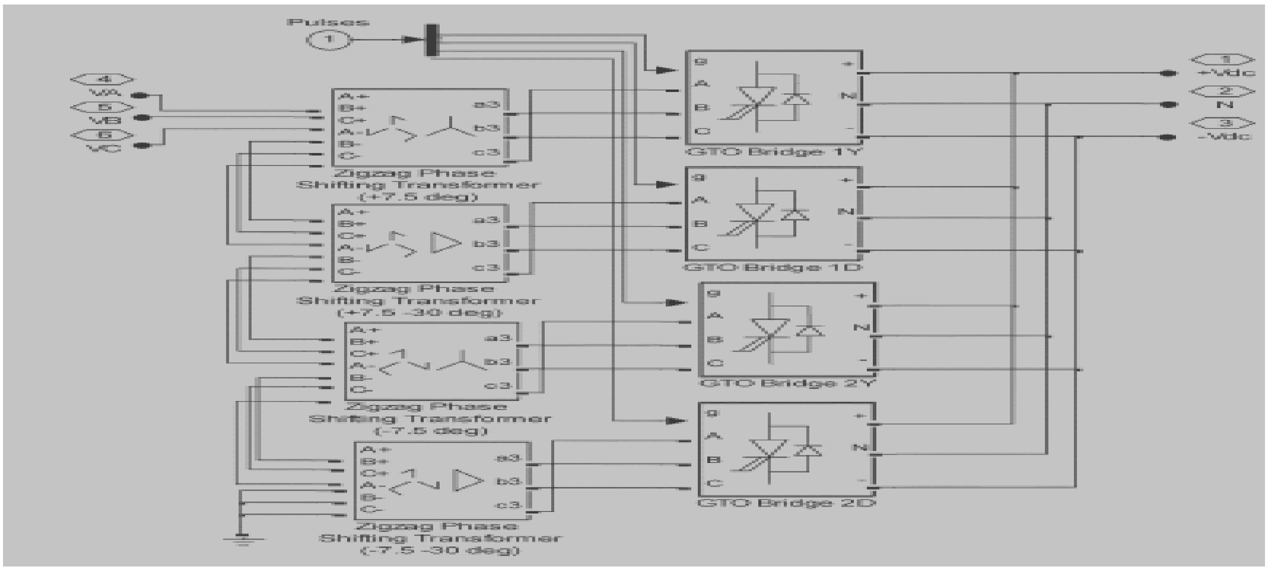


Fig. 1: 48 – Pulse quasi – harmonic neutralized GTO driver

and it can be adjusted from 0 –90 . The fundamental component of voltage source inverter has the amplitude of (1) As seen from above, the magnitude of the output voltage can be adjusted through changing the value of dead angle and/or the dc voltage of the capacitor. The phase angle of the output voltage can be adjusted by using the input signal from the pulse generator. When the dead angle the first significant harmonics of the voltage source inverter on the ac output are 47th and 49th and it is operated as a 48-pulse inverter. In this study, the STATCOM inverter is operated as 48-pulse inverter, that is to say, the dead angle kept constant during the operation, and the SSSC inverter is operated with a variable dead angle to control the amplitude of the injection voltage.

IV. UPFC CONTROL MODEL

The control system of the UPFC can be divided into two parts: the control of STATCOM and the control of SSSC.

A. STATCOM

The control of STATCOM (Fig.2) is used to operate the voltage source inverter to inject or absorb reactive power to regulate the connecting point voltage to the setting value . The three phase voltages at the connecting point are sent to the Phase-Lock-Loop to calculate the reference angle which is synchronized to the phase A voltage. The three phase currents of STATCOM are decomposed into their real part and reactive part via the *abc-dqo* transform using the phase-lock-loop angle as reference. The magnitude of the positive sequence component of the connecting point voltage is compared with the desired reference voltage, and the error is passed through a PI controller to produce the desired reactive current ; this current reference is compared with the reactive part of the shunt current to produce the error which will be passed through another PI controller to obtain the relative phase angle of the inverter voltage with respect to the phase A voltage. The phase angle together with Fig. Control model of SSSC.The phase-lock-loop signal are fed to the STATCOM firing pulse generator to generate the desired pulse for the voltage source inverter (the dead angle of STATCOM is kept fixed as).

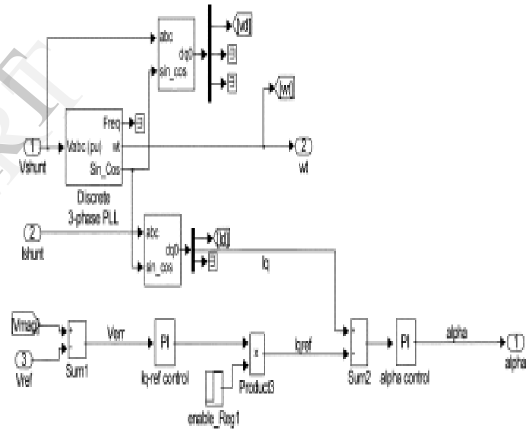


Fig :2 Control Model of STATCOM

B. SSSC

The control strategy for the SSSC is based on automatic power flow control in Fig.3. The series injected voltage is determined by a closed-loop control system to ensure that the desired active and reactive powers flowing in the transmission line are maintained despite power system changes. The desired and are compared with the measured positive active and reactive power flows in the transmission line, and the errors are used to derive the desired direct and quadrature component of the series inverter voltage, and,, respectively, through the PI controllers. The magnitude and phase angle of series converter voltage can be obtained by a rectangular to polar transformation of and component. The dead angle of SSSC inverter can be calculated using the relationships between and dc capacitor voltage , hence the phase angle , dead angle together with the phase-lock-loop signal are used by the SSSC firing pulse generator to generate the desired pulse for the SSSC voltage source inverter.

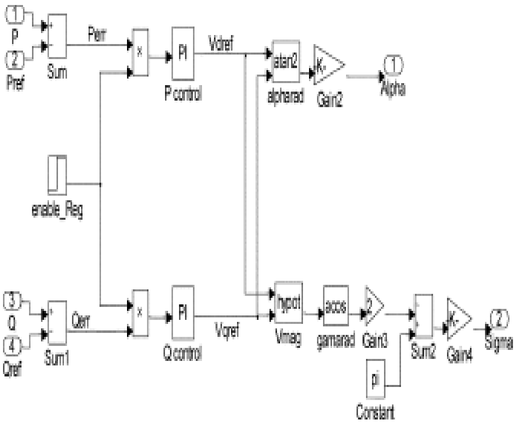
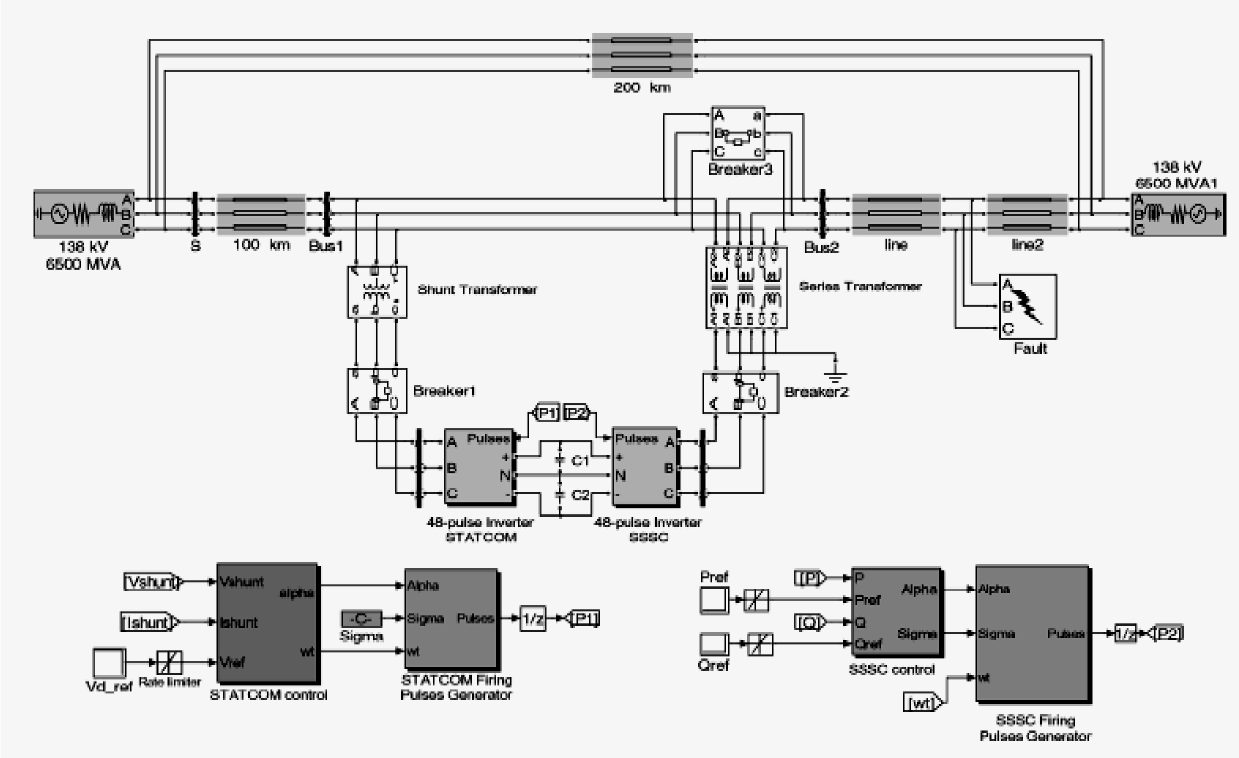


Fig :3 Control Model of SSSC

V. SIMULATION & RESULTS

SIMULINK is the software package for modeling, simulating and analyzing dynamic systems. It supports linear and non linear systems, modeled in continuous time, sampled time, or a hybrid of the system can be multi rate. For modeling, SIMULINK provides a block diagrams, using click and drag mouse operation. SIMULINK includes a comprehensive block library of sinks, sources,linearandnon linear components, and connecters. After we define a model, we can simulate it, using a choice of integration methods, either from the SIMULINK menus or by entering commands in MATALAB'S command window. Using scopes and other display blocks, we can see the simulation results while the simulation is running. In addition, we can the parameters and immediately see what happens, for "what if" exploration. Two advantages of SIMULINK are : access sophisticated routines a embedded in matlab tool box; and circuit equations are solved much faster than PSPICE. Thus SIMULINK requires less CPU run time and memory space. Two 200-km parallel 138-kV transmission lines terminated in two 6500-MVA short-circuit levels (SCLs) sources and the angle difference is 20 . The 160-MVA UPFC is installed in the middle of the second transmission line as shown in Fig.4. The simulation time step length is 0.02 ms. The UPFC consists of two 48-pulse voltage source inverters which are connected through two 2000 common dc capacitors. The first inverter known as STATCOM connects into the transmission first inverter known as STATCOM connects into the transmission system through a 15 kV/138 kV /Y shunt transformer, and injects or consumes reactive power to the transmission system to regulate the voltage at the connecting point; another inverter known as static synchronous series compensator (SSSC) connects into the system through a 15 kV/22 kV Y/Y series transformer to inject an almost sinusoidal voltage of variable magnitude and angle, in series with the transmission line to regulate the power flow through the transmission line.Fig;4 shows the system with out fault and its impedance value is calculated. Fig:5 shows the system with fault and its impedance value is calculated. Fig: 6&7 shows the system with UPFC without and with Fault . Fig: 8-12 shows the Simulationresults at various conditions .



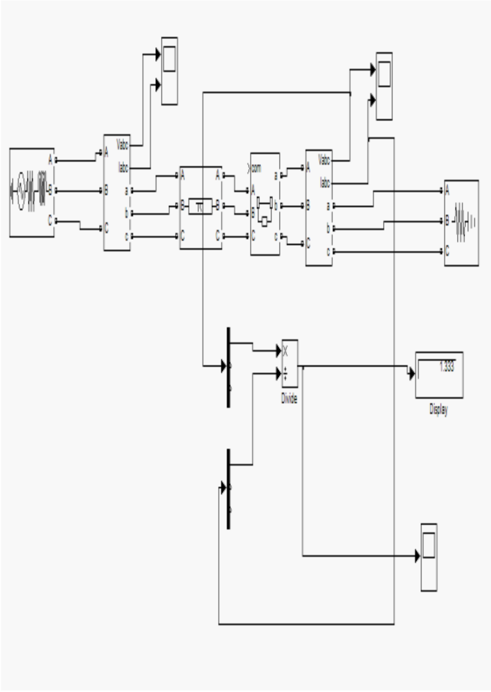


Fig.5. System without Fault

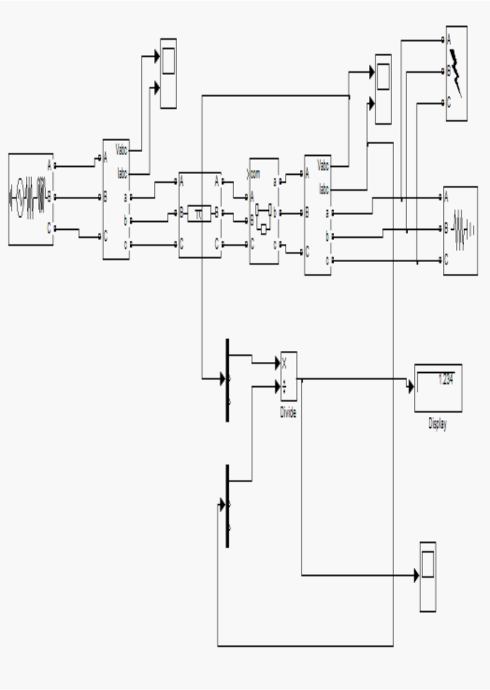


Fig.6. System with Fault without UPFC

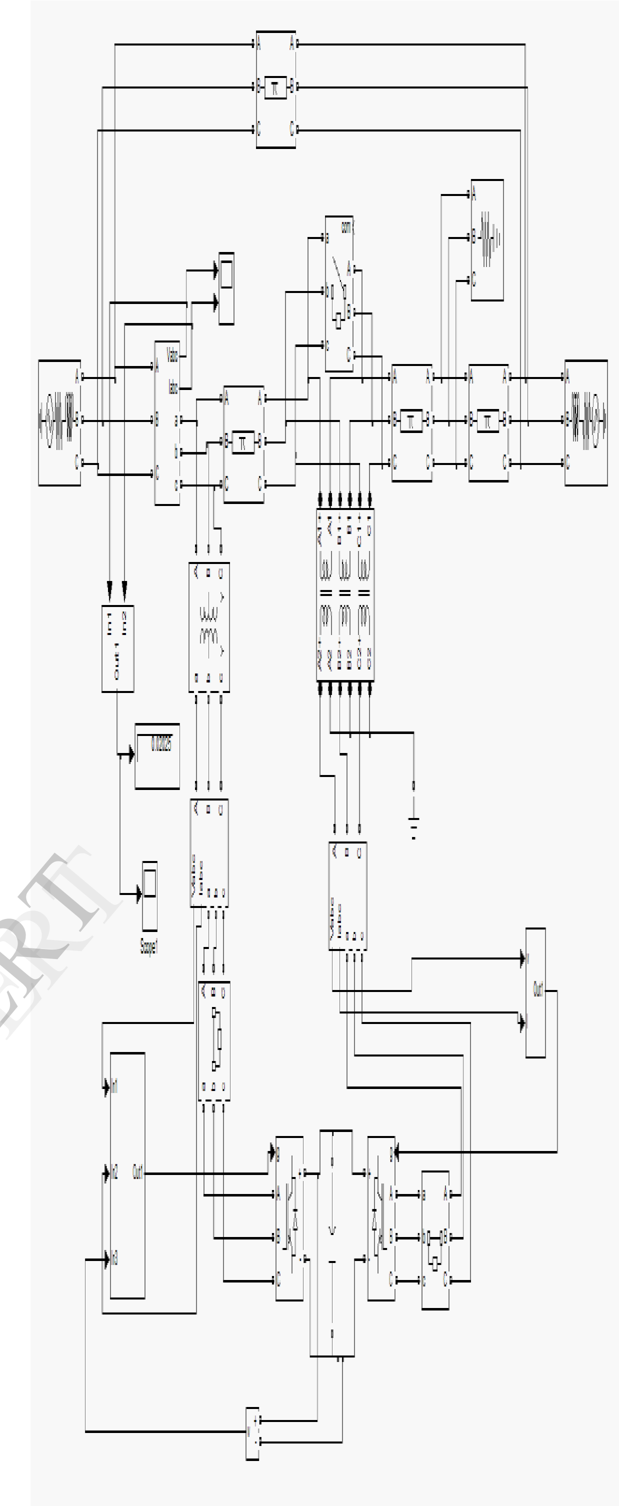


Fig.7. System with UPFC with out Fault

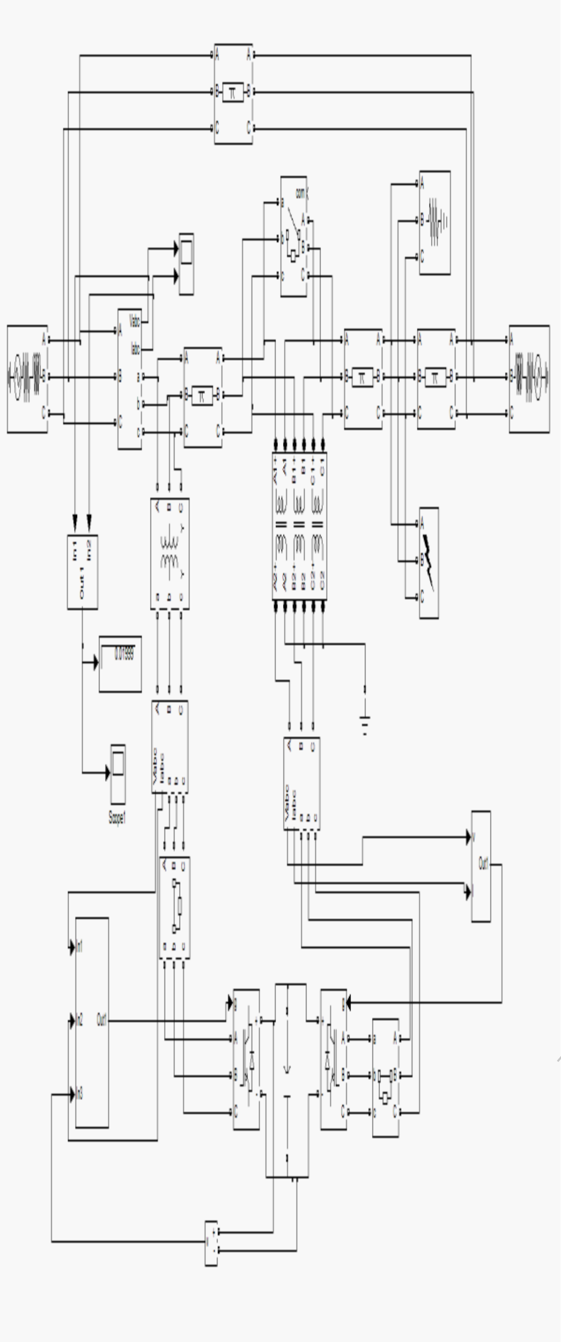


Fig.8. System with UPFC with Fault (D-Q METHOD)

Fig.9. The graph shows the three phase input voltage and current as a function of time. For the transmission system under normal condition and without UPFC

VARIOUS TYPES OF FAULT(A-G FAULT)

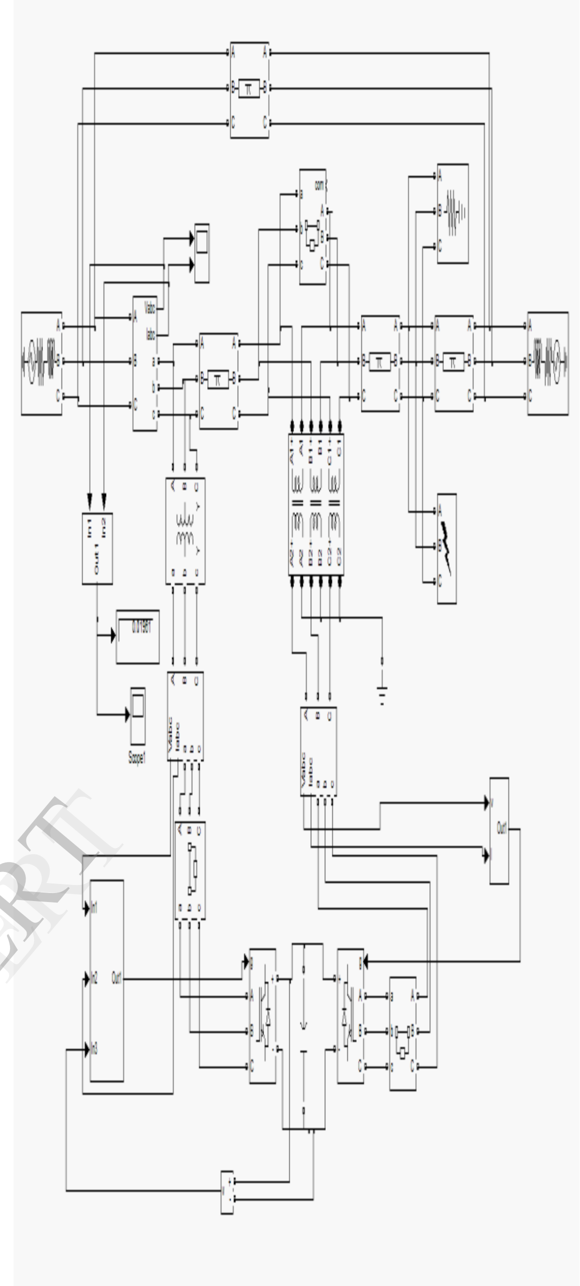
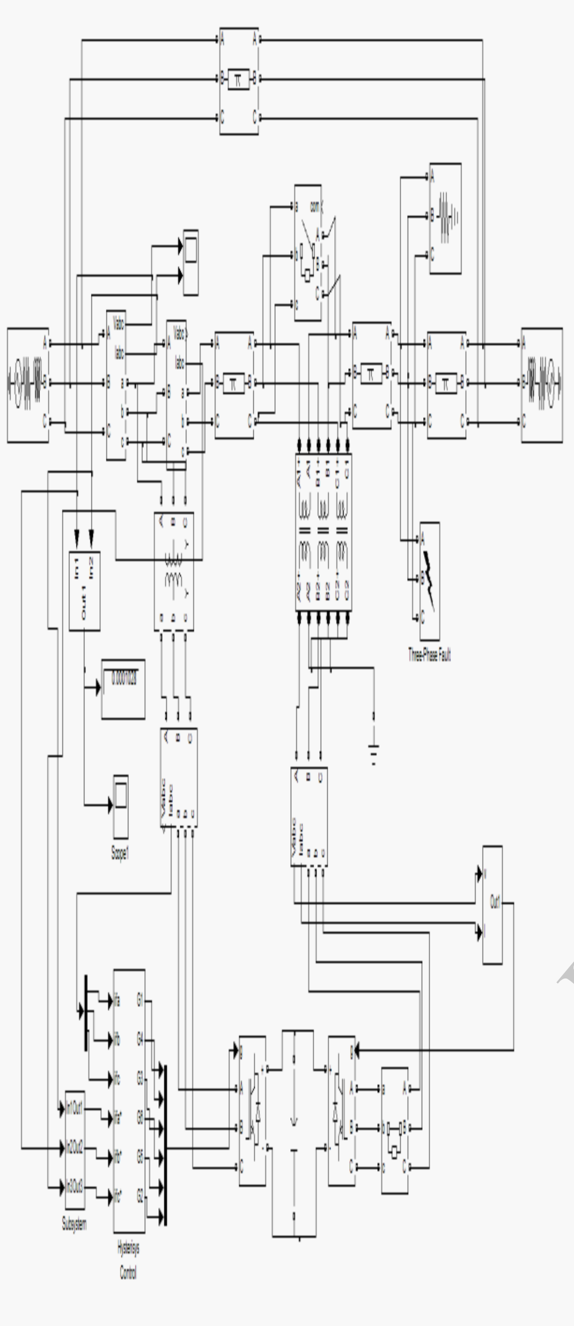


Fig. System with UPFC with A-G fault

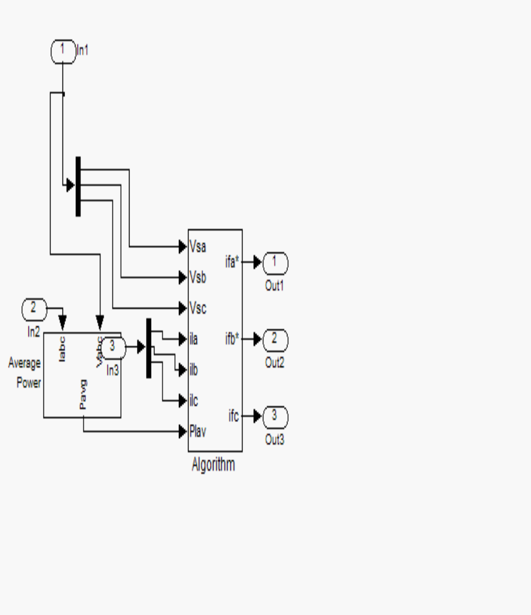
The impedance graph is simulated as shown in Fig.10.and its value is found to be **1.333Ω** .

VARIOUS CONTROL SCHEME (AP METHOD)

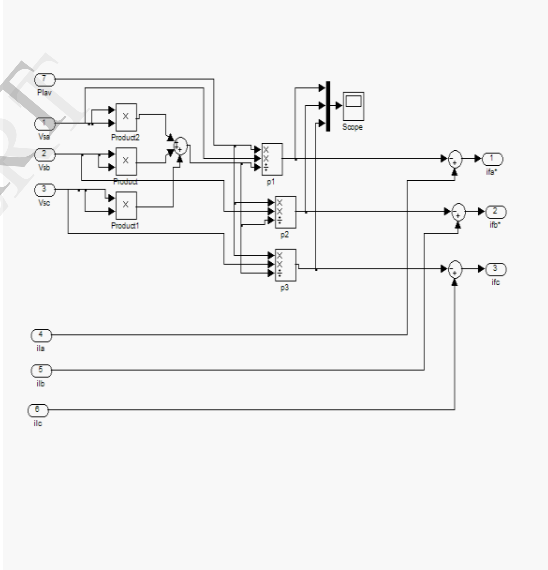


For the transmission system under faulty condition and without UPFC, the impedance graph is simulated as shown in Fig.11.& its value is found to be **1.234Ω**.During the occurrence of fault that's between 0.04 to 0.06 sec it is inferred that the impedance value is zero. Under fault

SUBSYSTEM



SUB SYSTEM- ALGORTHIM



Condition, a graph is simulated for output voltage & is inferred that during the time (0.04 to 0.06 sec) of fault the voltage reduces to zero. Under fault condition, a graph is simulated for output voltage & is inferred that during the time (0.04 to 0.06 sec) of fault the current goes to infinity as shown in fig.12.

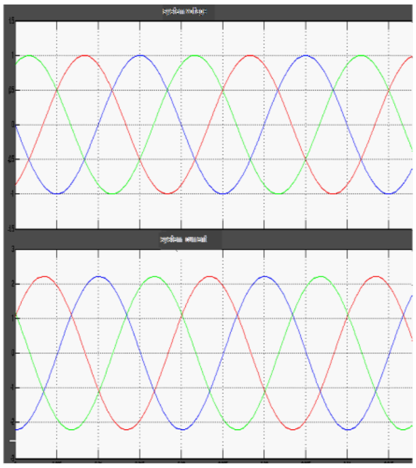


Fig.9. System Voltage & Current

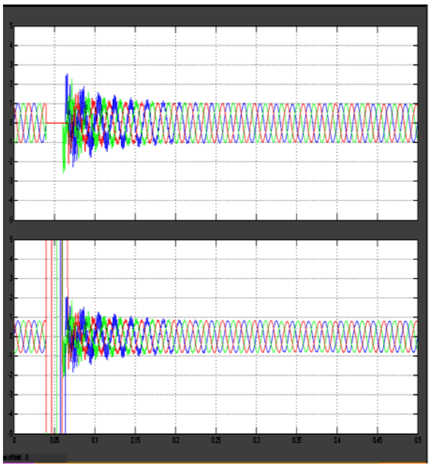


Fig.12.System Voltage & Current Under Faulty Condition

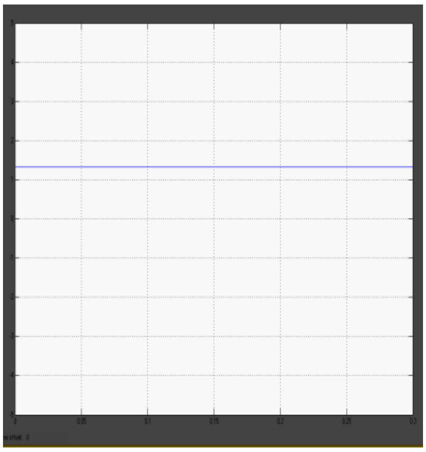


Fig.10. Impedance Under normal condition

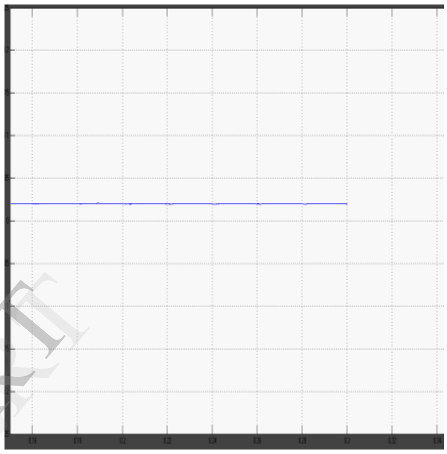


Fig.13. Impedance under normal condition with UPFC

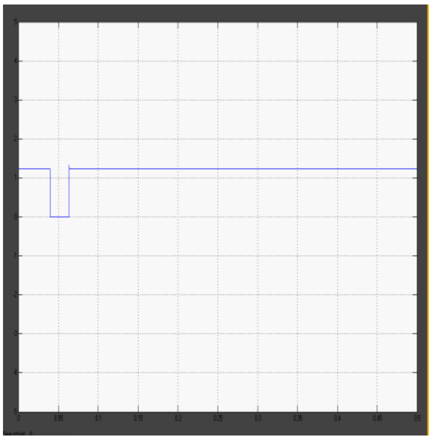


Fig.11. Change of Impedance Under Faulty Condition

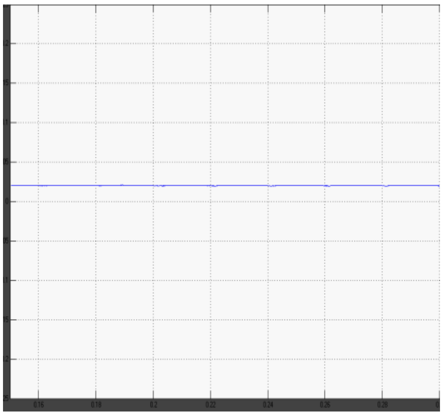


Fig: 14.Change of Impedance Under Faulty Condition With UPFC

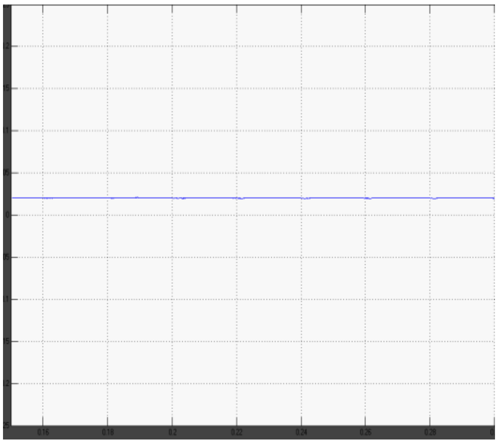


Fig: 15.Change of Impedance Under Faulty Condition With UPFC

TRAJECTORIES (D-Q method)

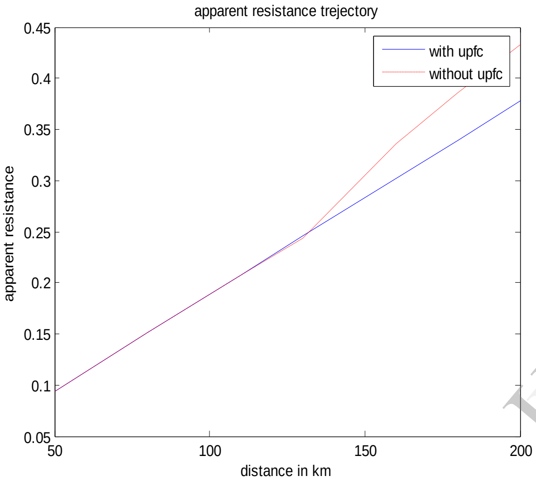


Fig:16. Apparent resistance with different fault Location

Fig .16 &17 depict the apparent resistance and reactance as a function of the fault Location with and without UPFC. Fig.18. depict the apparent impedance seen by A-G fault with and without UPFC. For the transmission system under normal condition and with UPFC, the impedance graph is simulated as shown in fig.13 & its value is found to be **0.02025Ω.**

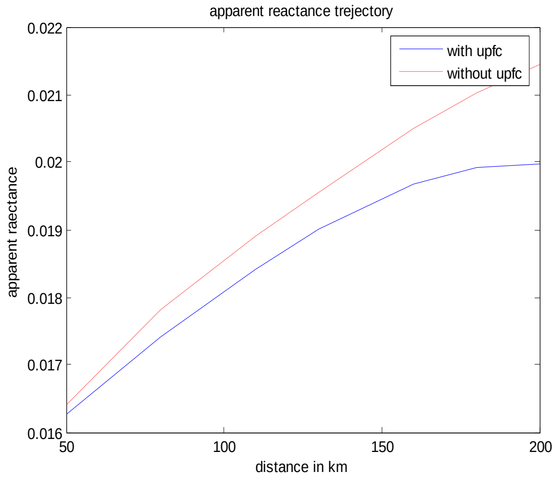


Fig:17 Apparent reactance with different fault Location

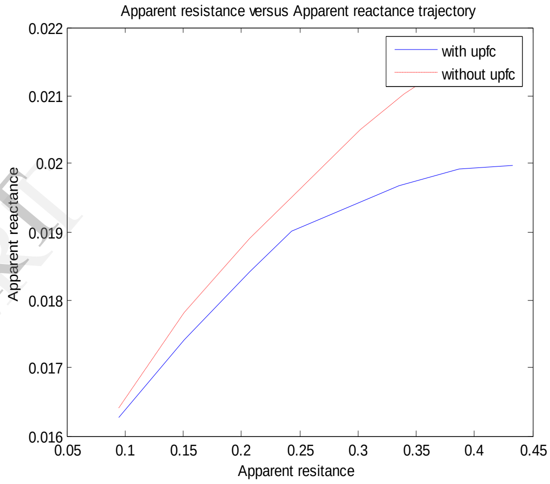


Fig:18 .Apparent impedance with different fault Location

For the transmission system under faulty condition & with UPFC, the impedance graph is simulated as shown in fig.14.-15 & its value is found to be **0.01999 Ω** the fault is assumed to be between A-G fault. The graph is also simulated for various faults (SL-G , LL-G ,LLL-G).

TABLE – I

The table –I shows the value of impedance for the system with and without UPFC under both normal and fault condition, the fault is assumed to be A-G fault.

condition	without fault(A-G)	with fault(A-G)
without UPFC	1.333 Ω	1.234 Ω
with UPFC	0.02025 Ω	0.01999 Ω

TABLE- II

The table –II shows the values of impedance for the system is tabulated for various types of faults (SL-G , LL-G , LLL-G) .

Condition	SLG FAULT			LLG FAULT			LLLG FAULT
	A-G	B-G	C-G	A-B-G	B-C-G	C-A-G	A-B-C-G
with out UPFC	1.234	1.234	1.234	1.234	1.234	1.234	1.234
with UPFC	0.01999	0.02032	0.0203	.01833	0.02038	0.02267	0.02028

TABLE-III

The table III shows the values of impedance for various control scheme with UPFC assuming A-G fault.

Methods	without fault	with fault
D-Q method	0.02025 Ω	0.01999 Ω
AP method	0.003821 Ω	0.003013 Ω

Hence analyzing method decides the operating characteristics of relay in the transmission system. From the above table III , it is concluded that AP method is giving larger deviation from the relay original characteristics than D-Q method. So D-Q method can be considered as better for analyzing relay characteristics .

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VI. CONCLUSION

The work has been done on making the model of a transmission system employing UPFC. A calculation procedure for the apparent impedance of the system with UPFC for a single phase-to-ground fault is given; this is to illustrate the adverse effect of the presence of a UPFC on the performance of a distance relay.

When the UPFC is operated as STATCOM, the apparent impedance is influenced by the reactive power injected/absorbed by the STATCOM, which will result in the under reaching or over reaching of distance relay.

The transmission system resistance, reactance and impedance for various distances with and without UPFC have been simulated and tabulated. From the simulated result the performance curves for with and without UPFC for resistance, reactance and impedance have been drawn respectively. The performance curve suggested that the actual line parameters getting deviated when including UPFC at various distance. Then the deviated line parameters will affect the performance of distance relay. Therefore the distance relay will act in under reaching or over reaching mode.

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