Study of the FACTS Equipment Operation in Transmission Systems

A PROJECT THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology
In
Electrical Engineering

By

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National Institute of Technology, Rourkela
Rourkela- 769008, Odisha

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Under the Guidance of
Prof. K.R.Subhashini

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National Institute of Technology

Certificate

This is to certify that the work contained in this thesis, titled **"STUDY OF THE FACTS EQUIPMENT OPERATION IN TRANSMISSION SYSTEMS"** submitted by **Piyush Panda** is an authentic work that has been carried out by them under my supervision and guidance in partial fulfillment for the requirement for the award of Bachelor of Technology Degree in Electrical Engineering at National Institute of Technology, Rourkela.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any Degree or Diploma.

Place: Rourkela

Date:14.05.2012

Prof. K.R.Subhashini

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Abstract

This report contains the study of Flexible AC Transmission System (FACTS) equipment operation in transmission systems. In the present scenario the demand for electrical energy has increased manifold. This has led to the facing of power transmission limitation crisis by energy transmission systems. The limitations occur due to maintaining a balance between supplying the allowed level of voltage and maintaining stability of the system. Due to the power crisis the FACTS devices play a crucial role in the present scenario. In energy transmission systems FACTS are effective equipments on power control. They help facilitating the improvement in power transmission capability while minimising the transmission losses and impact on the environment. They also aid in the improvement of power quality while maintaining the stability of the system.

The principal operating modes and applications of FACTS equipment in transmission and distribution system such as Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Thyristor controlled series capacitor (TCSC), Static Synchronous Series Compensator (SSSC) and Unified Power Flow Controller (UPFC) is discussed in this report. The characteristics of FC-TCR and UPFC were studied and their models were simulated in Matlab using simulink. In Fixed capacitor Thyristor Controlled Reactor the regulation of power flow was done by changing the firing angle of the thyristor. The compensation obtained was better than that of a normal transmission line. In case of Unified Power Flow Controller the injected voltage and the injected current were the control parameters. The power flow can be regulated by changing the magnitude or phase of the injected voltage while for the injected current the value of the injected current and the shunt resistance are varied for regulating power flow.

Acknowledgement

I am grateful to **The Department of Electrical Engineering**, for giving me the opportunity to carry out this project, which is an integral fragment of the curriculum in B. Tech programme at the National Institute of Technology, Rourkela.

I would like to express my heartfelt gratitude and regards to my project guide, **Prof. K. R. Subhashini**, Department of Electrical Engineering, for being the corner stone of my project. It was her incessant motivation and guidance during periods of doubts and uncertainties that has helped me to carry on with this project.

I would like to thank **Prof. B.D. Subudhi**, Head of the Department, Electrical Engineering for his guidance, support and direction. I am also obliged to the staff of Electrical Engineering Department for aiding me during the course of my project. I offer my heartiest thanks to my friends for their help in collection of data samples whenever necessary.

Last but not the least, I want to acknowledge the contributions of my parents and family members, for their constant and never ending motivation.

PIYUSH PANDA
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Chapter 1

Introduction

Introduction

Electrical energy plays an important role in the present industrial society and has immense importance to a nation's welfare and development. Hydro, thermal and nuclear power plants account for almost all of the energy generated. A lot of this energy is used for industrial, commercial, home, space and military applications with the application of power electronics. Power electronics technology has advanced a lot over the last two decades and as a result of this the reach of power electronics applications has spread to all voltage levels, starting from EHV transmission to low voltage circuits in the end user facilities. HVDC terminals, Static Var Compensation (SVC) systems, load transfer switches, static phase shifters, active line conditioning, energy storage, isolation switches and instantaneous backup power systems, renewable energy integration, and Various other applications are the commonly observed power electronics applications.

In an interconnected transmission network, power flow control is a key problem in designing and operating. Requirement of interconnected networks, unforeseen increase of load demands, limitations on installation of power plant in appropriate places and limitations on building new transmission lines are the factors that lead to such problems. The employment of FACTS devices in transmission lines becomes necessary owing to reasons like over loaded transmission lines in special paths, power flow in unwanted paths, and non-optimal operation of line capacity.

The major concern in world-wide distribution systems at present is power quality. For instance consumers like industrial plants mainly deal with automated processes and if the line voltage is not up to the levels of the expected quality due to voltage sags or flicker, they may incur economic losses. Therefore proper quality attached to the line voltage at the point of common coupling is very necessary. This quality cannot be achieved with conventional equipment in majority of the cases. In the last decade, improvement of power quality has been one of the most vital subjects in the development of distribution and low voltage systems. Development of devices like IGBTs (Insulated Gate Bipolar Transistors) and IGCTs (Insulated Gate Commutated Thyristors) has made it possible to build PWM converters. These converters are widely used for adjustable speed drives and are mass-produced for power ratings in the MVA range. The converters, along with conventional equipment and use of new improved control algorithms, are used for mitigation of power quality problems. They are also known as power conditioners.

1.1 Advantages of FACTS Devices

FACTS devices provide the following advantages:

- Improvement in power transmission capability
- Improvement of system stability and availability
- Improvement of power quality
- Minimising the environmental impact
- Minimising the transmission losses

1.2 Project Objective

The main objective of this project is to study the equipment operation of Various FACTS devices used in transmission systems.

1.3 Organization of the Thesis

This documentation deals with the study of the different FACTS equipment devices employed in transmission systems.

This thesis consists of four chapters.

Chapter 1 is an introduction and gives the overview of the project along with its main objective.

Chapter 2 discusses briefly about the concepts of FACTS and the theory about FACTS equipment.

Chapter 3 contains the simulation of the Various FACTS equipments in MATLAB/SIMULINK® and discusses the results.

Chapter 4 concludes the thesis and gives a brief summary of the work done.

Chapter 2

Flexible AC Transmission Systems (FACTS)

2.1 Introduction

In the past few years the demand for electrical energy has increased significantly and as a result energy transmission systems are facing power transmission limitation crisis. The limitations occur due to keeping a balance between maintaining stability and supplying the allowed level of voltage. As a result of this the practical operation capacity of the system is far less than the real capacity. This results in non-optimal operation of the energy transmission systems. One among the solutions to this problem of increasing power transmission capacity is construction of new transmission lines. This is not feasible both economically and practically. Due to the developing semiconductor industry and its applications in power systems, the concept of FACTS is offered, to enhance the real capacity of transmission lines without having to construct any new transmission lines. The major drawback in using thyristor switches is that the control for turn-off capability is not possible. Hence in a cycle, switching more than once is not possible. After the invention of IGBT and GTO which are semiconductor devices with controlled turn-off capability the transmission system was revolutionised. This development resulted in the use of VSCs in the field of energy transmission. The advantage of this is the generation and absorption of reactive power without the use of devices like capacitor or reactor. All FACTS equipment designed by Voltage Source Converters are known as FACTS new generation devices.

The approach of engineers towards planning and operation of power systems will be changed by the implementation of FACTS devices. The equipments can be applied in series, shunt or shunt-series in transmission lines, and the control of the operation parameters in transmission systems in steady state and system dynamic behavior in transient state can be achieved.

FACTS devices have the following applications [1]

- power flow control
- increase of transmission capability
- voltage control
- reactive power compensation
- stability improvement
- power quality improvement
- power conditioning
- flicker mitigation
- interconnection of renewable and distributed generation and storages

The use of FACTS-devices is achieved through switched or controlled shunt compensation, series compensation or phase shift control. The devices work electrically as fast current, voltage or impedance controllers. The reaction time allowed by power electronic is very short and goes down to far below one second. A structured overview on FACTS-devices is given ahead. The devices are mapped to their different fields of applications.

2.2 Overview

The growing capabilities of power electronic components have led to the development of FACTS-devices. For high and even highest voltage levels, devices for high power levels have been made available in converters. The network elements influencing the reactive power or the impedance of a part of the power system are the overall starting points.

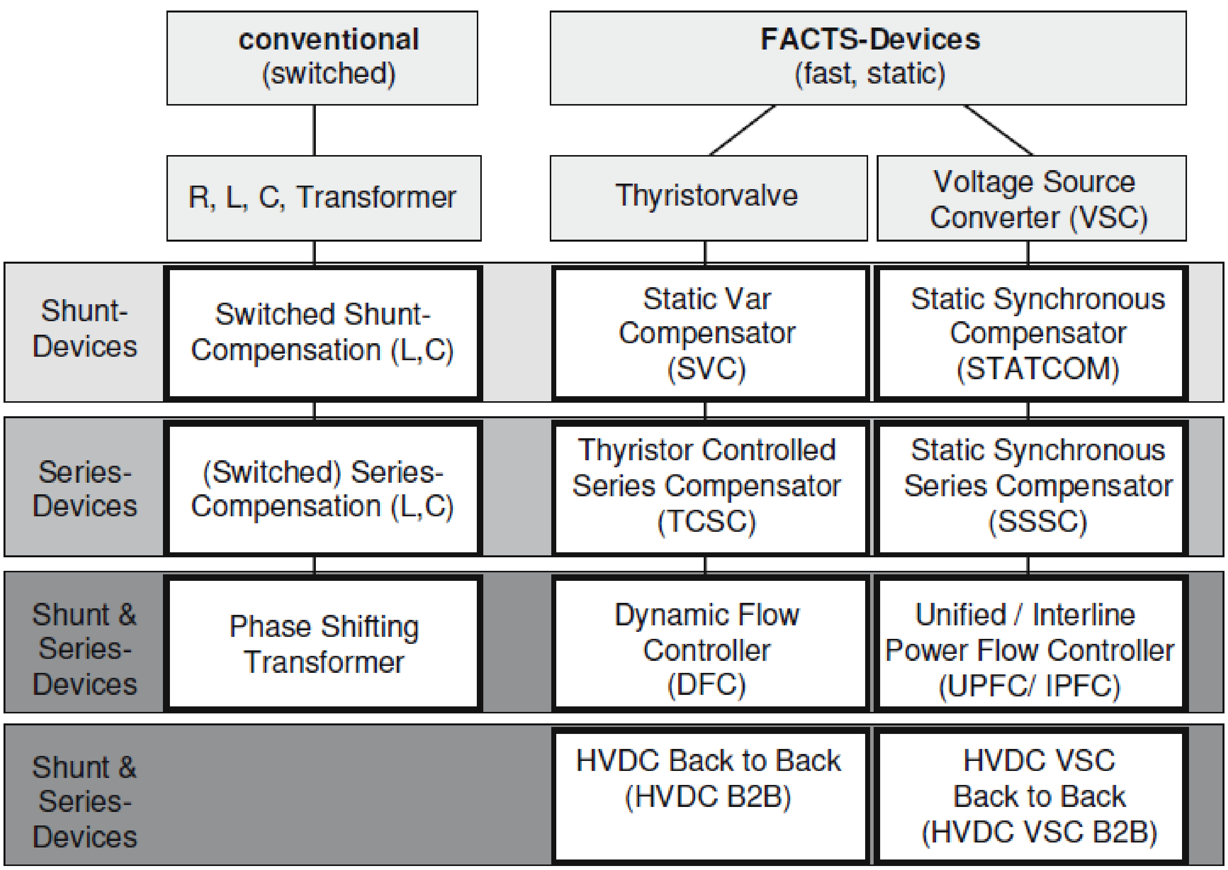


Fig.1: Overview Of major FACTS devices [1]

Fig. 1[1] gives a depiction of number of basic devices separated into the conventional ones and the FACTS-devices is done. For the FACTS side the taxonomy is in terms of dynamic and static. The term dynamic implies the fast controllability of FACTS-devices facilitated by the power electronics. This is one of the main differentiation factors from the conventional devices. The term static implies that no moving parts like mechanical switches are present in the devices to perform the dynamic controllability. Hence most of the FACTS-devices can be static as well as dynamic.

The left hand side column in Fig. 1 shows the conventional devices build out of fixed or mechanically switchable components like resistance, inductance or capacitance together with transformers. The FACTS-devices along with these elements use additional power electronic valves or converters to switch the elements in smaller steps or with switching patterns within a cycle of the alternating current. The left hand side column of FACTS-devices employs the use of thyristor valves or converters. These valves or converters are well known since several years. They have low switching frequency of once a cycle in the converters and hence the have low losses. The thyristors can be also used to simply bridge impedances in the valves.

The right hand side column of FACTS-devices has more advanced technology of voltage source converters based mainly on Insulated Gate Bipolar Transistors (IGBT) or Insulated Gate Commutated Thyristors (IGCT). Due to a pulse width modulation of the IGBTs or IGCTs, a free controllable voltage in magnitude and phase is provided by voltage source converters. The modulation frequency is high. As a result of this low harmonics are allowed in the output signal and disturbances coming from the network are even compensated. But with an increased switching frequency, the losses increase as well. This is the only disadvantage. This can be compensated by special designs of the converters.

2.3 Configuration Of FACTS Devices

2.3.1 Shunt Devices

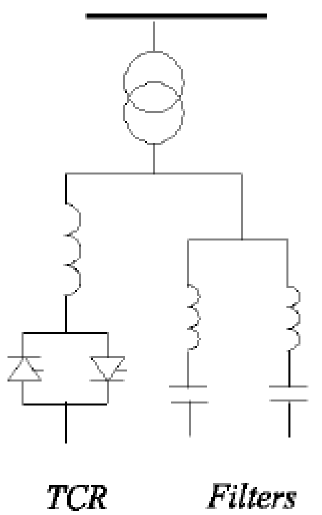
SVC or the version with Voltage Source Converter called STATCOM is the most used FACTS-device. These devices operate as reactive power compensators. The following are the major applications of the shunt devices in transmission, distribution and industrial networks [1]:

- Reduced network losses by reduction of unwanted reactive power flows
- Maintaining contractual power exchanges with balanced reactive power
- Compensation of consumers and improvement of power quality especially with huge demand fluctuations like industrial machines, metal melting plants, railway or underground train systems
- Compensation of Thyristor converters e.g. in conventional HVDC lines
- Improvement of static or transient stability.

In industrial applications almost half of the SVC and more than half of the STATCOMs are used .Power quality is the requirement of industry as well as commercial and domestic groups of users. The interruptions of industrial processes due to insufficient power quality or flickering lamps are not any more entertained. Weak network connections with severe voltage support problems are given a special attention.

2.3.1.1 <u>Static Var Compensator (SVC)</u>

Static Var Compensator is based on thyristor controlled reactors (TCR), thyristor switched capacitors (TSC), and/or Fixed Capacitors (FC) tuned to Filters. A TCR has a fixed reactor in series with a bi-directional thyristor valve. There are various types of TCR reactors like air core type, glass fibre insulated, epoxy resin impregnated [2].



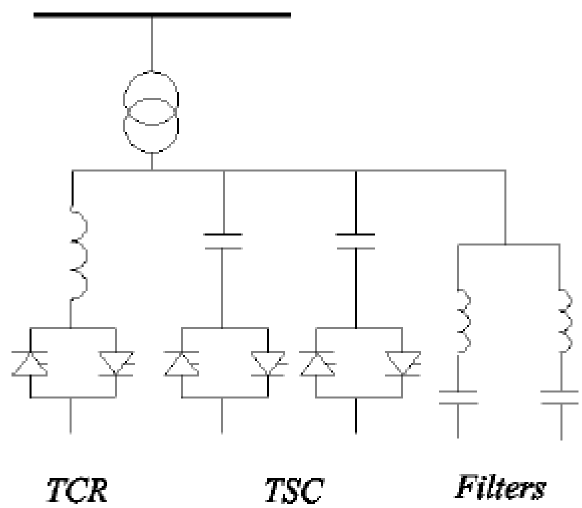


Fig. 2a: Configuration of TCR/FC Fig. 2b: Configuration of TCR/TSC

A capacitor bank which is in series with a bi-directional thyristor valve and a damping reactor which also has a function of detuning the circuit to avoid parallel resonance with the network consist the TSC. For an integral number of half-cycles of the applied voltage the thyristor switch acts to connect or disconnect the capacitor bank. For satisfaction of a number of criteria and requirements in the operation in the grid a complete SVC based on TCR and TSC may be designed in many ways. In Fig. 2a and 2b two very common design types are shown. Both have their specific merits.

In Fig. 3 below the V-I characteristics of the SVC is shown [1]

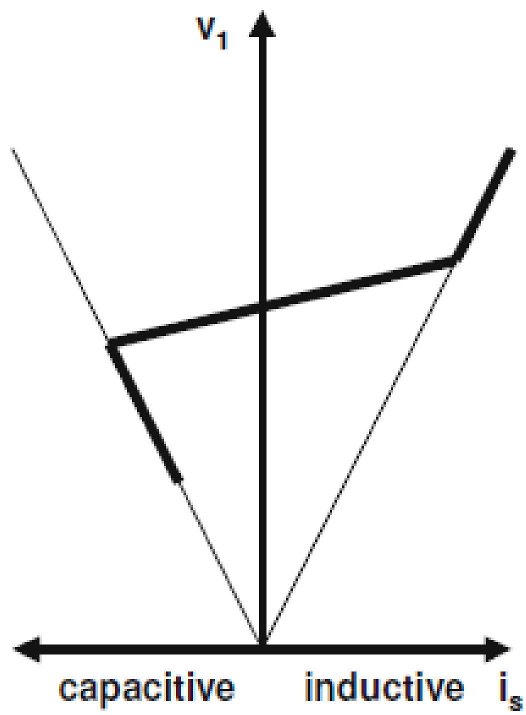


Fig.3: Voltage/Current Characteristics of SVC [1]

2.3.1.2 Static Synchronous Compensator (STATCOM)

In transmission lines STATCOM is applied in shunt and it has the capability to dynamically adjust the required reactive power within the capability of the converter. The controlled current drawn by the converter has two components: active component and reactive component. The active component automatically meets the requirement of active power in DC link capacitor, whereas the reactive component of current is used for desired reference level. Fig.4 shows the structure of the STATCOM [1] while the operational characteristic is shown in Fig. 5.

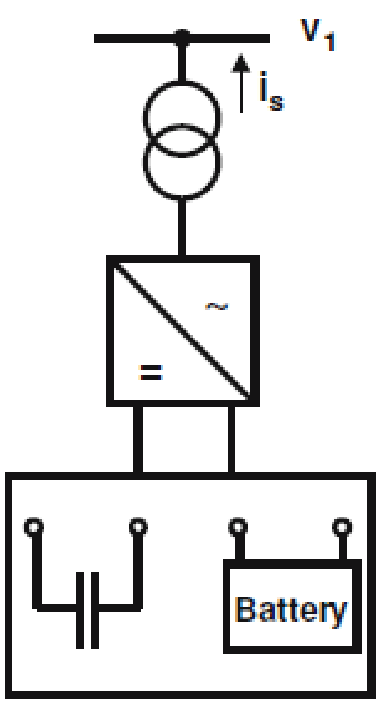


Fig.4: STATCOM Structure [1]

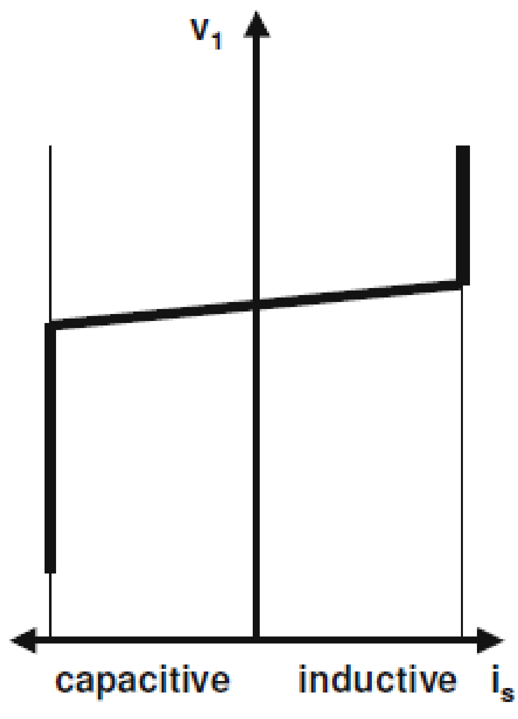


Fig.5: Voltage/Current Characteristics [1]

The control characteristic for the voltage is determined by the steepness of the static line between the current limitations. The STATCOM has the advantage that the reactive power provision is independent from the actual voltage on the connection point. This can be inferred from the diagram for the maximum currents being independent of the voltage in comparison to the SVC in Fig. 5. This means, that even during most severe contingencies, the STATCOM keeps its full capability.

In STATCOM there are two modes of operation [2]. They are as follows:

Reactive power (Var) control mode:-

An inductive or capacitive reactive power request is taken to be the reference input in reactive power control mode. The Var reference is transferred into a corresponding current request by the converter control and the gating of the converter is adjusted to establish the desired current.

Automatic voltage control mode:-

The voltage control mode is normally used in practical applications. In voltage control mode to maintain the transmission line voltage to a reference value at the point of connection the converter reactive current is automatically regulated.

2.3.2 Series Devices

From fixed or mechanically switched compensations the series devices have further developed to the Thyristor Controlled Series Compensation (TCSC) and Voltage Source Converter based devices. The major applications are [1]:

- reduction of series voltage decline in magnitude and angle over a power line
- reduction of voltage fluctuations within defined limits during changing power transmissions
- improvement of system damping resp. damping of oscillations
- limitation of short circuit currents in networks or substations
- avoidance of loop flows resp. power flow adjustments

2.3.2.1 Thyristor Controlled Series Capacitor (TCSC)

Specific dynamical issues in transmission systems are addressed by Thyristor Controlled Series Capacitors (TCSC). In case of large interconnected electrical systems it increases damping. It also overcomes the problem of Sub- Synchronous Resonance (SSR) [2]. Sub-Synchronous Resonance is a phenomenon that involves an interaction between large thermal generating units and series compensated transmission systems. The high speed switching capability of TCSCs provides a mechanism for controlling line power flow. This permits increased loading of existing transmission lines, and also allows for rapid readjustment of line power flow in response to various contingencies. Regulation of steady-state power flow within its rating limits can be done by the TCSC.

The TCSC resembles the conventional series capacitor from a basic technology point of view. All the power equipment is located on an isolated steel platform, including the Thyristor valve which is used for controlling the behaviour of the main capacitor bank. Similarly the control and protection is located on ground potential along with other auxiliary systems. The principle setup of a TCSC is shown in Fig.6 and Fig. 7 shows its operational diagram. The boundary of the operational diagram is determined by the firing angle and the thermal limits of the Thyristors.

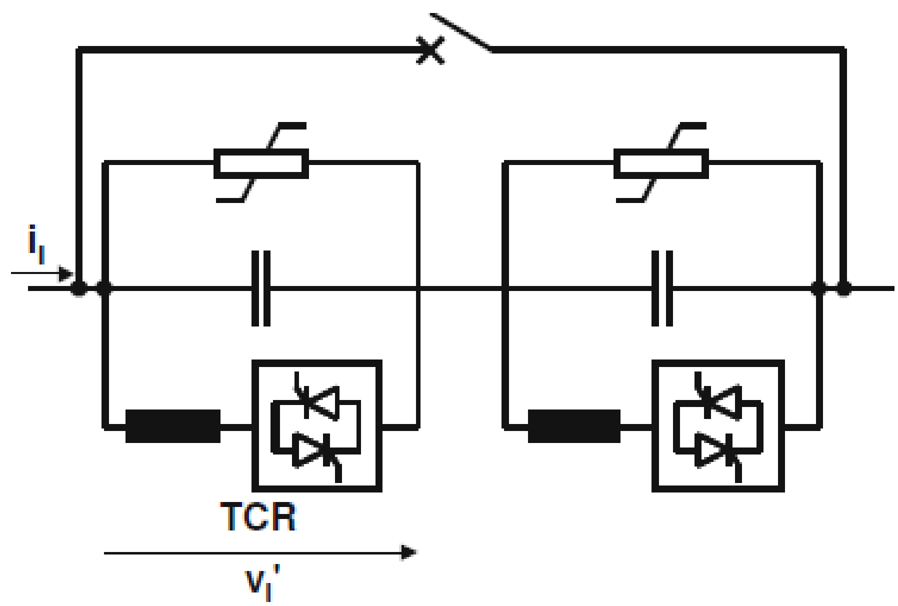


Fig. 6: Principle setup of TCSC [1]

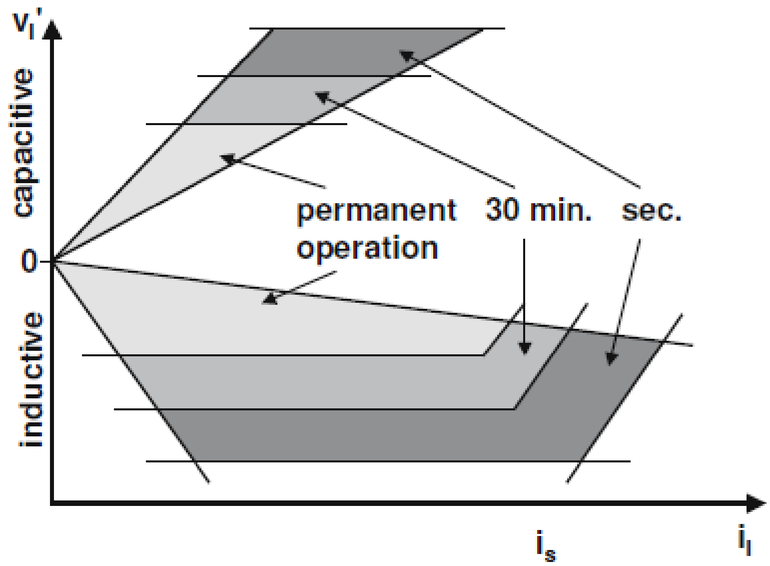


Fig. 7: Operational characteristics of TCSC [1]

2.3.2.2 Static Synchronous Series Compensator (SSSC)

The SSSC is connected in transmission line in series and it injects a voltage with controlled magnitude and angle into it. The flowing power on the line is controlled by the injected voltage [2]. The injected voltage is however dependent on the operating mode selected for the SSSC to control power flow. The principle setup of a SSSC is shown below in Fig. 8.

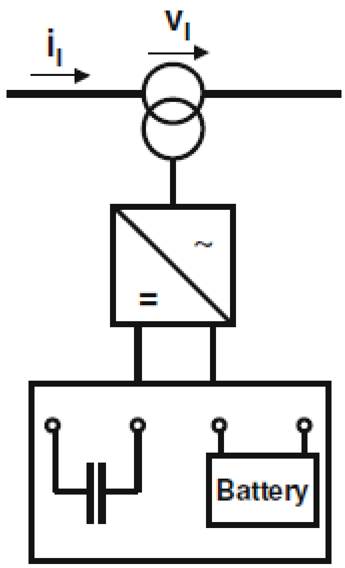


Fig. 8: Principle Setup of SSSC [1]

There are two operating modes which are as follows:

Line impedance compensation mode:-

When the injected voltage is kept in quadrature with respect to the line current, so that the series insertion emulates impedance when viewed from the line, to emulate purely reactive (inductive or capacitive) compensation. This mode can be selected to match existing series capacitive line compensation in the system.

Automatic power flow control mode:-

The magnitude and angle of the injected voltage is controlled so as to force such a line current that results in the desired real and reactive power flow in the line. In automatic power flow control mode, the series injected voltage is determined automatically and continuously by a closed-loop control system to ensure that the desired real and reactive power flow are maintained despite power system changes.

2.3.3Shunt and Series Devices

2.3.3.1 Unified Power Flow Controller

The UPFC is a combination of a static compensator and static series compensation. It acts as a shunt compensating and a phase shifting device simultaneously. The UPFC consists of a shunt and a series transformer, which are connected via two voltage source converters with a common DC-capacitor [2]. The DC-circuit allows the active power exchange between shunt and series transformer to control the phase shift of the series voltage [8]. The series converter needs to be protected with a Thyristor bridge. Due to the high efforts for the Voltage Source Converters and the protection, an UPFC is getting quite expensive, which limits the practical applications where the voltage and power flow control is required simultaneously.

CHAPTER 3

Simulation

&

Discussion

3.1 Simulation of Transmission Line Without FACTS Devices:-

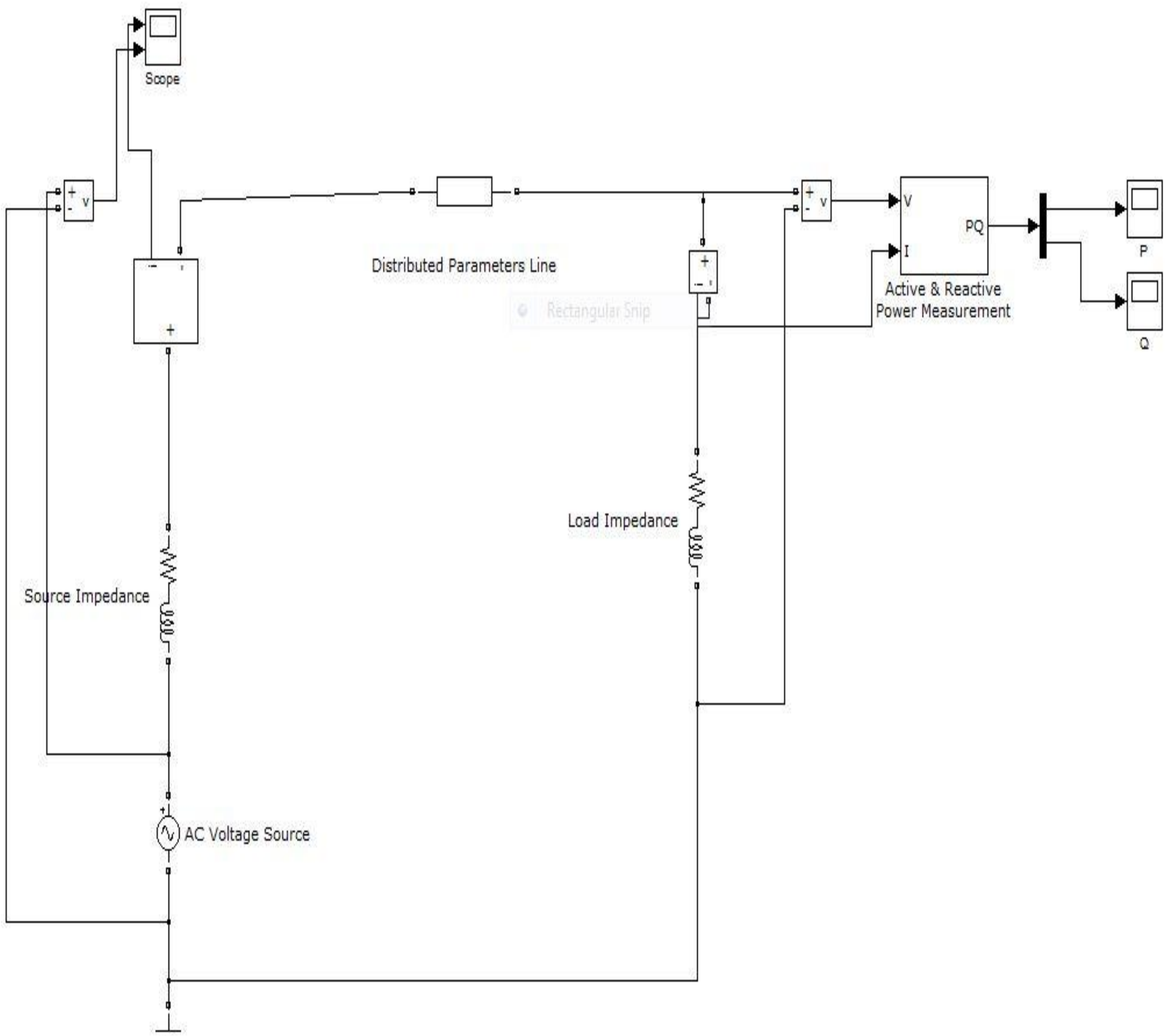


Fig.9: Transmission line model for 11kv

Fig.9 shows a transmission model of 11kv [9]. The transmission line is considered to be a short transmission line hence the capacitance of the line is neglected. The line parameters are given subsequently. The line length is 50 km. The resistance of the line is 0.1Ω/km and the inductance is 460 mH /km. The load impedance is (1+j0.02) Ω whereas the source impedance is taken to be (5.5+j0.05) Ω. The current and voltage measurement blocks are used to measure the voltage and current at source. By the use of Active and Reactive Power Measurement Block, the real and reactive power in the load is measured.

3.1.1 Results of Simulation

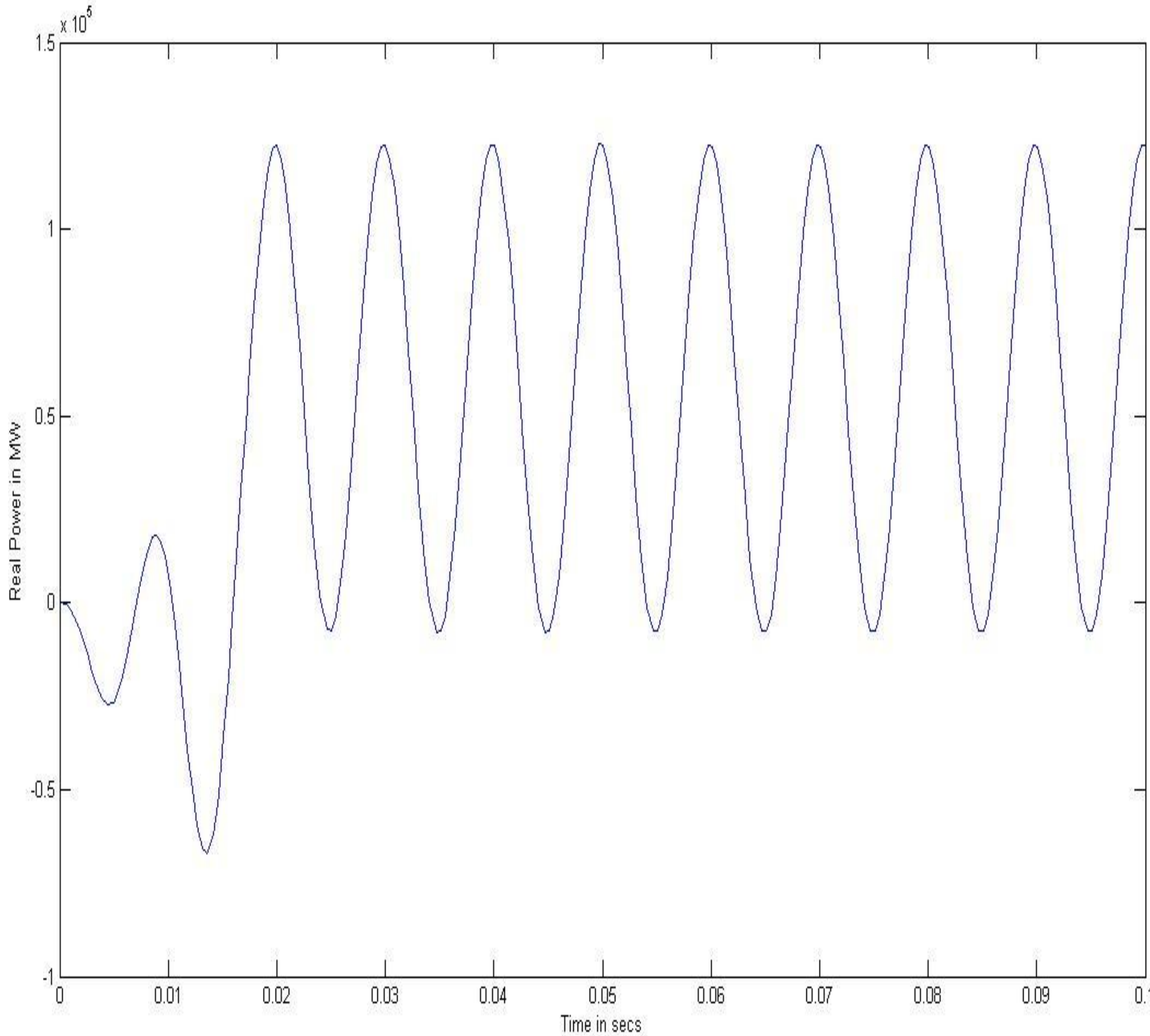


Fig.10: Graph of Real Power Vs Time

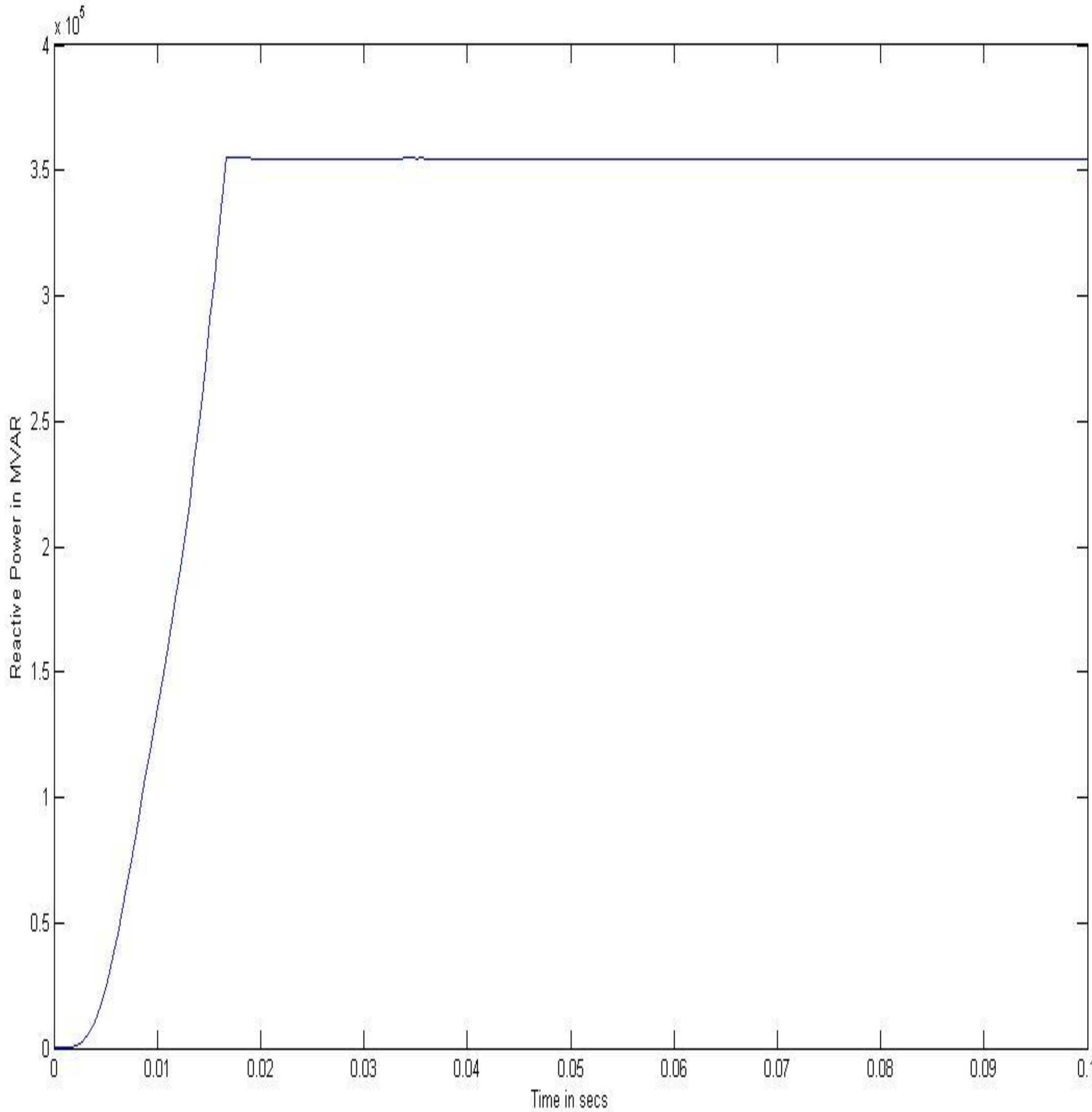


Fig.11: Graph of Reactive Power Vs Time

The value of Real power obtained from the simulation was found to be 0.12 MW as shown in Fig. 10.The power flow was obtained without any compensation. The value of reactive power obtained from the simulation was found to be 0.35 MVAR as shown in Fig.11. The power flow was obtained without any compensation. By introducing FACTS controller in the transmission line the power flow can be increased.

3.2 Simulation of Transmission Lines with Introduction of FACTS Devices

3.2.1 Introduction of Fixed Capacitor Thyristor Reactor

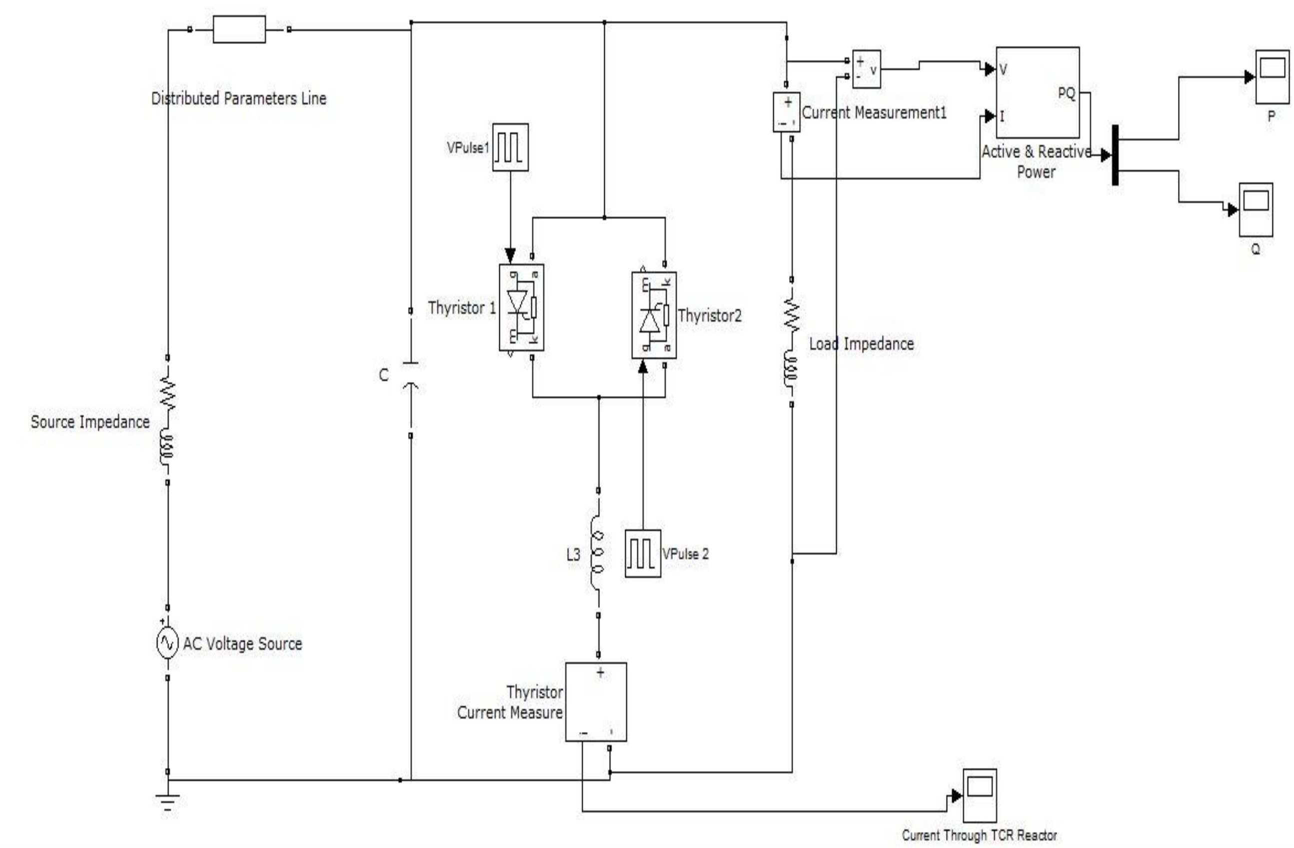


Fig.12: Transmission line model for 11kv with a Fixed Capacitor Thyristor Controlled Reactor

In Fig. 12 above the model of Fixed Capacitor-Thyristor Controlled Reactor (FC-TCR) with a line voltage of 11kV is shown [9]. The transmission line is considered to be a short transmission line hence the capacitance of the line is neglected. The line parameters are given subsequently. The line length is 50 km. The resistance of the line is 0.1Ω/km and the inductance is 460 mH /km. The load impedance is (1+j0.02) Ω whereas the source impedance is taken to be (5.5+j0.05) Ω. The current and voltage measurement blocks are used to measure the voltage and current at source. By the use of Active and Reactive Power Measurement Block, the real and reactive power in the load is measured. The value of the capacitor is taken to be 200µF. It can be changed according to need.

3.2.1.1 Results of Simulation

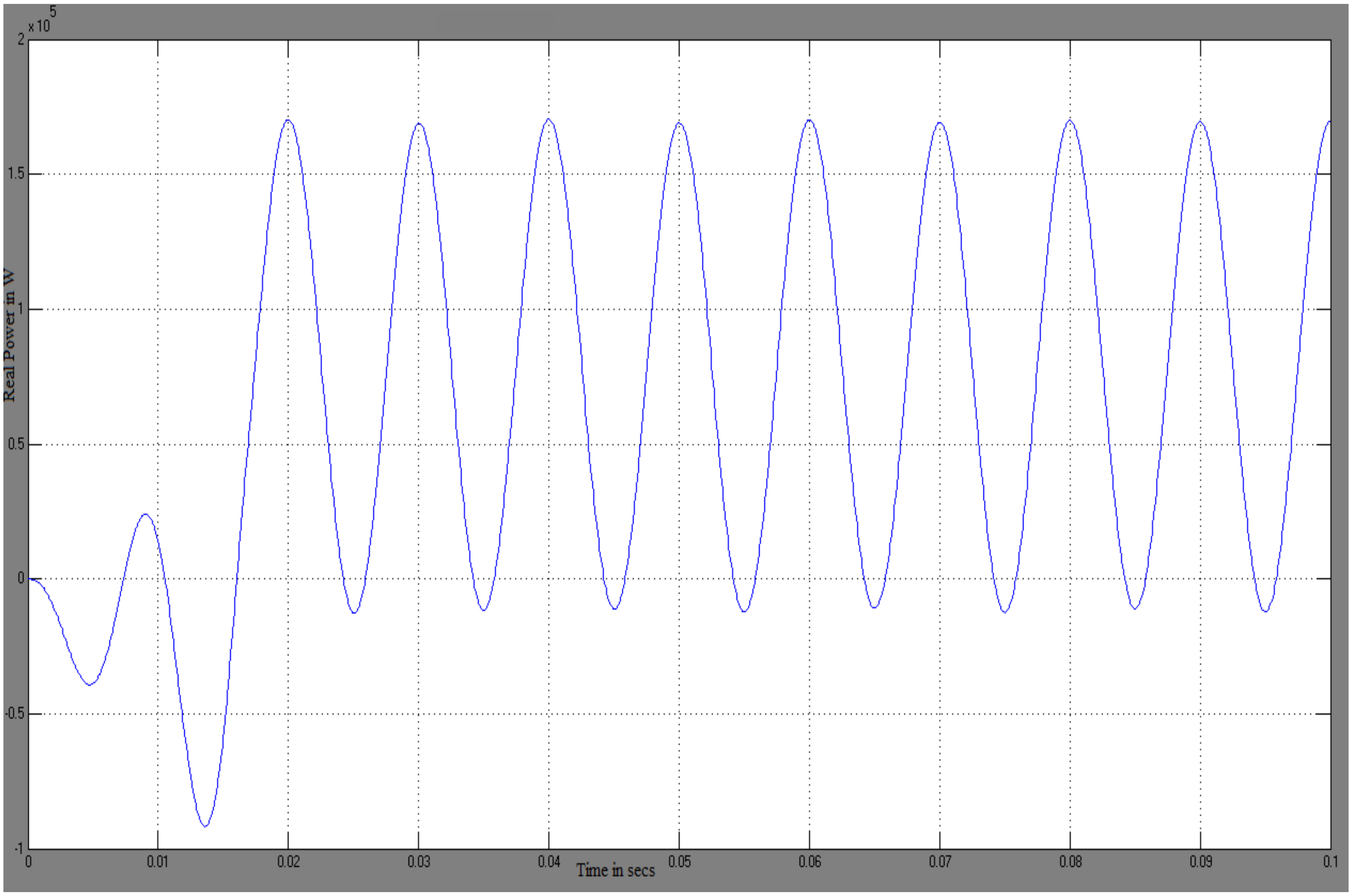


Fig.13: Graph of Real Power Vs Time

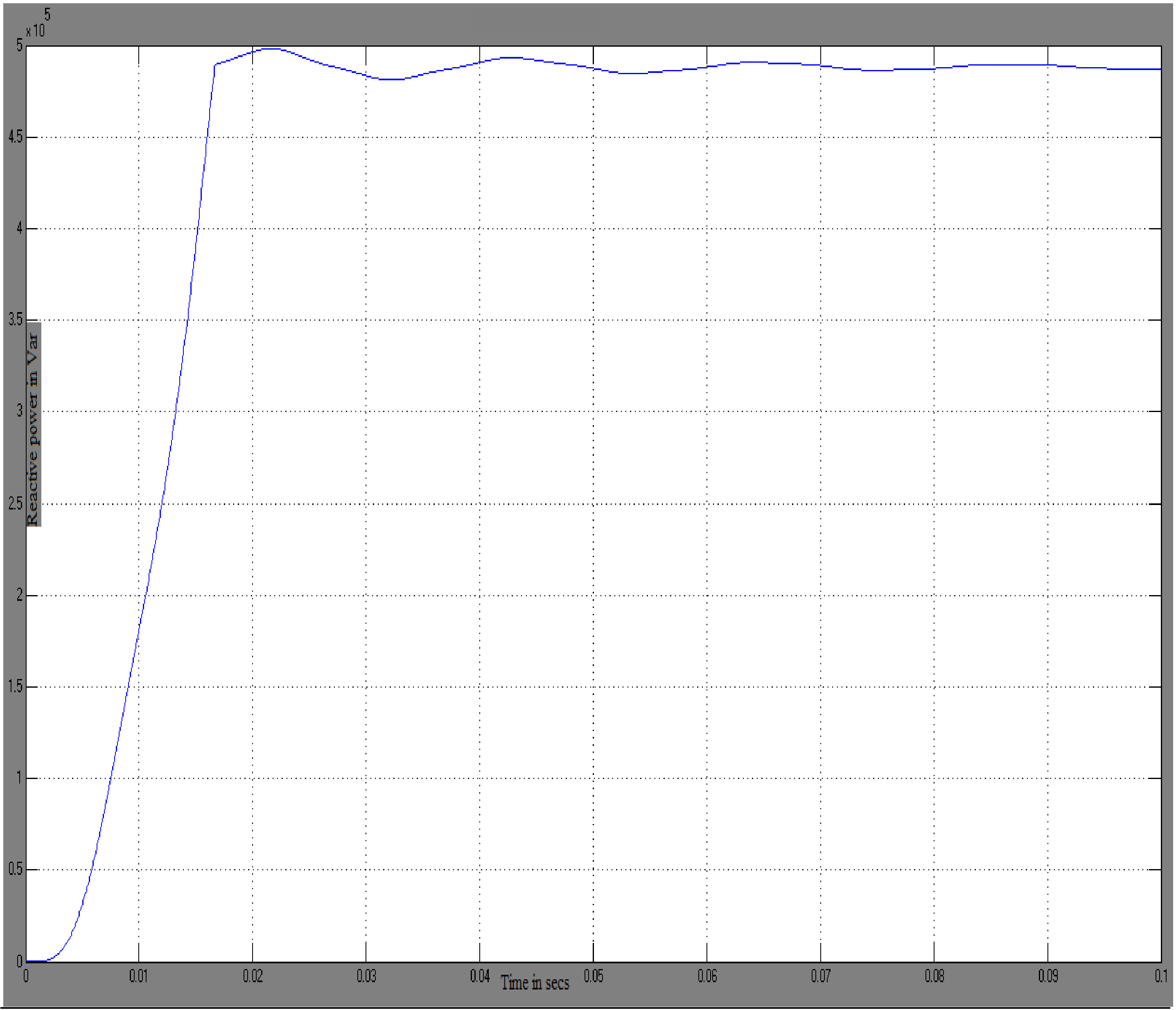


Fig.14: Graph of Reactive Power Vs Time

The value of Real power obtained is 0.17 MW as shown in Fig. 13.The power flow was obtained with compensation. The value of reactive power was obtained to be 0.5 MVAR as shown in Fig.14. The power flow was obtained with compensation. By introducing FACTS controller in the transmission line the power flow is seen to be increased.

The power in the load in case of a FC-TCR can be regulated by two factors

1. The capacitance C
2. The delay angle of the thyristor

3.2.1.1.1 Effect of Change in Value Of Fixed Capacitor

The change of power flow with change in the value of the capacitance is studied. The value of C is taken to be 300µF and the corresponding Graphs of active and reactive power is observed.

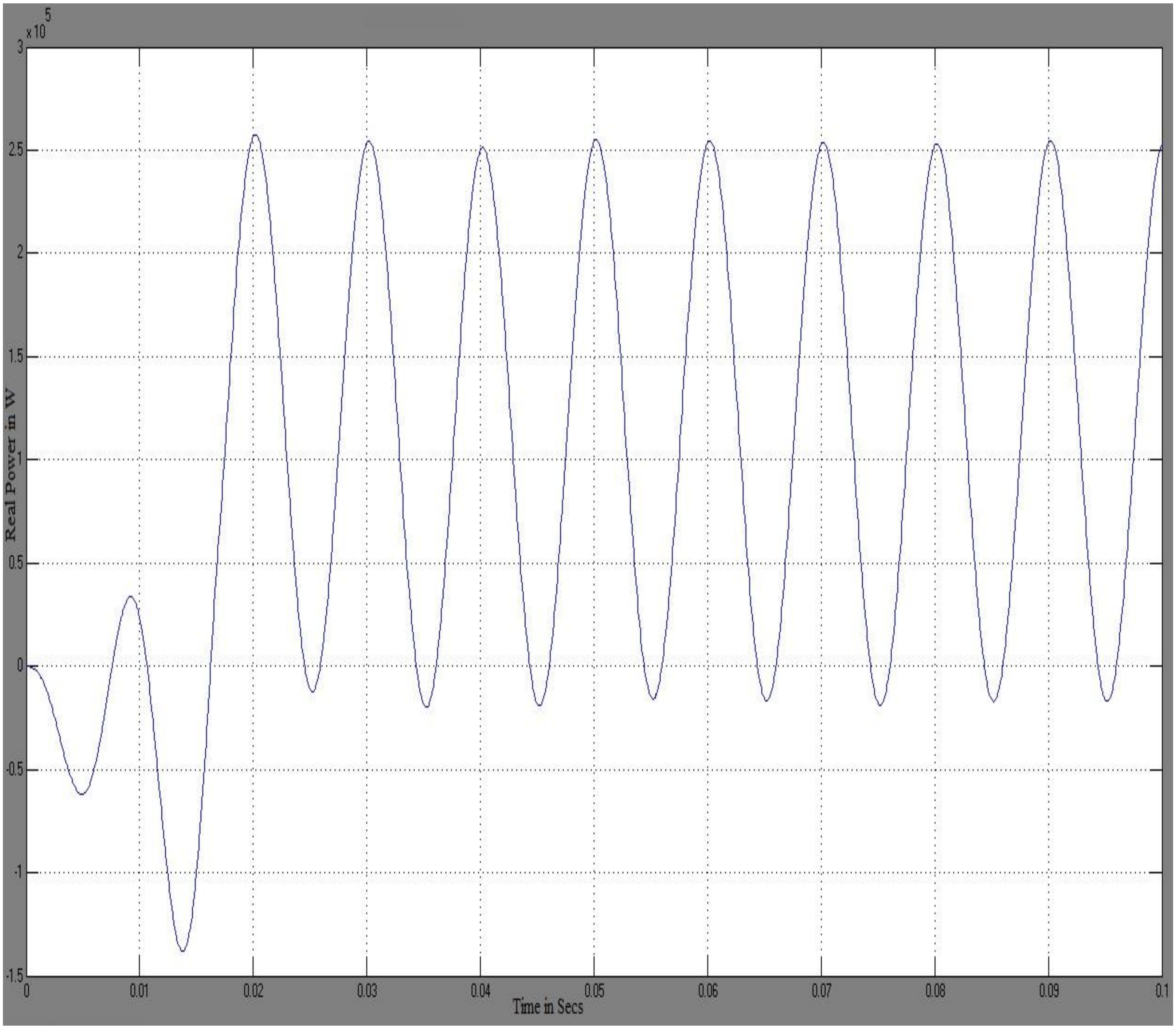


Fig.15: Graph of Real Power Vs Time for C=300μF

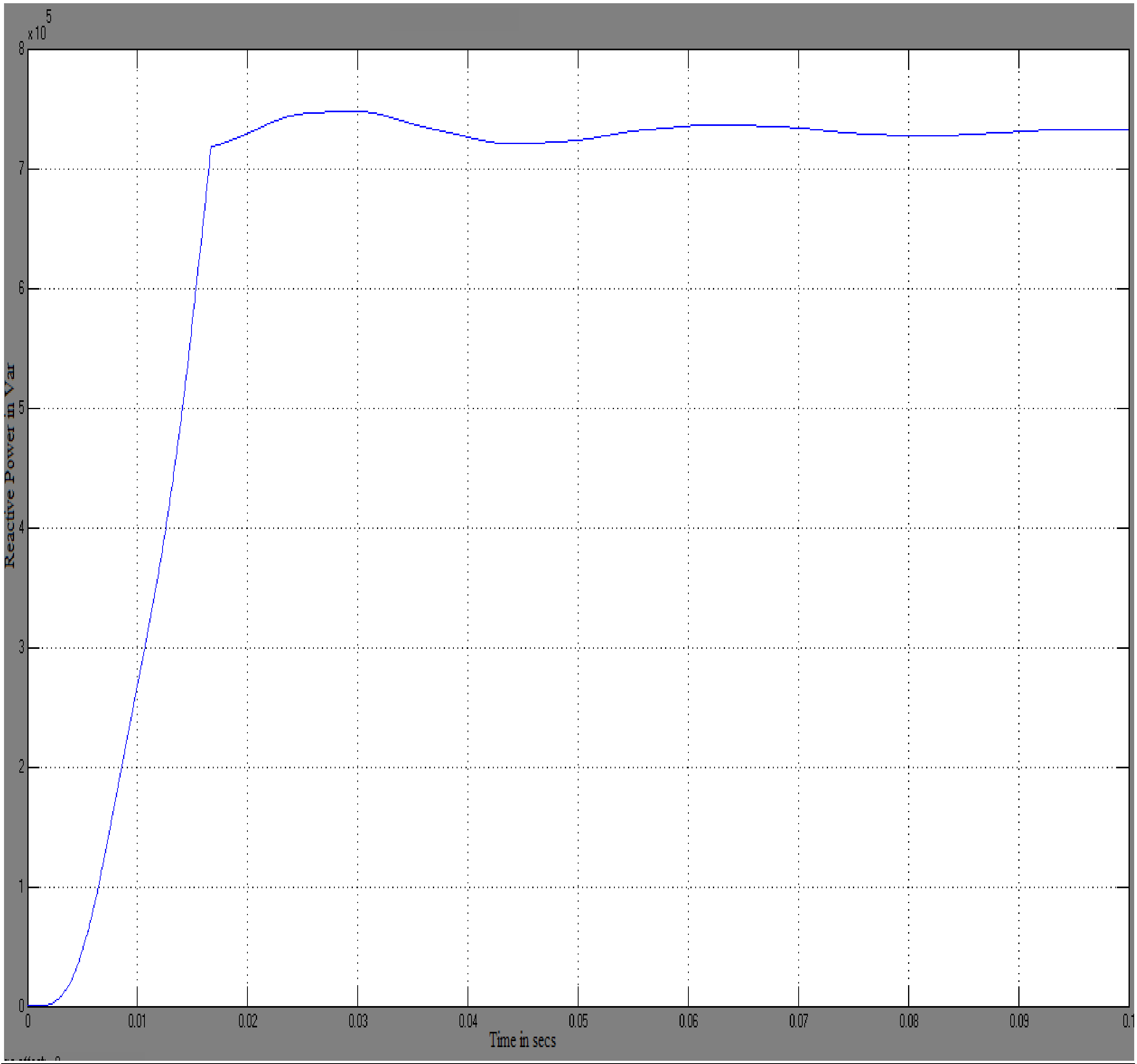


Fig.16: Graph of Reactive Power Vs Time for C=300μF

After simulation the value of real power was found to increase to 0.26M W (from Fig. 15) while the reactive power was found to increase to 0.74 MVAR (from Fig. 16). It concludes that with the increase in the value of the capacitor the real and reactive power in the load were also found to increase.

The change in values of active and reactive power was noted with the change in the value of fixed capacitor and tabulated. The table is given below

Table 1: Variation in Real Power and Reactive Power for different values of Capacitance

S.NO	CAPACITANCE (µF)	REAL POWER (MW)	REACTIVE POWER (MVAR)
1	200	0.17	0.5
2	300	0.26	0.74
3	400	0.41	1.22
4	500	0.78	2.22

From Table 1 it is seen that with the increase in the value of the fixed capacitor the active and reactive power values show an increase.

3.2.1.1.2 <u>Effect of Change in Firing Angle of The Thyristor</u>

The current in the reactor is varied by varying the firing angle of the thyristor. The method is known as firing delay angle control method. The variable Var absorption of the thyristor capacitor reactor opposes the variable Var generation of the fixed capacitor to give the total Var output. The thyristor controlled reactor is off at the maximum capacitive Var output[8]. For decrement of the capacitive Var output the current in the reactor is increased by decreasing the delay angle.

The change in power flow with change in the value of firing angle of the thyristor is studied. The thyristor angle was varied from 0^{o} to 180^{o} and the corresponding changes in the values of active power; reactive power and the current through the thyristor controlled reactor were noted down and tabulated.

The table is given below

Table 2: Variation of TCR Current and Powers for Different Firing Angles

Sl. No.	FIRING ANGLE (IN DEGREES)	CURRENT THROUGH TCR REACTOR (IN AMPERES)	REAL POWER (IN MW)	REACTIVE POWER (IN MVAR)
1	30	130	0.17	0.5
2	60	117	0.18	0.52
3	90	78	0.2	0.58
4	108	55	0.21	0.62
5	120	42	0.235	0.68
6	135	20	0.246	0.71
7	150	7.8	0.25	0.73
8	180	0.5	0.26	0.74

From Table 2 it is seen that with the increase in firing angle the capacitor current Varies from maximum value to zero. Subsequently the real power and the reactive power increase for increase in the firing angle.

3.2.2 Introduction of Unified Power Flow Controller

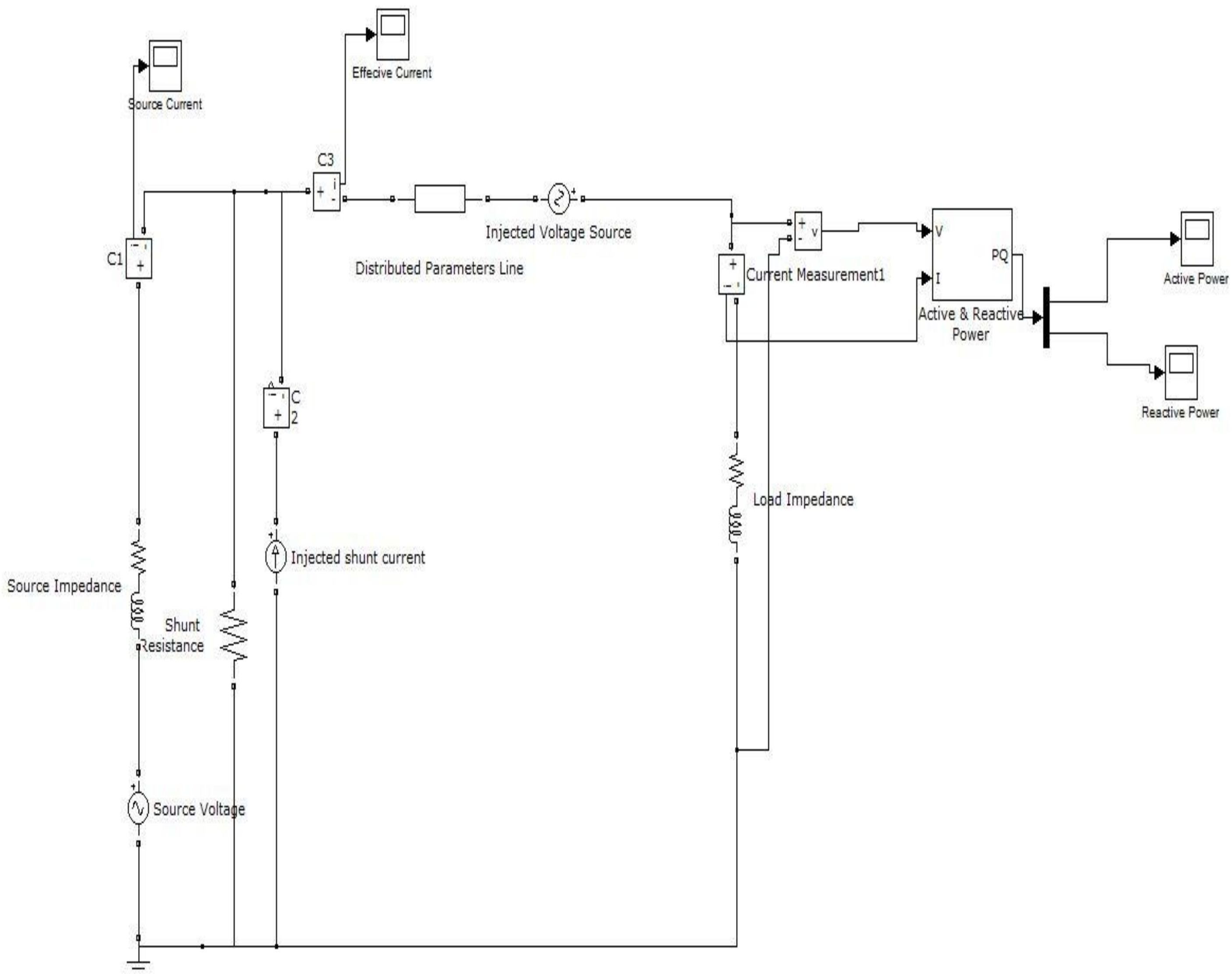


Fig.17: Transmission line model for 11kv with Unified Power Flow Controller

3.2.2.1 Results of Simulation

The circuit was simulated in Matlab using simulink. The Graphs of the real power, reactive power and effective current are plotted. The Graphs are given below

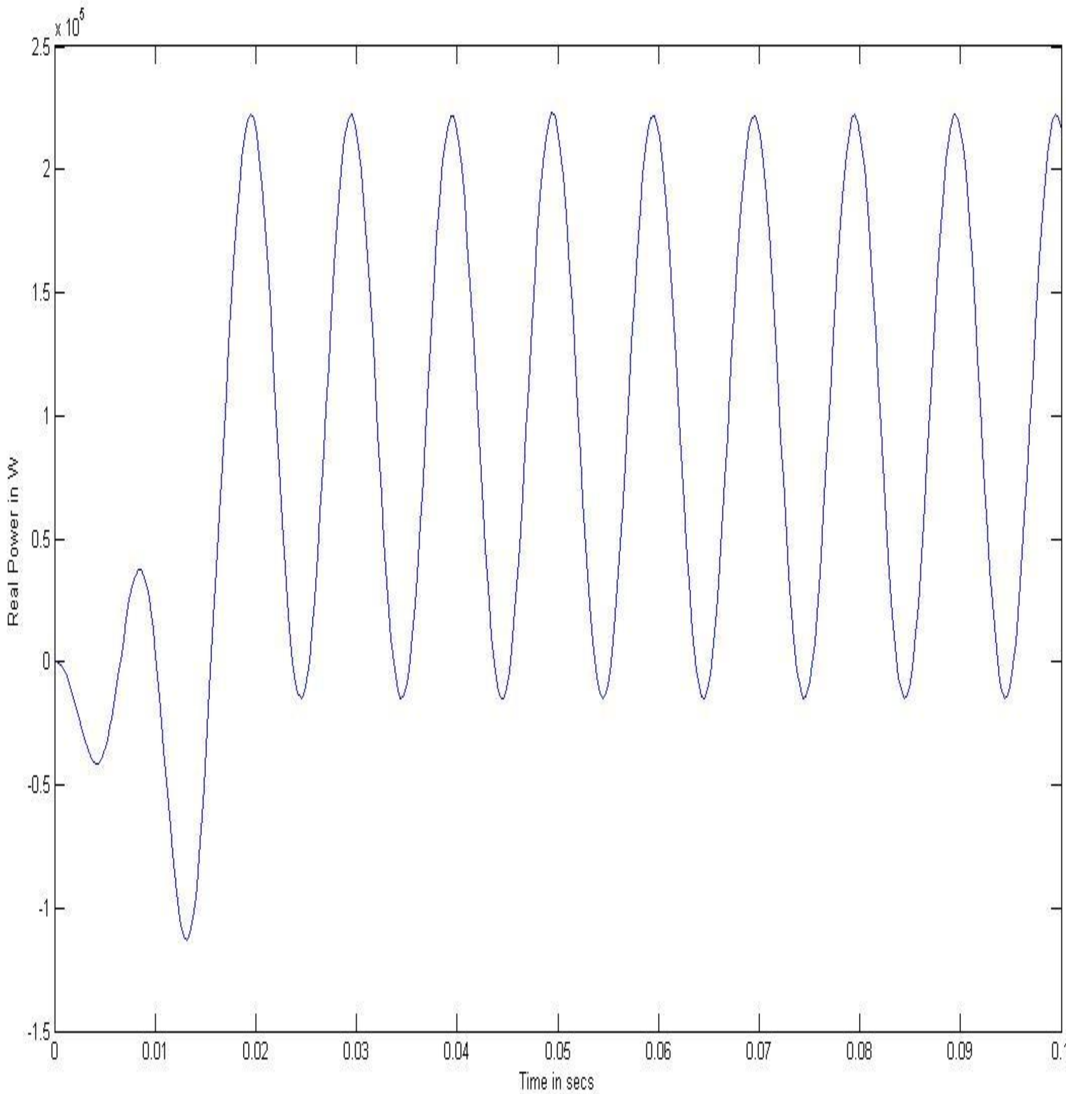


Fig.18: Graph of Real Power Vs Time

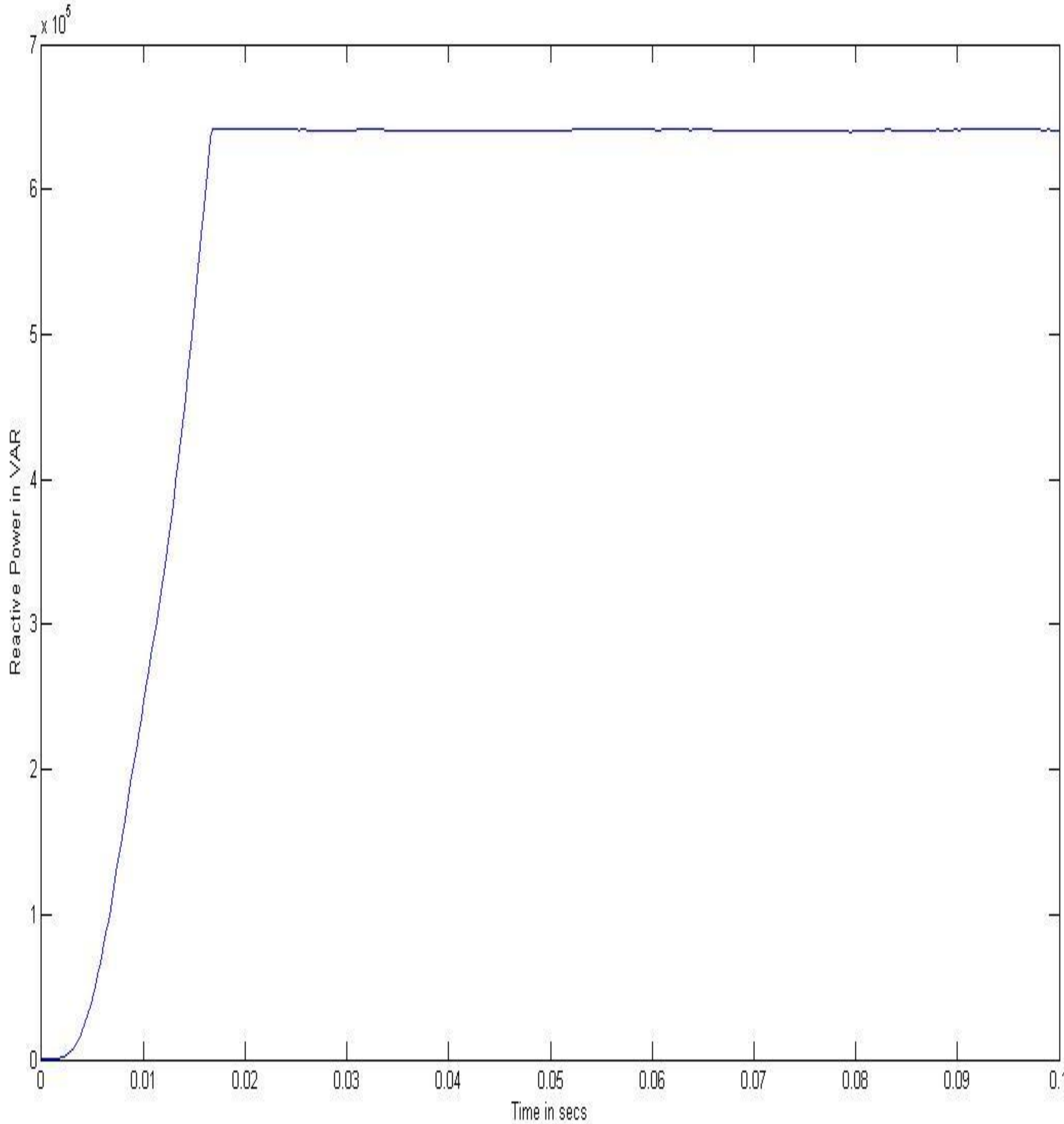


Fig.19: Graph of Reactive Power Vs Time

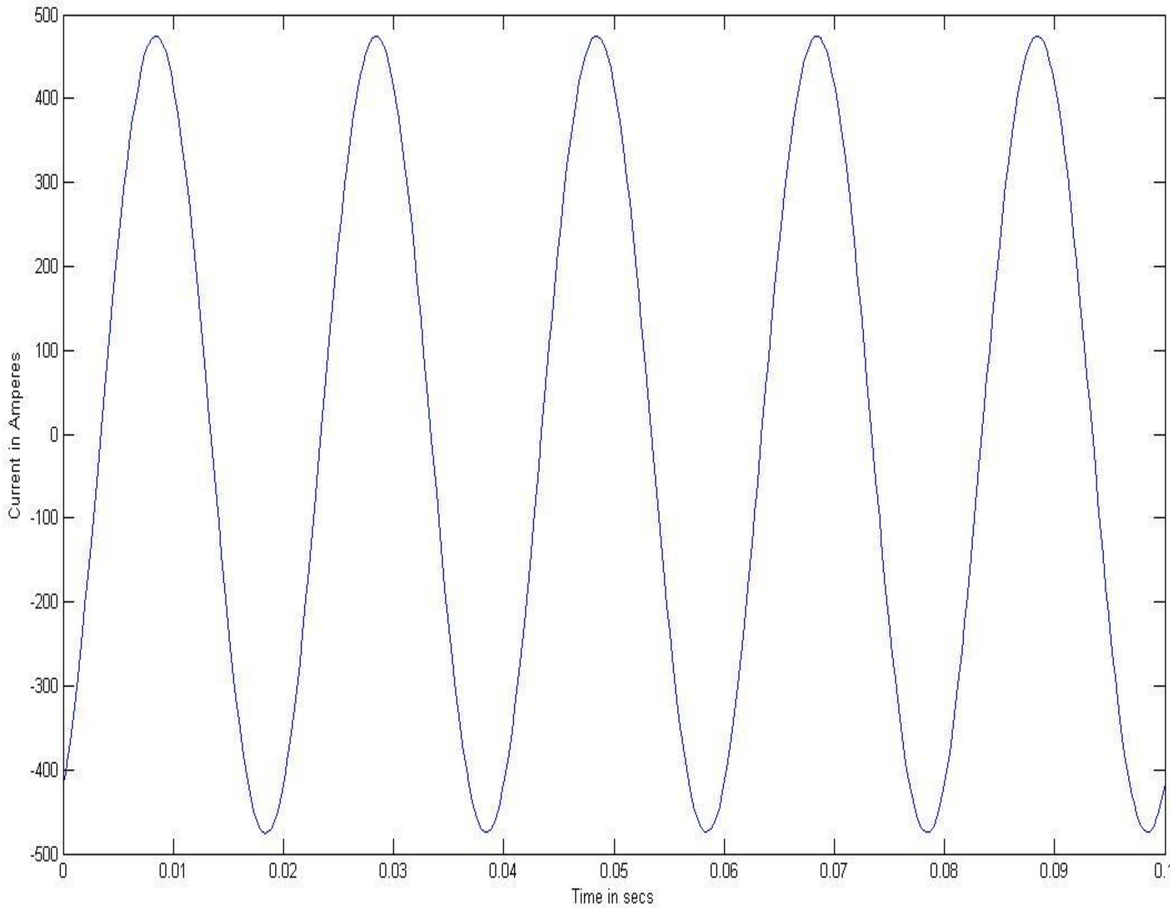


Fig.20: Graph of Effective Current Vs Time

The value of real power was obtained to be 0.23 MW as shown in Fig. 18 and the value of reactive power was obtained to be 0.66 MVAR as shown in Fig.19. There is a increase in the values of power. By introducing FACTS controller in the transmission line the power flow increased.

The power flow in the UPFC can be regulated by two factors:-

1. The injected voltage

2. The resistive shunt current

3.2.2.1.1 Effect of Injected Voltage

The injected voltage has two factors that can be regulated: Its magnitude and phase.

Table 3: Variation in Real Power and Reactive Power for different Magnitude of Injected Voltage

INJECTED VOLTAGE (IN VOLTS)	ACTIVE POWER (IN MW)	REACTIVE POWER (IN MVAR)
0	0.135	0.38
500	0.15	0.43
1000	0.16	0.47
2000	0.19	0.56
3000	0.22	0.65
4000	0.255	0.73

It can be seen from Table 3 the real and reactive powers increase with the increase in the magnitude of the injected voltage.

Table 4: Variation in Powers and Currents for different Phase Of Injected Voltage

PHASE OF THE INJECTED VOLTAGE(Φ) IN DEGREES	SOURCE CURRENT(I_S) IN AMPERES	EFFECTIVE CURRENT(I_A) IN AMPERES	ACTIVE POWER(P) IN MW	REACTIVE POWER (Q) IN MVAR
0	420	480	0.21	0.61
30	410	470	0.205	0.6
60	390	420	0.185	0.53
90	330	390	0.15	0.44
120	290	330	0.118	0.33
150	240	300	0.82	0.25
180	240	270	0.076	0.215
210	260	280	0.08	0.23
240	300	320	0.1	0.29
270	360	390	0.135	0.39
300	400	410	0.17	0.5
330	410	460	0.2	0.58
360	420	480	0.21	0.61

It can be seen from table 4 that with the increase in phase of the injected voltage the values of the active and reactive power decreases from 0º to 180º and then from 180º onwards it again starts increasing to the maximum value at 360º . It is concluded that the power flow in UPFC increases with increase in the magnitude of the injected voltage and decreases with the increase in the phase of the injected voltage.

3.2.2.1.2 Effect of Resistive shunt current

To control the effective current in the circuit a shunt resistance is connected in parallel with the resistive shunt current source.

Table 5: Variation in Real Power and Reactive Power for constant shunt resistance with varying resistive shunt current

SHUNT RESISTANCE (IN Ω)	RESISITIVE SHUNT CURRENT (IN AMPERES)	REAL POWER (IN MW)	REACTIVE POWER (IN MVAR)
10	50	0.13	0.37
	100	0.14	0.4
	200	0.15	0.45
	300	0.17	0.51

50	50	0.19	0.53
	100	0.2	0.58
	200	0.23	0.64
	300	0.25	0.72
100	50	0.2	0.59
	100	0.21	0.6
	200	0.23	0.67
	300	0.26	0.77
500	50	0.2	0.58
	100	0.21	0.61
	200	0.24	0.69
	300	0.26	0.785

Table 6: Variation in Real Power and Reactive Power for Varying shunt resistance with constant resistive shunt current source

RESISITIVE SHUNT CURRENT (IN AMPERES)	SHUNT RESISTANCE (IN Ω)	EFFECTIVE CURRENT (IN AMPERES)	REAL POWER IN MW	REACTIVE POWER (IN MVAR)
10	5	290	0.07	0.24
	10	355	0.12	0.36
	15	395	0.14	0.42
	20	400	0.151	0.45
	22	400	0.158	0.16
	25	402	0.16	0.48
20	1	215	0.046	0.137
	5	295	0.07	0.24
	10	350	0.13	0.36
	15	390	0.14	0.42
	20	400	0.16	0.46
	22	400	0.162	0.47

	25	402	0.165	0.48
50	1	220	0.098	0.14
	5	300	0.14	0.27
	10	380	0.155	0.4
	15	400	0.165	0.46
	20	405	0.17	0.5
	22	405	0.18	0.52
	25	402	0.17	0.53
100	1	220	0.049	0.135
	5	305	0.09	0.275
	10	380	0.135	0.39
	15	400	0.151	0.46
	20	405	0.16	0.5
	22	405	0.17	0.51
	25	410	0.18	0.525
200	5	230	0.105	0.31
	10	310	0.15	0.45

	15	390	0.175	0.52
	20	400	0.19	0.57
	22	405	0.2	0.58
	25	405	0.21	0.59
300	5	220	0.12	0.35
	10	315	0.17	0.51
	15	385	0.2	0.59
	20	400	0.215	0.63
	22	405	0.23	0.65
	25	405	0.24	0.68

From Table 5 it is seen that for a constant shunt resistance the active and reactive power values increase for an increase in the value of resistive shunt current. From Table6 it is seen that for a constant resistive shunt current the active and reactive power values increase for an increase in the value of shunt resistance

CHAPTER 4

Conclusion

The fundamental of FACTS was studied in this project and the literature review was done. The various operation modes and characteristics of the FACTS equipments were also studied. On simulation of the characteristics of a transmission line with and without the introduction of FACTS equipment in SIMULINK the following results were obtained .The real power without introduction of FACTS devices was obtained as 0.12 MW and after introduction of FACTS devices(FC-TCR) was 0.17 MW. The reactive power before the introduction of FACTS devices was obtained as 0.35 MVAR and after introduction of FACTS devices (FC-TCR) was 0.55 MVAR. An increase in power flow after introduction of FACTS device was observed. The variation of Real and Reactive power with change in capacitance was observed and tabulated. An increase in real and reactive power was noticed with increase in capacitance value. The variation of Real and Reactive power with change in firing angle of thyristor was observed and tabulated. An increase in real and reactive power was noticed with increase in the firing angle of the thyristor.

On introduction of Unified Power flow Controller the real power was measured to be 0.23 MW and the reactive power was measured to be 0.66MVAR. An increase in power flow after introduction of FACTS device was observed. The variation of Real and Reactive power with change in magnitude and phase of the injected voltage was observed and tabulated. An increase in real and reactive power was noticed with increase in the magnitude of the injected voltage while there was a decrease in the real and reactive power with the increase in phase of the injected voltage. The variation of Real and Reactive power keeping resistive shunt current constant and varying shunt resistance and keeping the shunt resistance constant and varying the resistive shunt current was observed and tabulated. An increase in real and reactive power was noticed in both the cases with increase in the value of the varying component.

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