FAULT CURRENT LIMITER AND THYRISTOR CONTROLLER BRAKING RESISTOR BASED CONTROL STRATEGY TO IMPROVE POWER SYSTEM TRANSIENT STABILITY

DISSERTATION
Submitted in partial fulfillment of the
requirement for the award of the
Degree of

MASTER OF TECHNOLOGY
IN
Electrical Engineering
(Power Systems)

By

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April 2014

CERTIFICATE

This is to certify that the Dissertation titled **Fault Current Limiter and Thyristor Controlled Braking Resistor based control strategy to improve power system transient stability** that is being submitted by **Hardeep Singh** is in partial fulfillment of the requirements for the award of MASTER OF TECHNOLOGY IN ELECTRICAL ENGINEERING, is a record of bonafide work done under my guidance. The contents of this dissertation, in full or in parts, have neither been taken from any other source nor have been submitted to any other Institute or University for award of any degree and the same is certified.

Mr. Kirpal Singh Doad

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ACKNOWLEDGMENT

I would like to thank Lovely Professional University for giving me the opportunity to use their resources and work in such a challenging environment.

First and foremost I take this opportunity to express my deepest sense of gratitude to my guide **Mr. Kirpal Singh Doad** for her able guidance during my report work. This report would not have been possible without his help and the valuable time that she has given me amidst his busy schedule.

I would also like to extend my gratitude to my friends and family who have always encouraged and supported me in doing my work.

Last but not the least I would like to thank all the staff members of Department of Electronics and Electrical Engineering who have been very cooperative with me.

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CERTIFICATE

This is to certify that **Hardeep Singh** bearing Registration no. **11202527** has completed objective formulation of dissertation titled, **"Fault Current Limiter and Thyristor Controlled**

Braking Resistor based control strategy to improve power system transient stability" under my guidance and supervision. To the best of my knowledge, the present work is the result of his original investigation and study. No part of the dissertation has ever been submitted for any other degree at any University.

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DECLARATION

I, Hardeep Singh, student of M.tech. Electrical Engineering under Department of Electronics and Electrical Engineering of Lovely Professional University, Punjab, hereby declare that all the information furnished in this Dissertation report is based on my own intensive research and is genuine.

This dissertation report does not, to the best of my knowledge, contain part of my work which has been submitted for the award of my degree either of this university or any other university without proper citation.

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ABSTRACT

With the increasing demand of electric power, power systems should be exploited near stability margins. In these conditions, transient stability problems become more serious. When a power system is subjected to a large disturbance, control actions need to be taken to limit the extent of the disturbance. Various methods have been taken to improve the transient stability of power systems, such as high-speed exiting, steam turbine fast-valving and dynamic braking. The wide usage of FACTS controllers is another method that helps to enhance power system transient stability. Using fault current limiter (FCL) reviewed as a necessary device for limiting fault current and improvement of power system transient stability in the past. When a fault occurs, the FCL generates impedance, which can limit the fault current. In addition to generating the impedance, FCL can increase output amounts of synchronous generator that decreases when the fault occurs. However, as FCLs installed in series with transmission lines that can be just operated during the period from the fault occurrence to the fault clearing, they cannot control the generator disturbances after the clearing of fault.

Dynamic Braking uses the concept of applying an artificial electrical load during a disturbance to absorb the excess transient energy and increase the electrical outputs of generator and therefore reduces rotor acceleration. With improvement in power electronic technologies, conventional circuit breaker controlled braking resistor is being replaced by thyristor controlled braking resistor (TCBR). In the decade, thyristor-controlled braking resistor switching strategies have been extensively studied by many researchers and several approaches have been developed.

In this proposed scheme by improved transient stability by using Fault current limiter (FCL) and Thyristor controlled braking resistor (TCBR). In the case of a severe fault occurrence in a power system, FCL is used for fault current limiting, transient stability enhancement and reduction of torsional oscillations and TCBR is used for fast control of generator disturbances. The effect of these two instruments discussed together in a single machine power system connected to the infinite bus with applying a three phase symmetrical fault.

The simulation results show the improvement of transient stability of the power system by using both devices.

LIST OF FIGURES

TABLE OF CONTENTS

CHAPTER 1 Page No.

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 1
INTRODUCTION

1.1 Power System Stability

Power system stability is the ability of the system to regain its original state after being subjected to disturbance. Power system stability is considered as the main problem for the secure system. Power system stability is defined as the ability of the system to maintain equilibrium during normal operating conditions and regain the equilibrium after being subjected to disturbance. In power system stability the restoring forces are equal or greater than the disturbing forces.

Instability in the system can be classified into many ways depending upon system configuration and operating modes. The stability problem is main in synchronous operation and as power system rely on synchronous machines for generation so their stability is important to maintain synchronism. [22]

The electrical power system is an interconnected system which includes thousands of electric elements.

Advantages of interconnected power system

- It provides us large amount of power and increases the reliability.
- It helps in reduction of machine size that is required for peak load and spinning reserve.
- It provides economical power to consumers.

Need of stability

- Analyzing the stability is easy. It helps in understanding instability.
- Factors which lead to instability are identified.

Power system is nonlinear system that operates in changing environment, load and changing parameters. When disturbance occurs the stability depends upon the initial conditions and the type of disturbance. Stability of a system is set to an equilibrium set to initial conditions.

There are disadvantages of using interconnected systems. They interconnected ties are relatively weak as compared to connections with in system. It leads to low frequency oscillations and much instability occurs when subjected to low frequencies.

Power system stability classified into three categories:

1. Steady-state stability:

Steady state stability is the ability of system to remain stable during steady state conditions and how much load can be transmitted by a generator without losing synchronism. Maximum power transmitted is called as steady state stability limit.

For n machine power system the active power in ith generator is defined by

$$P_i = \frac{U_{pi}^2}{Z_{ii}} \sin \propto_{ii} + U_{pi} \sum_{\substack{j=1 \\ i \neq i}}^{n} \frac{U_{pi}}{Z_{ij}} \sin\left(\delta_i - \delta_j - \alpha_{ij}\right) \quad (1.1)$$

Where U_{pi} be the magnitude of the internal voltage,

$Z_{ii}\left(\frac{\pi}{2} - \alpha_{ii}\right)$ is the driving point impedance,

$Z_{ij}\left(\frac{\pi}{2} - \alpha_{ij}\right)$ is the transfer impedance between machines i and j,

δi is the phase angle lead ith bus,

P_i is3 phase power of the generator.

Assuming that load angles of all other machines are constant, the steady-state stability limit can be predicted from equation (1.1).

2. Transient stability:

A common problem is the insidious nature of the oscillatory instability. Power flow over a tie line may be increased to supply remote load with no noticeable problems until the stability limit is reached. A slight increase in power flow beyond this limit results in oscillations in which amplitude increases quickly with no need for any system fault. At best system non-linearity limit oscillation amplitude. At worst, the oscillation amplitudes reach levels at which protective relays trip lines and generation, and this in turn causes partial or total system collapse.

3. Dynamic Stability:

A system is said to be dynamically stable if the oscillations do not acquire more than certain amplitude and die out quickly. Dynamic stability is a concept used in the study of transient conditions in power systems.

Any electrical disturbances in a power system will cause electromechanical transient processes. The electrical transient phenomena produced the power balance of the generating units is always disturbed and thereby mechanical oscillations of machine rotors follow the disturbance.[23]

To describe the transient phenomena, the well-known swing equation of the synchronous generators, derived from the torque equation for synchronous machine can be used:

$$T_{wi}\frac{d^2\delta_i}{dt^2} = P_{Mi} - D_i\frac{d\delta_i}{dt} - P_{Ei}$$

Where T_{wi} is impulse moment of the rotor of the generating unit,

D_i is the damping coefficient (representing the mechanical as well as the electrical damping effect), δ_i is the phase angle (load angle),

$P_{M\,i}$is the turbine power applied to rotor and

P_{Ei} is the electrical power output from the stator.

1.2 TYPES OF OSCILLATIONS

The disturbances which are occurring in power system include electromechanical oscillations of electrical generators and these oscillations are also called power swings and these must be effectively damped to maintain the system stability.

Electromechanical oscillations are classified in four categories:

1. Local oscillations: - Between a unit and rest of generating station and between the later and rest of power system. Frequency typically ranges from 0.2 Hz to 2.5 Hz.

2. Interplant oscillations: - Between two electrically close generating plants. Frequency can vary from 1 Hz to 2 Hz.

3. Inter area oscillations: - Between two major groups of generating plants. Frequencies are typically in the range of 0.2 Hz to 0.8 Hz, generally called low frequency oscillations.

4. Global oscillations: - Characterized by a common in phase oscillations of all generators as found on an isolated system. The frequency of such global mode typically 0.2 Hz.

1.2.1 Low Frequency Oscillations

Low frequency oscillations (LFOs) are generator rotor angle oscillations having a frequency between 0.1 Hz to 3.0 Hz and defined by how they are created or where they are located in the power system. The use of high gain exciters, poorly turned generation excitation and HVDC converters may create LFOs with negative damping; this is a small-signal stability problem. Mitigation of these oscillations is commonly performed with "supplementary stabilizing signals" and the networks used to generate these signals have come to be known as power system stabilizer networks. LFOs include local plant modes, control modes; torsional modes induced by the interaction between the mechanical and electrical modes of a turbine-generator system and inter area modes which may be caused by either high gain exciters or heavy power transfers across weak tie lines.

Low frequency oscillations can be created by small disturbances in the system such as changes in the load and are normally analyzed through the small-signal stability (linear response) of the power system. This small disturbances lead to a steady increase or decrease in generator rotor angle caused by the lack of synchronizing torque or to rotor oscillations of increasing amplitude due to a lack of sufficient damping torque. Lack of a sufficient damping torque on the rotor's low frequency oscillations is instability.

1.3 TRANSIENT STABILITY

Each generator operates at the same synchronous speed and frequency of 50 hertz while a delicate balance between the input mechanical power and output electrical power is maintained. Whenever generation is less than the actual consumer load, the system frequency falls. On the other hand, whenever the generation is more than the actual load, the system frequency rise. The generators are also interconnected with each other and with the loads they supply via high voltage transmission line.

An important feature of the electric power system is that electricity has to be generated when it is needed because it cannot be efficiently stored. Hence using a sophisticated load forecasting procedure generators are scheduled for every hour in day to match the load. In addition, generators are also placed in active standby to provide electricity in times of emergency. This is referred as spinning reserved.

The power system is routinely subjected to a variety of disturbances. Even the act of switching on an appliance in the house can be regarded as a disturbance. However, given the size of the system and the scale of the perturbation caused by the switching of an appliance in comparison to the size and capability of the interconnected system, the effects are not measurable. Large disturbance do occur on the system. These include severe lightning strikes, loss of transmission line carrying bulk power due to overloading. The ability of power system to survive the transition following a large disturbance and reach an acceptable operating condition is called transient stability. [26]

The physical phenomenon following a large disturbance can be described as follows. Any disturbance in the system will cause the imbalance between the mechanical power input to the generator and electrical power output of the generator to be affected. As a result, some of the generators will tend to speed up and some will tend to slow down. If, for a particular generator, this tendency is too great, it will no longer remain in synchronism with the rest of the system and will be automatically disconnected from the system. This phenomenon is referred to as a generator going out of step.

Acceleration or deceleration of these large generators causes severe mechanical stresses. Generators are also expensive. Damage to generators results in costly overhaul and long downtimes for repair. As a result, they are protected with equipment safety in mind. As soon as a generator begins to go out-of-step, sensor in the system sense the out-of-step condition and trip the generators. In addition, since the system is interconnected through transmission lines, the imbalance in the generator electrical output power and mechanical input power is reflected in a change in the flows of power on transmission lines. As a result, there could be large oscillations in the flows on the transmission lines as generator try to overcome the imbalance and their output swing with respect to each other.

During transient stability studies the following assumptions are:

1. Transmission line and synchronous machine resistances is neglected. Since resistance introduces a damping term in the swing equation and gives pessimistic results.
2. Effect of damper windings is neglected it gives pessimistic results.
3. Variation in rotor speed is neglected.
4. When mechanical input of a generator is constant and governor control loop is neglected. This leads to pessimistic results.
5. The generator is modeled as a constant voltage source behind a transient reactance, neglecting the voltage regulator action.
6. The loads are modeled as constant admittances and absorbed into the bus admittance matrix.

1.3.1 Mechanical Analogy

A mechanical analogy to this phenomenon can be visualized in fig.1.1. Suppose that there is a set of balls of different sizes connected to each other by a set of strings. The balls represent generators having a specific mechanical characteristic (that is, inertia). The strings represent the transmission line interconnecting the generators.

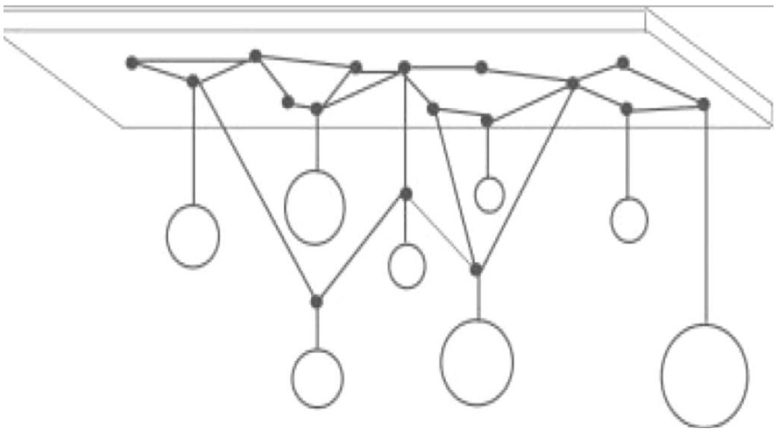

Fig.1.1 Mechanical Analogy of Transient Stability

Now suppose that there is a disturbance in which one of the balls is struck with a cue. The ball now begins to swing, and as a result, the string connected to the ball also oscillates. In addition, the other strings to which this string is connected are also affected, and this in turn affects the other balls connected to these strings. As a result, the entire interconnected system of balls is affected, and the system experiences oscillations in the strings and motion of the balls. If these oscillations in the strings become large, one of the strings may break away from the rest, resulting instability. On the other hand if the oscillation dies down and the entire system comes back to rest as in the situation prior to the ball being struck. This condition is analogous to a power system being "transiently stable".

In a power system, an additional important characteristic in the operating condition, as the loading on the system increases, the system becomes more stressed and operates closer to its limits. During these stressed condition, a small disturbance can make the system unstable. Dropping a marble into a pitcher of water provides a suitable analogy to understand why the operating condition makes a difference in maintaining transient stability. [23]

1. Take a pitcher and fill it with the water to quarter its capacity. Now drop a marble in the pitcher. The dropping of the marble is akin to a disturbance in the power system. In this situation no water from the pitcher will splash out, indicating the system is stable.
2. Now fill the pitcher with water close to it brim and drop the same marble into the pitcher. In this case, water will splash out, indicating the system is unstable.

In these two situations, the same disturbance was created. However, the system was operating at different conditions, and in the latter situation, the system was more stressed. Again, this analogy illustrates that the degree of stability is dependent on the initial operating condition.

1.3.2 Elementary View of Transient Stability

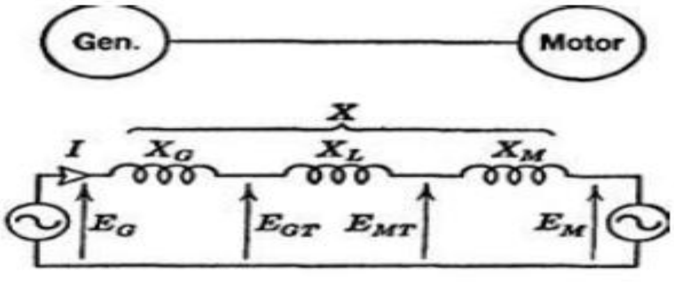

Fig.1.2 Simple two machine power system

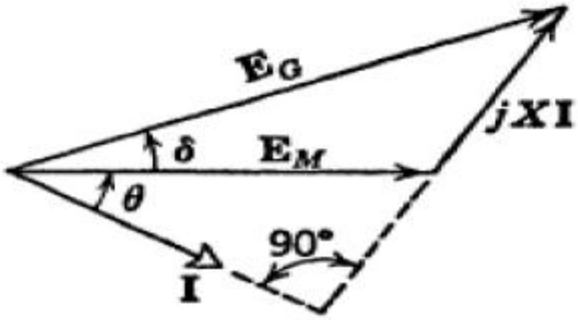

Fig.1.3 Phasor diagram of the different parameters

Consider the very simple power system of Fig.1.2, consisting of a synchronous generator supplying power to a synchronous motor over a circuit composed of series inductive reactance X_L. Each of the synchronous machines may be represented, at least approximately, by a constant-voltage source in series with a constant reactance. Thus the generator is represented by E_g and X_g; and the motor, by E_M and X_M. Upon combining the machine reactance and the line reactance into a single reactance, we have an electric circuit consisting of two constant-voltage sources, E_G and E_M connected through reactance $X = X_G + X_L + X_M$. It will be shown that the power transmitted from the generator to the motor depends upon the phase difference δ of the two voltages E_G and E_M. Since these voltages are generated by the flux produced by the field windings of the machines, their phase difference is the same as the electrical angle between the machine rotors.

The vector diagram of voltages is shown in Fig. Vectorially,

$$E_G = E_M + jX_I$$

(The bold-face letters here and throughout the book denote complex, or vector, quantities).

Hence the current is

$$I = \frac{E_G - E_M}{jX}$$

The power output of the generator and likewise the power input of the motor, since there is no resistance in the line is given by

$$P = R_e\left(\overline{E_g} I\right)$$

$$= R_e\left(\overline{E_g} \frac{E_g - E_m}{jX}\right)$$

Where Re means "the real part of" and ~E$_G$ means the conjugate of E$_G$.

Now let

$$E_M = E_M < 0$$

$$\text{And} \qquad E_G = E_G < \delta$$

$$\text{Then} \qquad \bar{E}_G = E_G < (-\delta)$$

$$\text{So,} \quad P = Re(E_G < -\delta \, \tfrac{E_G < \delta - E_M < 0}{X < 90^0})$$

$$= Re\left(\tfrac{E_G}{X} < (-90^0) - \tfrac{E_G E_M}{X} < (-90^0 - \delta)\right)$$

$$= -\tfrac{E_G E_M}{X} \cos(-90^0 - \delta)$$

$$= \tfrac{E_G E_M}{X} \sin \delta$$

This equation shows that the power *P* transmitted from the generator to the motor varies with the sine of the displacement angle δ between the two rotors, as plotted in Fig. The curve is known as a power angle curve. The maximum power that can be transmitted in the steady state with the given reactance *X* and the given internal voltages E_G and E_M is

$$P_M = \frac{E_G E_M}{X}$$

And occurs at a displacement angle $\delta = 90$. The value of maximum power may be increased by rising either of the internal voltages or by decreasing the circuit reactance.

1.3.3 Swing Equation

The electromechanical equation describing the relative motion of the rotor load angle (δ) with respect to the stator field as a function of time is known as Swing equation.

$$M \frac{d^2\delta}{dt^2} = P_t - P_u$$

Where M= inertia constant

P_t =Shaft power input corrected for rotational losses

P_u = $P_m \sin \delta$ = electric power output corrected for rotational losses

P_m = amplitude for the power angle curve

δ = rotor angle with respect to a synchronously rotating reference

1.3.4 Equal Area Criterion

To check the stability of a single machine infinite bus (SMIB) system, there is a simple and direct method which does not require the solution of the swing equation following disturbance(s). This method is known as equal area criteria for stability. The assumptions used in applying this criterion are

1. Constant mechanical power
2. No damping
3. Classical machine model

The basis for this method is that if the system is stable (in the first swing) the rotor angle (after the disturbance) reaches a maximum value (assuming that the rotor initially accelerates) and then oscillates about the final steady state value. (It is also assumed that stable steady state equilibrium exists for the post-disturbance system). Hence the stability is checked by monitoring the deviation of the rotor speed (dδ/dt) and ensuring that it becomes zero following the disturbance.[23]

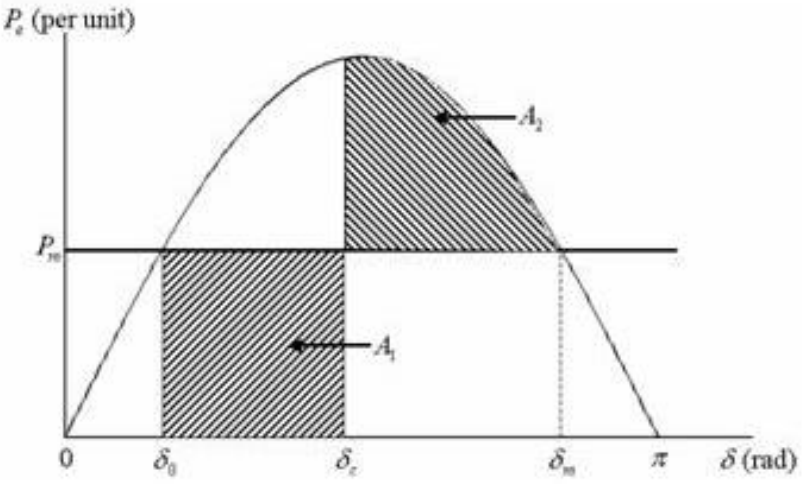

Fig.1.4 Power Angle Curve for Equal Area Criterion

Where,

$A1$= Area of acceleration

$A2$= Area of deceleration

If the area of acceleration is larger than the area of deceleration, i.e., $A1 > A2$. The generator load angle will then cross the point δm, beyond which the electrical power will be less than the mechanical power forcing the accelerating power to be positive. The generator will therefore start accelerating before is slows down completely and will eventually become unstable. If, on the other hand, $A1 < A2$, i.e., the decelerating area is larger than the accelerating area, the machine will decelerate completely before accelerating again. The rotor inertia will force the subsequent acceleration and deceleration areas to be smaller than the first ones and the machine will eventually attain the steady state. If the two areas are equal, i.e., $A1 = A2$, then the accelerating area is equal to decelerating area and this is defines the boundary of the stability limit.

Let the swing equation be given by

$$M\frac{d^2\delta}{dt^2} = Pa = P_m - P_e$$

Multiplying both sides by dδ/dt and integrating with respect to time, we get

$$M\int_{t_0}^{t}\frac{d\delta}{dt}\frac{d^2\delta}{dt^2}dt = Pa = \int_{t_0}^{t}(Pm - Pe)\frac{d\delta}{dt}dt$$

$$\frac{1}{2}M(\frac{d\delta}{dt})^2 = \int_{\delta_0}^{\delta}(Pm - Pe)d\delta$$

It is assumed at $t=t_0$, the system is at rest (equilibrium state) and the speed deviation is zero. The R.H.S of above equation can be interpreted, as the area between the curves Pm versus δ and Pe versus δ. Pm versus δ is a horizontal line as Pm is assumed as constant. The curve of Pe versus δ (power angle curve) gives the stability using equal area criteria.

If the system is to stable, then

$$\frac{d\delta}{dt}/_{\delta=\delta_{max}} = 0$$

This implies that the area denoted by

$$A = \int_{\delta 0}^{\delta max}(Pm - Pe)d\delta$$

Here in equal area, the condition of stability can therefore be stated as: the system is stable if the area under P_a (accelerating power) - δ curve reduces to zero at some value of δ. In other words, the positive (accelerating) area under P_a- δ curve must equal the negative (decelerating) area and hence the name ‘equal area ‘criterion of stability.

In brief:

1. The equal area criterion is also applicable for two-machine system (without an infinite bus) as it can be converted into a single machine equivalent.
2. The equal area criterion for stability is a special case of the direct method for the stability evaluation using energy functions.
3. Mathematically, the problem of determination of transient stability can be viewed as checking whether the initial system state for the post fault condition, lies in the region of stability surrounding the post-fault stable equilibrium point. Every SEP has a region of stability (which may be unbounded) or attraction, in which a trajectory approaches Sep as t→ α. A trajectory starting outside the region of stability will not approach SEP and may even be unbounded. The determination of stability boundary is a complex task. The use of energy functions helps to appropriate the stability boundary for a given fault or disturbance.

1.4 FLEXIBLE AC TRANSMISSION SYSTEMS (FACTS)

Flexible AC Transmission Systems is generally a power electronic based device and it is a static device is used for the AC transmission of electrical energy. It is meant to improve controllability and increase power transfer capability. Several FACTS-devices have been introduced for various applications worldwide. Various new type of device is introduced in this stage.

In most of the application they provide controllability is used to avoid cost intensive or landscape requiring of power system, for instance like upgrades or additions of substations and power line. FACTS device provide a better condition to operation condition and enhance the usage of existing installation. The basic applications of FACTS devices are:

- Power flow control

- Increase of transmission capability
- Voltage control
- Reactive power compensation
- Stability improvement
- Power quality improvement
- Power conditioning
- Interconnection of renewable and distributed generation and storages.

The FACTS controllers can be classified as

1. Shunt connected controllers
2. Series connected controllers
3. Combined series-series controllers
4. Combined shunt-series controllers

Depending on the power electronic devices used in the control, the FACTS controllers can be classified as

a) Variable impedance type
b) Voltage source converter (VSC) based.

The variable impedance type controllers include:

i. Static var compensator (SVC), (shunt connected)
ii. Thyristor controlled series capacitor or compensator (TCSC), (series connected)
iii. Thyristor controlled phase shifting transformer (TCPST) of static PST (combined shunt and series)

The VSC based FACTS controllers are:

i. Static synchronous compensator (STATCOM) (shunt connected)
ii. Static synchronous series compensator (SSSC) (series connected)
iii. Interline power flow controller (IPFC) (combined series-series)
iv. Unified power flow controller (UPFC) (combined shunt-series)

Some of the special purpose FACTS controllers are

a) Thyristor controller braking resistor (TCBR)
b) Thyristor controlled voltage limiter (TCVL)

c) Thyristor controlled voltage regulator (TCVR)

d) Interphase power controller (IPC)

The development of FACTS-devices has started with the growing capabilities of power electronic components. Devices for high power levels have been made available in converters for high and even highest voltage levels. The overall starting points are network elements influencing the reactive power or the impedance of a part of the power system. Figure 1.2 shows a number of basic devices separated into the conventional ones and the FACTS-devices. [24]

For FACTS side they provide in terms of static and dynamic need some explanation. The term dynamic are used to fast control providing in FACTS device in power electronic. This is one of the main differentiation factors from the conventional device. The other term static mean they have no moving part such as mechanical switches to perform the dynamic stability. Therefore most of the FACTS device is equally by static and dynamic. For the FACTS side the taxonomy in terms of 'dynamic' and 'static' needs some explanation.

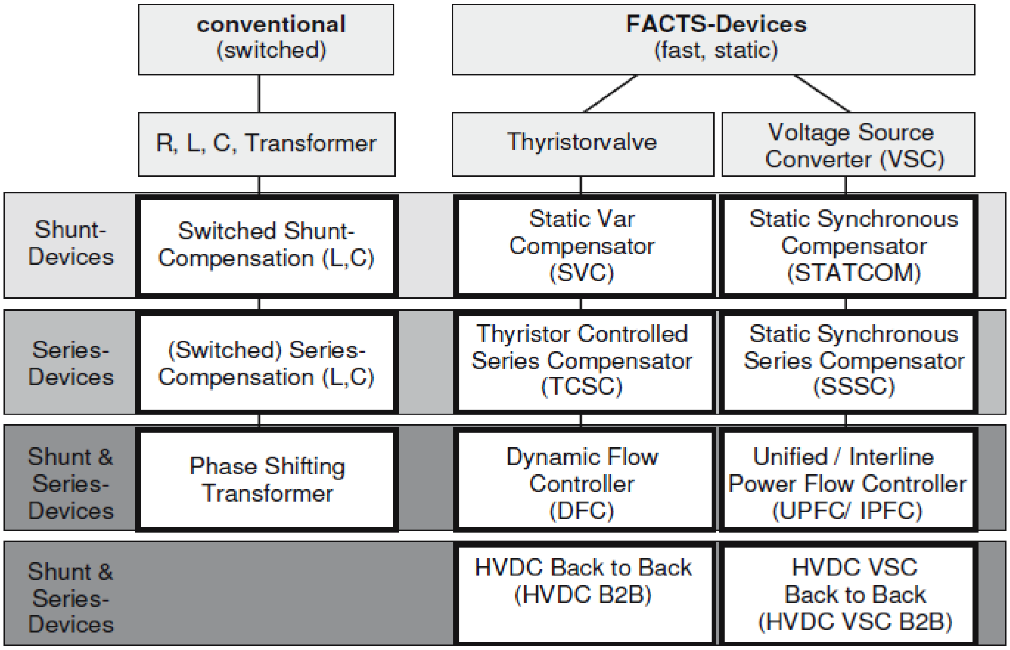

Fig.1.5 overview of major FACTS devices

The left column are shown in figure 1.5 show the conventional device provided fixed or mechanically switchable component such as resistance, inductance or capacitor are connection with transformers. The FACTS-devices contain these elements as well but 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 column of FACTS device is use for thyristor and converters. Since several years the valves or converter are well known. They have low losses because of their low switching frequency of once a cycle in the converters or the usage of the Thyristors to simply bridge impedances in the valves.

The right column of FACTS-devices contains more advanced technology of voltage source converters based today mainly on Insulated Gate Bipolar Transistors (IGBT) or Insulated Gate Commutated Thyristors (IGCT). Voltage Source Converters provide a free controllable voltage in magnitude and phase due to a pulse width modulation of the IGBTs or IGCTs. High modulation frequencies allow to get low harmonics in the output signal and even to compensate disturbances coming from the network. The disadvantage is that with an increasing switching frequency, the losses are increasing as well. Therefore special designs of the converters are required to compensate this.[24]

The benefits due to FACTS controllers are

1. They contribute to optimal system operation by reducing power losses and improving voltage profile.
2. The power flow in critical lines can be enhanced as the operating margins can be reduced due to fast controllability. In general, the power carrying capacity of lines can be increased to values up to the thermal limits.
3. The transient stability limit is increased thereby improving dynamic security of the system and reducing the incidence of blackouts caused by cascading outages.
4. The steady state or small signal stability region can be increased by providing auxiliary stabilizing controllers to damp low frequency oscillations.
5. FACTS controllers such as TCSC can counter the problem of sub synchronous resonance (SSR) experienced with fixed series capacitors connected in lines evacuating power from thermal power stations.
6. The problem of voltage fluctuations and in particular, dynamic over voltage can be overcome by FACTS controllers.

1.4.1 CONFIGURATIONS OF FACTS-DEVICES

1.4.1.1 Shunt Devices

The most used FACTS-device is the SVC or the version with Voltage Source Converter called STATCOM. These shunt devices are operating as reactive power compensators. The main applications in transmission, distribution and industrial networks are:

- Reduction of unwanted reactive power flows and therefore reduced network losses.
- Keeping of 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.

Almost half of the SVC and more than half of the STATCOMs are used for industrial applications. Industry as well as commercial and domestic groups of users require power quality. Flickering lamps are no longer accepted, nor are interruptions of industrial processes due to insufficient power quality. Railway or underground systems with huge load variations require SVCs or STATCOMs.

1.4.1.1.1 Static Var Compensator (SVC)

Static Var Compensator is the most important FACTS device and they are used several years to improve transient stability line economics by resolving dynamic voltage problems. They are more accuracy, availability and fast response for SVC to provide high performance steady state and transient voltage control. They are also used for dampen power swing, enhance transient stability and reduce system losses by optimized reactive power control.

A rapidly operating Static Var Compensator (SVC) can continuously provide the reactive power required to control dynamic voltage oscillations under various system conditions and thereby improve the power system transmission and distribution stability.

Applications of the SVC systems in transmission systems:

- To increase active power transfer capacity and transient stability margin
- To damp power oscillations
- To achieve effective voltage control

In addition, SVCs are also used

1. in transmission systems

- To reduce temporary over voltages
- To damp sub synchronous resonances
- To damp power oscillations in interconnected power systems

2. in traction systems

- To balance loads
- To improve power factor
- To improve voltage regulation

3. In HVDC systems

- To provide reactive power to ac–dc converters

4. in arc furnaces

- To reduce voltage variations and associated light flicker

When SVC is installed in suitable point in network for increase transfer and reduces losses and maintaining a smooth voltage profile under different network conditions In addition an SVC can mitigate active power oscillations through voltage amplitude modulation.

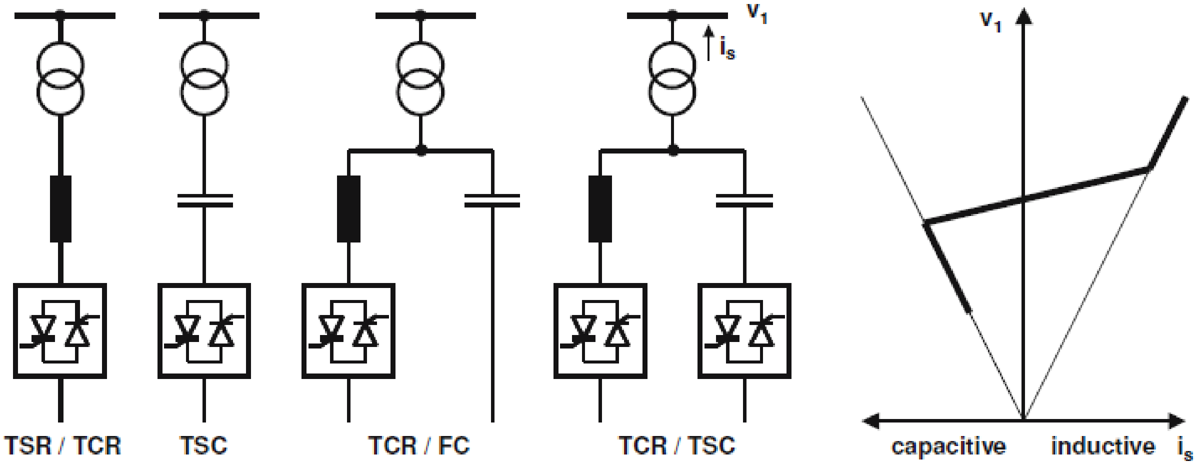

Fig.1.6 SVC building blocks and voltage / current characteristic

The main principle of SVC is consisting of Thyristor Switched Capacitors (TSC) And Thyristor Switched or Controlled Reactors (TSR/TCR). Figure shows the control of combination of these branches varies the reactive power. The first SVC was installed in 1972 for an electric arc furnace. On transmission level, the first SVC is used in 1979. It is widely used and most accepted FACTS device.

1.4.1.1.2 Static Compensator (STATCOM)

In 1999 the first SVC with Voltage Source Converter called STATCOM (Static Compensator) went into operation. The STATCOM has a characteristic similar to the synchronous condenser, but as an electronic device it has no inertia and is superior to the synchronous condenser in several ways, such as better dynamics, a lower investment cost and lower operating and maintenance costs. A STATCOM is build with Thyristors with turn-off capability like GTO or today IGCT or with more and more IGBTs. The static line between the current limitations has a certain steepness determining the control characteristic for the voltage.

The advantage of a STATCOM is that the reactive power provision is independent from the actual voltage on the connection point. This can be seen in the diagram for the maximum currents being independent of the voltage in comparison to the SVC. This means, that even during most severe contingencies, the STATCOM keeps its full capability.

In the distributed energy sector the usage of Voltage Source Converters for grid interconnection is common practice today. The next step in STATCOM development is the combination with energy storages on the DC-side. The performance for power quality and balanced network operation can be improved much more with the combination of active and reactive power.[24]

STATCOMs are based on Voltage Sourced Converter (VSC) topology and utilize either Gate-Turn-off Thyristors (GTO) or Isolated Gate Bipolar Transistors (IGBT) devices. The STATCOM is a very fast acting, electronic equivalent of a synchronous condenser. If the STATCOM voltage, Vs, (which is proportional to the dc bus voltage Vc) is larger than bus voltage, Es, then leading or capacitive VARS are produced. If the Vs is smaller than Es then lagging or inductive VARS are produced.

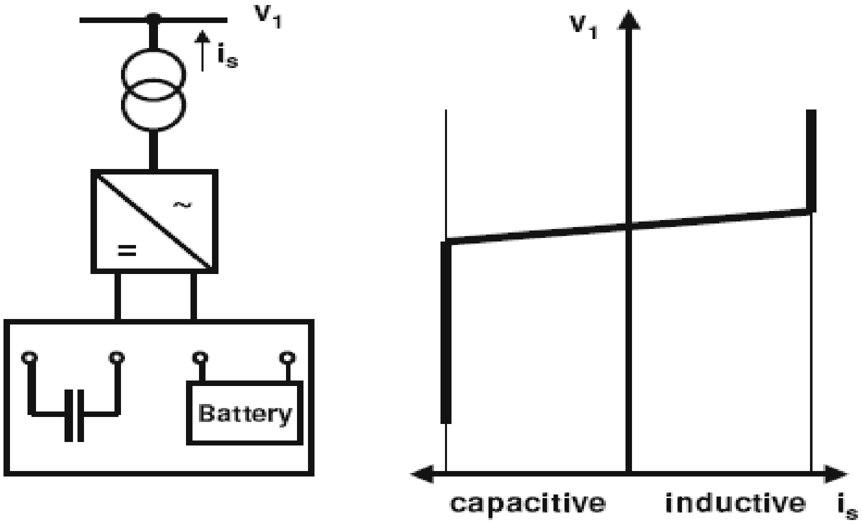

Fig.1.7 STATCOM structure and voltage / current characteristic

1.4.1.2 Series Devices

Series devices have been further developed from fixed or mechanically switched compensations to the Thyristor Controlled Series Compensation (TCSC) or even Voltage Source Converter based devices.

The main applications are:

- 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.

1.4.1.2.1 Thyristor Controlled Series Capacitors (TCSC)

Thristor controlled series capacitor (TCSC) are specific dynamical problem in transmission system. Firstly, when damping increase with large electrical systems are interconnected. Secondly it overcomes the problem of sub synchronous resonance (SSR), a phenomenon that involve in between large thermal generating units and series compensated transmission systems.

The TCSC's are high speed switching capabilities which provide mechanism for controlling the line power flow, which permit increased loading of existing transmission lines and allows for rapid readjustment of line power flow in response to various contingencies. It is also regulate steady state power flow within the limits.

From a principal technology point of view, the TCSC resembles the conventional series capacitor. All the power equipment is located on an isolated steel platform, including the Thyristor valve that is used to control the behavior of the main capacitor bank. Likewise the control and protection is located on ground potential together with other auxiliary systems. Figure shows the principle setup of a TCSC and its operational diagram.

Advantages

- Continuous control of desired compensation level
- Direct smooth control of power flow within the network
- Improved capacitor bank protection

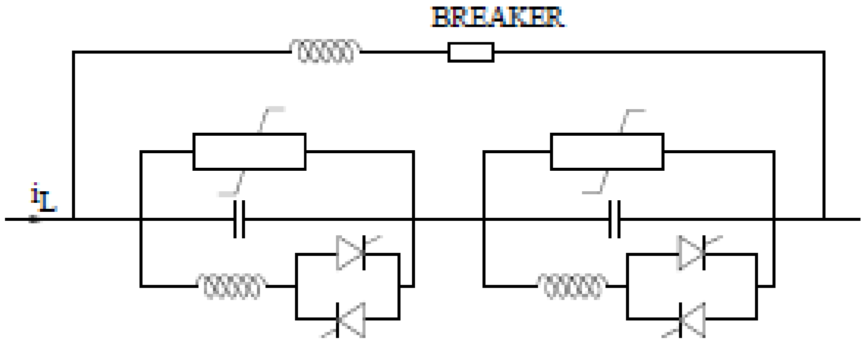

Fig.1.8 single line diagram of a TCSC

1.4.1.3 Shunt and Series Devices

1. Dynamic Power Flow Controller

A new device in the area of power flow control is the Dynamic Power Flow Controller (DFC). The DFC is a hybrid device between a Phase Shifting Transformer (PST) and switched series compensation.

A functional single line diagram of the Dynamic Flow Controller is shown in Figure 1.8. The Dynamic Flow Controller consists of the following components:

- A standard phase shifting transformer with tap-changer (PST)
- Series-connected Thyristor Switched Capacitors and Reactors (TSC / TSR)
- A mechanically switched shunt capacitor (MSC). (This is optional depending on the system reactive power requirements)

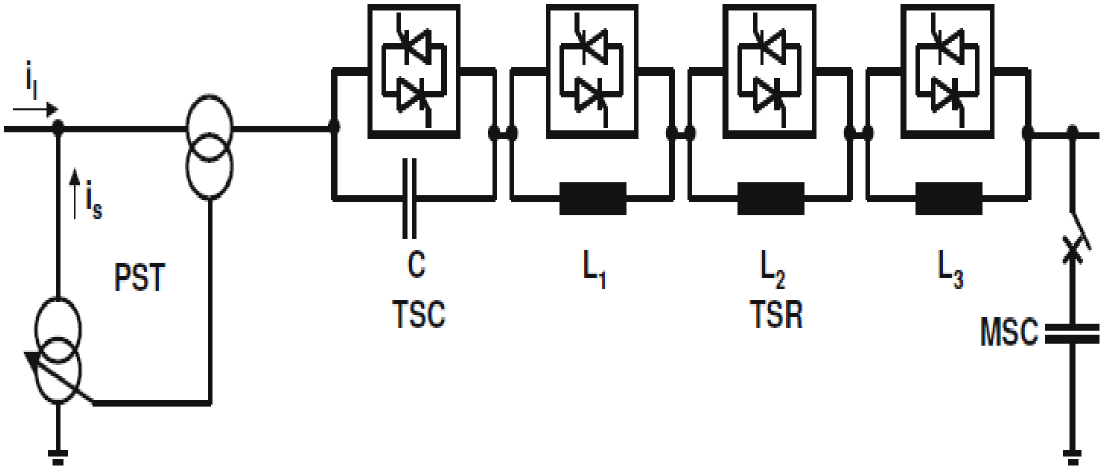

Fig.1.9 Principle configuration of DFC

On the base of system, DFC consist of a number of series connected thyristor switched capacitor or reactors (TSC or TSR) and mechanically switched shunt capacitor (MSC) which provide the voltage control in case of overload and other condition. Normally the reactance of reactors and the capacitors are selected based on a binary basis to result in a desired stepped reactance variation. If a higher power flow resolution is needed, a reactance equivalent to the half of the smallest one can be added.

The operation of a DFC is based on the following rules:

- TSC / TSR are switched when a fast response is required.
- The relieve of overload and work in stressed situations is handled by the TSC / TSR.
- The switching of the PST tap-changer should be minimized particularly for the currents higher than normal loading.
- The total reactive power consumption of the device can be optimized by the operation of the MSC, tap changer and the switched capacities and reactors.

1.4.1.3.1 Unified Power Flow Controller (UPFC)

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.

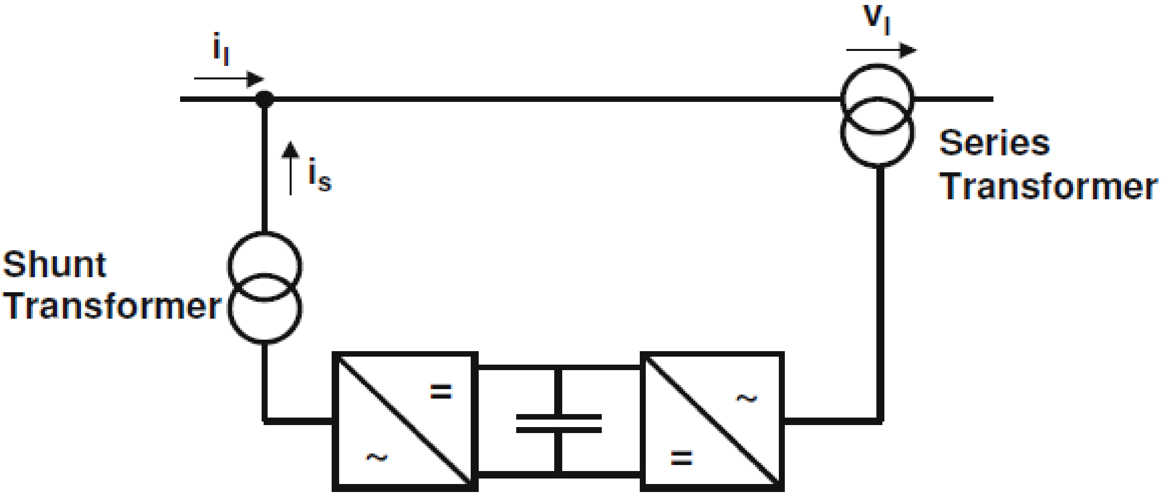

Fig1.10 Principle configuration of an UPFC

The UPFC consist of series and shunt transformer which are connected between two voltage source converters with a common DC capacitor. The DC circuit provides the active power exchange between the series and shunt transformer to control the phase shift of the series voltage. They provide the full controllability for voltage and power flow as shown in figure 1.9. Thyristor Bridge is needed to protect from the series converters. Due to high effect for the voltage source converter and protection, UPFC is quite expensive, which limits.

1.4.1.3.2 Thyristor Controlled Braking Resistor (TCBR)

This is also termed as Dynamic Brake and involves the use of braking re-sistors, mostly connected in shunt, which are switched in, following a fault clearing, to correct the temporary imbalance between the mechanical power input and electrical power output of generators. In principle, the use of braking resistors of suitable size and appropriate logic to implement controllable duration of resistor insertion can overcome the problem of transient instability. However, the cost of resistor capable of dissipating the required amount of energy and associated switching equipment is a deterrent as there have been very few applications so far. Peace River in British Columbia, Canada and Chief Joseph Substation of Bonneville Power Administration in Western USA are few of the modern applications of the concept.

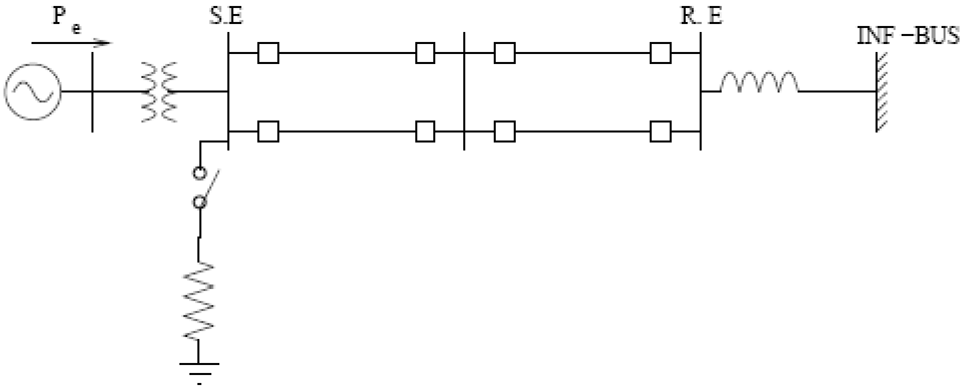

Fig.1.11 Application of shunt braking resistor

Fig.1.10 shows typical location of shunt connected resistors at the sending end of a long double circuit transmission line. When the inertia of the sending end generator is small compared to that of the receiving end, series braking resistors are also effective in controlling the relative angle.

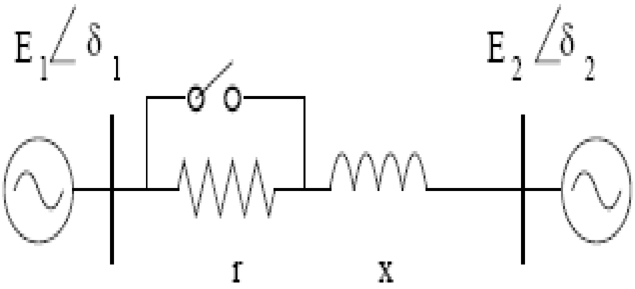

Fig.1.12 Application of series connected brake

Series braking resistors can be inserted by connecting them between the neutral and ground on the high voltage (line) side of the step-up trans- formers. This simplifies the design of the resistors from the insulation point of view. The other advantages of series connected dynamic brake are

i. Speed of insertion is related to opening of a circuit breaker across the resistor as opposed to the closing of a breaker as in the case of the shunt resistor. This permits faster action of the brake and is effective in reducing the severity of the fault in case of prolonged faults by stuck breakers. It is to be noted that series braking resistors are inserted as soon as the fault is detected while shunt resistors are switched on as soon as the fault is cleared.

ii. The peak value of the electrical power (in an equivalent single machine system) occurs when $(\delta_1 - \delta_2) > 90°$. This is beneficial as it allows more time for the synchronizing torques to act.

iii. The size and cost of series braking resistor tend to be smaller than that of the shunt resistor because of factors listed above.

TCBR can be used for a variety of functions in addition to prevention of transient instability during the first swing. These are:

1. Improve damping of low frequency oscillations.
2. Damping of Sub synchronous Resonance (SSR) that can result from fixed series compensation
3. Reduce and damp sub synchronous frequency shaft torques to enable high speed reclosing of lines near a power plant. This is significant even in the absence of fixed series compensation.
4. Facilitate synchronizing a turbine generator. Out-of-phase synchronizing can produce more severe shaft torques compared to a bolted three phase fault at the generator.

The case study reported in reference led to the following conclusions.

1. The proportional control using the speed deviation of the generator (on which the dynamic brake is acting) gives good result in damping of torsional oscillations of the turbo generator shafts. The control signal of speed deviation contains primarily the torsional modes and little of the modes belonging to the electrical network. This results in robust control action which is independent of the network configuration or fault type.

2. A high pass filter acting on the control signal can provide better damping of the torsional modes at the expense of the low frequency swing mode (mode zero). However, for high-speed reclosing applications, this is advantageous as the transient shaft torques's are better damped.

3. Simulation results on multimachine systems show that identical generators can be controlled by a single dynamic brake. In most cases, brake acting on one generator does not affect the torsional modes of a nearby non-identical generator, unless the two generators share a common (torsional) mode frequency.

The Dynamic Braking Technique has many advantages, such as simplification of application and control, effectiveness to cost and lower maintenance. As a result, it has recently been deployed in many power systems to enhance their stability margin. In these applications, Braking resistors help damp both oscillations and swings of the power systems. Since the development of the Flexible AC Transmission Systems (FACTS) technique, the Thyristor-Control Braking Resistor (TCBR) which has the capabilities of rapid action and accurate power control has become an effective device for power system transient stability augmentation. This thesis investigates a novel approach of devising control schemes for the TCBR systems without precise mathematical models. In accordance with accepted methodology, the transient characteristics of a power system could be determined from its operating conditions. Through these characteristics, the accelerating factors that result in the acceleration of the system could be obtained. The thesis first introduces an effective method to determine the accelerating factors of power systems based on their transient characteristics. Using this method, a TCBR control approach is proposed, from which, both conventional and fuzzy control strategy are presented. This thesis also discusses the design and modeling of the new controllers for the TCBR system. Moreover, two power system Simulink models are built and used to test the performance of the controllers; Within the framework of power system stability and control, one of the contributions of this thesis is the introduction of a novel Equal Area Criterion (EAC) based TCBR control approach, which enhances the power system transient stability. In comparison with traditional Dynamic

Braking method, the EAC based approach result in shorter settling time and smaller magnitudes in system swings.

1.4.1.3.3 Fault Current Limiters: An Overview

The Department of Energy's Office of Electricity Delivery and Energy Reliability's mission is to lead national efforts to modernize the electric grid, enhance the security and reliability of the energy infrastructure, and facilitate recovery from disruptions to the energy supply. To support this mission, the DOE's superconductivity program supports HTS power cable and fault current limiters technology development in an effort to modernize the electric grid.

For the past several years, Superconductivity News Update has provided, on behalf of the DOE's superconductivity program, news and educational information concerning superconductivity products. Our mission has been to educate and inform individuals on the benefits of superconductivity. In the past, our issues have focused on research milestones, DOE/private company news, superconductivity cable project statuses, and whatever newsworthy related information was available. However for this issue we would like to take a different approach. Instead of the normal newsletter, we would like to discuss what may be an unfamiliar superconducting product; fault current limiters (FCL).

What Is a FCL?

A fault current limiter is a device that uses superconductors to instantaneously limit or reduce unanticipated electrical surges that may occur on utility distribution and transmission networks.

Why do we need the FCL?

When an unplanned event, such as lightning or downed power lines, occurs, a large surge of power can be sent through the grid resulting in a fault. A fault is any abnormal situation in an electrical system in which the electrical current may or may not flow through the intended part/s at an abnormal level and can result in a partial or total local failure in the functioning of an electric system. Serious faults can generate surge currents more than one hundred times the normal operating currents. These faults can result in damage to expensive grid-connected equipment.

The development of new generating facilities and network upgrades can greatly increase the potential fault current on a network. The FCL eliminates or limits the fault current increases resulting when new generation and network upgrades occur. This potential for increased fault current makes it imperative that utilities invest in protective measures such as: new substations, splitting existing substation busses, or using multiple circuit breaker upgrades. These protective measures are extremely expensive to install and maintain. FCL's eliminate or greatly reduce the financial burden on the utilities by reducing the wear on circuit breakers and protecting other expensive equipment.

What are FCL benefits?

According to the DOE, utilities pay hundreds of millions of dollars each year to maintain and add new circuit breakers to their transmission systems to protect the grid. The DOE then explains that investing in “smart technologies” such as FCL can save billions of dollars on transmission and delivery (T&D) equipment and power plants. Utility benefits from FCL include increased safety, reliability, and power quality. Utilities can reduce or eliminate the cost of circuit breakers and fuses by installing FCL. At the same time, these allow utilities to avoid or delay upgrading existing circuit breakers and electrical substations to handle ever higher electrical surges. Fault currents in transformers, for instance, can run 10-20 times the steady state design current. FCL can reduce these fault currents to levels not exceeding 3-5 times the steady state current, protecting and extending the life of transformers and associated utility equipment.

Other FCL benefits:

- Reduce or eliminate wide-area blackouts, far fewer localized disruptions, and faster recovery when disruptions do occur
- Provide protection to T&D equipment, eliminate or reduce replacement of T&D equipment (i.e. circuit breakers)
- Avoid split buses, opening bus-tie breakers

- Higher system reliability
- Reduce voltage dips
- Enhance grid stability. Enables the creation of a safer, more reliable, more efficient, and affordable power delivery system

Fault current limiting techniques:

There are active and passive methods of employing fault reduction and limitation on power Systems. Passive techniques such as the physical design of the power system components (e.g. high impedance transformers), network splitting, and connecting generation at higher voltage levels and sequential tripping all are effective solutions that can be employed to increase the source impedance and reduce fault levels. However, each of the solutions listed above result in one of more of the following disadvantages;

- Lower system reliability
- increased operational complexity
- increased cost
- Reduction in power quality
- Degradation of power system stability

Alternatively the power system can be designed to have a relatively high normal operating Fault level which will result in increased power quality and higher overall equipment utilization. The actual fault currents could be limited to levels that are within the rating of the associated electrical equipment, so as to allow safe operation, reliable protection

Operation and effective fault clearances on the power system. There are so-called “active” devices that can be employed in power systems to reduce the actual current that flows during fault conditions. Some examples of active fault current limiting devices are listed below:

- Explosive Is Limiters and fuses
- Solid state fault current limiting circuit breakers
- Superconducting fault current limiters
- Interphase power controllers
- Active fault level management

All of the devices listed above effectively provide small impedance under normal system Operating conditions and increased impedance during fault conditions. An investigation Has been carried out to determine the current state of development of the various fault Limiting technologies and the market readiness for the implementation of the devices.

CHAPTER 2
LITERATURE REVIEW

Manish Kumar Saini andNaresh Kumar Yadav and Naveen Mehra [1] proposed that power system stability is a term to applied alternating current in electric power system denoting when condition in which various synchronous machine of the system remain in synchronism. In this paper to describes the multi machine power system example to demonstrate the features and scope of graphical simulink environment of general uses of MATLAB software.

In this paper, unified power flow controller is used to improve the transient stability of multimachine power system. Unified Power Flow Controller (UPFC) is used to control the power flow in the transmission systems by controlling the impedance, magnitude and phase angle. In this controller the main advantages in terms of static and dynamic operation of the power system. It method also brings new challenges in power electronics and power system design. The basic structure of UPFC consists of two voltage source inverter (VSI); where one converter is connected in parallel to the transmission line while the other is in series with the transmission line. This paper involves the designing of a single phase UPFC using MATLAB and Simulink software and constructing a lab scale model of the UPFC along with transient stability of multimachine power system.

Gundala srinivasa rao [2] in this paper to improve transient stability by using Fuzzy controlled TCSC. Power system is subjected to sudden changes in load levels. The important concept of the stability to determines the stable operation of power system. In rotor angle stability is taken as index but the concept of transient stability which is the function of operating condition and disturbances deals with the ability of the system to remain intact after being subjected to abnormal deviations. The system is said to be synchronously stable for a given fault if the system variables settle down to some steady-state values with time after the fault is removed.

In this paper, in order to improve the Transient Stability margin further series FACTS device has been implemented. In a fuzzy controlled Thyristor Controlled Series Compensation

(TCSC) device has been used here and the results highlight the effectiveness of the application of a TCSC in improving the transient stability of a power system.

In this paper, Trajectory sensitivity analysis (TSA) has been used to measure the transient stability condition of the system. TCSC is modeled by a variable capacitor the value of which changes with the firing angle. This is shown that TSA can be used in the design of the controller. The locations of the TCSC-controller for different fault conditions can also be identified with the help of TSA. The paper the advantage of the use of TCSC with a fuzzy controller over fixed capacitor operation.

Prechanon Kumkratug, [3] in this modern power system consists of the complicated network of transmission lines and carries heavy demand. One of the major interests of power utilities is the improvement of power system transient behavior. Static Synchronous Series Compensator (SSSC) is a power electronic based device that has the capability of controlling the power flow through a line. The SSSC is use to improve transient stability of power system and verify the effect of the SSSC on transient stability and the mathematical model and control strategy of a SSSC is presented. SSSC is represented by variable voltage injection with associate transformer leakage reactance and the voltage source. These series voltage injection model of SSSC is modeled into power flow equation and thus it is used to determine its control strategy. We can study the uses machine speed deviation to control it. These swing curves of the three phase faulted power system without and with a SSSC is tested and compared in various cases. The swing curve of system without a SSSC gets increases monotonically and thus the system can be considered as unstable whereas the swing curves of system with a SSSC can be considered as stable. SSSC can improve transient stability of power system.

Satvinder Singh, Atma Ram, Nitin Goel, Pawan Kumar [4] proposes a method of designing the studies of the comparative performance of SVC (Static Var Compensator) and UPFC (Unified Power Flow Controller) for the improvement of transient stability of multi-machine system. The UPFC is more effective FACTS (Flexible AC Transmission System) device for controlling active and reactive power flow in a transmission line and power oscillation damping by controlling its series and shunt parameter. Simulation is carried out in MATLAB/Simulink environment for multi-machine system to analyses effects of SVC and UPFC on transient stability system. The performance of UPFC is compared with SVC. The simulation results demonstrate the effective and robustness of the proposed UPFC for transient stability improvement of the system.

Surinder Chauhan, Vikram Chopra, Shakti Singh [5] in this paper by using a static synchronous compensator is one of the FACTS devices used to improve the transient stability of the power system. In this paper the fuzzy logic controller is designed. The inputs to the fuzzy logic are the alternator speed i.e. ω and the output is the firing angle α of the voltage source converter. The proposed controller is tested on two machine system using Matlab Simulink. The Results compared with conventional PI STATCOM Controller.

Carlo Cecati and Hamed Latafat, [6] to study the transient stability of a two machine infinite bus system when affected by large disturbances by comparison of time domain approach versus transient energy function. Then decentralized nonlinear controller is embedded within the power system and simulation results show that the transient stability has been greatly enhanced. Based on existing transient energy function of uncontrolled power system the controlled power system has been represented as a forced Hamiltonian system. The Lyapunov function is suitable for transient stability analysis of this controlled power system has been used for stability. Simulations in different operating points show the enhancement of transient stability of power system with controller in both time domain approach and energy function method.

Kumar, Arun, [7] this paper presents a comprehensive review on enhancement of power system stability such as rotor angle and frequency stability and voltage stability by using different FACTS controllers such as TCSC;SVC; SSSC; STATCOM; UPFC; IPFC in an integrated power system networks. Also the presents the current status of the research and developments in the field of the power system stability such as rotor angle stability; frequency stability and voltage stability enhancement by using different FACTS controllers in an integrated power system networks. Authors strongly believe the useful to the researchers for finding out the relevant references in the field of enhancement of power system stability by using different FACTS controllers in a power system network.

Jignesh S. patel and Manish N. Sinha, [8] discussed that power system stability is a term applied to alternating current electric power systems; denoting a condition in which the various synchronous machines of the system remain in synchronism, or "in step" with each other. Instability denotes a condition involving loss of synchronism, or falling "out of step". The fault is occurrence in a power system causes transients. In practice the fault generally occurs in the load side. We were controlling load side which will lead to complex problem in order to avoid that we are controlling the generator side. This paper covers the transient stability analysis of 400 kV substations. A three phase fault is located at specified bus to analyze the effect of fault location in critical clearing time on the system stability.

Mureithi C. M , Ngoo L. M, Nyakoe G. N, [9]in this paper the high reactive power demand by the induction motor load during fault condition due to reduced bus voltages may cause a generator to behave like a voltage source behind the synchronous reactance and its terminal voltage reduces leading to the possibility of a voltage collapse scenario. The reliability of these systems and in an attempt to reduce system oscillations. Power System Stabilizers (PSS) have used to add damping by controlling the excitation system. They are Studies on a SMIB and those using static loads have shown that a well-tuned PSS using a Fuzzy Logic Controller (FLPSS) can effectively improve power system dynamic stability. Paper investigates the impact of the FLPSS in maintaining voltage stability in a system with induction motor loads. The large induction motor is introduced as a load in a multi machine system and the impact of the FLPSS are investigated by introducing a temporary three phase fault. The comparison the FLPSS is compared to other PSS found in literature. This results indicate that the FLPSS may lead the generator to lose its capability to maintain constant voltage and hence lead to the stalling of the induction motor load soon after the fault is cleared.

Mokhtari, M., [10] in this paper the transient stability of the power system with the use of distributed static series compensator (DSSC) is enhanced. First of all, a detailed simulation model of the DSSC has presented. DSSC has a function like static synchronous series compensator (SSSC) but is in smaller size and lower price along with more other capabilities. In DSSC lies in transmission lines in a distributed fashion. It is study comprising two-machine power system has been put under investigation through the extensive time domain simulations. The sequel the DSSC has been incorporated in the studied system in different cases. This Simulation results is approve the DSSC ability for increasing transient stability margin of the power system.

B.Y.Bagde and P.M.Meshram [11] in this paper to describe the transient stability poses challenging computational and analytical problems due to its non-linear nature. SIME (Single Machine Equivalent) is a method which transforms the dynamics of multi machine power system into single machine which is then analyzed to find whether the system is stable or unstable. This instability is detected at an instant before the system actually goes unstable. The suitable control actions can now be taken within this margin so as to make the system stable. SIME are the best features of Time Domain method and Direct Method to carry out transient stability analysis. Simulation is done for a contingency and critical clearing time and stability margin are found. This technique is tested on 50 machine IEEE test system. It is instability is detected Generation scheduling is done to stabilize the system.

Haman, T., [12] in this paper by using FACTS systems is one of the latest methods which has been used to improve transient stability of power systems. These flexible systems have been major determinant of transient stability improvement by power swing damping. There are numerous suggested control methods for UPFC control. In this paper we will consider and compare two neural network control methods which are based on H_{infin} learning method and discrete control method. These control methods are implemented on both single-machine and multi-machine systems. The results of simulation showed that RBFNN has better performance in domain and swing reduction by far and can be used as an appropriate option in real time calculations.

Mansour A. Mohamed George G. Karady Ali M. Yousef, [13] this paper discusses the proposes of transient angle stability agents to enhance power system stability. The transient angle stability agents divided into two strategy agents. This first strategy agent is a prediction agent that will predict power system instability. The prediction agent’s output the second strategy agent which is a control agent is automatically calculating the amount of active power reduction that can stabilize the system and initiating a control action. The new proposed strategies are applied to a realistic power system, the IEEE 50- generator system. The results show that the proposed technique can be used on-line for power system instability prediction and control.

KA Folly, Member, IEEE, B. S. Limbo, [14] this paper discusses the experience of the authors in using MATLAB Power System Toolbox for the transient stability studies of an AC/DC Interconnection power system. This modified two-area power system model with HVDC Link is used in the investigation. It shown that the AC line became weaker (as compared to the DC line); the transient stability of the interconnected AC/DC system is negatively affected. The use of power system stabilizer (PSS) was critical in maintaining the stability of the system.

Sidhartha Panda Ramnarayan N. Patel, [15] Shunt Flexible AC Transmission System (FACTS) devices it is placed at the mid-point of a long transmission line, they play an important role in controlling the reactive power flow to the power network and hence both the system voltage fluctuations and transient stability. In this paper deals with the location of a shunt FACTS device to improve transient stability in a long transmission line with predefined direction of real power flow. This validity of the mid-point location of shunt

FACTS devices is verified with different shunt FACTS devices, namely static var compensator (SVC) and static synchronous compensator (STATCOM) in a long transmission line by using the actual line model. It is observed that the FACTS devices when placed slightly off-centre towards sending-end and give better performance in improving transient stability and the location depends on the amount of local/through load.

Dr. Tarlochan kaur and Sandeep kakran, [16] in this paper to improve the transient stability of long transmission line system by using SVC. In the present time power systems are being operated nearer to their stability limits due to economic and environmental reasons. The maintaining a stable and secure operation of a power system is a very important and challenging issue. Transient stability has given much attention by power system researches and planners in recent years and being regarded as one of major sources of power system insecurity. Shunt FACTS device an important role in improving the transient stability and increasing transmission capacity and damping low frequency oscillations. In this paper to describes the shunt FACTS device SVC is used in a two area power system for improving the transient stability. MATLAB software is used.

Yuning Chen, M.E. El-Hawary, [17] in this paper a new braking resistor approach using the equal area criterion (EAC) is presented to improve the transient stability of power systems. The conventional and a fuzzy logic controller have been developed and compared. This proposed approach was tested on a single machine system and on the IEEE WSCC multimachine test system. The simulation results indicate that the proposed approach provides a simple and effective method for the transient stability improvement.

Rubaai A., Cobbinah D, [18] in this paper by using the thyristor controlled system dynamic braking resistor and the nonlinear optimal control theory are approached simultaneously within a hierarchical framework. The creates a multiple local feedback controllers that can be realistically implemented using only local measurements and whose performance is consistent with respect to changes in network configuration, loading and power transfer conditions. By controlling the firing-angle of the thyristor braking resistor controls the accelerating power in each generator and thus enhances the stability margins and damping oscillations. The local controllers rely only on information particular to their own subsystem; interconnection effects and the nonlinearities introduced by them are accounted for by a supervisory controller. In this proposed control strategy was tested on the IEEE Western States Coordinating Council (WSCC) test system. The results show that the method is capable of bringing the system under control when starting with inherently unstable conditions then disturbances is increased.

Souza, C.L,[19] this technique aims to analyze the transient stability of electrical power systems including the influence of induction generators driven by prime movers whose primary fuel is the industrial wastes of sugar cane alcohol plants. In a steady state these machines work with the synchronous generators attending part of the active power demand (cogeneration) and during disturbances they also act to improve the system transient stability. Used an existing transient stability program; some simulations are run to compare the performance of a typical electrical system with and without the presence of induction generators.

Rahim A.H.M.A, Alamgir D.A.H, [20] in this paper the control strategy for dynamic braking resistor and shunt reactor is proposed for stabilization of electric generators subjected to large disturbances. Time optimal control is derived as a function of synchronous machine power; its rotor angular position and speed deviation. This response for a single-machine system with the proposed control has been obtained using the steepest-descent method. These new strategy has also been tested on two multimachine systems. It results indicate that the proposed strategy provides a simple and effective method of stabilization under transient emergency conditions. It found that the strategy is very effective in controlling first swing instability.

Chi-Shan Yu, [21] this paper explains the improvement of the optimal aim strategy (OAS) for the design of a thyristor controlled series compensator controller has been proposed to enhance the inter-area transient stability of interconnected power systems. Due to some problems created in applying conventional OAS to the power system transient stability control and some solutions have been proposed to improve the conventional OAS and the analytic design procedures also have been proposed to achieve the desired performance. In this addition for multimachine inter-area transient stability OAS control; the reduced order model has been proposed to design the improved OAS command. Shaping of the reduced order model involves the real-time measurements which are available from phasor measurement units (PMUs). Finally, some simulation studies are employed to test the controller.

CHAPTER 3

PRESENT WORK

3.1 OBJECTIVE

The main objective of my thesis to improve power system transient stability by using FACTS device such as TCBR and FCL. They have to improve rotor speed, mechanical power, reactive power and active power by improvement of reactive power the voltage stability of a system also get improve. By using FCL and TCBR a noticeable improvement in rotor speed stability happens and it can be seen that the first swing of rotor speed in this case is restrained effectively. And without using TCBR and FCL rotor speed has severe oscillations that may cause power system instability.

3.2 MODELLING AND CONTROL STRATEGY

3.2.1 Thyristor controlled braking resistor (TCBR)

A. Operating Principles:

Thyristor controlled braking resistor is connected to the generator are shown in figure 3.1. Where Pm is the mechanical input power and Pe is the electrical output power respectively. Pt is the power delivered to the network and Pr is the power absorbed by the resistor of TCBR. Vt is the voltage of the bus terminal and Rr is the value of the braking resistor.

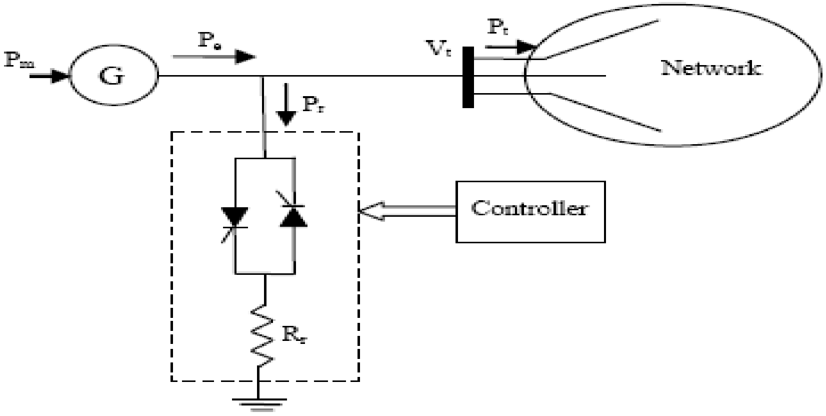

Fig.3.1 Schematic diagram of a TCBR connected to the generator

From Fig. 2 the output power Pe is:

$$P_e = P_r + P_t \qquad (1)$$

And the absorbed power by TCBR is:

$$\mathrm{Pr} = \frac{\mathrm{V}_\mathrm{t}^2}{\mathrm{R}_\mathrm{r}} \qquad (2)$$

When switch the TCBR, the power absorbed by the braking thyristor and electric power output of the generator will be increased. Figure 3 show the characteristics of power angle, it that the connection of the braking resistor offsets the machine power angle curve by the magnitude of Pr.

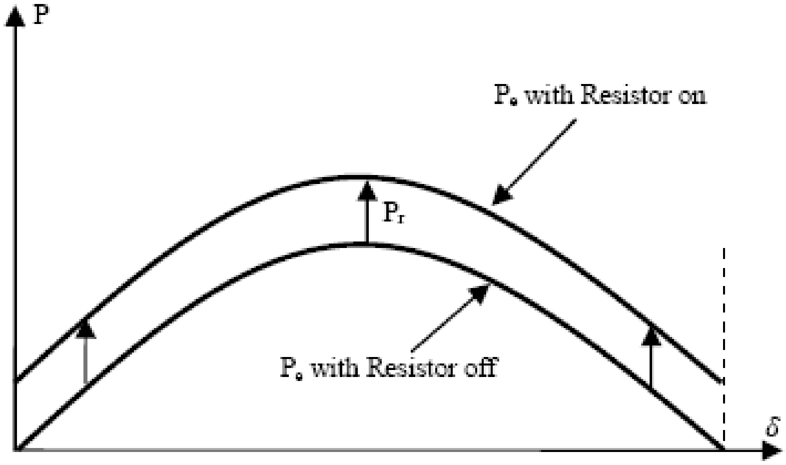

Fig.3.2 Power-angle characteristic of power system with TCBR

B. Conventional Control Strategy

The main idea of conventional control strategy is that when the mechanical input power is above the output power of the machine drops and to reduce all accelerating area A1. Then braking resistor will be switched and resistor power should be controlled and equal to the accelerating power at rotor angle. In other hand, electrical output power is equal to the value of input power at rotor angle, so area A1 will be eliminated. But the rotor deviation is the function of time; the result will be shown by setting the value of resistor power and equal to the accelerating power at each time deviation.

Let ΔPe denotes accelerating power, the equation is written as:

$$P_r = P_m - P_e = \Delta P_e \tag{3}$$

For a practical application system, assume that fault occurs at time t=0. To take the system delay into account, (3) becomes:

$$Pr_n = Pm_n - Pe_n = \Delta Pe_n \tag{4}$$

When the effect of resistor power, (4) can be written as:

$$Pr_n = Pm_n - (Pe_n - Pr_{n-1}) = \Delta Pe_n \tag{5}$$

Where n is the current time step. Prn-1 is the resistor power determined at the previous time step. Again, because of system delay, (1) is rewritten as:

$$Pe_n = Pm_n - Pt_n \tag{6}$$

From (5) and (6), resistor power is,

$$Pr_n = Pm_n - Pt_n \tag{7}$$

Let ΔPt denote Pm –Pt, the resistor power can then be expressed by:

$$Pr_n = \Delta Pt_n \tag{8}$$

From (6) and (8), (4) can be rewritten as:

$$\Delta Pe_n = Pm_n - Pt_n - Pr_{n-1}$$

$$\Delta Pe_n + Pr_{n-1} = Pm_n - Pt_n = \Delta Pt_n \tag{9}$$

Substituting (7) into (9), one can get:

$$\begin{aligned}\Delta Pe_n + Pr_{n-1} &= \Delta Pe_n + Pm_{n-1} - Pt_{n-1} + Pr_{n-2} \\ &= \Delta Pe_n + \Delta Pe_{n-1} + Pr_{n-2} \\ &= \Delta Pe_n + \Delta Pe_{n-1} + \Delta Pe_{n-2} + \cdots + \Delta Pe_0 + Pr_{-1}\end{aligned} \tag{10}$$

Where, $P_{r-1} = P_{m-1} - P_{t-1}$. P_{m-1} and P_{t-1} are the Pm and Pt values before the disturbance, obviously:

$$Pr_{-1} = 0 \tag{11}$$

From (10) and (11), (9) becomes:

$$\Delta Pt_n = \Delta Pe_n + Pr_{n-1} = \sum_{i=0}^{n} \Delta Pe_i \tag{12}$$

To ensure the stability of the system and avoid over damping, a positive rotor speed deviation constraint is important. The resistor should be switched on only if both rotor speed deviation and the accelerating power are positive. The control strategy is given by:

$$if\ \Delta\omega_n > 0$$

$$Pr_n = \sum\nolimits_{i=0}^{n} \Delta Pe_i$$

$$else,$$

$$Pr_n = 0$$

Since direct measurements of ΔPei are difficult, it can be simplified by using the swing equation given by:

$$\Delta\dot{\omega} = \frac{1}{M}P_m - \frac{D}{M}\Delta\omega - \frac{1}{M}P_e$$

The swing equation can be written as:

$$M\Delta\dot{\omega} + D\Delta\omega = P_M - P_e = \Delta P_e \qquad (13)$$

From (8) and (13), (12) is expressed as:

$$Pr_n = \Delta Pt_n = \sum_{i=0}^{n} \Delta Pe_i = \sum_{i=0}^{n}(M\Delta\ddot{\omega}\imath + D\Delta\omega_i) \qquad (14)$$

Therefore, the control strategy can be concluded as:

$$if\ \Delta\omega_n > 0,$$

$$Pr_n = \sum_{i=0}^{n}(M\Delta\ddot{\omega}\imath + D\Delta\omega_i)$$

Else,

$$Pr_n = 0 \qquad (15)$$

The control strategy only requires the measurement of machine rotor speed deviation A w, which is easy to do. For the online implementation, (15) can be implemented using:

$$Pr_n = Pr_n + Pr_{n-1}$$

Where, $Pr_n = M\Delta\dot{\omega}n + D\Delta\omega_n\ and\ Pr_{n-1}$ is the value of resistor power at the pervious time step. To reduce the integral error, when the braking resistor is off, Pr_{n-1} is reset and kept as 0.

The firing angle α to switch the thyristor on is calculated from the value of the braking resistor power. The average power consumed by the braking resistor is given by:

$$Pr = \left(\frac{V_t^2}{\pi Rr}\right)(\pi - \alpha + 0.5\sin(2\alpha)) \qquad (16)$$

α can be obtained online by utilizing the linear interpolation technique introduced in. A dead zone is needed to keep the braking resistor from being active during normal steady state operation where small fluctuations in voltage occur constantly.

3.2.2 Modelling Of FCL

Fault current limiters are used to consist of a detector, a controller and a limiter resistor. When the use of Fault current limiter, the one necessary thing to limit the fault current and improve the power system transient stability. Hence the FCL are installed in series with transmission lines and it just operation when the fault is occurrence, during this period it’s clearing the fault. And after the clearing the faults they cannot be control the generator disturbances.

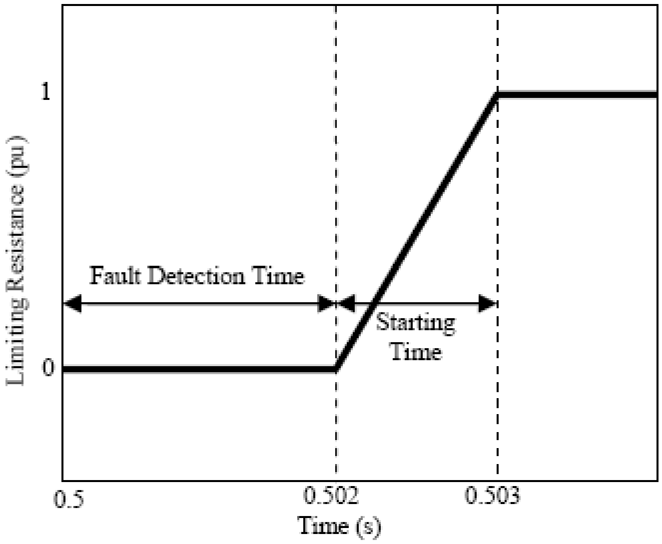

Fig.3.3 FCL characteristic

When change in over time for limiting resistance are created in FCL as shown in figure 4. Let us consider that the limiting resistance value is 1.0 pu, fault detection time and starting time of limiting resistance is 2 msec and 1 msec. When the FCL start to operate at time 0.502 sec and it just increase the limiting resistance linearly from 0.0 pu to 1.0 pu within 1 msec. Although this effect of improvement of transient stability are change and it's depend on the limiting resistance value, 1.0 pu is the most effective value on the transient stability improvement and is determined based on the result of simulation using various limiting resistance values.

CHAPTER 4

MATLAB DESIGN OF CASE STUDY AND RESULTS

Consider a single machine system shown in fig.4.1 this in which source is connected at one end while load is connected at the other end. A synchronous generator of 1000MVA, 21 kV is connected at sending end with a step-up transformer to attain 230 kV. The transmission system of 230 kV is considered for carrying out stability analysis. Then again step-down transformer to attain 21 kV is connected with load of 100 kW. In this stability analysis, following four cases are studied. Simulation is carrying out in MATLAB.

Case 1:- Without any FACTS device:-

It is the case when no FACTS device is connected in the transmission system as shown in figure. The waveform obtained show that number of oscillations produced are much more than obtained when FACTS device is connected. Various waveforms including rotor speed, mechanical power, reactive power and active power are shown in fig. 4.2, 4.3, 4.4, 4.5 and 4.6 respectively.

Case 2:-With TCBR:-

It is the case when TCBR is connected in the transmission system as shown in figure. The waveform obtained show that numbers of oscillations produced are much less than obtained when no FACTS device is connected. Various waveforms including rotor speed, mechanical power, reactive power and active power are shown in fig. 4.7, 4.8, 4.9, 4.10 and 4.11 respectively.

Case 3:- With FCL:-

It is the case when FCL is connected in the transmission system as shown in figure. The waveform obtained show that numbers of oscillations produced are much less than obtained when no FACTS device is connected. Various waveforms including rotor speed, mechanical power, reactive power and active power are shown in fig. 4.12, 4.13, 4.14, 4.15 and 4.16 respectively.

Case 4:-With FCL and TCBR:-

It is the case when FCL and TCBR are connected in the transmission system as shown in figure. The waveform obtained show that numbers of oscillations produced are very less than that obtained from three previous cases and Better result are obtained in this case. Various waveforms including rotor speed, mechanical power, reactive power and active power are shown in fig. 4.18, 4.19, 4.20, 4.21 and 4.22 respectively.

CASE (A): WITHOUT TCBR AND FCL

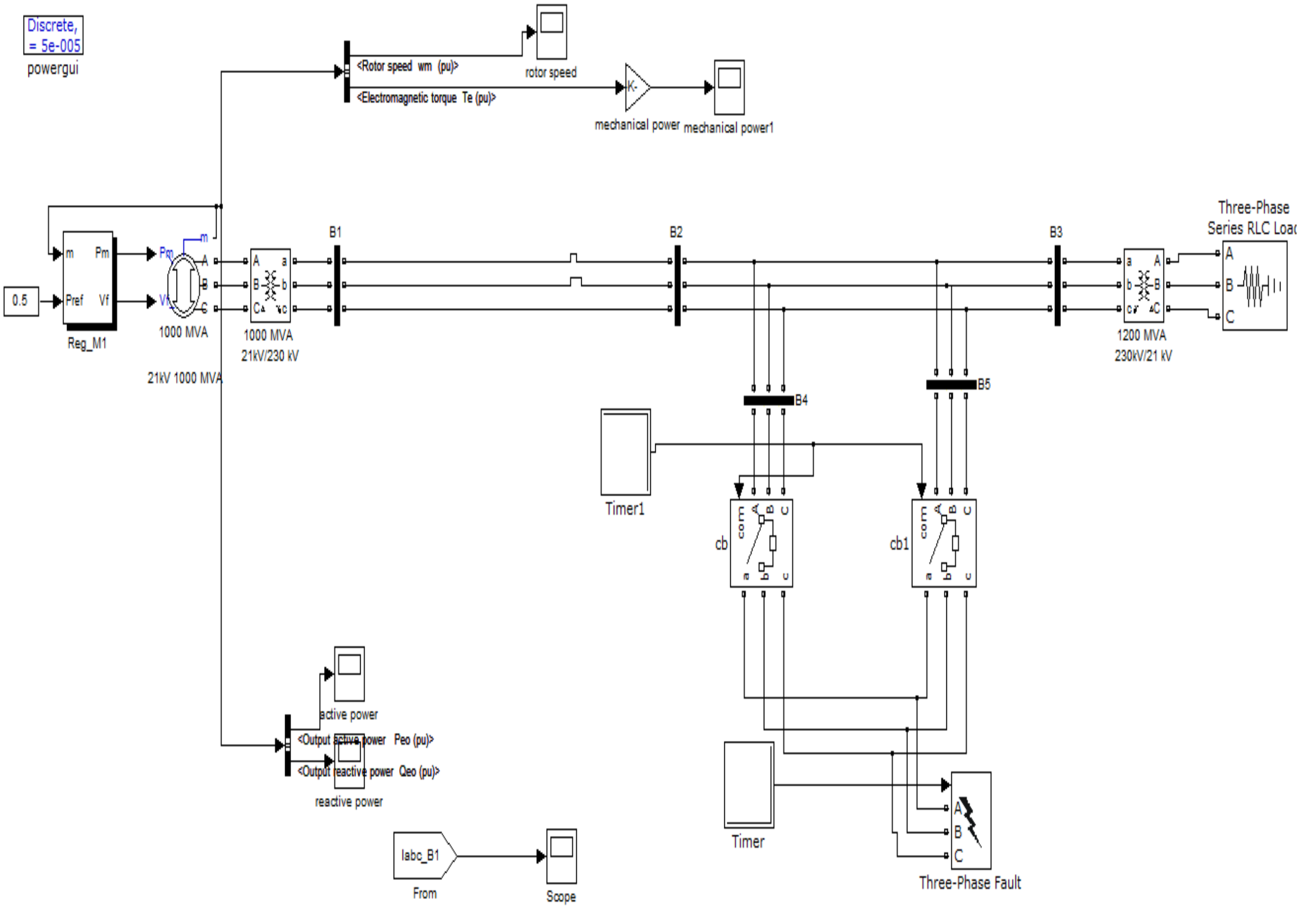

Fig.4.1 Simution without TCBR and FCL

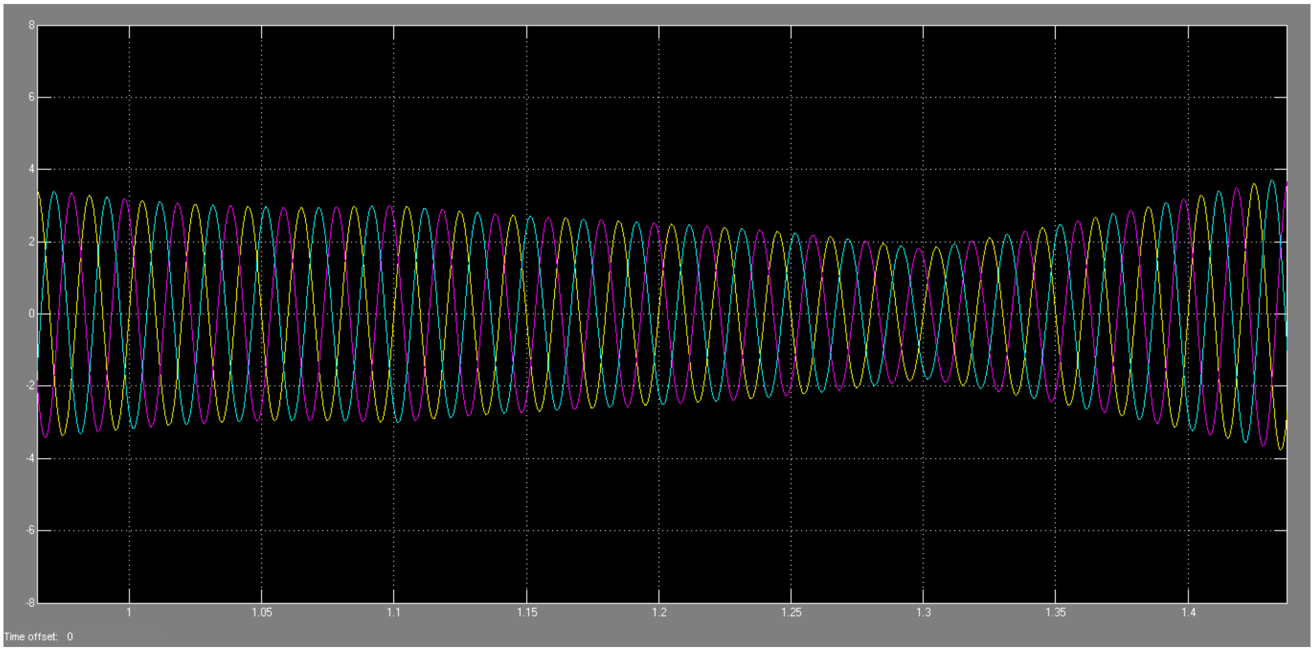

Fig.4.2 Graph of 3-Phase Fault Current at Y-Side of the Transformer

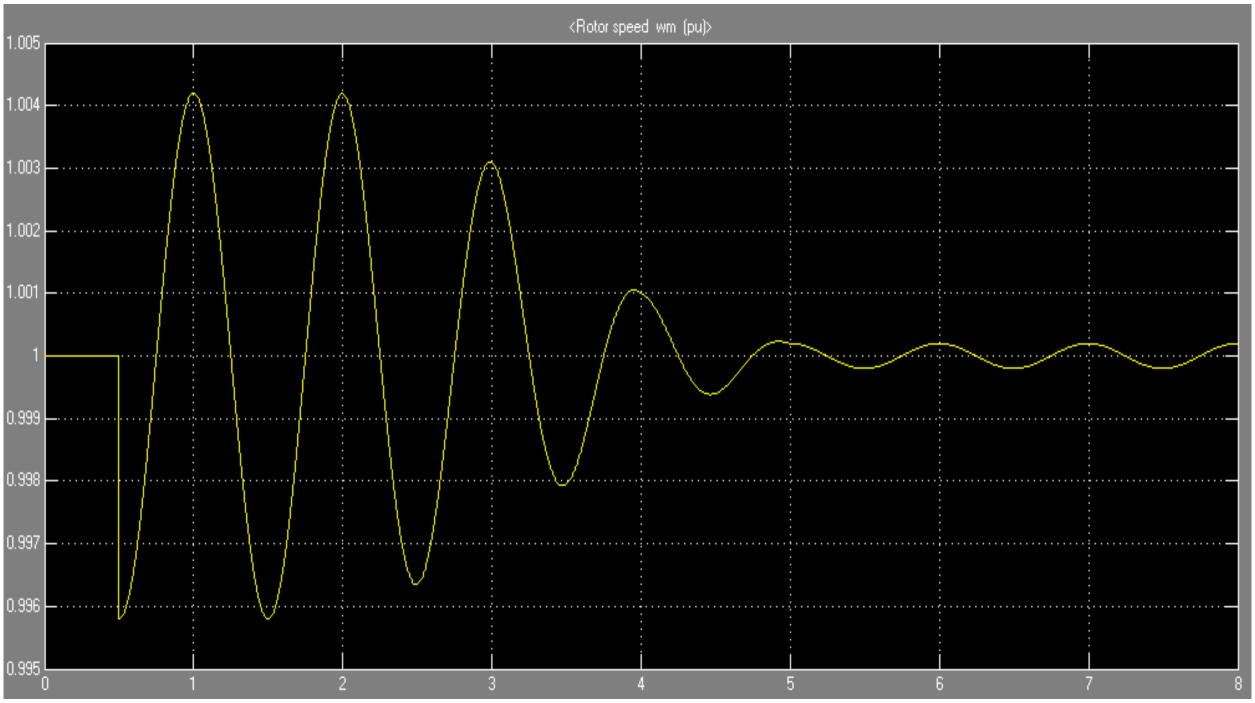

Fig.4.3 Graph of Rotor Speed without FACTS

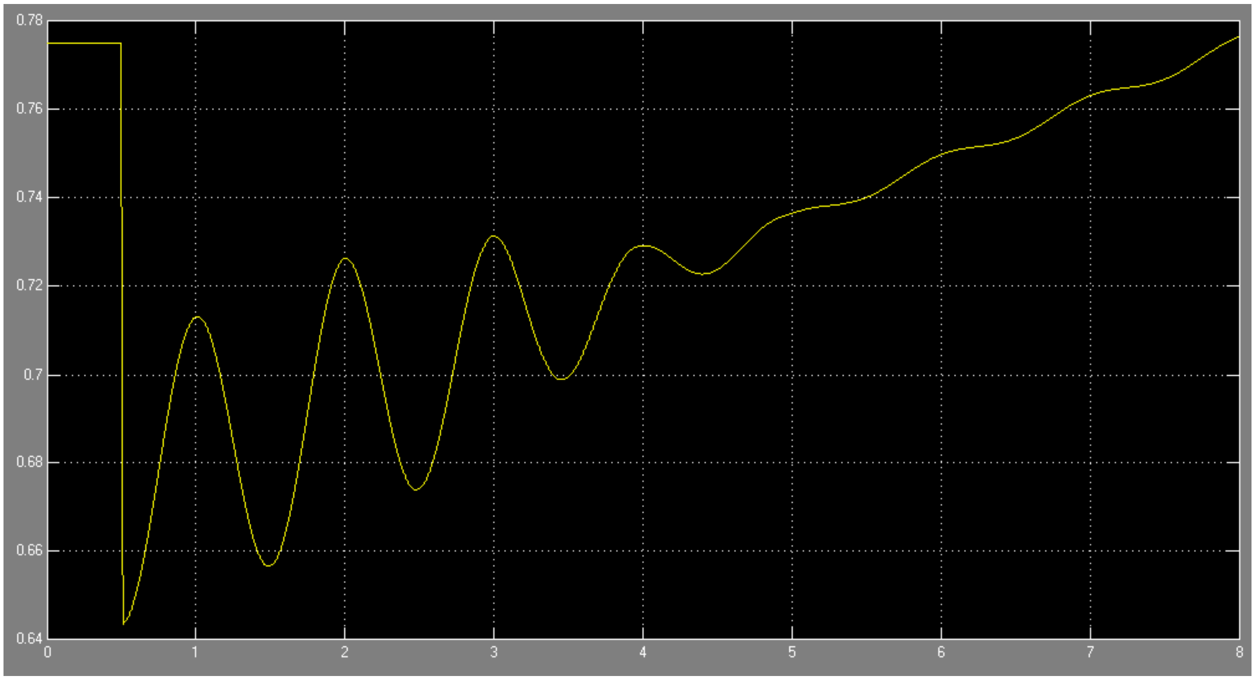

Fig.4.4 Graph of Mechanical Power without FACTS

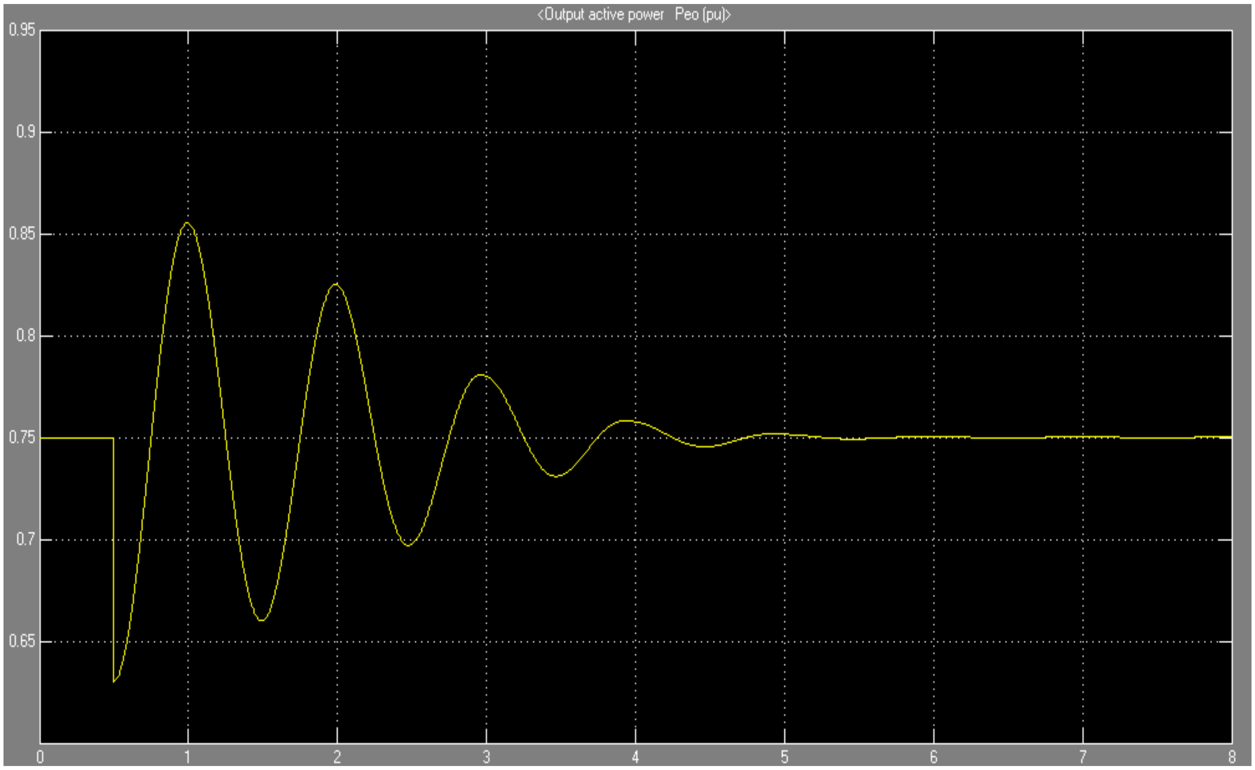

Fig.4.5 Graph of Active Power Without FACTS

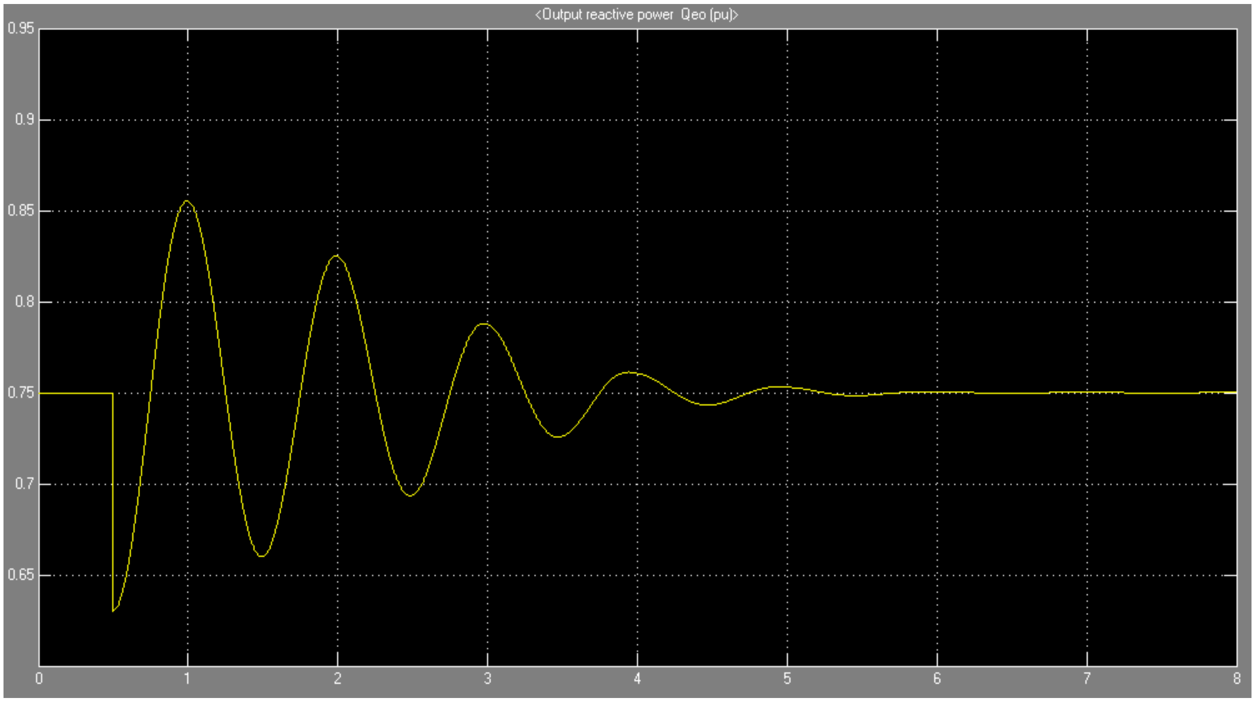

Fig.4.6 Graph of Reactive Power Without FACTS

CASE (B): With TCBR

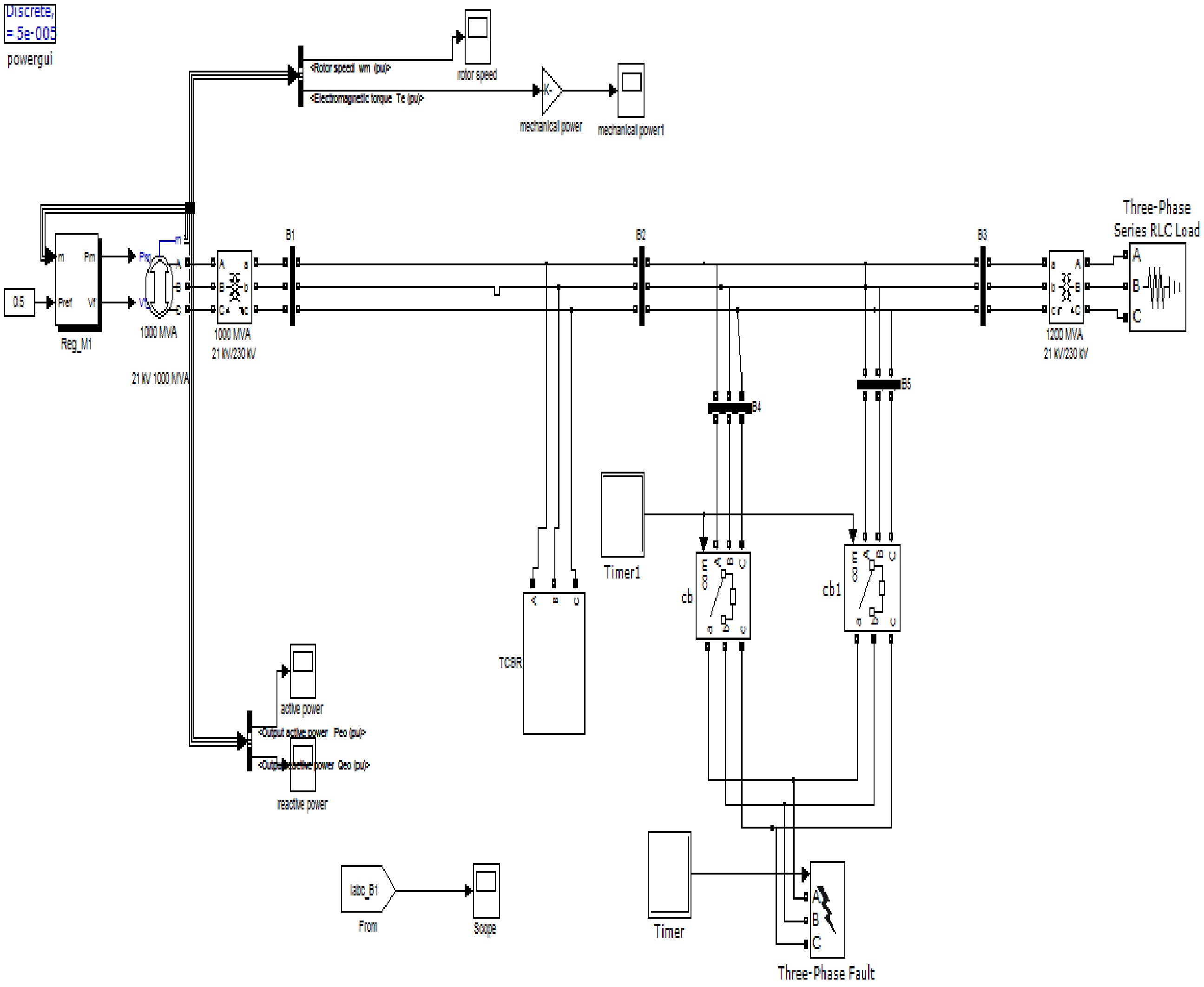

Fig.4.7 Simution with TCBR

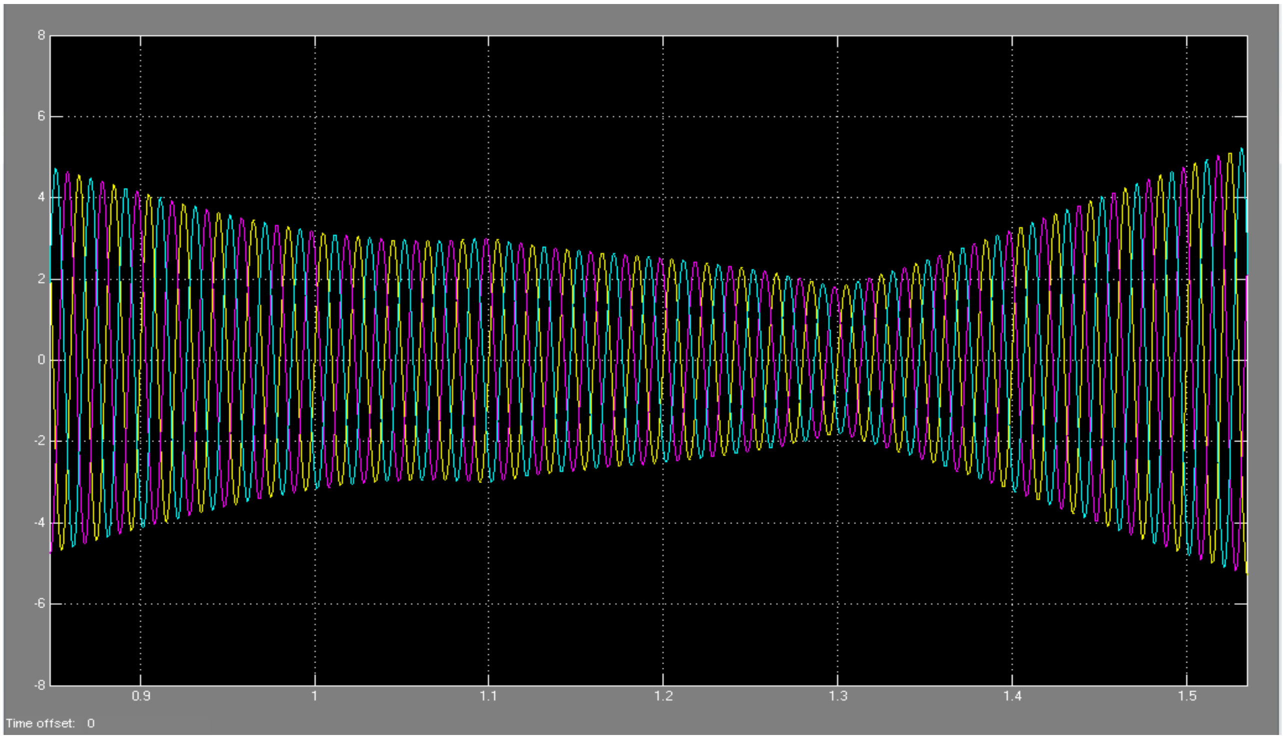

Fig.4.8 3-Phase Fault Current at Y-Side of the Transformer

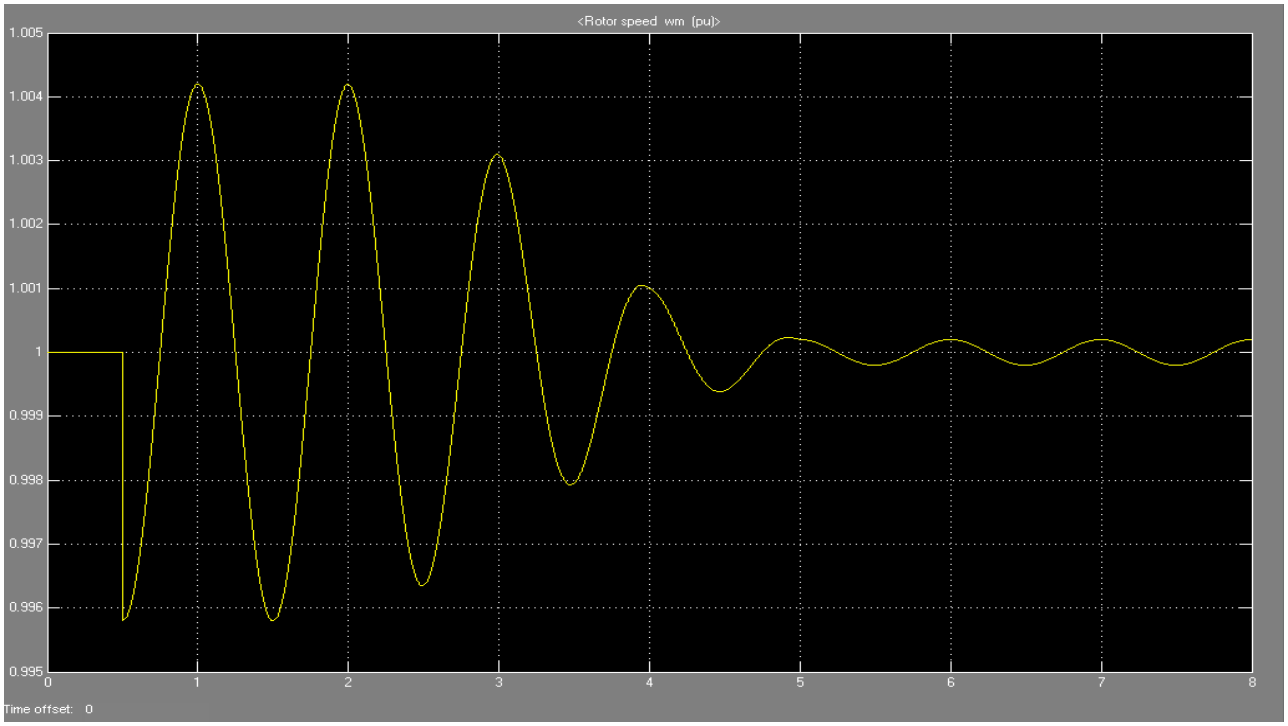

Fig.4.9 Graph of Rotor Speed With TCBR

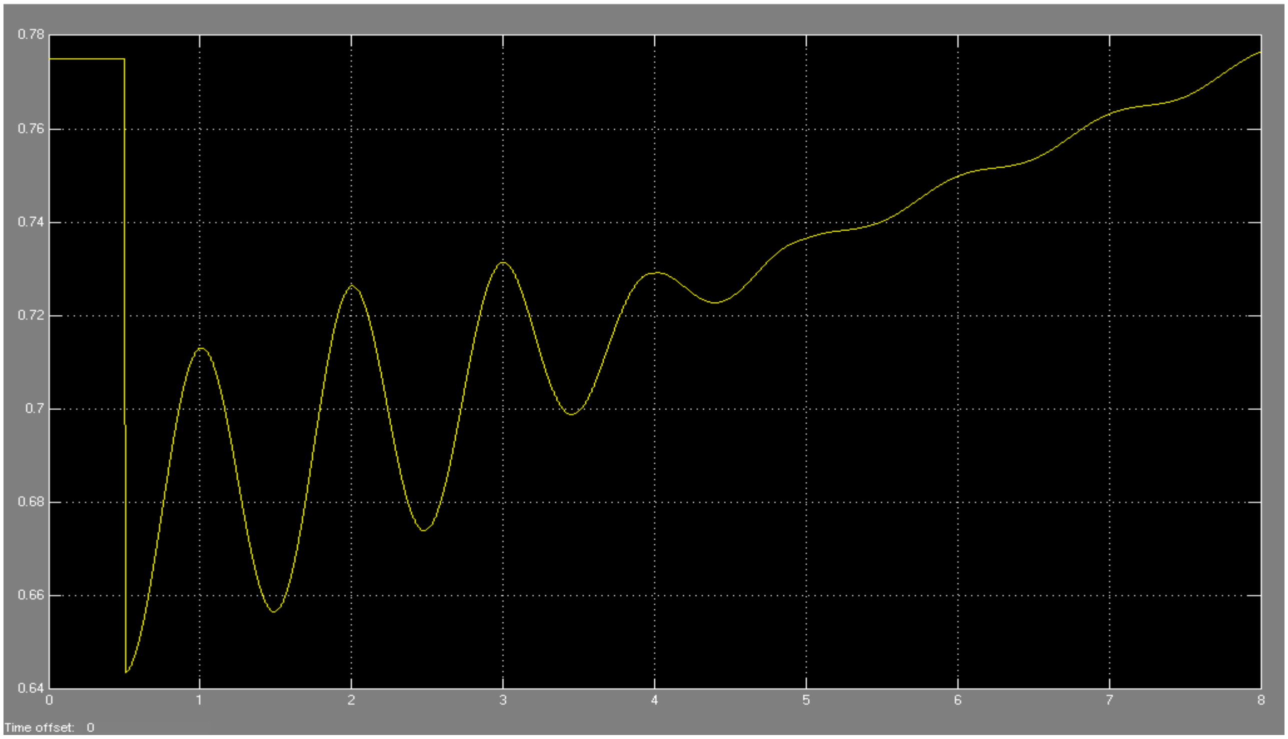

Fig.4.10 Graph of Mechanical Power With TCBR

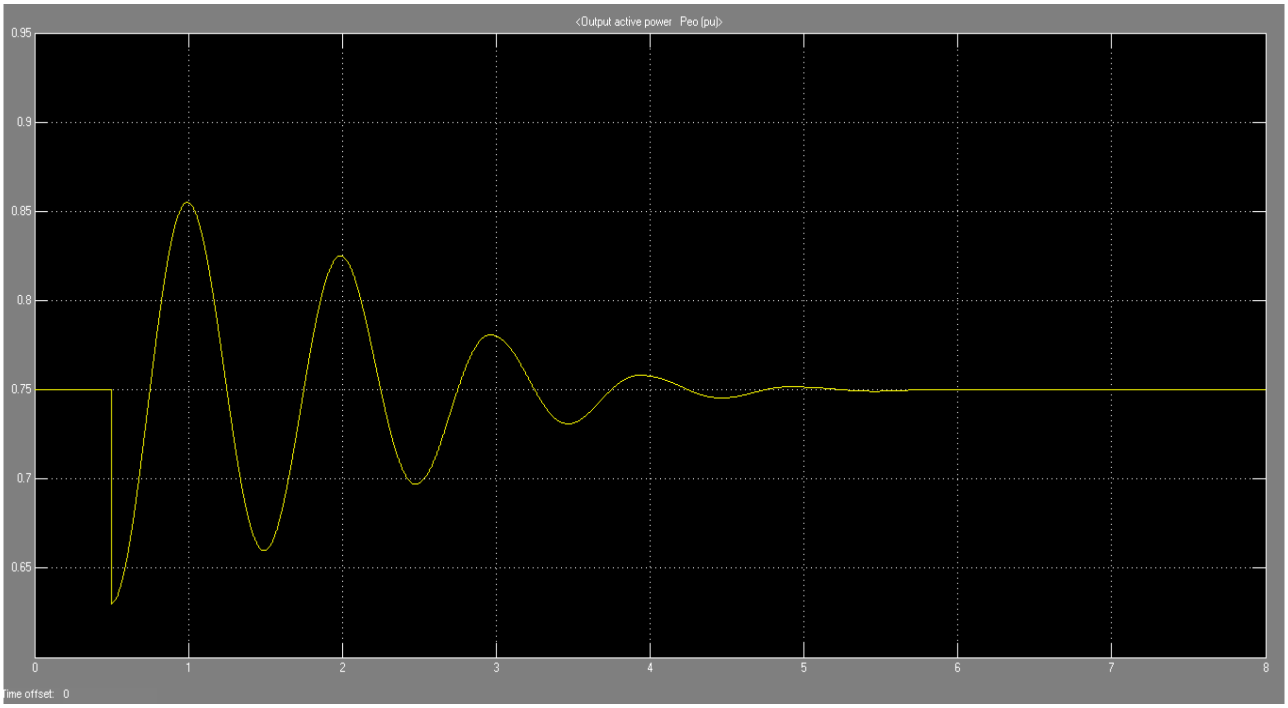

Fig.4.11 Graph of Active Power With TCBR

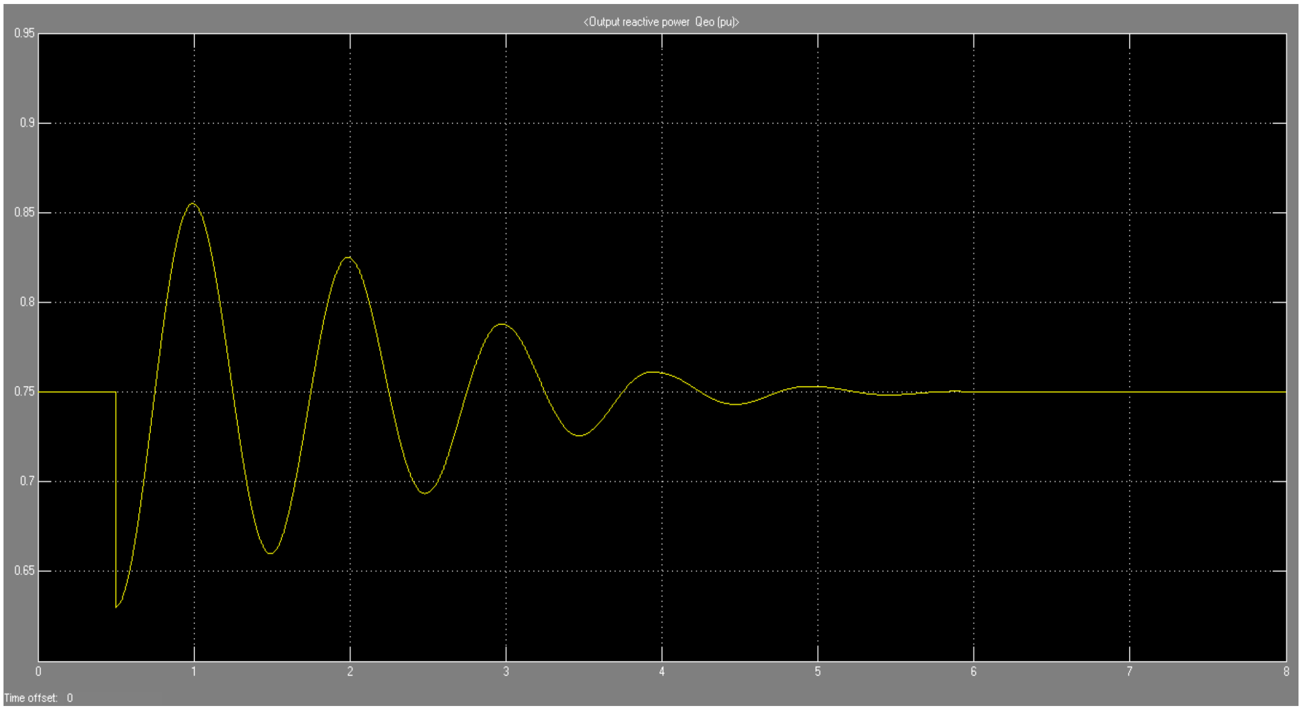

Fig.4.12 Graph of Reactive Power With TCBR

CASE (C): With FCL

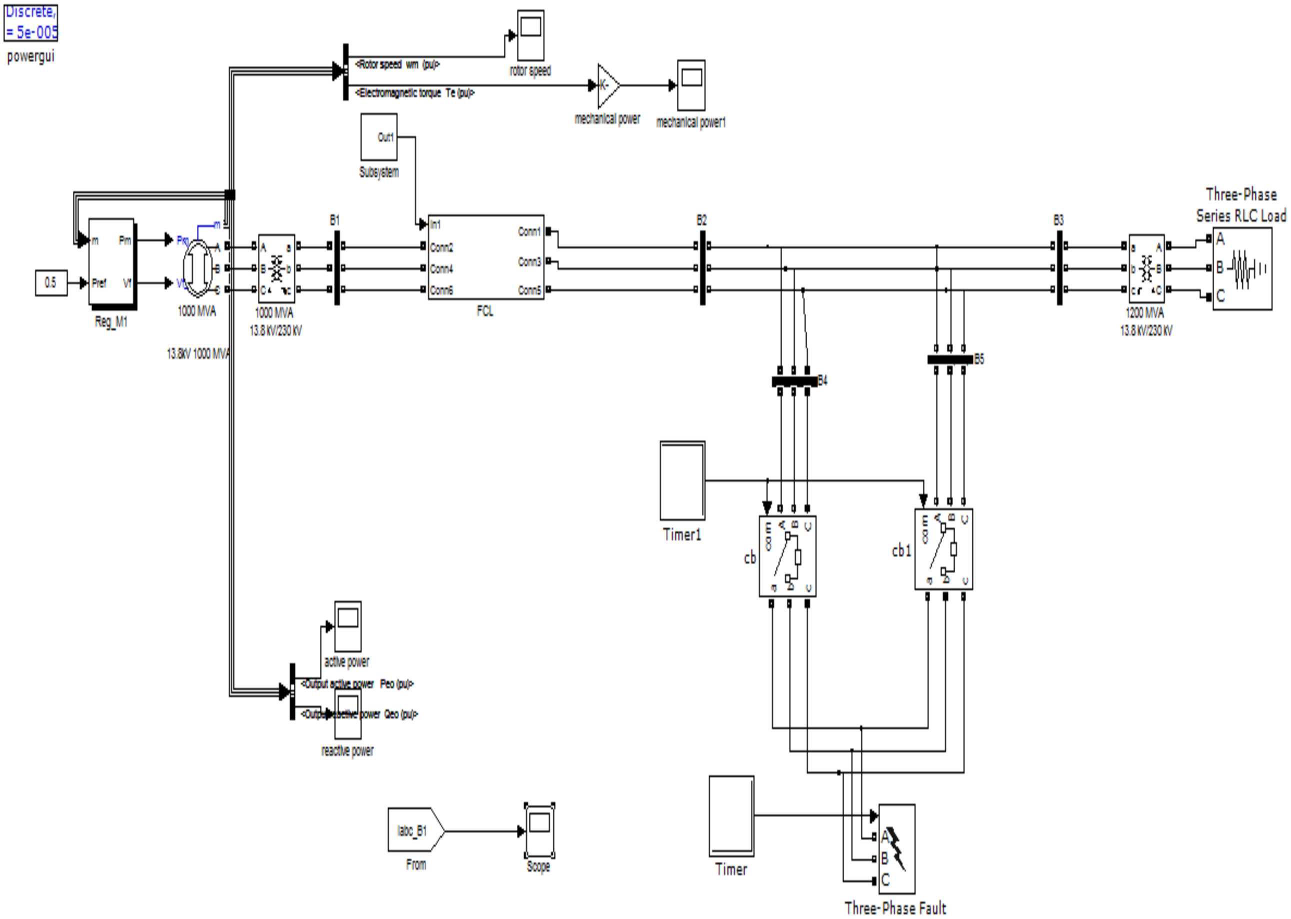

Fig.13 Simution with FCL

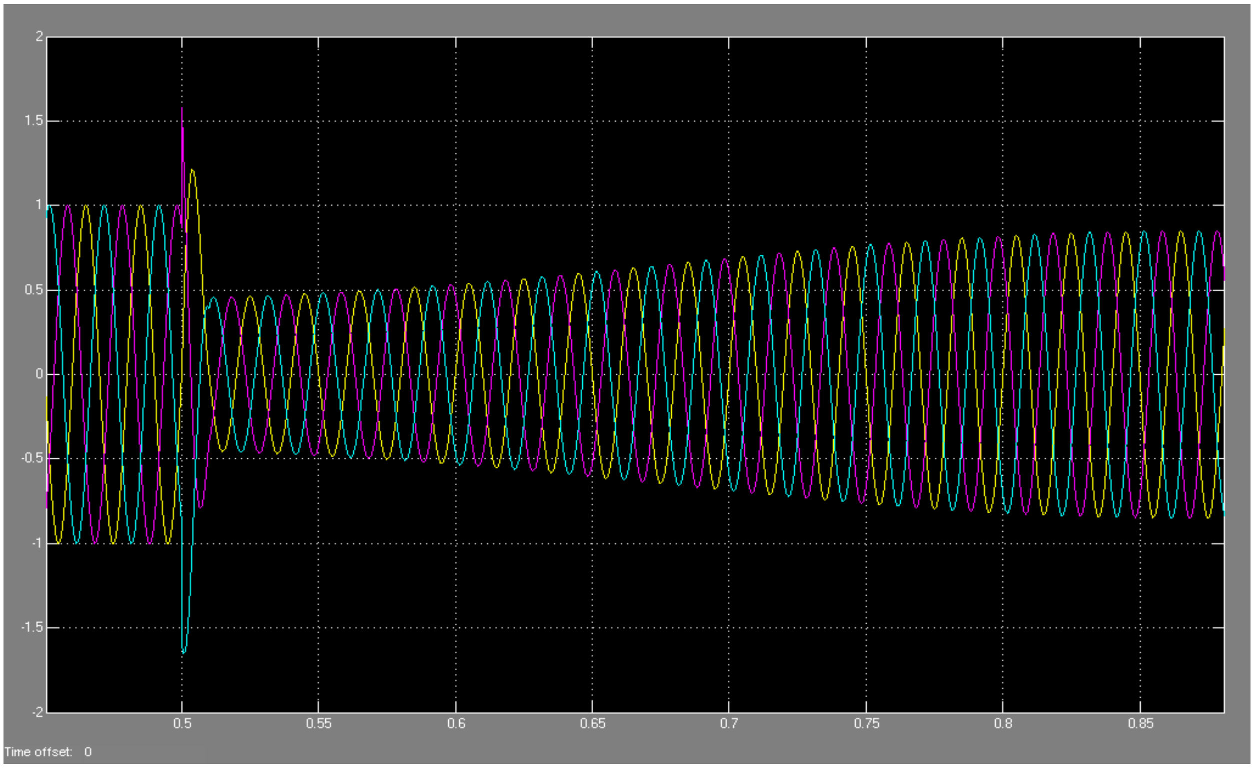

Fig.4.14 3-Phase Fault Current at Y-Side of The Transformer

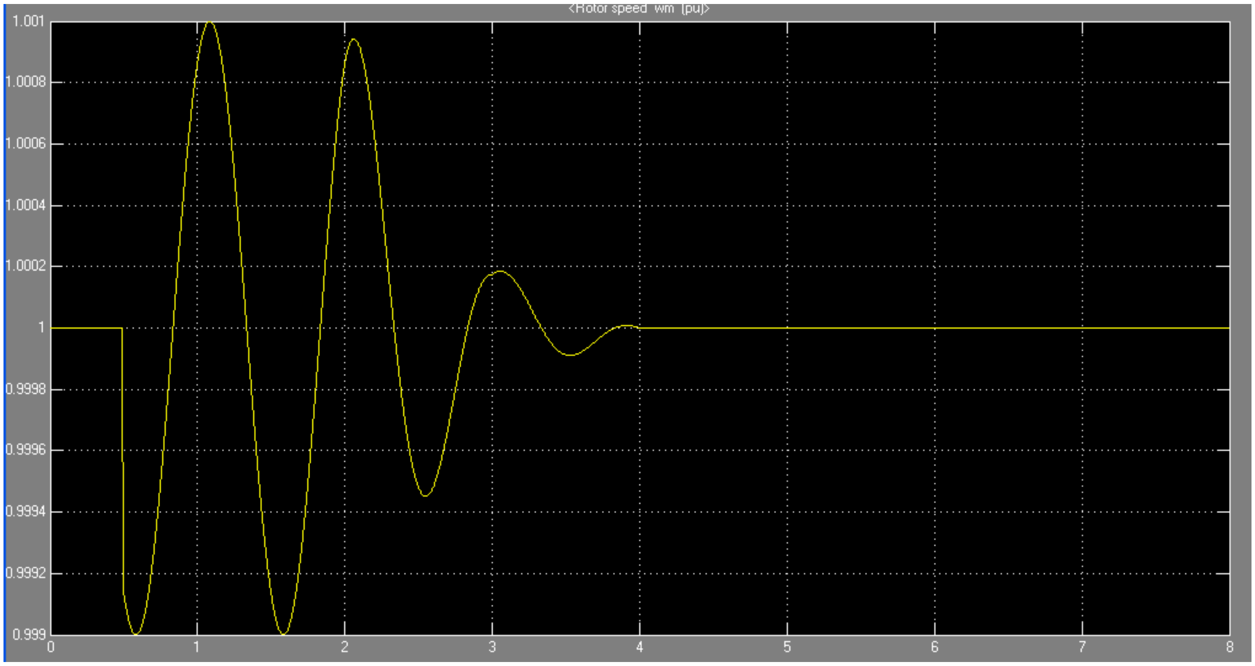

Fig.4.15 Graph of Rotor Speed with FCL

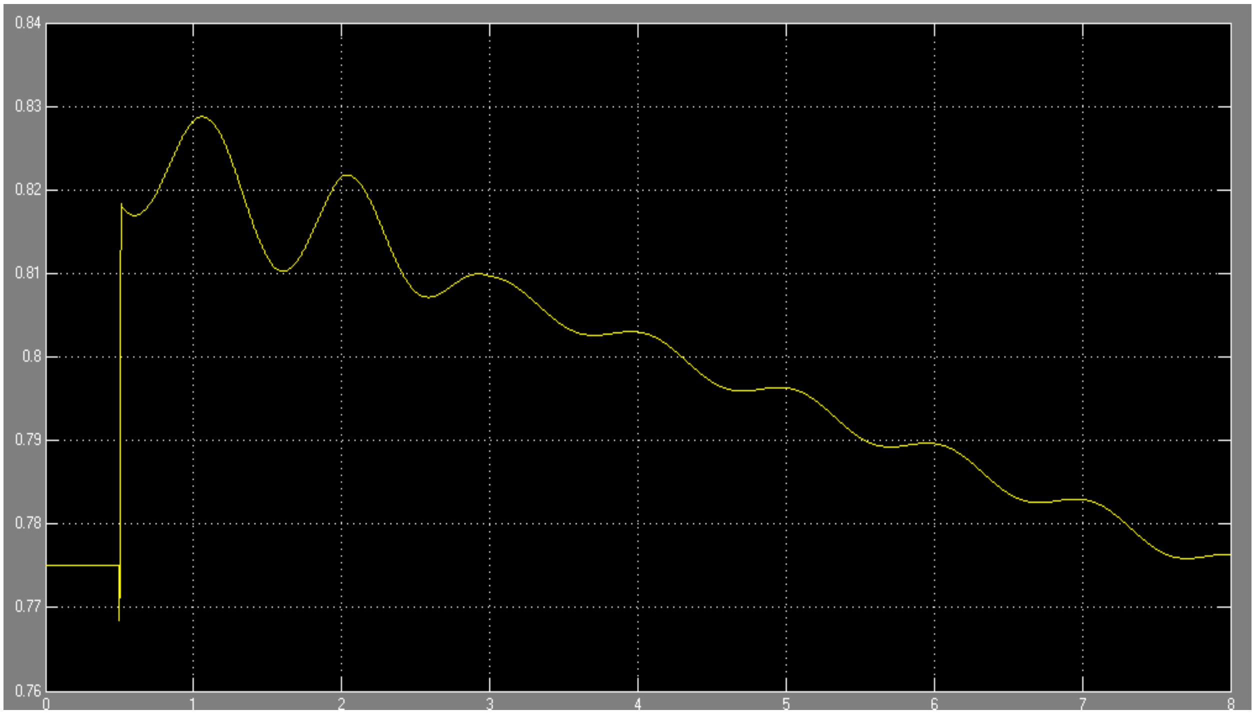

Fig.4.16 Graph of Mechanical Power with FCL

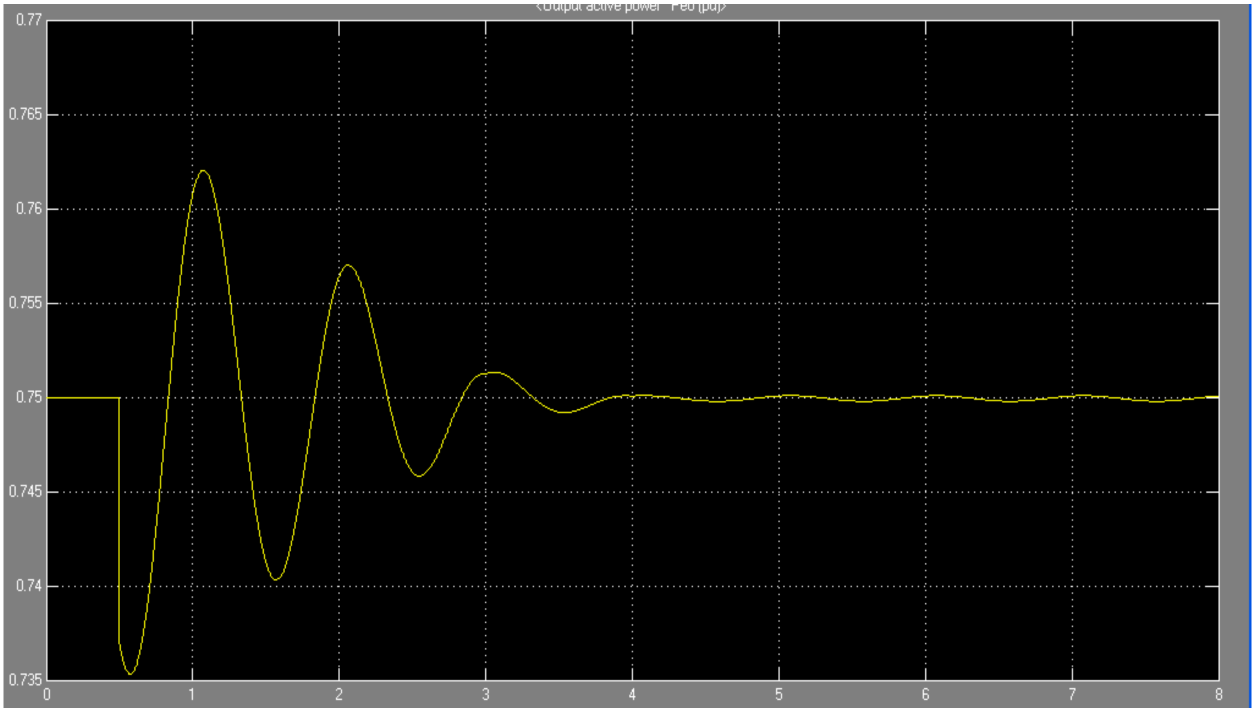

Fig.4.17 Graph of Active Power with FCL

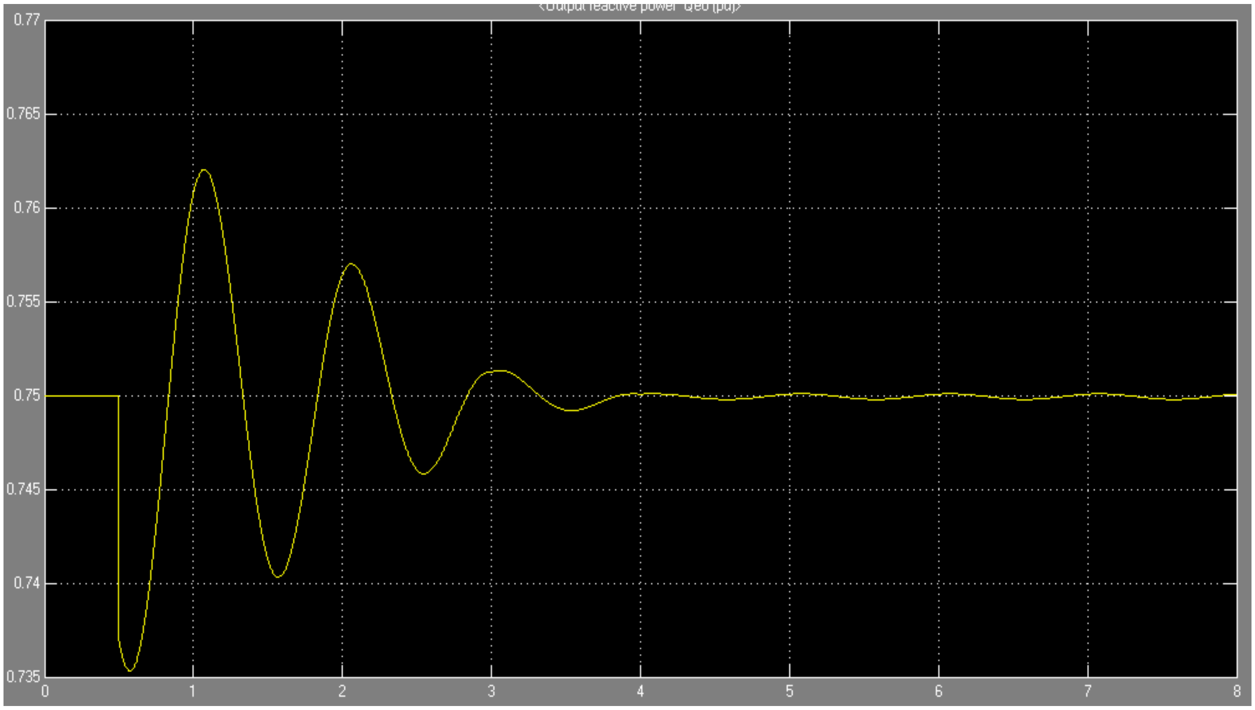

Fig.4.18 Graph of Reactive Power with FCL

CACE (D): With FCL and TCBR

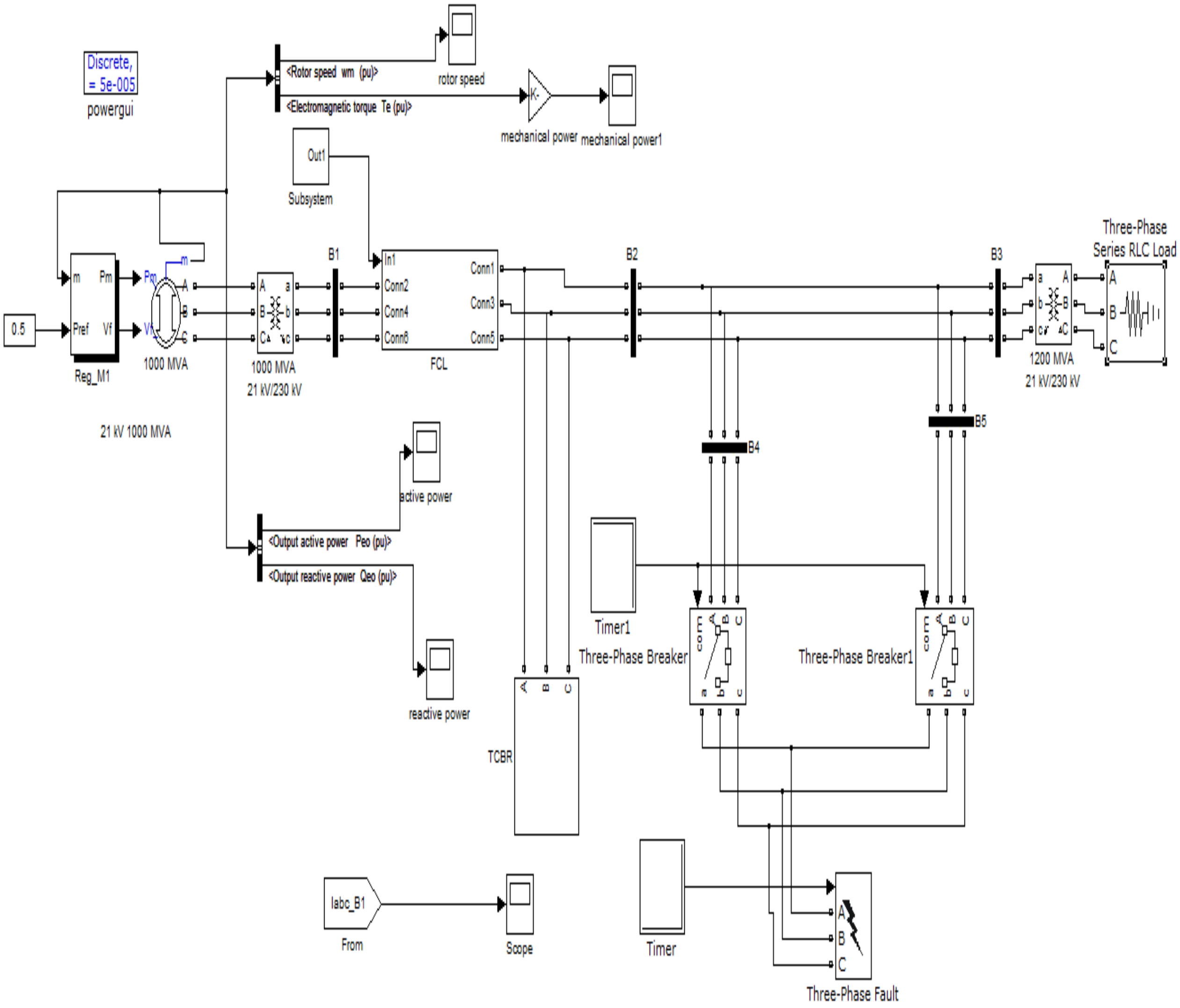

Fig.4.19 Simution with TCBR and FCL

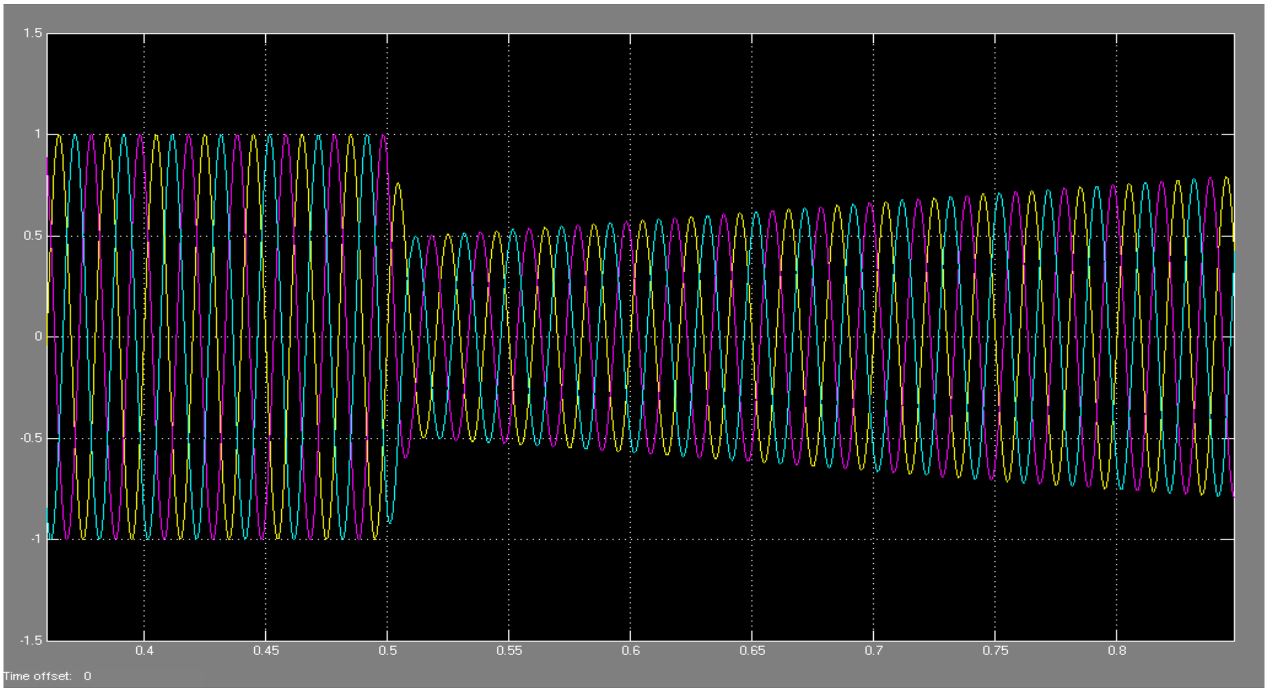

Fig.4.20 3-Phase Fault Current at Y-Side of the Transformer

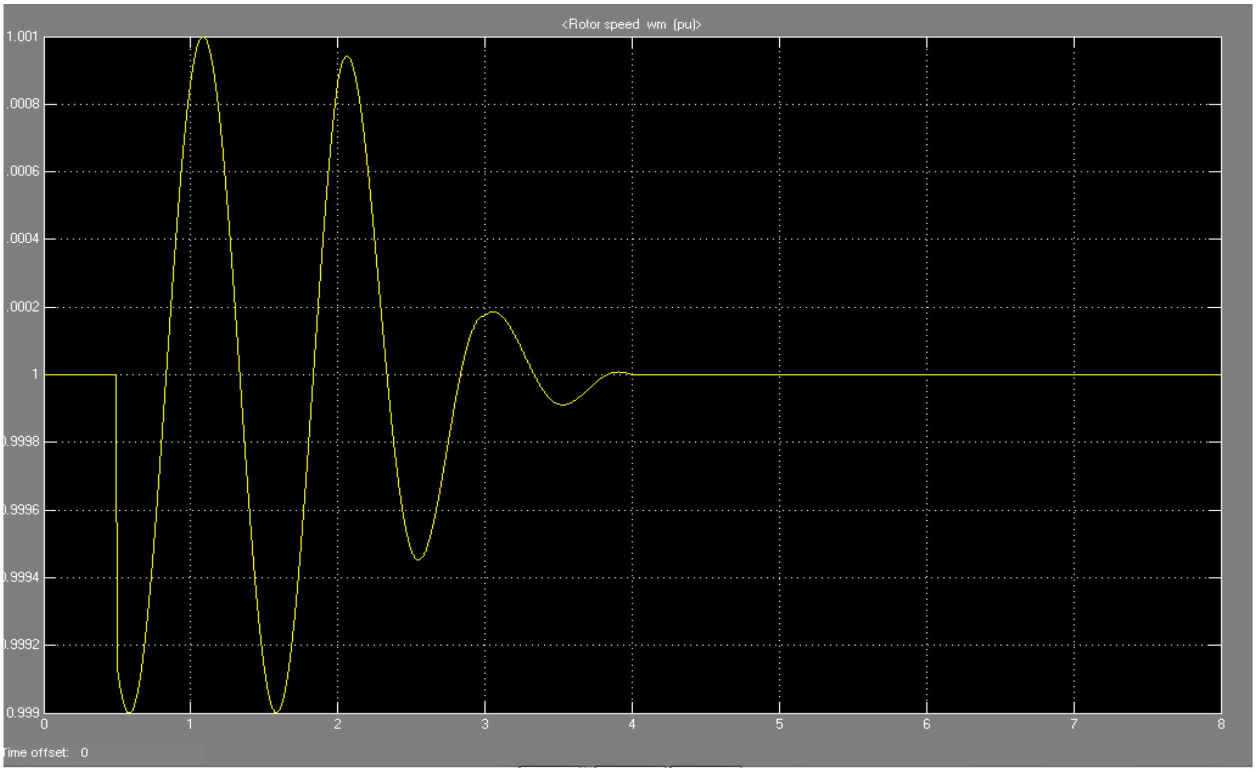

Fig.4.21 Graph of Rotor Speed with FCL and TCBR

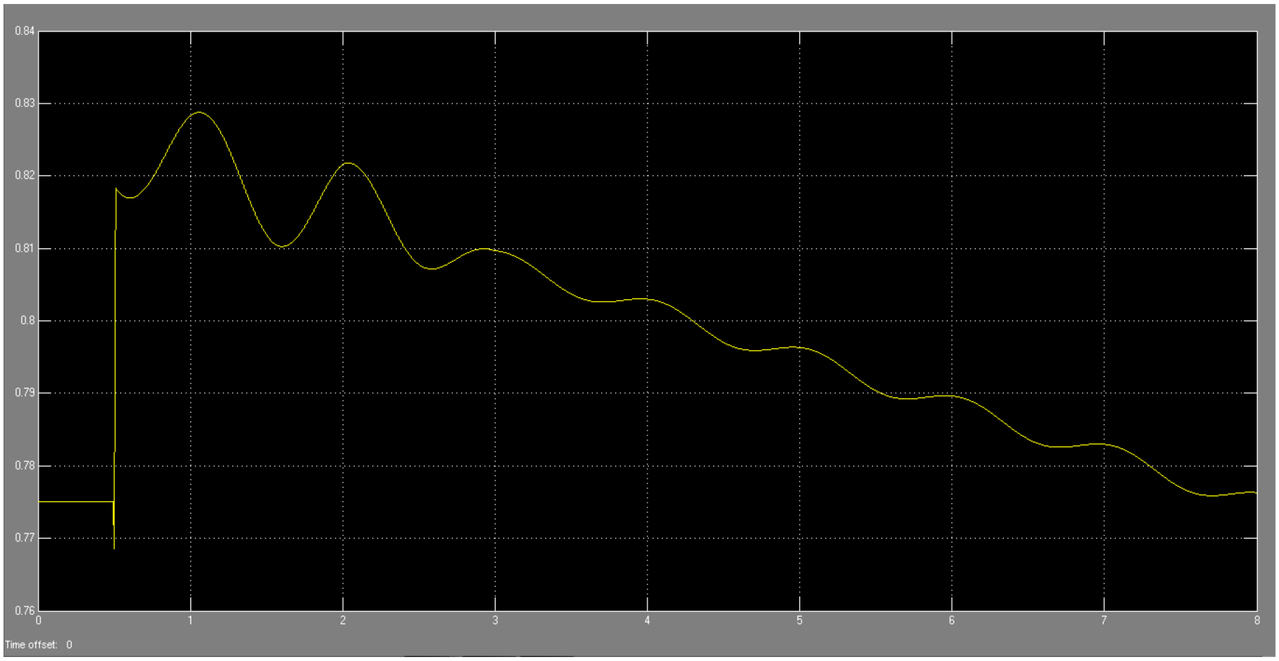

Fig.4.22 Graph of Mechanical Power with FCL and TCBR

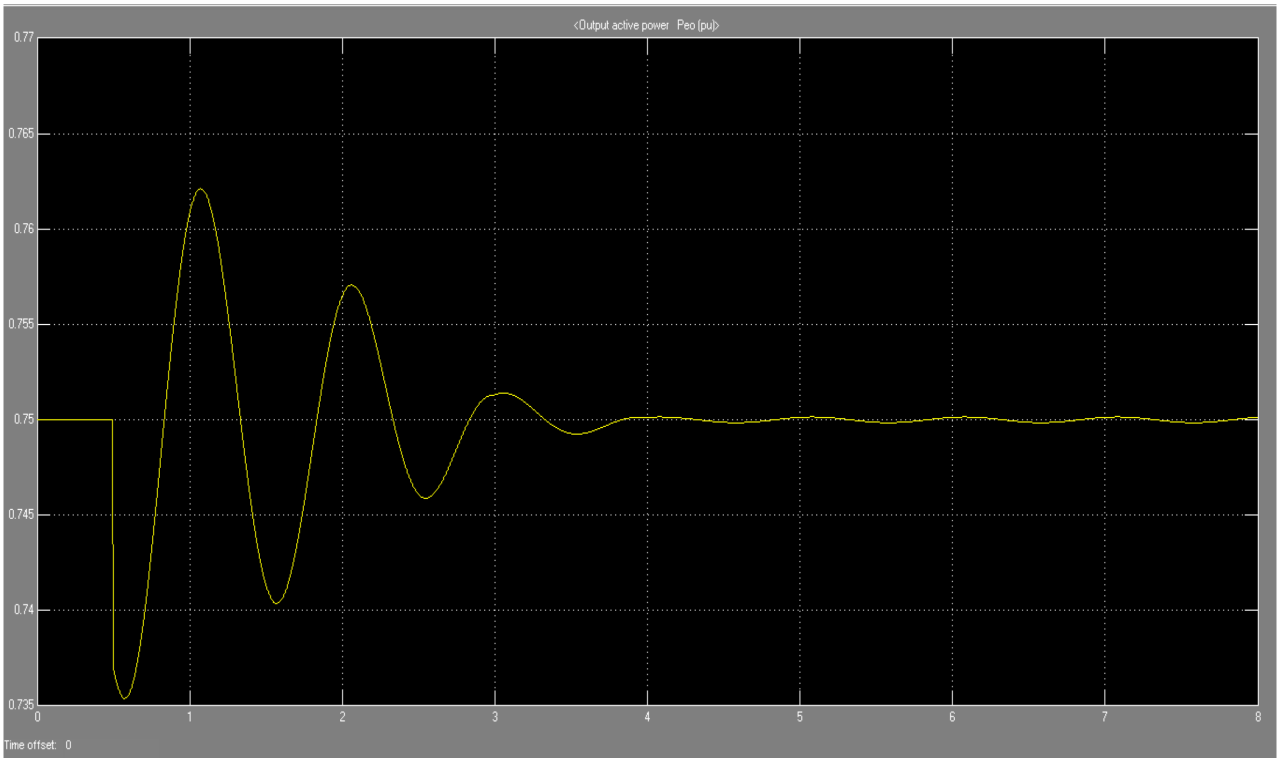

Fig.4.23 Graph of Active Power with FCL and TCBR

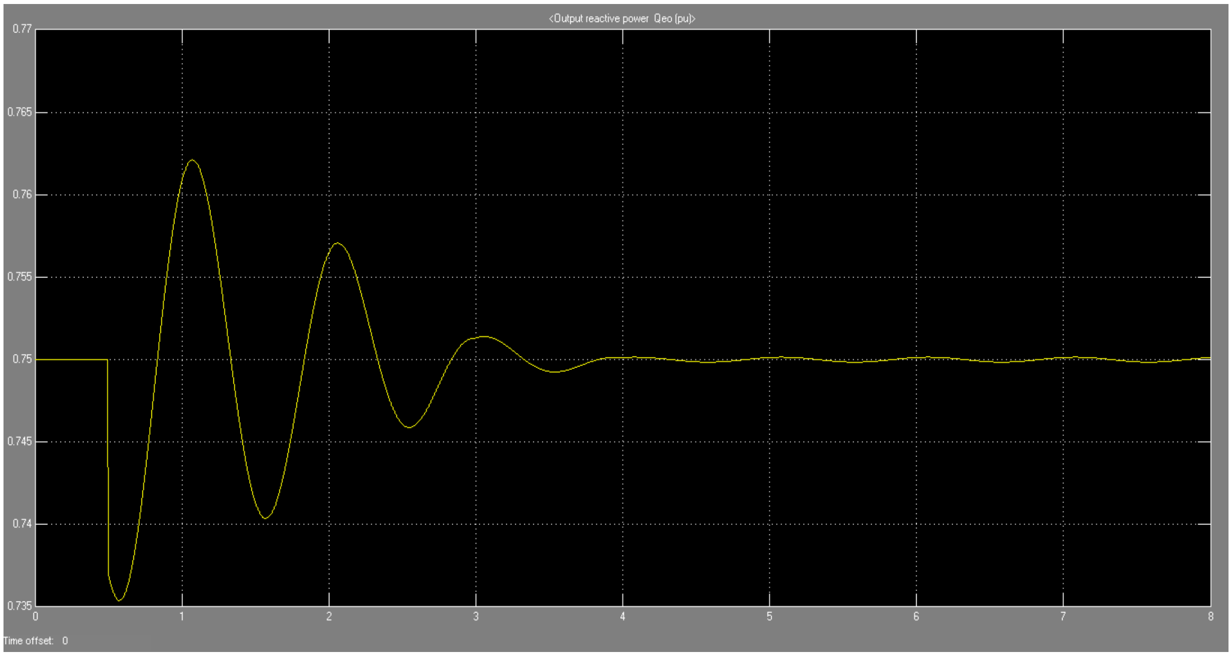

Fig.4.24 Graph of Reactive Power with FCL and TCBR

CONCLUSION

In order to improve power system transient stability the use of both devices, fault current limiter and thyristor Controlled braking resistor is proposed in this thesis. Simulation results on the single machine power system clearly indicate that by using both of devices transient stability will be improved properly. On the other hand, the simulation results show that by using the conventional control strategy of the TCBR it can be reached to proper results. However, using other control methods like fuzzy control will have better results.

FUTURE SCOPE

The method of improvement of stability used in this work can be much more improved by using artificial intelligent techniques. Better results can be obtained using fuzzy logic, artificial neural network, genetic algorithm, etc.

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1. **Hardeep Singh,** "Review of Power System Transient Stability", IJETED Journal, Issue 4, Vol. 3, April-May, 2014.

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