A REVIEW OF POWER QUALITY IMPROVEMENT USING UNIFIED POWER FLOW CONTROLLER

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Abstract— In this paper, a method of improving power quality of power system using the unified power flow control is proposed. A unified power flow controller is a flexible ac transmission system (FACTS) device for providing fast-acting reactive power compensation on a high-voltage electricity transmission network. The controller can control active and reactive power flow in transmission line. The UPFC uses a combination of static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) coupled via a common dc voltage link. This report also includes control methods, MATLAB simulation results and other key information.

Keywords— UPFC, FACTS, Power quality, STATCOM, SSSC.

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1 INTRODUCTION

The unified power flow controller was proposed for real time control and dynamic compensation of ac transmission system, providing the necessary functional flexibility to resolve many of the problem faced by utility industry.

The sources of power quality problem are: power electronics devices, arcing devices, load switching, large motor starting, embedded generation, sensitive equipment, storm, network equipment and design.

Active and reactive power is controlled at load end to achieve aims like to provide energy without interruption, without harmonics distortion and with tension regulation between very narrow margins. [1]

The increasing complexities of large interconnected networks had fluctuations in reliability of power supply, which results in system instability and uncontrolled power flow can lead to the blackout in some part of the world.

In order to overcome such power quality issues and to achieve desired power flow and system reliability without reduction in system stability and security In late 1980's the electric power research institute (EPRI) introduced a concept of flexible ac transmission devices technology (FACTS) which provides the ability to increase the controllability and to improve the power flow in the transmission system. [2]

2 Power Quality

Power quality refers to maintaining a sinusoidal waveform of bus voltages at rated voltage and frequency. The waveform of electric power at generation station is purely sinusoidal and distortion free.

Power quality in electrical network is one of today's most concerned areas of electrical power system. The power quality has some seriuos implication on consumer, utilities and electrical equipment manufacturer. Modernization and automation of industries involves increasing use of computers, microprocessors and power electronics systems such as adjustable speed drives. Integration of non-conventional generation technologies such as fuel cells, wind turbine and photovoltaic with utility grids often requires power electronics devices. The power electronics devices contributed to power quality problems. Under the deregulated environment, in which electrical utilities are expected to compete with each other, the consumer satisfaction becomes very important. The impact of power quality is increasingly felt by consumers- industrial, commercial and even residential. [3]

The power quality problems felt by electrical utilities are as follows:

- Poor load power factor
- Harmonics content in load
- Notching in load voltage
- DC offset in load voltage
- Unbalanced load
- Supply voltage distortion
- Voltage regulation
- Transient disturbances
- Frequency variation

Most of these power quality problems are related to reactive power compensation and harmonics distortion. In order to overcome such issues FACTS controller is used.

3 FACTS Controller

FACTS controllers are used for the dynamic control of voltage, impedance and phase angle of high voltage AC transmission lines. FACTS controllers can be divided into four categories. [4]

1-Series controller

2-Shunt controller

3-Series series controller

4-Series shunt controller

3.1 Series controller

Series controllers [fig 3.1] inject voltage in series with the line. As long as the voltage is in phase quadrature with the line current, the series controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well.

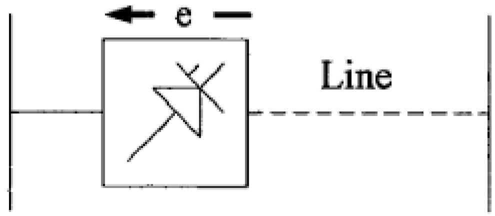

Fig3.1Static Synchronous Series Compensator (SSSC)

3.2 Shunt controller

All shunt controllers [fig 3.2] inject current into the system at the point of connection. As long as the injected current is in phase quadrature with the line voltage, the shunt controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well.

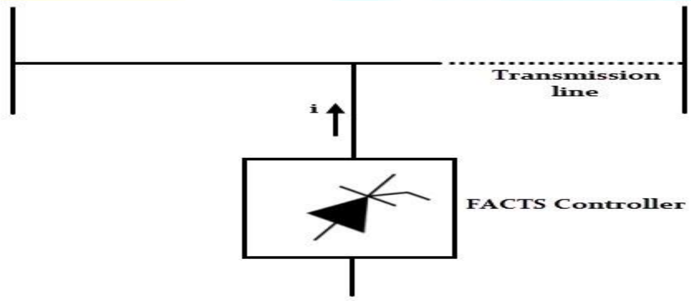

Fig3.2Static Synchronous Compensato(STATCOM)

3.3 Series-Series controller

This could be a series combination of separate series controllers, which are controlled in a coordinated manner, in a multilane transmission system. Or it could be a unified controller, in which series controllers provide independent series reactive compensation for each line but also transfer real power among the lines via the power link.

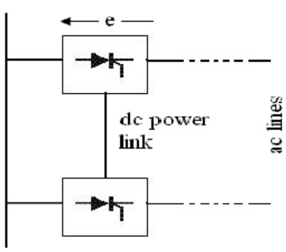

Fig 3.3 combined series series controller

3.4 Series- Shunt controller

This could be a combination of separate shunt and series controllers, which are controlled in a coordinated manner, or a unified power flow controller with series and shunt elements. In principle, combined shunt and series controllers inject current into the system with shunt part of the controller voltage in series in the line with the series part of the controller. However, when the shunt and series controllers are unified, there can be a real power exchange between the series and shunt controllers via the power link.

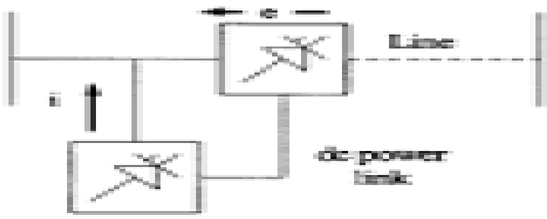

Fig 3.4 combined series shunt controller

4 The Proposed System

The Unified power flow controller (UPFC) concept was proposed by Gyugyi in 1991. In the late 1980s, the Electric Power research Institute (EPRI) formulated the Flexible AC transmission voltage and power flow and reduces dynamic disturbances.

Facts controller enhances the value of ac transmission assests by controlling one or more parameters like system stability, loop flows, voltage limits thermal limits of either line or equipment, high short circuit level limits.

Makombe and Jenkins experimentally proved that a UPFC can control the three control parameters either individually or in appropriate combinations at its series-connected output while maintaining reactive power support at its shunt-connected input device is to enhance the useable transmission capacity of lines and control the power flow. [5]

4.1 Construction of UPFC

It consists of two voltage source converters (VSC) one shunt connected and the other series connected. The DC capacitors of the two converters are connected in parallel (see Fig. 4.3).The two converters work as STATCOM and SSSC controlling the reactive current and reactive voltage injected in shunt and series respectively in the line. Interconnection enable the two converters to exchange real (active) power between the two converters. The active power can be either absorbed or supplied by the series connected converter.

Series converter or Static Synchronous Series Compensator (SSSC) is used to add controlled voltage magnitude and phase angle in series with the line, while shunt converter or Static Synchronous Compensator (STATCOM) is used to provide reactive power to the ac system, beside that, it will provide the dc power required for both inverter. Each of the branches consists of a transformer and power electronic converter.[6]

The reactive power in the shunt or series converter can be chosen independently, giving greater flexibility to the power flow control. The coupling transformer is used to connect the device to the system.

4.1.1 STATCOM

A static synchronous generator [fig 4.1} operated as shunt connected static var compensator whose capacitive or inductive current can be controlled independent of the ac system voltage. [7] For the voltage sourced converter its ac output voltage is controlled such that it is just right for the required reactive current flow for any bus voltage dc capacitor voltage is automatically adjusted as require serving as a voltage for the converter. STATCOM is also designed to work as active filter to remove harmonics.

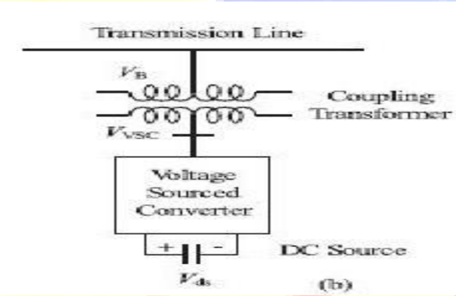

Fig 4.1 static synchronous compensator

4.1.2 SSSC

A static synchronous series generator [fig 4.2]operated without any external energy source as a series compensator whose output voltage is in quardrature with the line current for the pupose of increasing or decreasing overall reactive voltage drop across the line and thereby controlling the transmitted power.the sssc may include transiently rated energy absorbing or energy storing elements to enhance the dynamic behavior of power system by additional temporary real power compensation to increase or decrease the overall voltage drop across the line.[8]

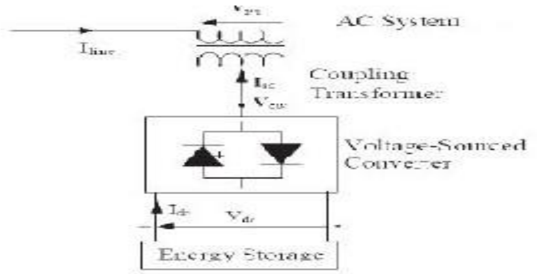

Fig 4.2 static synchronous series compensator

The fig 4.3 shows the schematic diagram of the three phase UPFC connected to the transmission line.

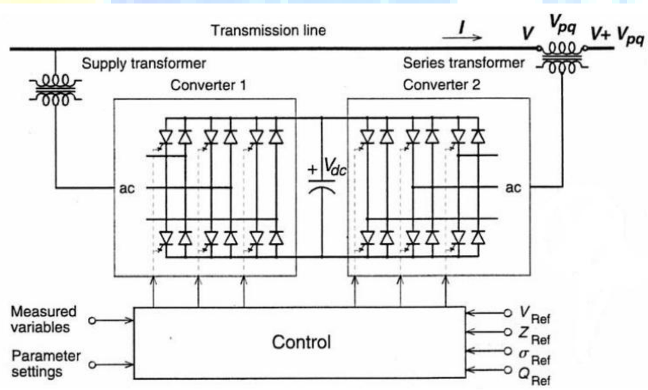

Fig 4.3 the schematic diagram of upfc connected to transmission line

4.2 Operating Principle of UPFC

A basic UPFC functional scheme is shown in fig.4.4

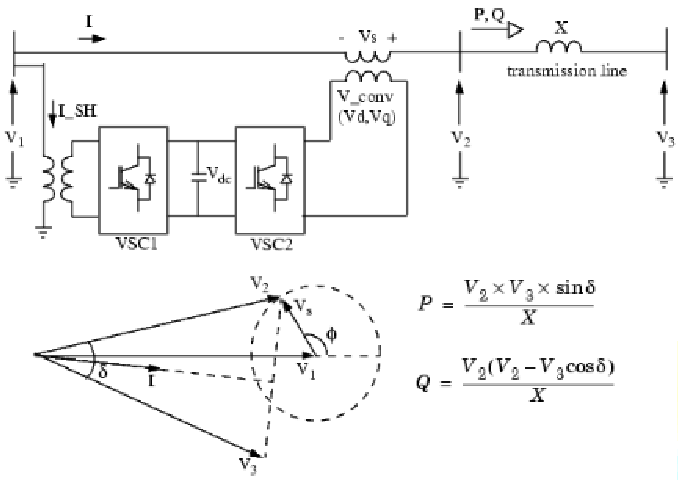

Fig 4.4 functional scheme of UPFC

One VSC is connected to in shunt to the transmission line via a shunt transformer and other one is connected in series through a series transformer. The DC terminal of two VSCs is coupled and this creates a path for active power exchange between the converters. VSC provide the main function of UPFC by injecting a voltage with controllable magnitude and phase angle in series with the line via an injection transformer. This injected voltage act as a synchronous ac voltage source. The transmission line current flows through this voltage source resulting in reactive and active power exchange between it and the ac system. The reactive power exchanged at the dc terminal is generated internally by the converter. The real power exchanged at the ac terminal is converted into dc power which appears at the dc link as a real power demand. And VSC1 is to supply or absorb the real power demanded by converter2 at the common dc link to support real power exchange resulting from the series voltage injection. This dc link power demand of VSC2 is converted back to ac by VSC1 and coupled to the transmission line bus via shunt connected transformer. In addition, VSC1 can aslo generate or absorb controllable reactive power if it is required and can provide independent shunt compensation for the line and thus no reactive power flow through UPFC DC link. [9]

4.2.1 MATHEMATICAL ANALYSIS

The equivalent circuit of UPFC is given in fig 4.5

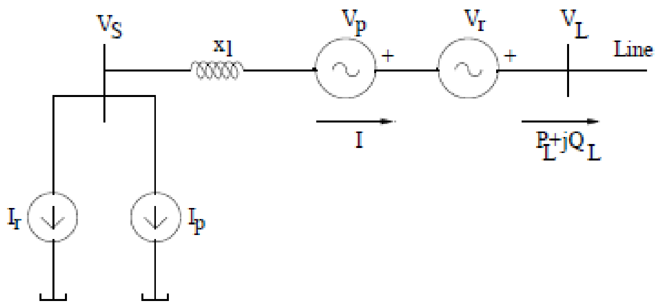

Fig 4.5 equivalent circuit of UPFC

The shunt converter draws both active (Ip) and reactive current (Ir). The active current (Ip) is not independent and is related to Vp by the relation in steady state.

$$V\,Ip = IVp$$

The equivalent circuit of the UPFC can be viewed as a two port network. The shunt converter is connected at one port while the Series converter is connected in series with the line at the other port. The voltage at the latter port is denoted by V_L . If the series injected voltages, Vp and Vr are controlled to regulate the power and reactive power in the line; these quantities are conveniently measured at the line side port of the UPFC.Since the voltage V_L is normally uncontrolled, the complex power P_L+Q_L Need not describe a circle for constant (magnitude) VC. Actually, it can be shown that P_L +Q_L describes an ellipse in the P-Q plane shown in fig 4.6.

The complex power S_L is given by

$S_L = P_L + Q_L = I^*V_L$

$= \frac{VL^* - VR^*}{-jXL} V_L$

Since$V_R = V_L - \delta/2$

$V_L\hat{} = V_S\hat{} + V_C\hat{}$

$= V\angle\delta/2 + V_C \angle\beta$

P_L and Q_L can be expressed as

$P_L = P_O + (VV_C/X_L)\ \mathrm{Sin}\ (\delta/2+\beta)$

$Q_L = Q_O + (VV_C/X_L) - (VV_C/X_L)\mathrm{Cos}(\delta/2+\beta) + 2VV_C/X_L \cos(\delta/2-\beta)$

Since $P_O = V^2/X_L$ and $Q_O = V^2/X_L(1-\mathrm{Cos}\ \delta)$

Defining Q_o' as

$Q_o' = Q_o + V^{2/}X_L$

We can finally obtain the equation involving P_L and Q_L after eliminating β

The final equation is

$$(P_L-P_O)^2 (5 - 4 \cos \delta) + (Q_L-Q_O')^2 - 4(P_L-P_O)(Q_L - Q_O')\sin\delta = V^2 - V_C^{2/}X_L^2(2 \cos \delta - 1)^2$$

The above is an equation of ellipse with a centre (P_O, Q_O+V^2/X_L) as shown in fig 4.6

It is to be noted that Ir can be controlled to regulate the voltage V_S if it is not regulated by the generator connected at the sending end. [10] Thus, three variables, V_S, P_L and Q_L can be regulated by controlling Ir; V_C and β. It is assumed that there are no constraints imposed by the equipment ratings that will limit the control objectives.

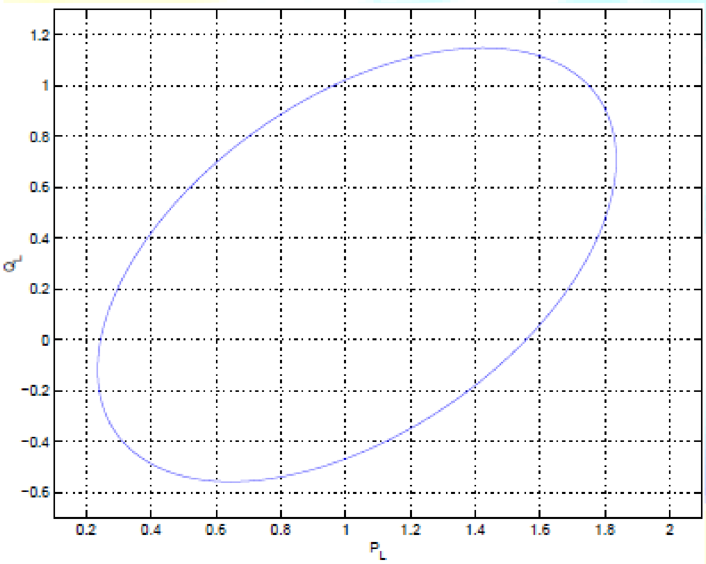

Fig 4.6 operating refion of P_L-Q_L PLANE

4.3 Control schemes

UPFC consists of two converters that are coupled on the DC side, the control of each converter is explained below:

4.3.1 Control of shunt converter

There are two operating (control) modes for a STATCOM or the shunt converter. [11] These are, 1-VAR control mode- where the reactive current reference is determined by the inductive or capacitive VAR command. The feedback signals are obtained from current transformers (CT) typically located on the bushings of the coupling (step down) transformer.

2-Automatic voltage control mode-where the reactive current reference is determined by the output of the feedback voltage controller which incorporates a droop characteristic (as in the case of a SVC or a STATCOM). The voltage feedback signals are obtained from potential transformers (PT) measuring the voltage V1 at the substation feeding the coupling transformer.

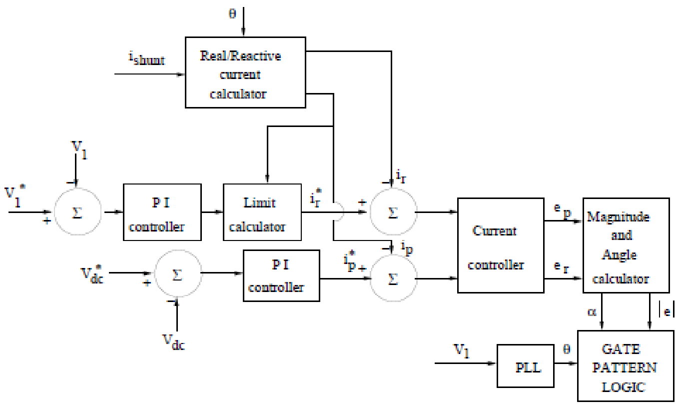

Fig 4.7 block diagram of shunt controller

4.3.2 Control of series converter

There are four operating (control) modes for SSSC or the series converter. These are:

1-Direct voltage injection mode - where the converter simply generates a voltage phasor in response to the reference input. A special case is when the desired voltage is a reactive voltage in quadrature with the line current.

2-Phase Angle Shifter Emulation mode - where theinjected voltage is phase shifted relative to the voltage by an angle specified by the reference input.

3-Line impedance emulation mode - where the series injected voltage is controlled in proportion to the line current.

4-Automatic power flow control mode - where the reference inputs determine the required real power (P) and the reactive power (Q) at a specified location in the line. [12]

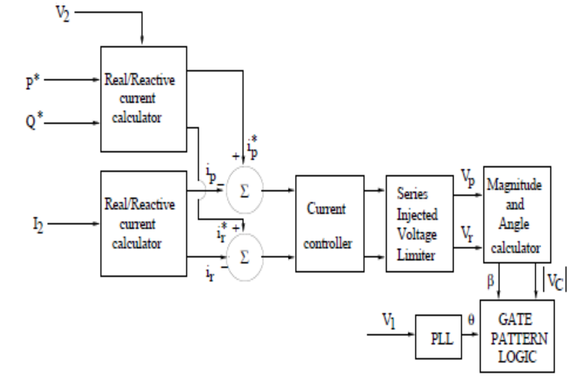

Fig 4.8 block diagram of series controller

5 Simulink Model using Matlab

Simulation model for single line transmission system of 33 KV line is shown in fig 5.1. [13]

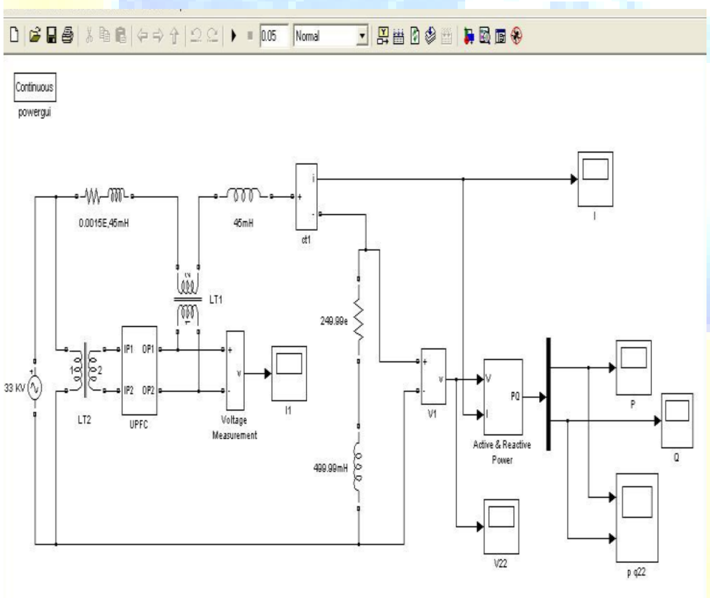

Fig 5.1 simulation model

Corresponding results of magnitude of voltage, current, real power and reactive power is shown in fig 5.2

At steady state time t=0.02 seconds with UPFC magnitude of voltage is 31.28 KV, magnitude of current is 106 amp, real power is 1.4974MW, reactive power is 87MVAR observed.

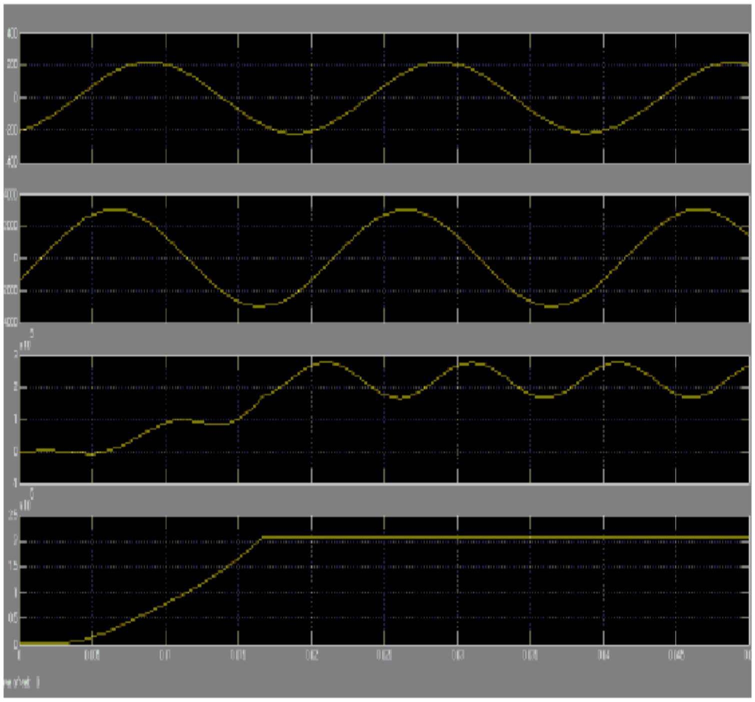

Fig 5.2 simulation result

6 Conclusion

In this study, MATLAB/ SIMULINK model is used to simulate the model of UPFC connected with transmission lines of 33kV. This paper gives control and performance of the UPFC used for power quality improvement by controling settings of the UPFC controllers. Simulation results show the effectiveness of UPFC to control the real and reactive powers as well as voltage magnitude and current magnitude. It is found that there is an improvement in the real power and reactive power and voltage & current magnitude through the transmission line when UPFC is connected.

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