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An Implemented Approach of Fuzzy Logic Based Controlled STATCOM

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Abstract—*Transmission networks of modern power systems are becoming increasingly stressed because of growing demand and restrictions on building new lines. One of the consequences of such a stressed system is the threat of losing stability following a disturbance. Flexible ac transmission system (FACTS) devices are found to be very effective in stressing a transmission network for better utilization of its existing facilities without sacrificing the desired stability margin. Flexible AC Transmission System (FACTS) controllers, such as Static Synchronous Compensator (STATCOM) and Static VAR Compensator (SVC), employ the latest technology of power electronic switching devices in electric power transmission systems to control voltage and power flow. A static synchronous compensator (STATCOM) is a shunt device of the flexible AC transmission systems (FACTS) family. The STATCOM regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from power system. When system voltage is low, STATCOM generates reactive power and when system voltage is high it absorbs reactive power. The STATCOM system mainly comprised of three main parts : a Voltage Source converter , a set of coupling reactors or coupling transformer and a controller.*

Keywords— *FACTs, STATCOM, AC , VAR,SVC*

I. INTRODUCTION

Modern electric power system is facing many challenges due to day by day increasing complexity in their operation and structure. In the recent past, one of the problems that got wide attention is the power system instabilities. With the lack of new generation and transmission facilities and over exploitation of the existing facilities geared by increase in load demand make these types of problems more imminent in modern power systems. Demand of electrical power is continuously rising at a very high rate due to rapid industrial development. To meet this demand, it is essential to raise the transmitted power along with the existing transmission facilities. The need for the power flow control in electrical power systems is thus evident. Thus, this requires a review of traditional methods and the creation of new concepts that emphasize a more efficient use of already existing power system resources without reduction in system stability and security. In the late 1980s, the Electric Power Research Institute (EPRI) introduced a new approach to solve the problem of designing and operating power systems; the proposed concept is known as Flexible AC Transmission Systems (FACTS). The two main objectives of FACTS are to increase the transmission capacity and control power flow over designated transmission routes .Basically, FACTS controllers can be divided into four categories:

1) Series Controller
2) Shunt Controller
3) Combined series-series Controller
4) Combined series-shunt Controller

Static Synchronous Compensator (STATCOM): The STATCOM is the solid – state based power converter version of the SVC. The concept of STATCOM was proposed by Gyugyi in 1976 .The STATCOM has quick response as compared to SVC. Power Converter employed in the STATCOM mainly of two types i.e. is Voltage Source Converter and Current Source Converter. In Current source Converter direct current always has one polarity and the power reversal takes place through reversal of dc voltage polarity while In Voltage Source Converter dc voltage always has one polarity, and the power reversal takes place through reversal of dc current polarity. Voltage source converter can operate on higher efficiency in high power applications. Because of the above reasons Voltage source converter is Preferred over Current source converter and now these days it act as a basic electronic block of a STATCOM that converts a dc voltage at its input terminals into a three-phase set of ac voltages at fundamental frequency with controllable magnitude and phase angle .Two VSC technologies can be used for the VSC:

1) VSC using GTO-based Square wave inverters and special interconnections transformers.

2) Voltage source converter using IGBT based PWM inverters.

A STATCOM can be used for voltage regulation in a power system, having as an ultimate goal the increase in transmittable power, and improvements of steady-state transmission characteristics and of the overall stability of the system. The major advantages of STATCOM over the SVC are:

1) Continuous and dynamic voltage control.
2) The STATCOM can supply required reactive current even at low values of bus voltages
3) High dynamic and fast response time.
4) STATCOM can have a short time overload capability, with proper choice of device ratings and thermal design.
5) STATCOM can allow for real power modulation if it has energy storage at its DC terminals.

II. LITERATURE SURVEY

Schauder *et al*. proposed a vector control scheme for control of reactive current using STATCOM in [1] They described two controller structures for the STATCOM one of which involves both magnitude and phase control of inverter, and the other structure uses only phase angle control. **Laszlo Gyugyi**, *et a*l. gave the basic concept of STATCOM using voltage-source converter [2] in basic operation of STATCOM and the functional control scheme to control the STATCOM used for both reactive and real power compensation are given in this paper. Study of multilevel topologies of STATCOM has been presented in [3] [4]. The thyristor controlled STATCOM with new double firing phase control which makes it possible to control the active and the reactive power directly and independently without any sacrifice of the harmonic characteristic is presented in [5].

Design of voltage controller and the analysis of its dynamic behaviour using Eigen value analysis and its simulation are presented in [6] the paper concentrates on the application of STATCOM for the reactive power compensation of a long transmission line by regulating the voltage at its midpoint. Design of a nonlinear controller for STATCOM based on the differential algebra theory is presented in [7]. The controller designed by this method allows linearizing the compensator and controlling directly the capacitor voltage and output reactive power of the STATCOM.A rule based controller for STATCOM was proposed in [8]. The paper analyzes the synchronizing and damping torque induced on the shaft of the generator by STATCOM in a single machine infinite bus (SMIB) system. Based on the synchronizing and damping torque coefficient calculation, a rule based controller, which employs bang bang, fuzzy logic or fixed parameter PI control strategy according to operation state of the system is designed to compromise the conflict between the control objectives. **M.Moaddies**, *et al*. [9] described a technique to control the harmonic output of a STATCOM using a PWM scheme with a minimal number of additional switching. Fuzzy logic controllers are also used for STATCOM in interconnected system to improve the dynamic behaviour of the system [10] a robust non linear controller is proposed for STATCOM voltage control in [11].

III.OPERATING PRINCIPLE

Fig. 1 shows single line diagram of two area system (area 1 & area 2). Area1 (1000 MW hydraulic generation plant) connected to Area 2(5000 MW hydraulic generation Plant.) through 500 kV, 700 km transmission line.

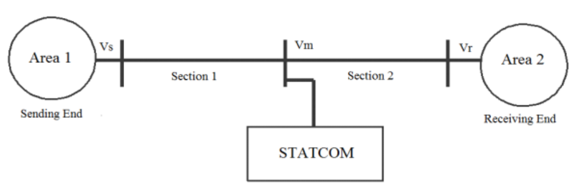

Fig. 1 Two Machine Systems

Both plants fed to a load centre, modelled by a 5000 MW resistive load. System is initialized so that line carries 950 MW which is close to its surge impedance loading. In order to maintain system stability Static synchronous compensator of 200 MVA is connected at midpoint of transmission line. By connecting it at midpoint the power transfers capability of system increases significantly [13], [14]. STATCOM is made up of a coupling transformer, a VSC and a dc energy storage device. The energy storage device is a relatively small dc capacitor, and hence the STATCOM is capable of only reactive power exchange with the transmission system. A functional model of a STATCOM is shown in fig. 2.

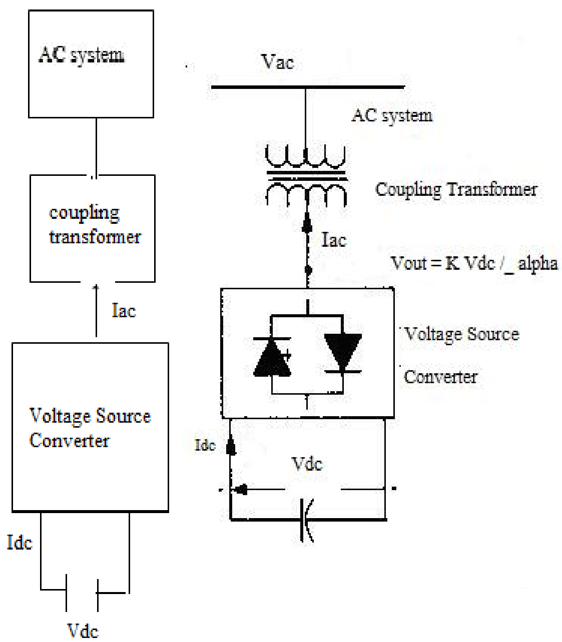

Fig.2 Functional Model of Statcom

The STATCOM's output voltage magnitude and phase angle can be varied. By changing the phase angle a of the operation of the converter switches relative to the phase of the ac system bus voltage, the voltage across the dc capacitor can be controlled, thus controlling the magnitude of the fundamental component of the converter ac output voltage, as Vout = kVdc.

If the amplitudes of the ac system and converter output voltages are equal, there will be no ac current flow in/out of the converter and hence there will be no reactive power generation/absorption. The ac current magnitude can be calculated using the following equation

$$I_{ac} = \frac{V_{out} - V_{ac}}{X}$$

And the corresponding reactive power exchanged can be expressed as follows:

$$Q = \frac{V_{out} V_{out} - V_{out} V_{ac} \mathrm{Cos}a}{X}$$

The real power exchange between the voltage-sourced converter and the ac system can be calculated using:

$$P = \frac{V_{ac} V_{out} \mathrm{Sin}a}{X}$$

Power Angle Equation: The expression establishing the relationship between the active power transferred (Pe) to the system and the angle δ is known as power angle equation. The expression for the active power transferred to the system is given by:

$$P_e = \frac{EV}{X} \mathrm{Sind}$$

The maximum steady state power transfer occurs when δ = 90degree. From equation

$$P_{emax} - \frac{EV}{X} \mathrm{Sin}90 = \frac{EV}{X}$$

$$P_e = P_{emax} Sind$$

SWING CURVE: When the swing equation is solved we obtain the expression for power angle as a function of time. A graph of solution is called swing curve of the machine and inspection of the swing curve of all machine of the system will show whether the machine remain in synchronism after a disturbance or not. If δ increases continuously with time the system is unstable. While if δ starts decreasing after reaching a maximum value it is inferred that the system will remain stable

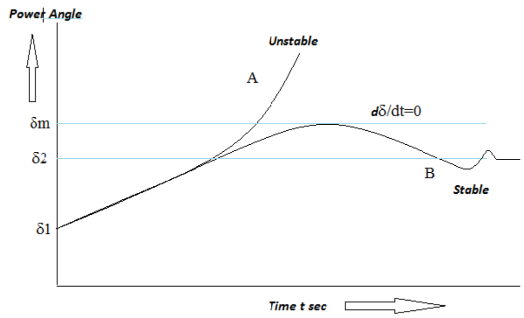

Fig.3 Power Angle v/s Time

IV. PROPOSED WORK

The application of FACTS controllers creates new challenges for power engineers. The effectiveness of these controllers will depend on the development of adequate and dependable control strategies. Due to the fast response of such controllers, study of a wide spectrum of transient behaviour, including network dynamics, generator rotor low frequency oscillations and tensional oscillations, etc are necessity.

Motivated by these observations, the objectives of this report are:

1) To develop a two machine transmission system installed with STATCOM using Matlab Simulink
2) To design a fuzzy logic based STATCOM controller for improving power system transient stability.

Modelling of STATCOM : The STATCOM is modeled by a voltage source connected to the power system through a coupling transformer. The source voltage is the output of a voltage-sourced converter (VSC) realizing the STATCOM. From the Fig. 4 STATCOM is assumed at the midpoint of the transmission line. The phase angle of the source voltage is equal as that of the midpoint voltage. Therefore, there is exchange of only reactive power and no real power between the STATCOM and the ac system [3], [20].

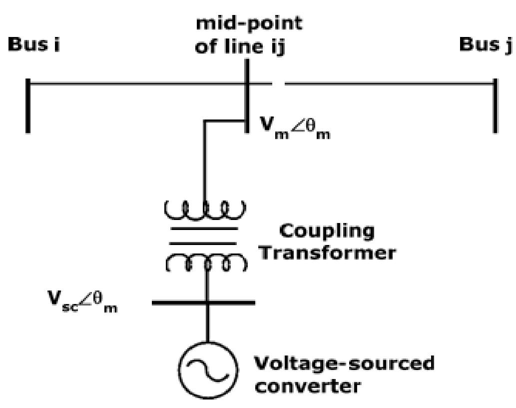

Fig. 4 Representation of STATCOM

The expressions for the current flowing from the STATCOM to the system and the reactive power injection are given as

$$I = \frac{s(Vc - Vm)m}{i^{jx}}$$

$$Q = \frac{VM^2(VSC/VM - 1)}{X}$$

The STATCOM is a voltage-sourced-converter (VSC)-based shunt-connected device. By injecting a current of variable magnitude in quadrature with the line voltage, the STATCOM can inject reactive power into the power system .The STATCOM does not employ capacitor or reactor banks to produce reactive power as does the SVC, but instead uses a capacitor to maintain a constant dc voltage for the inverter operation. An equivalent circuit for the STATCOM is shown in Fig.

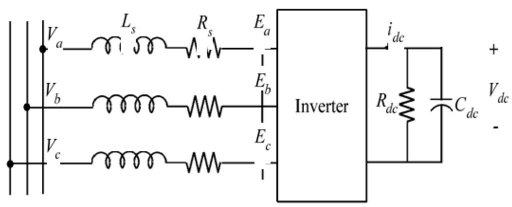

Fig.5 Equivalent circuit of the STATCOM

The loop equations for the circuit may be written in vector form as

$$\frac{d}{dt} iabc = \frac{Rs}{Ls} iabc + \frac{1}{Ls}(Eabc - Vabc)$$

where R_S and L_S represent the STATCOM transformer losses, E_{abc} are the inverter ac side phase voltages, V_{abc} are the system-side phase voltages, and i_{abc} are the phase currents. The output of the STATCOM is given by

Ea=kVdc COS (ωT+α).

Where V_{dc} is the voltage across the dc capacitor, k is the modulation gain, and a is the injected voltage phase angle. By defining a proper synchronous reference frame, the dynamic model can be simplified.

Fuzzy Logic Controller: Fuzzy logic controller is used for automatic generation control in a two area system. Basic block diagram of fuzzy logic controller is as shown under.

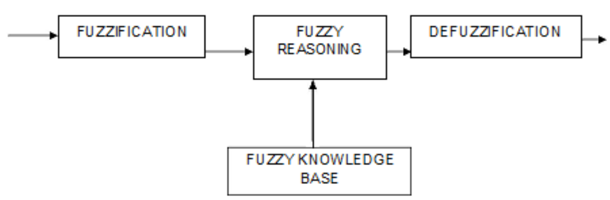

Fig.6 Basic structure of fuzzy logic controller.

The basic configuration of Fuzzy Logic Controller (FLC) consists of four main parts

(i) Fuzzification
(ii) Knowledge base
(iii) Decision-making logic and
(iv) De- fuzzification

The functions of the above modules are described below.

(i) The Fuzzification:

(a) Measure the values of input variables

(b) Perform a scale mapping that transforms the range of values of input variables into corresponding universe of discourse.

(c) Performs the function of fuzzification that converts input into suitable linguistic values, which may be, viewed labels of fuzzy sets.

(ii) The Knowledge Base:
It consists of data base and linguistic control rule base.

(a) The database provides necessary definitions, which are used to define linguistic control rules and fuzzy data, manipulation in an, FLC.

(b) The rule base characterizes the control goals and control policy of the domain experts by means of set of linguistic control rules.

(iii) The Decision Making Logic:

It is the kernel of an FLC; it has the capability of simulating human decision making based on fuzzy concepts and of inferring fuzzy control actions employing fuzzy implication and the rules of inference in fuzzy logic.

(iv) The De-fuzzification :

A scale mapping which converts the range of values of input variables into corresponding universe of discourse. De-fuzzification, which yields a non-fuzzy, control action from an inferred fuzzy control action.

V. SIMULATION RESULTS

1. System installed with PI based STATCOM controller (under fault): Now System is installed with PI based STATCOM and fault having clearing time of 0.1 sec is given. System becomes stable after fault and various responses are shown below:

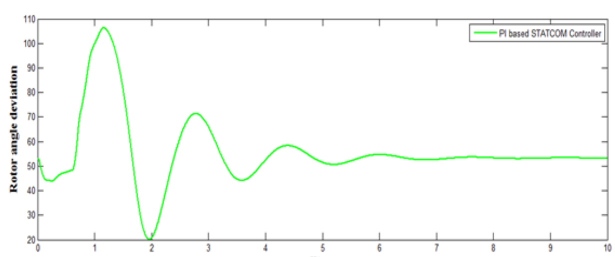

Fig.7 *Rotor angle deviation with time*

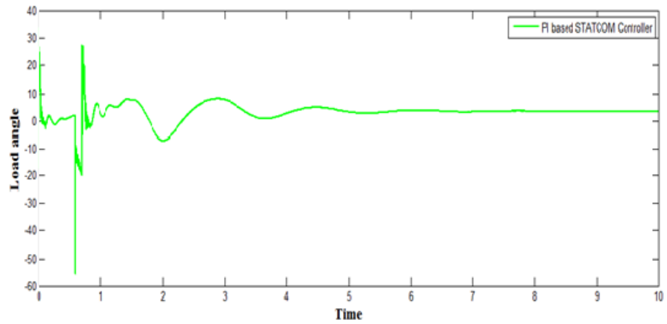

Fig. 8 *Load angle with time*

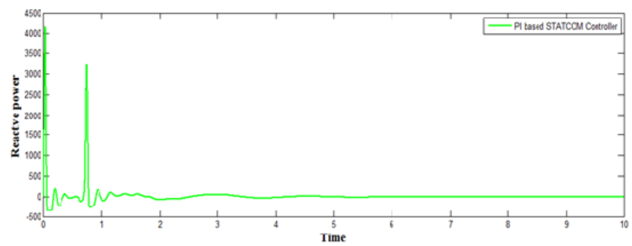

Fig.9 *Reactive Power with time*

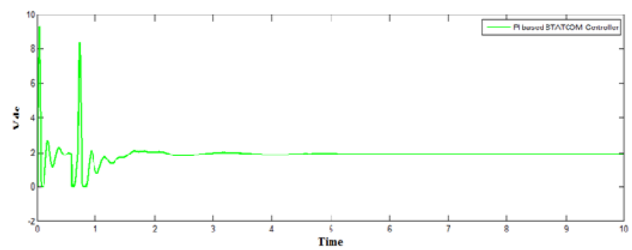

Fig.10 *Variation of* V_{dc} *with respect to time*

2. Comparison between PI based and fuzzy based STATCOM controller :

Responses below shows the comparison between fuzzy based and PI based STATCOM controller

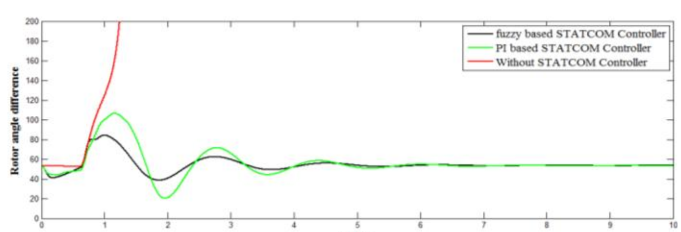

Fig 11 *Deviation of rotor angle difference with time.*

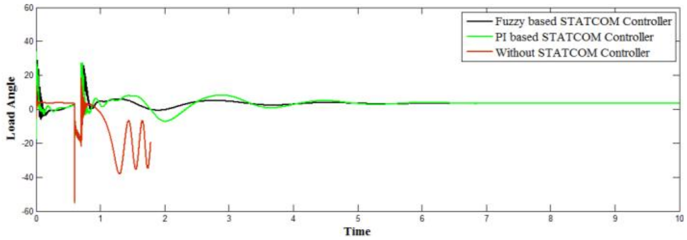

Fig. 12 *Load angle with time.*

From Fig 11 & Fig 12.it's clear that fuzzy based STATCOM controller is more successful in damping of rotor angle and Load angle variation as compared to PI based STATCOM.

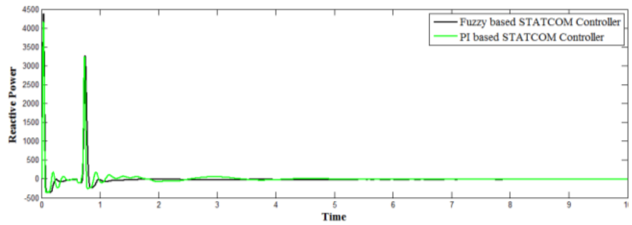

Fig 13. *Reactive Power with time*

Fig.13 shows comparison between reactive power of fuzzy based and PI based STATCOM controller.

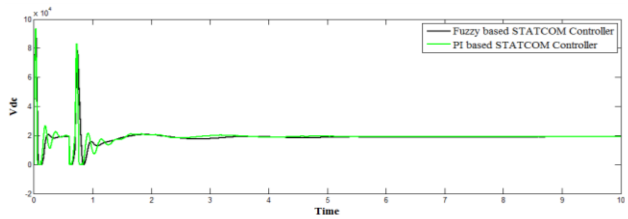

Fig 14. *V_{dc} with time*

Fig 14 shows the comparison between V_{dc} (voltage across Capacitor) of Fuzzy based STATCOM and conventional PI based STATCOM with time

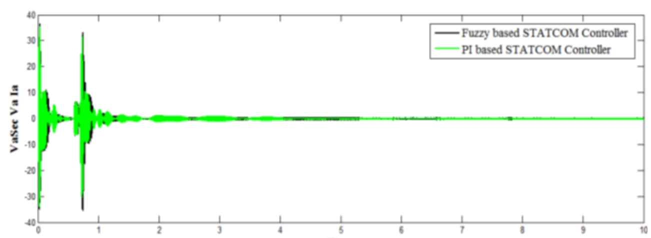

Fig 15. *Variation of V_{aSec} V_a I_a*

Fig 15 shows the comparison between voltage, current of bus B2 and transformer secondary voltage of Fuzzy based and PI based static synchronous compensator with time

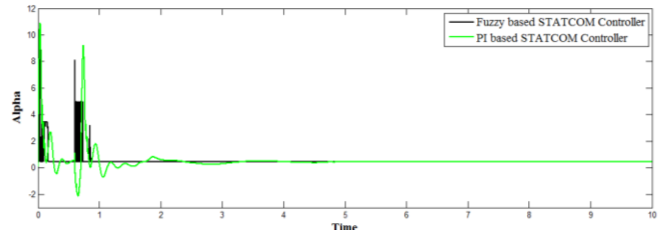

Fig 16. *Alpha with time*

Fig 16 shows the comparison between angle Alpha of voltage source converter of fuzzy based STATCOM controller and PI based STATCOM with time.

VI. CONCLUSION

The above result has been successfully observed using matlab based simulator. The results of PI based and fuzzy based with different parameters shows clearly the variations and hence using fuzzy logic STATCOM's various parameter are completely controlled.

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