Voltage Regulation of Non Linear Load Using STATCOM with Fuzzy Technique

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Abstract: STATCOM can provide fast and efficient reactive power support to maintain power system voltage stability. In the literature, various STATCOM control methods have been discussed including many applications of proportional-integral (PI) controllers. However, these previous works obtain the PI gains via a trial-and-error approach or extensive studies with a tradeoff of performance and applicability. Hence, control parameters for the optimal performance at a given operating point may not be effective at a different operating point. This paper proposes a new control model based on adaptive PI control, which can self-adjust the control gains during a disturbance such that the performance always matches a desired response, regardless of the change of operating condition. Since the adjustment is autonomous, this gives the plug-and-play capability for STATCOM operation. In the simulation test, the adaptive PI control shows consistent excellence under various operating conditions, such as different initial control gains, different load levels, and change of transmission network, consecutive disturbances, and a severe disturbance. In contrast, the conventional STATCOM control with tuned, Fuzzy gains usually performs fine in the original system. This total project done in MATLAB SIMULATION Software.

1. Introduction

Voltage stability is a critical consideration in improving the security and reliability of power systems. The static compensator (STATCOM), a popular device for reactive power control based on gate turnoff (GTO) thyristors, has gained much interest in the last decade for improving power system stability the control logic is implemented with the PI controllers. The control parameters or gains play a key factor in STATCOM performance. Presently, few studies have been carried out in the control parameter settings. The PI controller gains are designed in a case-by-case study or trial-and-error approach with tradeoffs in performance and efficiency. Generally speaking, it is not feasible for utility engineers to perform trial-and-error studies to find suitable parameters when a new STATCOM is connected to a system. Further, even if the control gains have been tuned to fit the projected scenarios, performance may be disappointing when a considerable change of the system conditions occurs, such as when a line is upgraded or retires from service. The situation can be even worse if such transmission topology change is due to a contingency. Thus, the STATCOM control system may not perform well when mostly needed.

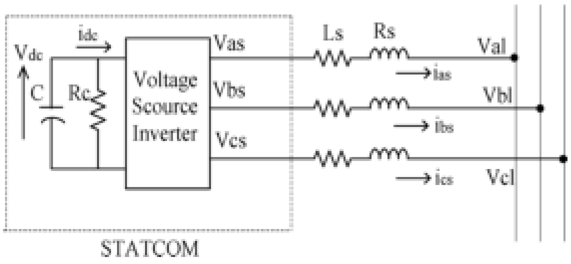


Figure.1. Equivalent circuit of STATCOM..

2. STATCOM Model and Control

The equivalent circuit of the STATCOM. In this power system, the resistance in series with the voltage- source inverter represents the sum of the transformer winding resistance losses and the inverter conduction losses. The inductance represents the leakage inductance of the transformer. The resistance in shunt with the capacitor represents the sum of the switching losses of the inverter and the power losses in the capacitor. the three-phase STATCOM output voltages; , and are the three- phase bus voltages; and , and are the three-phase STATCOM output currents .

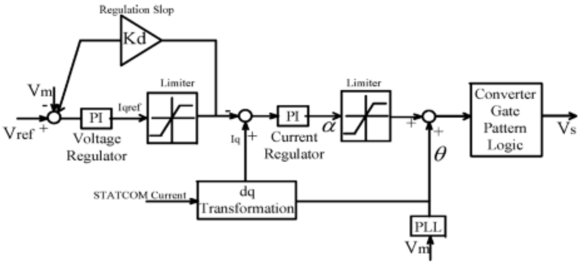


Figure. 2. Traditional STATCOM PI control block diagram.

2.1 STATCOM Dynamic Model

The three-phase mathematical expressions of the STATCOM can be written in the following form

$$L_s\frac{di_{as}}{dt}=-R_si_{as}+V_{as}-V_{al}$$
$$L_s\frac{di_{bs}}{dt}=-R_si_{bs}+V_{bs}-V_{bl}$$
$$L_s\frac{di_{cs}}{dt}=-R_si_{cs}+V_{cs}-V_{cl}$$
$$\frac{d}{dt}\left(\frac{1}{2}CV_{dc}^2(t)\right)=-[V_{as}i_{as}+V_{bs}i_{bs}+V_{cs}i_{cs}]-\frac{V_{dc}^2(t)}{R_c}$$

- (1)

$$\frac{d}{dt}\begin{bmatrix} i_{ds} \\ i_{qs} \\ V_{dc} \end{bmatrix}=\begin{bmatrix} -\frac{R_s}{L_s} & \omega & \frac{K}{L_s}\cos\alpha \\ -\omega & -\frac{R_s}{L_s} & \frac{K}{L_s}\sin\alpha \\ -\frac{3K}{2C}\cos\alpha & -\frac{3K}{2C}\sin\alpha & -\frac{1}{R_cC} \end{bmatrix}\begin{bmatrix} i_{ds} \\ i_{qs} \\ V_{dc} \end{bmatrix}$$

- (2)

the phase-locked loop (PLL) provides the basic synchronizing signal which is the reference angle to the measurement system. Measured bus line voltage is compared with the reference voltage , and the voltage regulator provides the required reactive reference current. .

$$\frac{d}{dt}\begin{bmatrix} i_{ds} \\ i_{qs} \\ V_{dc} \end{bmatrix}=\begin{bmatrix} -\frac{R_s}{L_s} & \omega & \frac{K}{L_s}\cos\alpha \\ -\omega & -\frac{R_s}{L_s} & \frac{K}{L_s}\sin\alpha \\ -\frac{3K}{2C}\cos\alpha & -\frac{3K}{2C}\sin\alpha & -\frac{1}{R_cC} \end{bmatrix}\begin{bmatrix} i_{ds} \\ i_{qs} \\ V_{dc} \end{bmatrix}$$

$$-\frac{1}{L_s}\begin{bmatrix} V_{dl} \\ V_{ql} \\ 0 \end{bmatrix}$$

-

(3)

The droop factor is defined as the allowable voltage error at the rated reactive current flow through the STATCOM. The STATCOM reactive current is compared with, and the output of the current regulator is the angle phase shift of the inverter voltage with regard to the system voltage. The limiter is the limit imposed on the value of control while considering the maximum reactive power capability of the STATCOM.

3. ADAPTIVE PI CONTROL FOR STATCOM

The STATCOM with fixed PI control parameters may not reach the desired and acceptable response in the power system when the power system operating condition changes. An adaptive PI control method is presented in this section in order to obtain the desired response and to avoid performing trial-and-error studies to find suitable parameters for PI controllers when a new STATCOM is installed in a power system. With this adaptive PI control method, the dynamical self-adjustment of PI control parameters can be realized. An adaptive PI control block for STATCOM. The measured voltage and the reference voltage , and the axis reference current and the current are in per unit values. The proportional and integral parts of the voltage regulator gains are denoted by and , respectively. Similarly, the gains and rep- resent the proportional and integral parts, respectively, of the current regulator. In this control system, the allowable voltage error is set to 0. The , and can be set to an arbitrary initial value such as simply 1.0. One exemplary desired curve is an exponential curve in terms of the voltage growth, which is set as the reference voltage in the outer loop. Other curves may also be used than the depicted exponential curve as long as the measured voltage returns to the desired steady-state voltage in desired time duration. The process of the adaptive voltage-control method for STATCOM.

In the inner loop, is compared with the -axis current . Using the similar control method like the one for the outer loop, the parameters and can be adjusted based on the error. Then, a suitable angle can be found and eventually the dc voltage in STATCOM can be modified such that STATCOM provides the exact amount of reactive power injected into the system to keep the bus voltage.

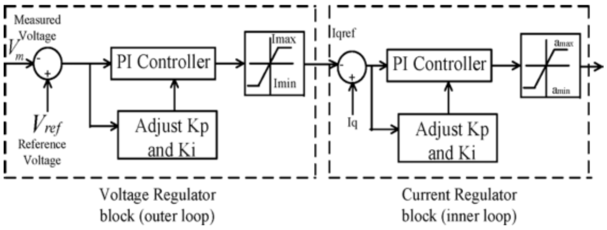


Fig 3 : Adaptive PI control block for STATCOM.

When the measured bus voltage over time the target steady-state voltage, which is set to 1.0 per unit, The discussion and examples, is compared with . Based on the desired reference voltage curve, and are dynamically adjusted in order to make the measured voltage match the desired reference voltage, and the axis reference current can be obtained. In the inner loop, is compared with the -axis current. Using the similar control method like the one for the outer loop, the parameters and can be adjusted based on the error. Then, a suitable angle can be found and eventually the dc voltage in STATCOM can be modified such that STATCOM provides the exact amount of reactive power injected into the system to keep the bus voltage at the desired value. It should be noted that the current and the angle and are the limits imposed with the consideration of the maximum reactive power generation capability of the STATCOM controlled in this manner. If one of the maximum or minimum limits is reached, the maximum capability of the STATCOM to inject reactive power has been reached. Certainly, as long as the STATCOM sizing has been appropriately studied during planning stages for inserting the STATCOM into the power system, the STATCOM should not reach its limit unexpectedly.

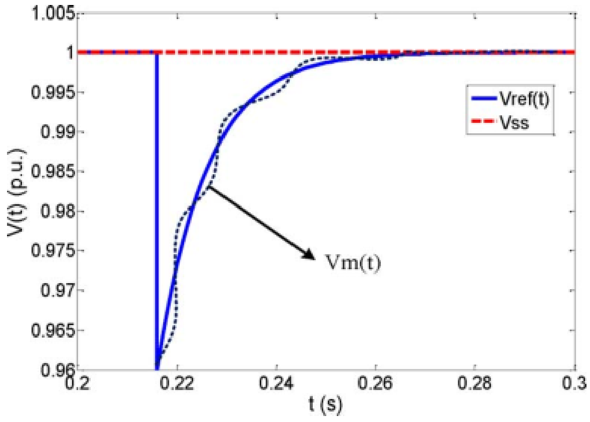


Fig 4: Reference voltage curve.

4. Derivation of the Key Equations

Since the inner loop control is similar to the outer loop control, the mathematical method to automatically adjust PI controller gains in the outer loop is discussed in this section for illustrative purposes. A similar analysis can be applied to the inner loop.

$$\begin{bmatrix} V_{dl}(t) \\ V_{ql}(t) \\ 0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix}\begin{bmatrix} V_{al}(t) \\ V_{bl}(t) \\ V_{cl}(t) \end{bmatrix}.$$

- (4)

$$V_m(t) = \sqrt{V_{dl}^2(t) + V_{ql}^2(t)}.$$

- (5)

$$\mathrm{V}_{\mathrm{ref}}(t) = V_{ss} - (V_{ss} - V_m(t))e^{-\frac{t}{\tau}}.$$

- (6)

$$\Delta\mathrm{V}(t)K_{p\_V}(t) + K_{i\_V}(t)\int_t^{t+T_s}\Delta\mathrm{V}(t)dt = I_{qref}(t+T_s)$$

- (7)

-

$$K_{p\_V}(t) = \frac{k_V \times \Delta\mathrm{V}(t)}{\left(\Delta\mathrm{V}(t) + m_V \times \int_t^{t+T_s}\mathrm{A}dt\right)}$$

- (8)

$$K_{p\_I}(t) = \frac{k_I \times \Delta\mathrm{I}_q(t)}{\left(\Delta\mathrm{I}_q(t) + m_I \times \int_t^{t+T_s}\mathrm{B}dt\right)}$$

- (9)

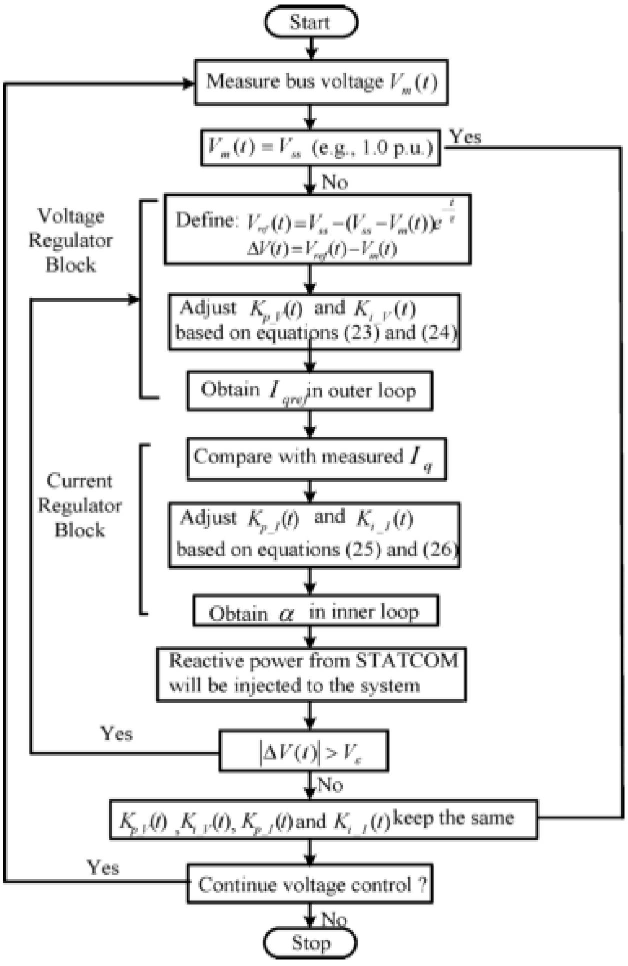
$$k_V = \frac{\mathrm{R} \times \Delta\mathrm{V}(t_0)}{\left(K_{p\_V}(t_0)\Delta\mathrm{V}(t_0) + K_{i\_V}(t_0)\int_{t_0}^{t_0+5\tau}\Delta\mathrm{V}(t)dt\right) \times \Delta\mathrm{V}_{\max}}.$$

-

(10)

5. Adaptive PI control algorithm flowchart.

Flowchart of the proposed adaptive PI control for STATCOM, The adaptive PI control process begins at Start. The bus voltage over time is sampled according to a desired sampling rate. Then, is compared with, then there is no reason to change any of the identified parameters, and. The power system is running smoothly. On the other hand, then adaptive PI control begins. The measured voltage is compared with , the reference voltage defined, Then, and are adjusted in the voltage regulator block (outer loop) based on and which leads to an updated via a current limiter.



Adaptive PI control algorithm flowchart.

Then, the is compared with the measured the control gains and are adjusted based on. Then, the phase angle is determined and passed through a limiter for output, which essentially decides the reactive power output from the STATCOM.

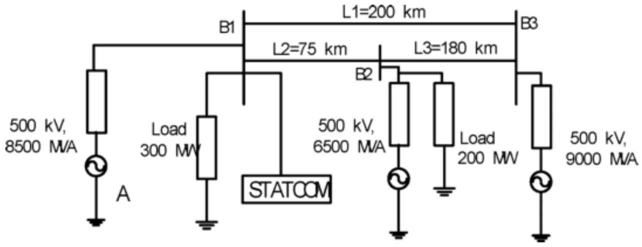


Fig 5: Study system

Block and current regulator blocks are reentered until the change is less than the given threshold. Thus, the values for, and are maintained. If there is the need to continuously perform the voltage-control process, which is usually the case, then the process returns to the measured bus voltage. Otherwise, the voltage-control process stops (i.e., the STATCOM control is deactivated).

6. Using Fuzzy Logic

Fuzzy Logic has two different meanings. Fuzzy Logic is a logical system, which is an extension of multivalve logic. However, in a more extensive sense Fuzzy Logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp limits in which membership is a matter of degree. Fuzzy logic controllers have the advantages of operating with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity. Fuzzy logic control generally consists of three stages: fuzzification, Inference, and Defuzzification. For simplicity a membership capabilities is Triangular. Fuzzification is using continuous universe of discourse. Implication is using Mamdani's "min" operator. Defuzzification is using the "height" method. FLC block diagram.

The nonlinear fuzzy logic controller is used to overcome the problems generated by different uncertainties existing in power systems when designing electromechanical oscillation damping controllers. Power systems are large scale systems with high nonlinearity, so there is a considerable uncertainty in every part of them. Fuzzy logic performs as a powerful tool to confront these uncertainties Fuzzy Logic is an advantageous approach to diagram input space to a output space. Mapping input to output is the beginning phase for everything. Consider the following examples With data about how good your service was at a restaurant, a fuzzy logic system can tell you what the tip should be.

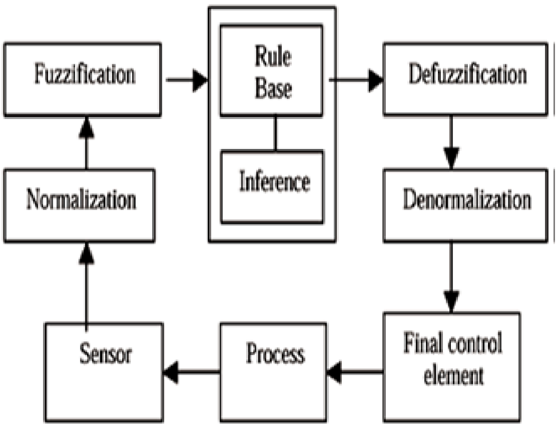


Fig.6: Block diagram of Fuzzy Logic Controller

6.1 Fuzzification

Membership capability values are assigned to linguistic variables, using seven fuzzy subsets. NB(Negative Big), NM(Negative Medium), NS(Negative Small), ZE(Zero), PS(Positive Small), PM(Positive Medium), PB(Positive Big).

ΔE E	NB	NS	ZE	PS	PB
NB	ZE	ZE	NB	NB	NB
NS	ZE	ZE	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS
PS	PS	PS	PS	ZE	ZE
PB	PB	PB	PB	ZE	ZE

Fuzzy Inference is a method that interprets the values in the input vector and, based on user defined rules, allots values to the output vector.

Utilizing the GUI editors and viewers in the Fuzzy Logic Toolbox, you can construct the rules set, define the membership capabilities, and analyze the behavior of a Fuzzy Inference System (FIS).

Key features :

- Specialized guis for building fuzzy inference systems and review and analyzing results.
- Membership capabilities for making fuzzy inference systems.
- Support for AND, OR, and NOT logic in user defined rules.
- Standard Mamdani and Sugeno-sort fuzzy inference systems.

- Automated membership capability shaping through neuro adaptive and fuzzy clustering learning methods.
- Ability to insert a fuzzy inference system in a Simulink model.

7. Simulation Model And Results

7.1 If Load Value Changes Suddenly:

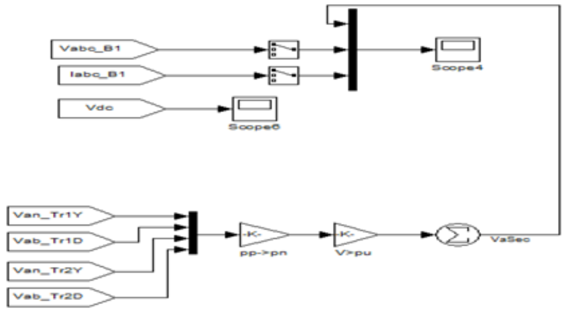


Fig 7.1 Internal Structure Of STATCOM PI Controller

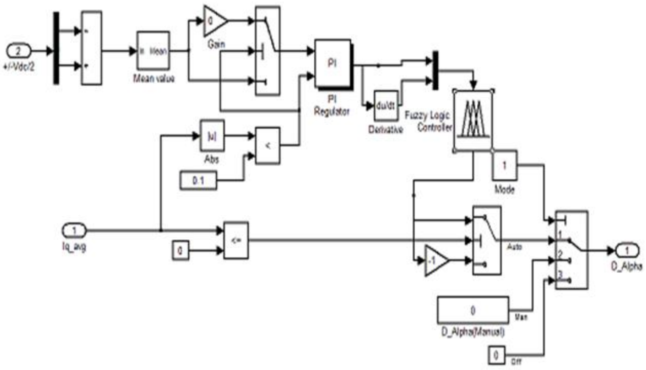


Fig.7.2 : Internal Structure Of Fuzzy Controller

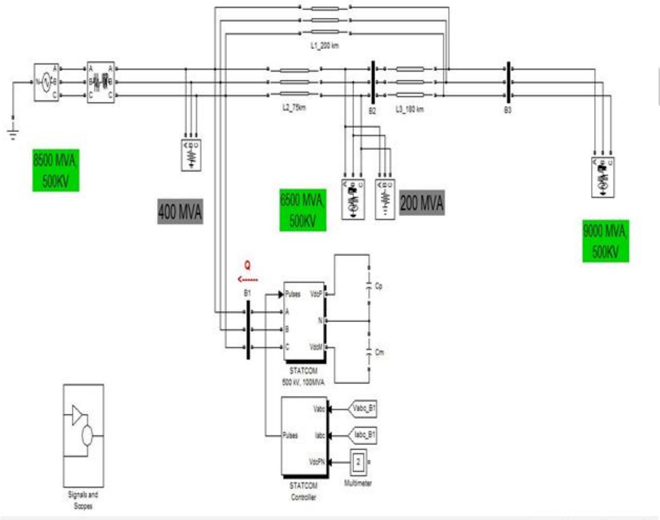


Fig.7.3: Test System for load change

The nonlinear fuzzy logic controller is used to overcome the problems generated by different uncertainties existing in power systems when designing electromechanical oscillation damping controllers .Power systems are large scale systems with high nonlinearity, so there is a considerable uncertainty in every part of them.

Fuzzy logic performs as a powerful tool to confront these uncertainties. The fuzzy logic approach provides a model-free method for STATCOM control and can be effective over a wide range of power system changes.

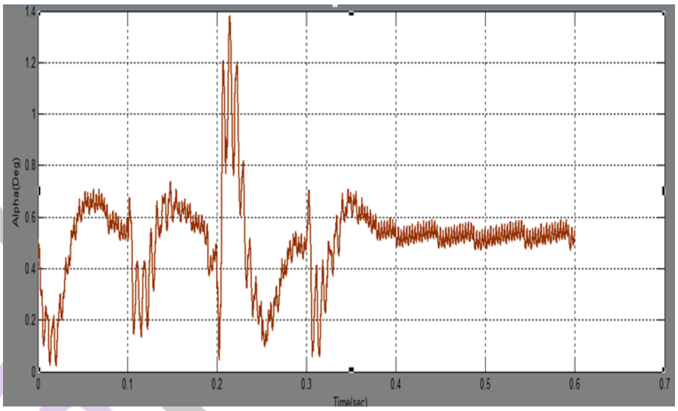


Fig.7.4: Alpha with flexible Control

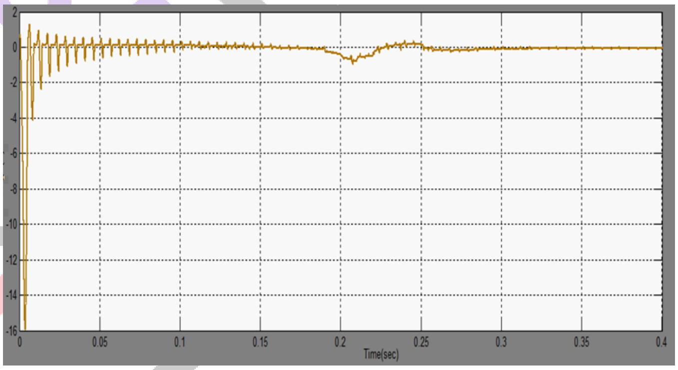


Fig.7.5: Alpha with Fuzzy Control

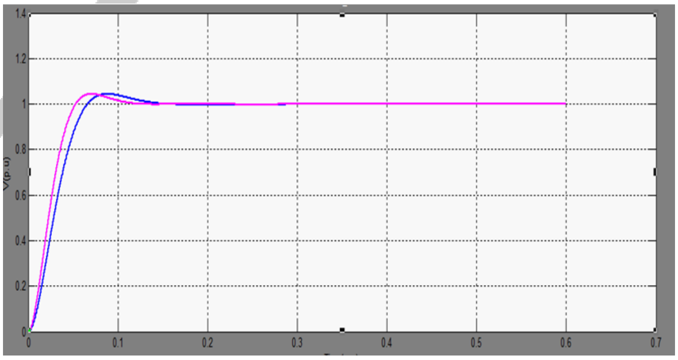


Fig.7.6: Voltage With flexible Control

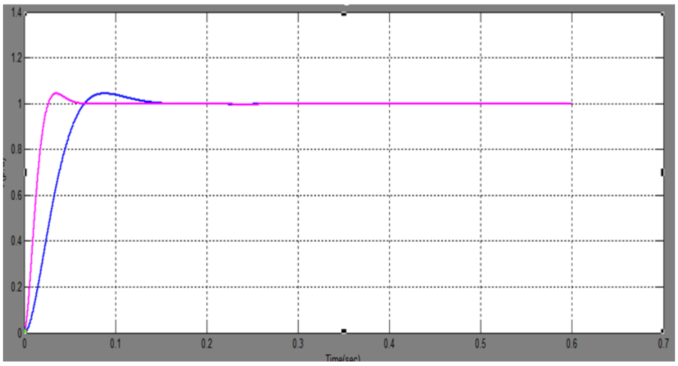


Fig.7.7: Voltage with Fuzzy Control

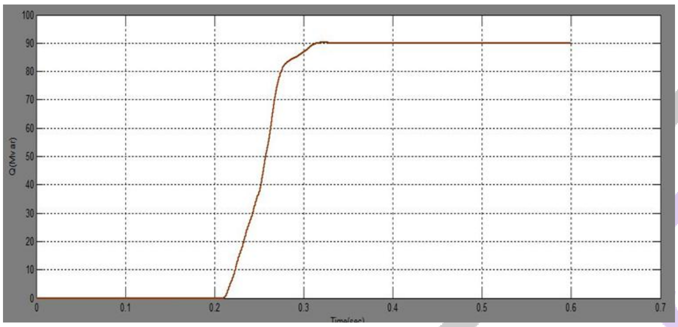


Fig.7.8: Reactive Power With Adaptive Control

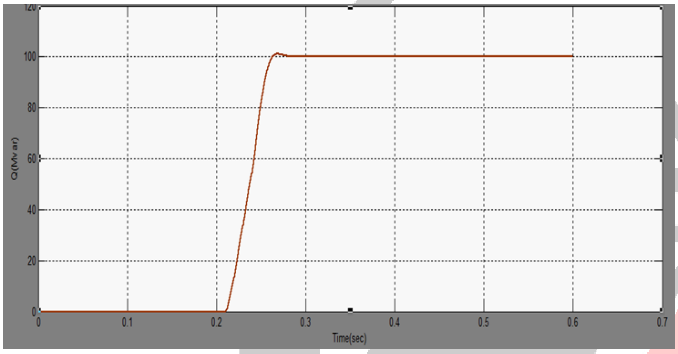


Fig.7.9: Reactive power With Fuzzy Control

7.2 If The PI Values Are Changed:

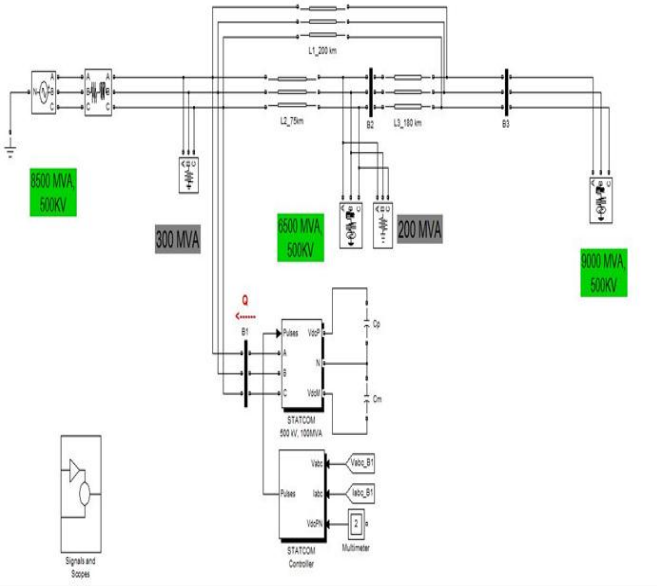


Fig.8: Test system for PI value change

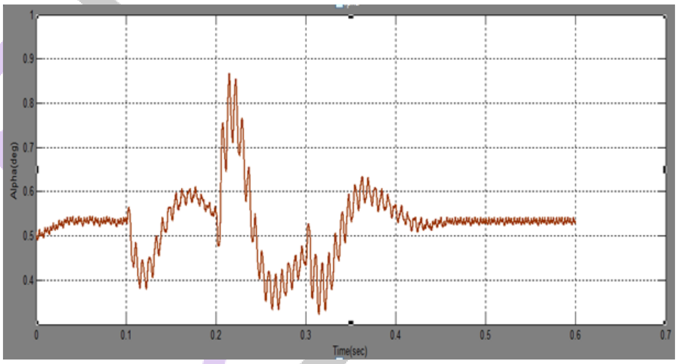


Fig.8.1: Alpha With flexible Control

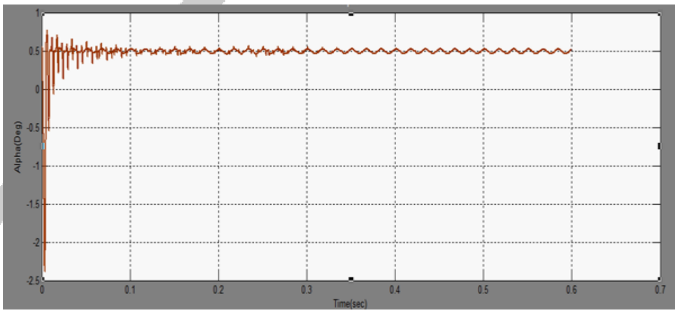


Fig.8.2 Alpha with Fuzzy Control

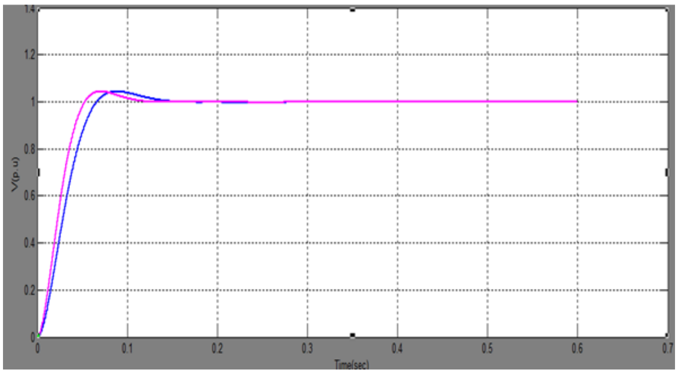


Fig.8.3: Voltage with Flexible Control

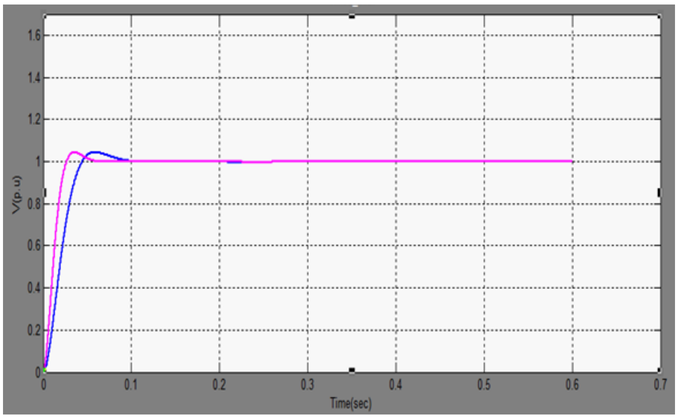


Fig.8.4 Voltage with Fuzzy Control

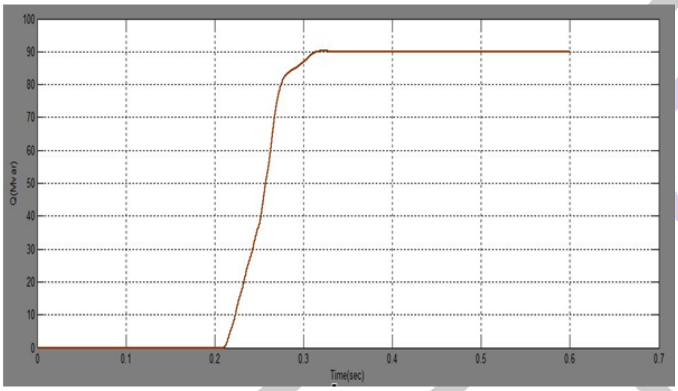


Fig.8.5: Reactive Power with Flexible Control

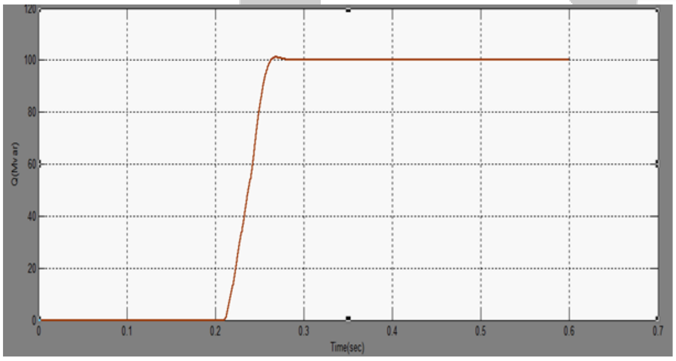


Fig.8.6 Reactive power with Fuzzy Control

CONCLUSION

In the literature survey, various STATCOM control methods have been discussed including many applications of PI controllers. However, these previous works obtain the PI gains via a trial-and-error approach or extensive studies with a tradeoff of performance and applicability. Hence, control parameters for the optimal performance at a given operating point may not always be effective at a different operating point.

To address the challenge, a new control model based on adaptive PI control is proposed, which can self-adjust the control gains dynamically during disturbances so that the performance always matches a desired response, regardless of the change of operating condition. Since the adjustment is autonomous, this gives the "plug-and-play" capability for STATCOM operation.

In the simulation study, the proposed adaptive PI control for STATCOM is compared with the conventional STATCOM control with pre tuned fixed PI gains to verify the advantages of the proposed method.

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