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Efficient Transmission Line Voltage Regulation Using Fuzzyfied Soft Static VAR Compensator

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Abstract- In the current scenario, due to the technological advancement the precise and regulated electricity requirement continuously increases. This requires precise electricity generation and transmission. Due to physical and financial restrictions transmission lines are not capable to cope up with such fast development. Hence there is a requirement of devices which can control the random fluctuations comes in the transmission line voltage during transmission. The devices used in this regard are known as Flexible AC Transmission Systems (FACTS), provides the opportunity to influence power flows and voltages and therefore enhances system security. From the last few years static Var compensator plays an important role in voltage regulation in AC Transmission Systems. The situations in transmission systems are very much vague or imprecise; it is not possible to handle it properly with the help of conventional techniques. Zadah in his paper proved that, imprecise situations can be properly handled using fuzzy logic. To incorporate this advantage of fuzzy logic, this paper deals with the designing and implementation of fuzzified static VAR compensator for efficient voltage regulation of AC Transmission lines. The combination of static VAR compensator with fuzzy logic will be a definite and efficient solution for a good voltage regulation requirement.

Key words –Transmission line voltage regulation, FACTS, Fuzzy logic controller, Static VAR Compensator.

I. INTRODUCTION

An inherent characteristic of electric energy transmission and distribution by alternating current (AC) is that real power is generally associated with reactive power. AC transmission and distribution associated with relative power. AC transmission and distribution lines are dominantly reactive networks, characterized by their per-mile series inductance and shunt capacitance. Thus, load and load power factor changes alter the voltage profile along the transmission lines and can cause large amplitude variations in the receiving end voltage. Most of loads are not tolerant to voltage variation.

Under voltage causes degradation in the performance of loads such as induction motors, light bulbs, etc.; overvoltage causes magnetic saturation and resultant harmonic generation, as well as equipment failure due to insulation breakdown. Reactive power also increases transmission losses. Power System Stability is the ability of the system to regain its original operating conditions after a disturbance to the system. Power system transient stability analysis is considered with large disturbances like sudden change in load, generation or transmission system configuration due to fault or switching [1]. Dynamic voltage support and reactive power compensation have been identified as a very significant measure to improve the transient stability of the system.

Flexible AC Transmission Systems (FACTS) devices with a suitable control strategy have the potential to increase the system stability margin [2, 3]. Shunt FACTS devices play an important role in reactive power flow in the power network. In large power systems, low frequency electro-mechanical oscillations often follow the electrical disturbances. Generally, power system stabilizers (PSS) are used in conjunction with Automatic Voltage Regulators (AVR) to damp out the oscillations [3]. However, during some operating conditions this device may not produce adequate damping and other effective alterations are needed in addition to PSS [4, 5].

Another means to achieve damping is to use the same shunt FACTS device Static VAR Compensator (SVC) designed with auxiliary controllers [6]. Therefore SVC is more effective and if accommodated with supplementary controller, by adjusting the equivalent shunt capacitance, SVC will damp out the oscillations and improves the overall system stability [7]. The system operating conditions change considerably during disturbances. Various approaches are available for designing auxiliary controllers in SVC. In [8] a proportional integral derivative (PID) was used in SVC. It was found that significant improvements in system damping can be achieved by the PID based SVC. Although PID controllers are simple and easy to design, their performances deteriorate when the system operating conditions vary widely and large disturbances occur. Fuzzy logic control approach is an emerging tool for solving complex problems whose system behavior is complex in nature. An attractive feature of fuzzy logic control is its robustness in system parameters and operating conditions changes [9, 10]. Fuzzy logic controllers are capable of tolerating uncertainty and imprecision to a greater extent [11].

This paper deals with a method based on fuzzy logic control for SVC controller which damp out the oscillations at a faster rate.

II. MODELING AND CONTROL OF SVC

The Static VAR Compensator is basically a shunt connected variable VAR generator whose output is adjusted to exchange capacitive or inductive current to the system. One of the most widely used configurations of the SVC is the FC- TCR type in which a Fixed Capacitor (FC) is connected in parallel with Thyristor Controlled Reactor (TCR). The magnitude of the SVC is inductive admittance B_L (α) is a function of the firing angle α and is given by

$$B_L(\alpha) - \frac{2\pi - 2\alpha + \sin 2\alpha}{\pi X_c} \qquad \text{……….(1)}$$

For $\pi/2 \le \alpha \le \pi$ where $X_c = V_c^2 / Q_l$, where V_S = SVC bus bar voltage and Q_L = MVA rating of reactor. As the SVC uses a fixed capacitor and variable reactor combination (TCR- FC), the effective shunt admittance is

$$B_S = \frac{1}{X_c} - B_L(\alpha) \qquad \text{……….(2)}$$

Where X_C=Capacitive reactance. An SVC with firing control system can be represented, for the sake of simplicity by a first order model characterized by a gain K_{SVC} and time constants T_1 and T_2 as shown in Figure (1) The controller send firing control signals to the thyristor switching unit to modify the equivalent capacitance of the SVC. The fuzzy controller provides a auxiliary control, which is in addition to the voltage feedback loop.

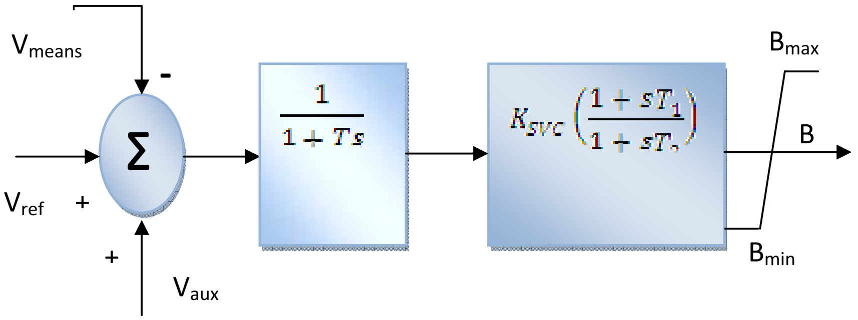


Figure (1) Block representation of SVC control

The auxiliary control loop of the SVC uses stabilizing signals, such as speed, frequency, phase angle difference etc.

III. METHODOLOGY

The Static VAR Compensator is basically a shunt connected variable VAR generator whose output is adjusted to exchange capacitive or inductive current to the system. One of the most widely used configurations of the SVC is the FC- TCR type in which a Fixed Capacitor (FC) is connected in parallel with Thyristor Controlled Reactor (TCR).in the previous chapters we have seen that, the conventional static VAR compensator is not able to provide an efficient voltage regulation due to the fact that, the line voltage fluctuations are very much random and imprecise. So for efficient line voltage regulation some tool is required, which can precisely handle the random line voltage fluctuations. The best tool for handling imprecise situations is Fuzzy logic. Hence conventional static VAR compensator along with fuzzy is the best fitted combination for achieving an efficient line voltage regulation.

3.1 Voltage Regulation of AC lines using Fuzzified Static VAR compensator

The Static Var Compensator (SVC) is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids [1]. The SVC regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the SVC generates reactive power (SVC capacitive). When system voltage is high, it absorbs reactive power (SVC inductive). The variation of reactive power is performed by switching three-phase capacitor banks and inductor banks connected on the secondary side of a coupling transformer. Each capacitor bank is switched on and off by three thyristor switches (Thyristor Switched

Capacitor or TSC). Reactors are either switched on-off (Thyristor Switched Reactor or TSR) or phase-controlled (Thyristor Controlled Reactor or TCR). Fig.6.1 shows a single-line diagram of a static VAR compensator and a simplified block diagram of its control system. The control system consists of

- A measurement system measuring the positive-sequence voltage to be controlled. A Fourier-based measurement system using a one-cycle running average is used.
- A voltage regulator that uses the voltage error (difference between the measured voltage V_m and the reference voltage V_{ref}) to determine the SVC susceptance B needed to keep the system voltage constant
- A distribution unit that determines the TSCs (and eventually TSRs) that must be switched in and out, and computes the firing angle α of TCRs
- A synchronizing system using a phase-locked loop (PLL) synchronized on the secondary voltages and a pulse generator that send appropriate pulses to the thyristors.

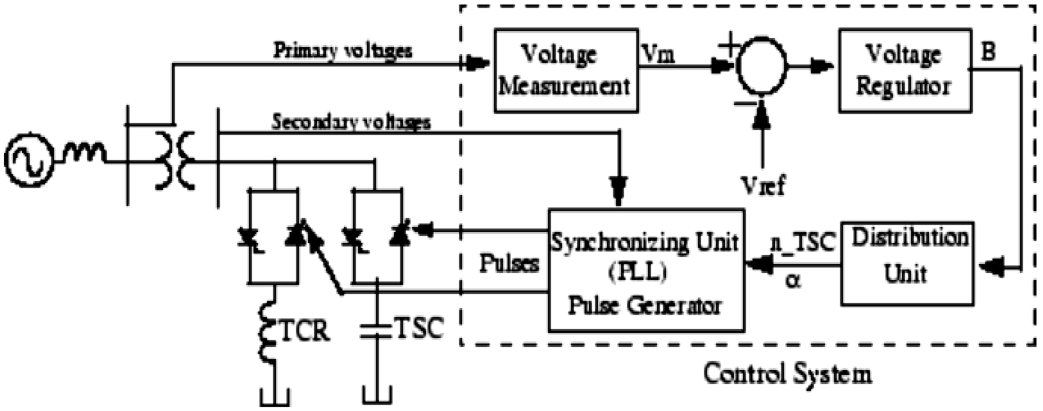


Figure (2). Single Phase Conventional SVC Voltage Regulator.

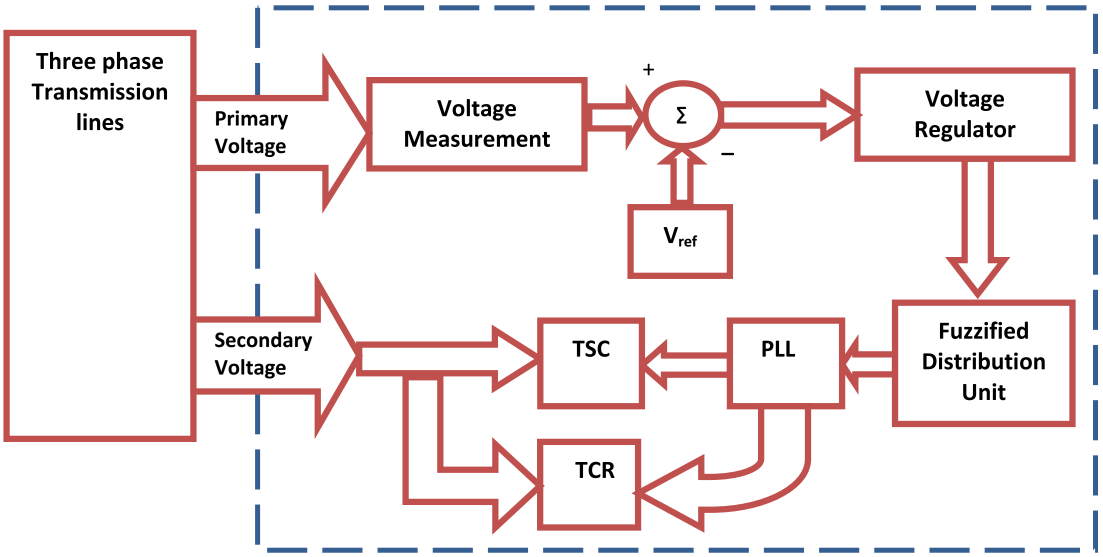
The model shown in figure(2), can be used in three-phase power systems together with synchronous generators, motors, and dynamic loads to perform transient stability studies and observe impact of the SVC on electromechanical oscillations and transmission capacity. The most important problem with this conventional regulator using SVC is with the distribution unit, this unit accepts BSVC as a input and calculates firing angle α without any prior knowledge. This project basically deals with the modification of distribution unit with Fuzzified distribution unit.

The methodology of the project work is shown in the figure (3) with the help of block diagram representation.

The SVC control system consists of the following four main modules:

i. Measurement System measures the positive-sequence primary voltage. This system uses discrete Fourier computation technique to evaluate fundamental voltage over a one-cycle running average window. The voltage measurement unit is driven by a phase-locked loop (PLL) to take into account variations of system frequency.

ii. Voltage Regulator uses a PI regulator to regulate primary voltage at the reference voltage (1.0 pu specified in the SVC Controller block menu). A voltage droop is incorporated in the voltage regulation to obtain a V-I characteristic with a slope (0.01 pu /100 MVA). Therefore, when the SVC operating point changes from fully capacitive (+300 Mvar) to fully inductive (-100 Mvar) the SVC voltage varies between 1-0.03=0.97 pu and 1+0.01=1.01 pu.



Fuzzified Static VAR

iii. conventional SVC the Distribution Unit uses the primary susceptance Bsvc computed by the voltage regulator to determine the TCR firing angle α and the status (on/off) of the three TSC branches. The firing angle α as a function of the TCR susceptance B_{TCR} is implemented by a look-up table from the equation

$$B_{TCR} = \frac{2(\pi-\alpha)+\sin(2\alpha)}{\pi} \qquad \text{……….(3)}$$

Where BTCR is the TCR susceptance in pu of rated TCR reactive power (109 Mvar).

In this project the conventional method of calculation of fairing angle α using look up table is replaced by Fuzzy logic approach, and hence the new distribution unit is known as Fuzzified Distribution unit.

iv. Firing Unit consists of three independent subsystems, one for each phase (AB, BC and CA). Each subsystem consists of a PLL synchronized on line-to-line secondary voltage and a pulse generator for each of the TCR and TSC branches. The pulse generator uses the firing angle α and the TSC status coming from the Distribution Unit to generate pulses. The firing of TSC branches can be synchronized (one pulse is sent at positive and negative thyristors at every cycle) or continuous. The synchronized firing mode is usually the preferred method because it reduces harmonics faster.

3.2. Development of Fuzzified Distribution Unit

The conventional distribution unit deals with the calculation of firing angle α with the help of look up table based on the equation

$$B_{TCR} = \frac{2(\pi-\alpha)+\sin(2\alpha)}{\pi} \qquad \text{………. (3)}$$

This method of calculation of firing angle lacking with the handling of imprecise fluctuations in line voltage and hence not able to provide efficient voltage regulation. Hence for handling of such fluctuations fuzzy logic has been used. Figure (4) shows the developed fuzzified distribution unit simulation diagram.

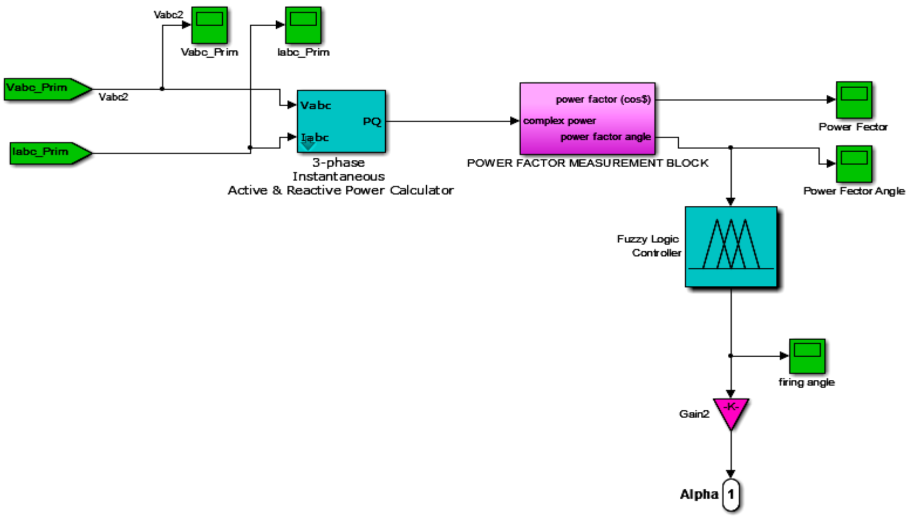


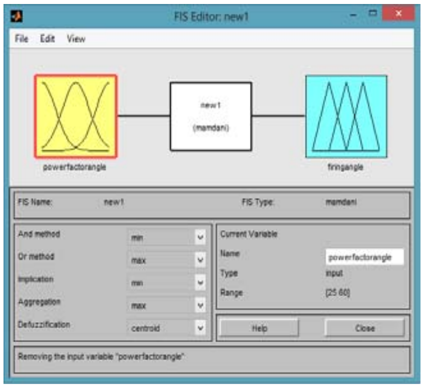
Figure (4) Fuzzified distribution unit simulation diagram.

The calculation of firing angle from fuzzified distribution unit is based on power factor angle; in the next section the calculation of firing angle based on fuzzy rule base system will be discussed.

3.2.1. Fuzzy controller for fuzzified distribution unit

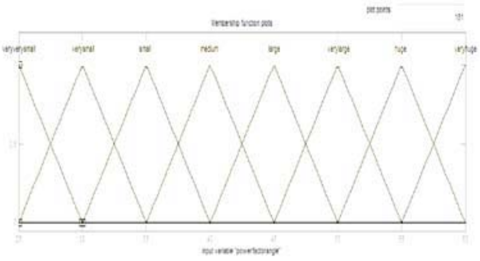
Fuzzified distribution unit is based on the control mechanism of developed fuzzy controller using fuzzy inference system shown in figure (4). Figure (5) shows the member ship functions for input variable power factor angle developed to handle imprecise situations. Similarly the plot of figure (6) shows the membership functions designed for output variable firing angle. The rule base developed for fuzzy controller is as follows

1. If (powerfactorangle is veryverysmall) then (firingangle is veryverysmall) (1)
2. If (powerfactorangle is verysmall) then (firingangle is verysmall) (1)
3. If (powerfactorangle is small) then (firingangle is small) (1)
4. If (powerfactorangle is medium) then (firingangle is medium) (1)
5. If (powerfactorangle is large) then (firingangle is large) (1)
6. If (powerfactorangle is verylarge) then (firingangle is verylarge) (1)
7. If (powerfactorangle is huge) then (firingangle is huge) (1)
8. If (powerfactorangle is veryhuge) then (firingangle is veryhuge) (1)



FIS Name: new1
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: powerfactorangle
Type: input
Range: [25 60]
Removing the input variable "powerfactorangle"

Figure (4) developed fuzzy controller



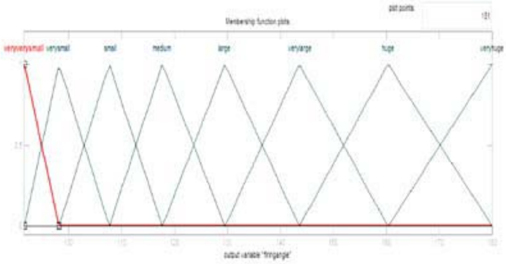
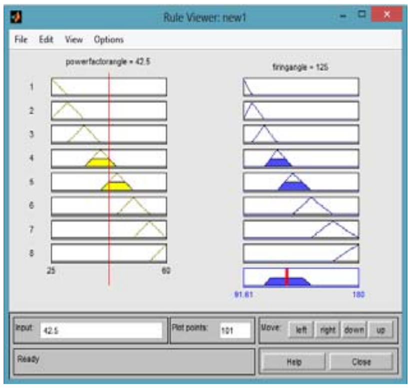


Figure (5) Membership function for input variable.   Figure (6) Membership function for output variable.



Input: 42.5
Plot points: 101

Figure (7) Rule viewer for the Developed fuzzy controller.

IV. RESULTS AND DISCUSSIONS

The voltage regulation using Fuzzified static var compensator has been successfully implemented in the Simulink. This section deploys the results obtained and steady state and dynamic performance analysis of results obtained. For the efficient Voltage regulation the reference voltage is taken as 1.0 pu. Waveforms of Figure (8) illustrates, SVC voltage regulator Dynamic Response to System Voltage variations.

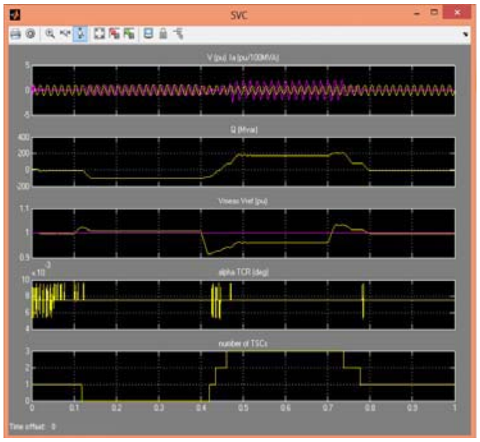


Figure (8) Steady-State and Dynamic Performance of the SVC Voltage Regulator

Initially the source voltage is set at 1.004 pu, resulting in a 1.0 pu voltage at SVC terminals when the SVC is out of service. As the reference voltage Vref is set to 1.0 pu, the SVC is initially floating (zero current). This operating point is obtained with TSC1 in service and TCR almost at full conduction but the conduction angle is continuously controlled by fuzzy controller, which was not in case of conventional SVC controller.

At t=0.4 s the source voltage is suddenly lowered to 0.93 pu. The SVC reacts by generating 256 Mvar of reactive power, thus increasing the voltage to 0.974 pu. At this point the three TSCs are in service and the

TCR absorbs approximately 40% of its nominal reactive power. Observe on the last trace of the scope how the TSCs are sequentially switched on and off. Each time a TSC is switched on the TCR α angle changes from no conduction to partially or fully conduction depending on the requirement. Finally, at t=0.7 s the voltage is increased to 1.0 pu and the SVC reactive power is reduced to zero. The TCR voltage and current in branch AB as well as thyristors pulses are displayed in on the TCR AB scope. Figure (9) shows three cycles when the firing angle α vary.

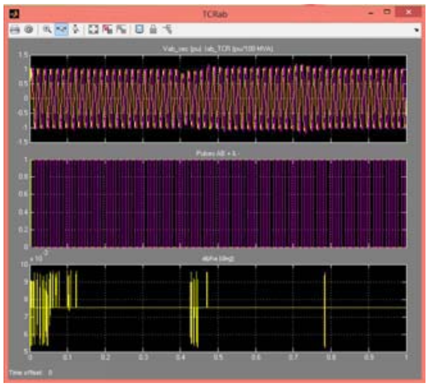


Figure (9) Steady-State Volt and Current in TCR AB

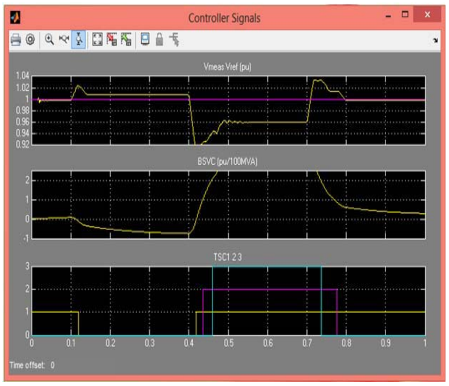


Figure (10) control signals for the voltage regulation.

Since the firing angle calculation through fuzzy controller is depends on the power factor and power factor angle, hence the analysis of this voltage regulator is highly depends on these parameters. Figure (11) and figure (12), shows the variation in the power factor and power factor angle and figure (13) shows the obtained firing angle α based on power factor angle.

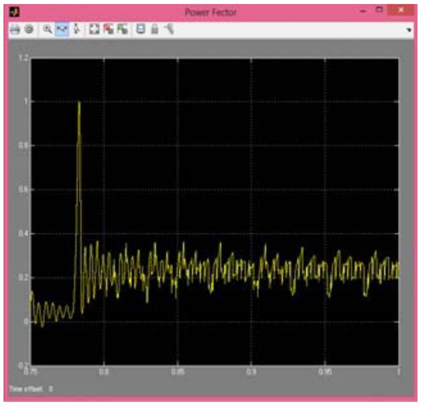


Figure (11) Power factor variation.

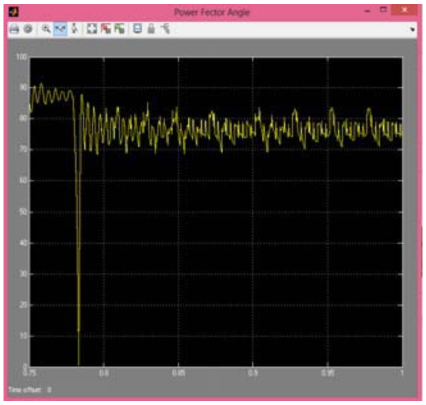


Figure (12) Power factor Angle variations

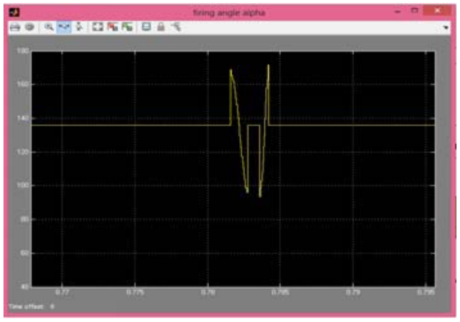


Figure (13) Obtained Firing Angle.

From figures it is found that for the efficient voltage regulation it is most important to control the switching of TCRs. In case of conventional SVC this can be done by either setting firing angle α to 180 for off condition or by setting firing angle α to 90 degree for full conduction, this method creates a drawback that TCR takes little time to make full conduction or to go in complete off condition. Hence due to this extra time either extra reactive power is supplied or absorbed, so creates deficiency in voltage regulation. This problem is resolved in this project by making the firing angle α variable using fuzzy logic, hence TCRs are not allowed to go in complete conduction instead it is used in partial conduction mode.

V. CONCLUSIONS

The advancement in the technology like home equipments and plant equipments, demands for precession and highly regulation in the received voltage from energy generator through the lines, because in current scenario the equipments are very much sensitive to supply voltage regulation. Any kind of fluctuation either damage the costly equipment or may harm full for further used equipments. The algorithm of this project work shows an efficient solution of this problem.

The conventional SVC is able to provide voltage regulation up to some extent due to deficiencies in its control mechanism. Due to the use Fuzzy logic approach this project has shown a good efficient voltage regulation as discussed in earlier section.

During the analysis it is found that, the conventional SVC voltage regulator takes approximately 95% settling time 135 ms to control under voltage or over voltage fluctuations. On the other hand the developed technique based on fuzzy logic takes only 30% settling time 65ms to control under voltage or over voltage fluctuations, which is just half as required by Conventional SVC. Therefore the results obtained shows that developed algorithm is rigid against the random voltage fluctuations in transmission line, and provides an efficient voltage regulation.

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