ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 3, Special Issue 2, March 2016

Fuzzy PI Controller based Static Var Compensator for Voltage Flicker Mitigation

K.VAISHNAVI
Dept of Electronics and Communication Engineering
Bharathiyar Institute of Engineering &Technology
Tamilnadu, India
Vaishnavikumar791@gmail.com

***Abstract*-Static Var Compensator (SVC) is a shunt type Flexible AC Transmission (FACTS) device which is used in power system for the purpose of voltage and reactive power control. In this paper, SVC has been proposed for effective mitigation of voltage flicker in the power system. The presence of voltage flicker is harmful to the power system because it will cause additional power losses. Controller parameter with proportional–integral controller, fuzzy logic controller and fuzzy proportional–integral controller of signals in the system are estimated. The results obtained show that SVC with fuzzy PI controller is very efficient and effective for the flicker mitigation when compared to proportional–integral controller, fuzzy logic controller. Static Var Compensators (SVC) are preferred due to low cost and simple control strategy.**

***Keywords*— Static Var Compensator (SVC), Thyristor Controlled Reactor (TCR), Thyristor Switched Capacitor (TSC), Fuzzy proportional-integral (PI) Controller.**

I.INTRODUCTION

Power quality is the issue that is becoming increasingly important to electricity consumers at all levels of usage. Voltage flicker and voltage fluctuation are two of the major power quality problems associated in the power system.So voltage flicker mitigation is essential for the power system. Rahman Hasani et.al [1] aims at utilizing the Static VAR Compensator SVC for simultaneously load balancing and voltage flicker elimination due to arc furnace loads. STATCOM for mitigation of voltage flicker produced by electric arc furnace is modeled and simulated in [2]. Durga Prasad Alampalli et.al [3] attempts to design and simulate the Fuzzy logic control of firing angle for SVC (TCR & FC-TCR) in order to achieve better, smooth and adaptive control of reactive power. The design, modeling and simulations are carried out for λ /8 Transmission line and the compensation is placed at the receiving end (load end). Karuppanan P et.al [4] are proposed a Phase Locked Loop (PLL) circuit in conjunction with Proportional Integral (PI) or Proportional

Integral Derivative (PID) or Fuzzy Logic Controller (FLC) based shunt Active Power Line Conditioners (APLC) for the power-quality improvement such as current harmonics and reactive power compensation due to the non-linear/unbalanced loads. Mitigation of voltage fluctuation and voltage flicker by SVC and also a phase to phase "open+close" control strategy for industrial SVC was proposed [5].Power quality improvement using fuzzy logic control have been presented . An SVC consists of a thyristor-controlled reactor (TCR) and a thyristors switched Capacitor (TSC) and compensates loads through the generation or absorption of reactive power. Static Var Compensator (SVC) are more effective for providing fast-acting reactive power compensation[6].The problem of voltage flicker on nonlinear loads are mitigated using STATCOM [7].Power quality improvement using adaptive shunt active filter is proposed [8].Mitigation of voltage flicker using PSCAD was performed [9]. D.Thukaram et.al [10] have analyzed a fixed capacitor-thyristor-controlled reactor type for minimum harmonic injection. Voltage flicker mitigation is performed using UPQC in [11]. The operation of thristor-controlled reactor and Static Var Compensator (SVC) controller for voltage flicker mitigation was proposed [12]-[13]. The voltage flicker and harmonics are reduced by comparing TCR and inverters [14].Although the active power filter, UPQC and static synchronous compensator (STATCOM) are used for power quality improvement they are too expensive for customers.

This paper deals with the reduction of voltage flicker using SVC based on PI, Fuzzy logic controller and Fuzzy PID controller. Section II deals with Static Var Compensator, Section III deals with proposed control strategy and section IV deals with Modeling of SVC, Section V deals with simulation results.

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II. STATIC VAR COMPENSATOR

The Static Var Compensator (SVC) is a shunt type FACTS device which is used to improve the power quality for the purpose of voltage and reactive power control. 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). The TSC branches are tuned with the series reactor to different dominant harmonic frequencies.The use of AC arc furnace usually comes with heavy harmonics and large negative sequence current. Large amount of reactive power demand and reactive power variation result in the voltage fluctuation and flicker, which also reduces the efficiency.

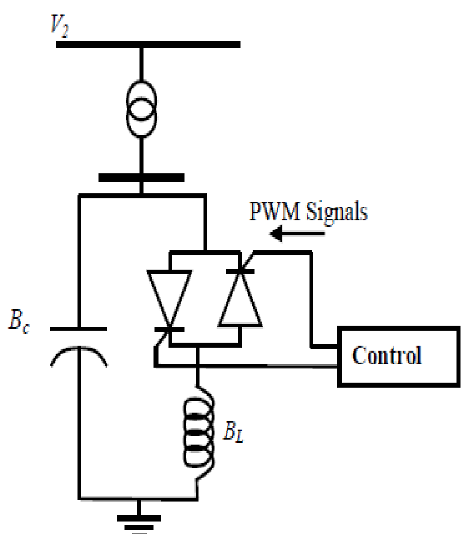

Fig.1 Schematic diagram of an SVC

SVC system can not only supply sufficient reactive power, but also eliminate the harmonics generated by rectifiers and prevent equipments from voltage fluctuation and flicker.

III.PROPOSED CONTROL STRATEGIES FOR FLICKER MITIGATION

3.1. PI CONTROLLER

PI controller is a feedback controller which drives the plant to be controlled with a weighted sum of the error and the integral of that value. The proportional response can be adjusted by multiplying the error by constant K_P, called proportional gain. The contribution from integral term is proportional to both the magnitude of error and duration of error. The proportional function is to adjust controller output according to the size of error while function of integral is to eliminate the steady state offset.

The benefit of the PI controller is that it can be adjusted empirically by adjusting one or more gain values and observing the change in system response.

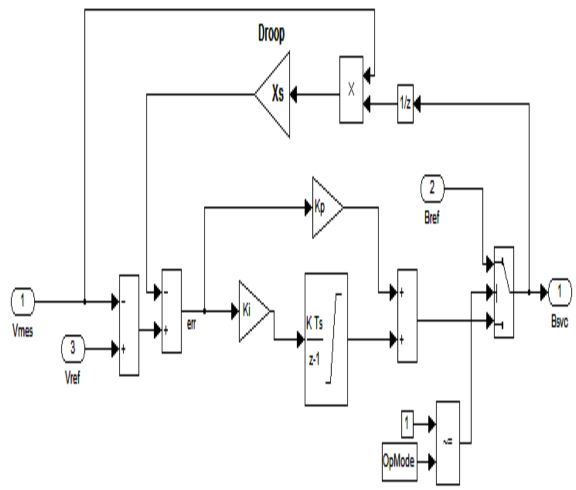

Fig.2 Simulation of SVC using PI Controller

3.2. FUZZY LOGIC CONTROLLER

In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. Since the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required in FC.A fuzzy logic controller has four main components as shown in Figure:

i).Fuzzification

ii).Inference engine

iii).Rule base

iv).Defuzzification

Fuzzy logic is based on linguistic variables.The first step in designing fuzzy inference mechanism is to identify effective input variables and output decision variables, and then qualify them with membership functions. Membership functions determine that how variables belong to a fuzzy set. This process is called fuzzification. After fuzzification, we should define rules based on linguistic variables and the physical dynamic of the system. Then fuzzy inference mechanism determines effective rules and based on these rules, decision variables are produced. Finally the fuzzy

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decision variables are converted to real numbers through the process of defuzzification.

In order to define fuzzy membership function (MF), designers choose many different shapes based on their preference and experience. There are generally four types of membership functions used:

i). Trapezoidal MF

ii).Triangular MF

iii).Gaussian MF

iv).Generalized bell MF

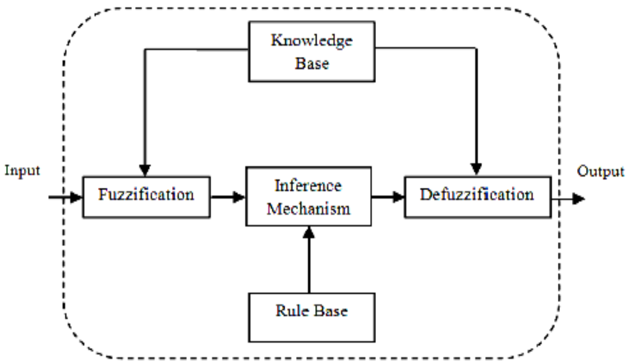

Fig.3 Schematic representation of Fuzzy Logic Controller.

Implementation of an FLC requires the choice of four key factors

i) Number of fuzzy sets that constitute linguistic variables.
ii) Mapping of the measurements onto the support sets.
iii) Control protocol that determines the controller behaviour.
iv) Shape of membership functions.

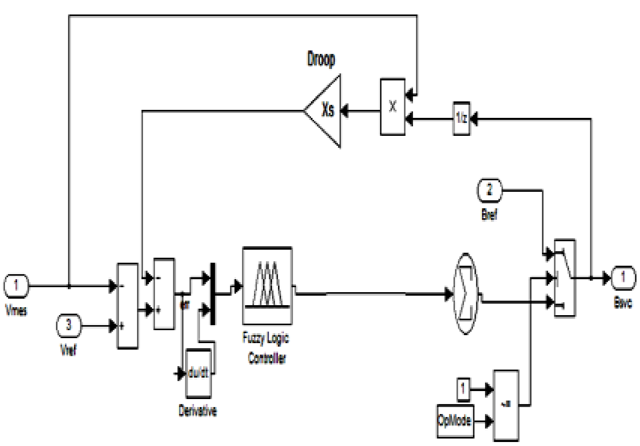

Fig.4 Simulation of SVC using Fuzzy logic Controller

3.3. FUZZY LOGIC PI CONTROLLER

In large power plants more than one PI controller are used. Traditionally these PI controllers are tuned with constant parameters which are not robust enough when there is change in design parameters. In order to overcome this problem different methods are proposed. Fuzzy-PI Controller is one of them.Fuzzy PI controller is preferred over the conventional PI and Fuzzy logic controller because of its robustness to system parameter variations during operation and its simplicity of implementation. The proposed Fuzzy PI Controller scheme exploits the simplicity of the mamdani type fuzzy systems that are used in the design of the controller and adaptation mechanism.

For voltage regulator the difference between Vmeas and Vref i.e. error and its derivative are taken as input for fuzzy adjuster. This fuzzy adjuster is used to adjust the parameters of proportional gain Kp and integral gain Ki .

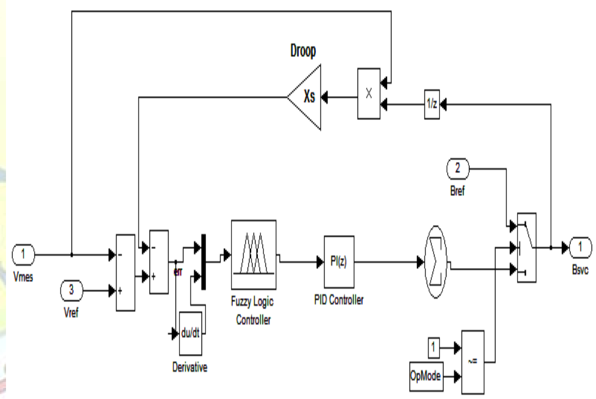

Fig.5 Simulation of SVC using Fuzzy PI Controller

3.4. ADJUSTING FUZZY MEMBERSHIP FUNCTIONS AND RULES

In order to improve the performance of FLC, the rules and membership functions are adjusted. The membership functions are adjusted by making the area of membership functions near ZE region narrower to produce finer control resolution. On the other hand, making the area far from ZE region wider gives faster control response. Also the performance can be improved by changing the severity of rules .An experiment to study the effect of rise time (Tr), maximum overshoot (Mp) and steady-state error (SSE) when varying Kp and Ki was conducted. The results of the experiment were used to develop 25-rules for the FLC of Kp and Ki are the output variables and from error and change of error are the input variables. Triangular membership functions are selected.

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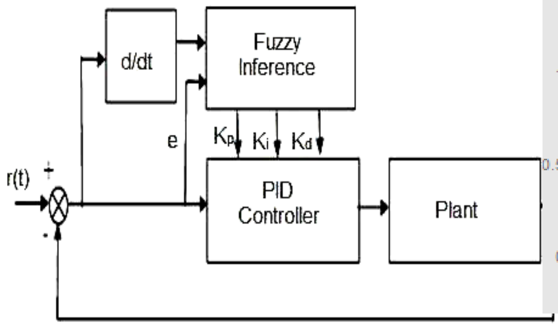

Fig.6 Block diagram of Fuzzy PI Controller

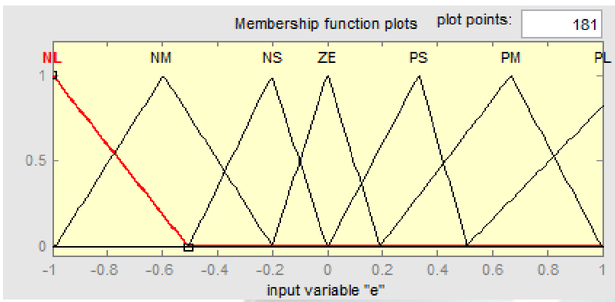

Fig.6a Membership Function for Input Variable Error, 'e'.

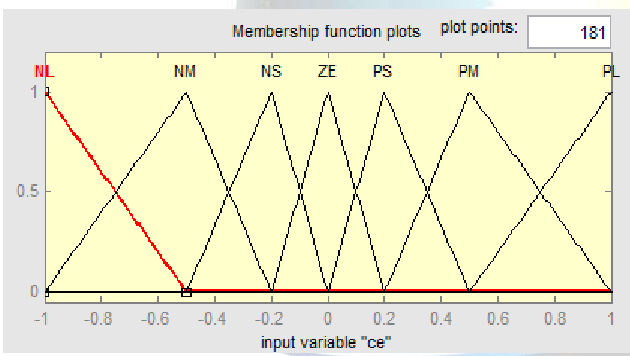

Fig .6b Membership Function for Input Variable Change in Error, 'ce'.

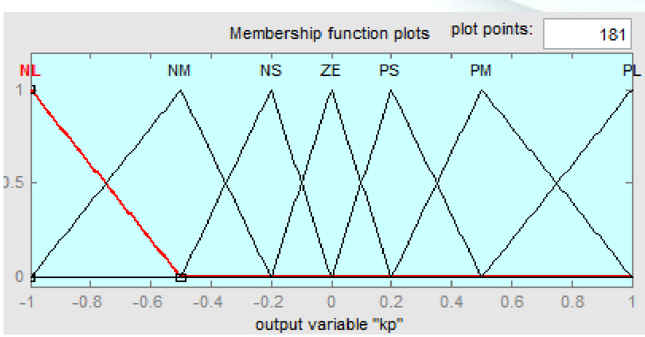

Fig .6c. Membership Function for Output Variable Change in Control Signal, 'Kp'.

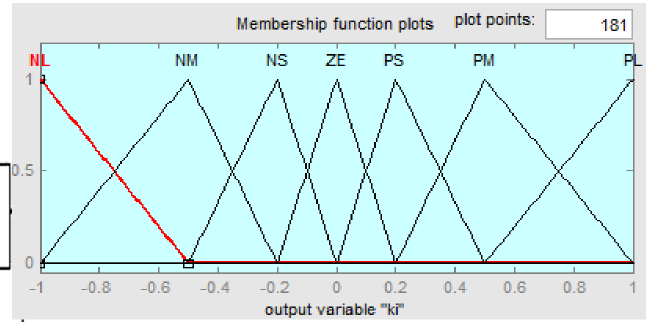

Fig .6d. Membership Function for Output Variable Change in Control Signal, 'Ki'.

Table:1 Kp Fuzzy Control Rules

E\CE	**NL**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PL**
NL	PL	PL	PM	PM	PS	ZE	ZE
NM	PL	PL	PM	PS	PS	ZE	NS
NS	PM	PM	PM	PS	ZE	NS	NS
ZE	PM	PM	PS	ZE	NS	NM	NM
PS	PS	PS	ZE	NS	NS	NM	NM
PM	PS	ZE	NS	NM	NM	NM	NL
PL	ZE	ZE	NM	NM	NM	NL	NL

Table: 2 Ki Fuzzy Control Rules

E\CE	**NL**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PL**
NL	NL	NL	NM	NM	NS	ZE	ZE
NM	NL	NL	NM	NS	NS	ZE	ZE
NS	NL	NM	NS	NS	ZE	PS	PS
ZE	NM	NM	NS	ZE	PS	PM	PM
PS	NM	NS	ZE	PS	PS	PM	PL
PM	ZE	ZE	PS	PS	PM	PL	PL
PL	ZE	ZE	PS	PM	PM	PL	PL

IV.MODELLING OF SVC

Consider the single line diagram of a system as shown in fig.2.It is widely known that the voltage fluctuations and flicker at the point of connection are mainly caused by a rapid change in the reactive power of the load. The TCR can quickly alter the inductive current of a device in a continuous

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way by changing the firing angle of the thyristor, connected in series with the reactor, and thus adjust the reactive power as the system demands. Using a suitable controller for the control of the reactive power of the SVC, the voltage fluctuations can be decreased to an acceptable level. The control algorithm is essential for a proper and efficient operation of the TCR.

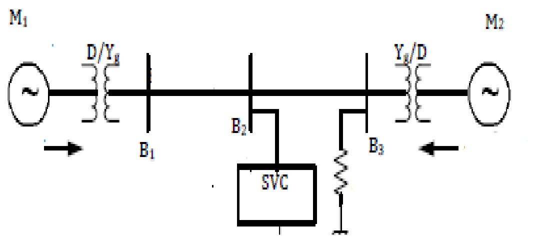

Fig.7 Simplified representation of Single line diagram with SVC

A Static Var Compensator (SVC) is used to regulate voltage on a 735-kV distribution line. The network model involves a high-voltage network equivalent with its short-circuit reactance and resistance network. The 600-V load connected to bus B3 through a 35kV/600V transformer represents a plant absorbing continuously changing currents, similar to an arc furnace, thus producing voltage flicker. The variable load current magnitude is modulated at a frequency of 50 Hz so that its apparent power varies approximately between 200 MVA and 100 MVA. This load variation will allow you to observe the ability of the SVC to mitigate voltage flicker. The SVC regulates bus B2 voltage by absorbing or generating reactive power. This reactive power transfer is done through the leakage reactance of the two winding transformer by generating a secondary voltage in phase with the primary voltage (network side). This voltage is provided by a voltage-sourced PWM inverter. When the secondary voltage is lower than the bus voltage, the SVC acts like an inductance absorbing reactive power. When the secondary voltage is higher than the bus voltage, the SVC acts like a capacitor generating reactive power.

V.SIMULATION RESULTS

The voltage and current waveforms at the 35-kV voltage level with a connected SVC in p.u. are shown in Fig. 8

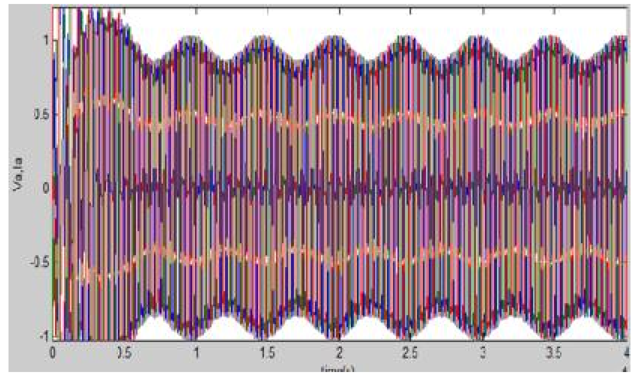

Fig.8 Voltage and Current waveform.

The simulation of the realistic model with the SVC connected at the 35-kV voltage level was performed. Waveforms of the simulated signals of the active and reactive power can be seen in Fig. 9 and Fig.10.

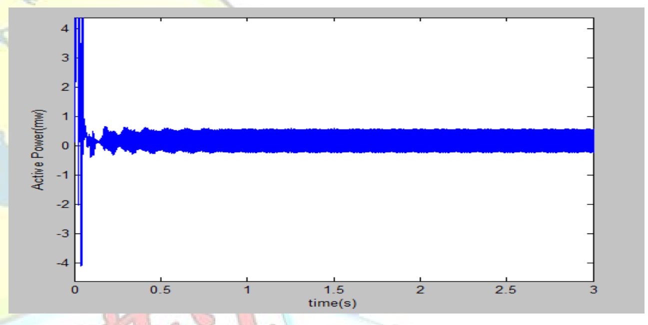

Fig.9 Active Power with SVC

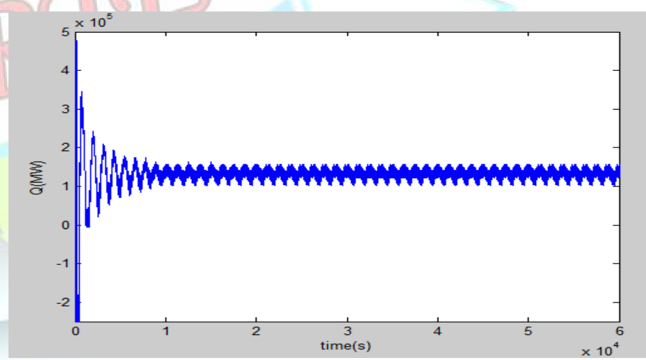

Fig.10 Reactive Power with SVC.

Fig.11 shows the voltage flicker in p.u. at the 35-kV voltage level connecting SVC. It shows the oscillations of the RMS voltage that cause the appearance of flicker in the electric power system. By connecting PI controller based SVC, voltage flicker reduces to 1.7p.u.

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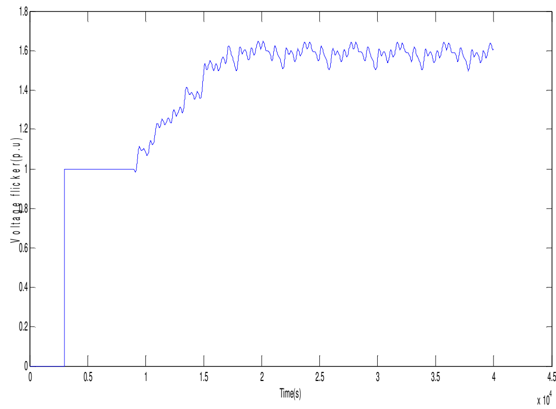

Fig.11 Voltage flicker with PI controller

Fig.12 shows the voltage flicker in p.u. at the 35-kV voltage level connecting SVC. It shows the oscillations of the RMS voltage that cause the appearance of flicker in the electric power system. By connecting fuzzy logic controller based SVC, voltage flicker reduces to 1.2p.u.

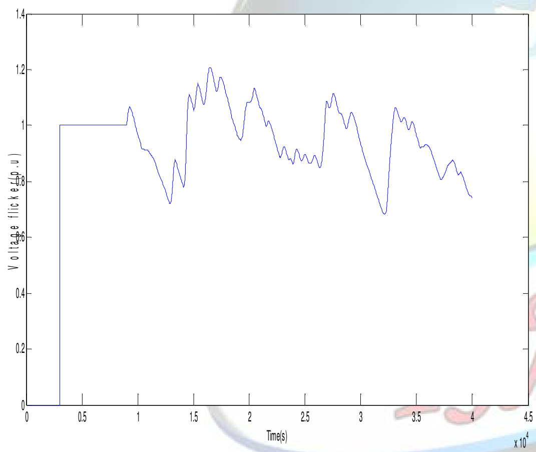

Fig.12 Voltage flicker with Fuzzy logic controller

Fig.13 shows the voltage flicker in p.u. at the 35-kV voltage level connecting SVC. It shows the oscillations of the RMS voltage that cause the appearance of flicker in the electric power system. By connecting fuzzy PI controller based SVC, voltage flicker reduces to less than 1.0p.u.

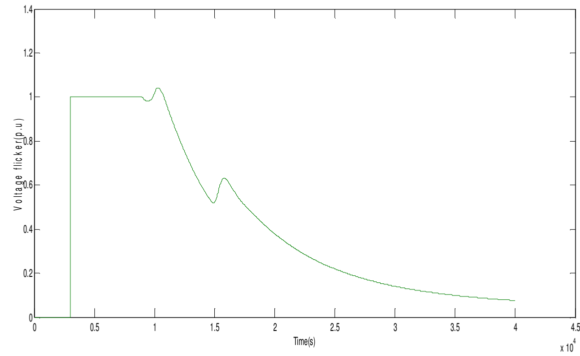

Fig.13 Voltage flicker with Fuzzy PI Controller

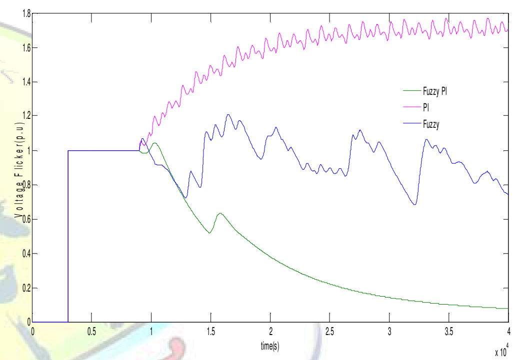

Fig 14.Comparsion of PI,Fuzzy and Fuzzy PI Controller

TABLE.2 PERFORMANCE OF SVC.

CONTROL STRATEGY WITH SVC	VOLTAGE FLICKER(p.u)
PI	1.7
FUZZY	1.2
FUZZY PI	≤1.0

VI.CONCULSION

SVCs are preferred for varying loads due to low cost and simple control strategy. This paper demonstrates mitigation of voltage flicker with SVC using PI, Fuzzy and Fuzzy PI controller. Fuzzy PI controller is preferred over the conventional PI and Fuzzy logic controller because of its robustness to system parameter variations during operation and its simplicity of implementation. When voltage is low SVC generate reactive power. The Simulation result shows how the SVC device improve the power quality. With MATLAB simulations it is observed that SVC provides an

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effective reactive power control irrespective of load variation and reduce voltage flicker and voltage fluctuation.

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