MAINTAINING VOLTAGE PROFILE OF POWER SYSTEM USING INTELLIGENT SVC

DISSERTATION
SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY

In POWER SYSTEMS

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2015

Certificate

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Abstract

One of the major requirements in power system is to provide continuous supply of energy to load centers, with acceptable quality good enough for consumers. In this context, supply voltage is needed to be in limits we desire. This is needed for healthy operation of loads, as well as suppliers. This is vital as the system is pushed to the maximum feasible limits. Hence, there is need for obtaining voltage close to the desired rated value. The control systems used for obtaining response quickly and accurately. Many controllers were developed for the above requirement of desired result and SVC, a first generation static controller provides quick control action with use of proper control. Many other techniques are used for obtaining the desired result. With the commencement of intelligent techniques for control in power systems, responses near about desired values are now being obtained.

Fuzzy logic, one among various members of the class of intelligent techniques used in power systems, has been tested for many controllers and has proved its value. For complex and non-linear problems like reactive power control and voltage stability problem, hence it is used mostly among other techniques. In this work a Fuzzy Logic Controller (FLC) was designed and its performance to a number of changes in power system was compared with conventional PI controller.

In the work, FLC for an SVC for voltage control has been designed and used. It is seen that FLC is better than PI control. In some cases where the PI control failed FLC was able to provide the required control. During the energization also the settling time by FLC is almost half that of PI control. Also, the performance was improved with the use of FLC, as burden and losses were reduced. On instances where there is requirement of stiff bus voltage, FLC provides responses which are close and around the desired one and also fast. So FLC has been observed to be much better than PI controller for voltage stability.

Acknowledgement

First and foremost, I express my sense of gratitude to my supervisor Prof. Narendra Kumar, Department, Electrical Engineering, Delhi Technological University for his guidance, supervision, support, motivation and encouragement throughout the period this work was carried out. His readiness for consultation at all times, his educative comments, his concern and assistance has been invaluable.

I wish to take this opportunity to express my gratitude to Prof. Madhusudan Singh, Head of the Department, Electrical Engineering for his constant encouragement during the conduct of the project work. I express my gratitude to all the faculty members of Electrical Department for their motivations from time to time.

I also thank all the non-teaching staff of the Electrical Engineering Department for their fullest cooperation. I would like to thank all those who have directly or indirectly helped me in completion of the thesis.

Finally I would like to thank my parents for supporting me through the journey, thanks will be too small a word to say for the things they did for me and my Brother and his wife for their love and care, they always took me as a child. Also I would like to thank my friends for being there, no matter what time it was they were always there for me.

Truly the journey of M.tech would not have reached its destination without these people I would like to individually thank *Divya, Rajat, Prateek, Rahul, Manu, Vandana, Neha*, for their love and care, truly I am blessed to have friends like you.

Last but not the least I would like to thank god for keeping me well and blessing me throughout the journey and for the future as well.

CONTENTS

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AI	Artificial Intelligence
ESCR	Effective Short Circuit Ratio
FACTS	Flexible AC Transmission Systems
FC	Fixed Capacitor
FLC	Fuzzy Logic Controller
MV	Membership Value
PI	Proportional Integral
TCR	Thyristor Controlled Reactor
TSC	Thyristor Switched Capacitor
T1,T2	Thyristors
SVC	Static VAR Compensator
J	$\sqrt{-1}$
P	Real power absorbed by load
Q	Reactive power absorbed by load
S	Apparent power absorbed by load
V	Voltage across load
V_{REF}	Reference Voltage
ΔV	Change in Voltage
ΔV_{SVC}	Change in Voltage across SVC
I	Current through source

I_{SVC}	Current through SVC
I_{LOAD}	Current through load
ΔI	Change in current through load
ΔI_{SVC}	Change in current through SVC
α	Firing angle
$\Delta\alpha$	Change in Firing angle
R_{TH}	Thevenin's Resistance
R_{LOAD}	Load Resistance
X_S	Synchronous Reactance
X_{LOAD}	Load Reactance
B_{SVC}	SVC Suspetance
B_{MIN}	Minimum Suseptance
B_{MAX}	Maximum Suseptance
K_{SL}	Current Droop of SVC
Z_{EQ}	Equivalent Impedance
K_N	System Gain
K_P	Proportional Gain
K_I	Integral Gain
T_D	Thyristor Dead Time
T_Y	Thyristor firing delay time
$G_Y(s)$	Thyristor Control System

error	Deviation of V from Vref
$error_{NEW}$	Error in present half cycle
$error_{OLD}$	Error in previous half cycle
U	Universe of Discourse
x	Element of a fuzzy set

Chapter 1

Introduction

From the first ever power system designed till now electrical engineers have solved many typical problems and one of them is to maintain a good Voltage profile. So the concept of Voltage Control and Reactive power control comes into picture. Voltage at the terminals of the equipment of the system is to be maintained within permissible limits and these limits are the one deciding the nature of voltage profile whether it is good or not. Also prolonged operation of the equipments at voltage outside these limits leads to adverse effects as the performance of the equipment is very much dependent on the voltage across that particular equipment. Reactive power has to be minimized to ensure reduction in losses to a practical minimum, for which the voltage at various buses in a power system are to be kept inside the limits. So the need for maintaining voltage profile at the load terminals is of equal priority to both consumer and distributor.

1.1 Scope and Objective of Study

Loads are the major contributor of voltage stability related issues so there is a need to control the voltage near the load centers. This goal can be achieved by supplying the required reactive power at the load centers. Earlier the use of capacitors at the necessary locations has been much used concept, but at lightly loaded conditions the voltage could not be maintained and voltage gave undesired values. Synchronous Condensers are also used for supplying variable amount of reactive power into the system. The overexcited synchronous machine used for the purpose of supplying the reactive power are heavy and slow in reacting to the demands so the controlling action is not quick enough. Static VAR Compensator (SVC) is a first generation static controller, which is capable of injecting variable amount of reactive power, by varying the shunt connected reactance. With the use of proper control technique SVC can be used in many applications.

For a quicker and precise response, good control strategy is required. In this respect there has been a continual effort being made by the engineers to obtain response identical to the desired one. In this process, numerous types of control techniques were formed and tested. Proportional –

Integral (PI) control is being highly used due to accuracy in achieving desired set point of result. The deviation of response from the desired point may be referred as error. The control action is achieved by bringing one signal which is some set gain times of error, added with another set gain times the integral of error. This sort of control leads to oscillations of reducing magnitude over the desired value and finally the response would oscillate with very little magnitude, which is well within the limits set.

Later, with the arrival of control techniques like those of artificial Intelligence (AI) techniques the time taken for maintaining the output response within the acceptable band was reduced by a great order. With them the response was obtained with better accuracy and time is also saved as the response time is less. Many a time where the use of PI controller has not paid much gain or has failed to produce the desired results there also AI techniques were able to make desired results possible. The objective in this study is to design a controller so as to maintain a healthy voltage profile and that too as quickly as possible and hence improve the system performance.

1.2 Choice of control Technique

Fuzzy Logic Control (FLC) is one of the AI techniques. Proposed by Zadeh, it is an extended form of multi level logic. In a short span, FLC has gained popularity that is immense, especially at places where systems were described in linguistic terms and had very poor mathematical models. Many physical systems lack a proper mathematical model and hence the application of FLC works around pretty well. Also FLC does nonlinear mapping of data vector to scalar, in the universe of discourse.

Over the past few years, FLC has been tested and used in power system application and it has proven its worth in all cases whether the problem may contain highly complex and non linear nature of mathematics. So due to all these reasons mentioned FLC has gained a name.

As fuzzy logic control was proposed and based on error in the response and change in error of the response, the control action is of corrective nature. This results in minimum amount of oscillations. This reduces the burden on system and improves the performance as well as life of equipment.

1.3 Organization of Report

This report is in nine chapters, where the first chapter is Introduction. Here the problem of Voltage Stability and control techniques being used are introduced. Also the choice of control technique is mentioned. Later it is followed by a brief literature survey, where some selected papers in this aspect were surveyed. Followed by it is a brief description of voltage stability problem. It starts with the generalized classification of voltage stability problems. Then discussion is made about the voltage stability problem in a simple load connected to infinite bus system. Also the effect of shunt connected capacitor on voltage stability is discussed. It is finally concluded with a brief discussion on effect of local voltage control on voltage stability of an interconnected power system.

In the fourth chapter SVC for voltage control is discussed with simple introduction to SVC and its steady state characteristics. The influence of SVC on system voltage is discussed. Later the design methodology of PI controller with simplistic design is discussed.

In the next chapter, brief discussion on FLC is done. It starts with a formal introduction to fuzzy logic and describes its few advantages and then discusses some terms much used in fuzzy logic and fuzzy control. It also depicts a simplified block diagram of a fuzzy control system.

In the next chapter, entitled Problem Formulation, the system under consideration is described and the various equations relating to the instantaneous values of voltage and current of the system are obtained. Also the gains for PI controller are calculated. The design of proposed FLC is explained in detail. The membership functions used, the rules of the rule base considered, operators of fuzzy functions along with fuzzifier and defuzzifier used are explained. Then the various disturbances that are being used are enlisted.

Followed in a chapter entitled results and discussions, where for the disturbances enlisted in the previous chapter, the variations in voltage across load are plotted. For some selected disturbances the variations are expanded for a better view. Also, for few disturbances the variations of current are also depicted. Finally with a brief summary of selected results is displayed. Then the conclusions made from the study and future scope of this study are discussed in brief.

Chapter 2

Review of Literature

P. Kundur, et al [2], various power system stability problems are identified and are classified. Definitions of various terms in voltage stability were mentioned and brief explanation was also done. The usage of term for transient voltage stability was regretted and relationship between rotor angle stability and voltage stability was discussed.

T.V. Cutsem, [4], describes about the behaviour of voltage across load starting from a simple load connected to infinite bus system to a complex interconnected system. The concept of nose curves for identifying maximum loading is explained. Also the power responses for various load types with voltage changes were described. The required perspectives in voltage stability analysis and design of controllers for voltage stability were discussed.

C.M. Arora, et al, [6] discusses about the maximum loading that can be done at a bus in an interconnected system. Also, improvement of load ability at a bus with injection of reactive power at that bus and hence improving voltage stability of the whole system was described. It has been re-established that voltage stability, though essentially a local phenomena, but can have global effects. Also, improvement of global voltage stability by improving voltage stability locally has been discussed.

N.G. Hingorani, [6] defines various terms related to Flexible AC transmission. It throws light on various applications of FACTS devices in power systems. It gives details of the first time application of particular FACTS devices with its location and purpose. It explains the need for tighter control of power flow in lines and increased transmission capacity with the use of thyristors controlled devices. It also states the need for cost effective controllers and the controller size for economic usage of FACTS devices.

T.L. Baldwin, et al, [7] portrays resistance welders as a source of voltage fluctuations and flicker. With their random nature of use and their low power factor leads to occurrences in sags. With the use of mini-static compensator, solution to this problem was proposed for improving voltage quality. Model of Thyristor Switched Capacitor (TSC) based SVC was obtained and simulated for their steady state and dynamic performance. This approach is of local aspect voltage quality across load and hence in system.

N. Mithulananthan, et, al, [8] models SVC as variable shunt connected reactance and STATCOM as variable current source. The various were made with help of controller so as to attain a desired performance of system. The effect of them on oscillations in power systems was compared. Application of shunt connected devices in voltage control and other application in dynamic prospective was dealt. Placement of FACTS device in power system was proposed by ranking the buses from weakest to the strong and FACTS device placed at weakest bus.

C.A. Canizares, et al [9] gives the numerically well behaved equations describing the steady state behaviour of SVC where the start is made from flat start or an initial guess made by user. The best starting point if firing angle α is proposed as 92°. If solution of those equation exists then the desired value is attainable with use of SVC else desired reference value is unattainable.

U. Eminglo, et al [11] simulates various types of dynamic load variations connected with the use of SVC for voltage control. This simulation was done for various types of loads, which were represented as exponential form and with empirical exponents. With SVC being connected at the same bus where load is connected, for a three bus system, load bus voltage was maintained at reference value with the use of PI controller.

A.M. Sharaf, et al [12] proposes an intelligent rule based control of SVC for voltage control. This artificial intelligent control was based on zonal action based on set of rules. The control is based on error which is defined as deviation of bus voltage from reference value. In comparison with conventional PI control, this intelligent method gave a superior performance, for the simulated case.

C.A. Canizares, et al [13], compares shunt connected FACTS devices with power system stabilizer for improving performance of Italian power system. The representation of complex interconnected system as a simple bus of fixed voltage and an impedance in series was proposed, for local area control. Also representation of SVC as a variable reactance was supported. Secondary voltage was maintained at the regulated value and improved transfer capability was calculated with use of shunt connected devices.

J.M. Mendel, [16] proposes idea of a tutorial where various applications of Fuzzy Login in many control problems could be discussed. The usage of linguistic terms in many applications is supported and design of fuzzy logic controllers based on these terms was described. Detailed theoretical comparison between probability and fuzzy logic has been done. Various operators in fuzzy logic and their usage with different types of membership functions were discussed.

R.C. Bansal, [17] gives a detailed list of applications of fuzzy logic in power systems. The merits and demerits of fuzzy logic applied to power system problems were discussed. Owing to the non-linear nature of reactive power control problem, fuzzy logic was proposed to be most effective for such problems. As it was observed that during the period 1994 to 2001, fuzzy logic was used the most for reactive power control, in comparison to other areas of power systems.

C.M. Arora, et al, [18] enlists various applications of intelligent techniques for various power system problems. It was expressed that for control applications, techniques capable of fast controlling action are need of the hour and intelligent techniques were among the best modes of control available. Artificial Neural Networks, Expert Systems and Fuzzy Logic are some intelligent techniques used for control much effectively over other intelligent techniques. Hybridization of techniques was proposed as future of intelligent techniques in power systems which are capable of bringing the operation of power system a step closer to ideal operation desired.

C.C. Lee, [19], [20] explains fuzzy control applied to many applications and guides is choosing membership functions for desired application. The composition of knowledge base of a fuzzy logic controller as data base was described. The implementation of various rules fired was explained with a graphical view. Also various chips designed for such purpose were mentioned.

B.K. Bose, [21] elucidates various applications of intelligent techniques in power electronic drives and power systems. Simple diagrammatic approach of fuzzy controller was proposed and applied to speed control problems. Identification of control variables for fuzzy logic control and developing rules for them was discussed by example. Also other artificial intelligent techniques for similar applications were proposed and compared.

C.Weindl, et al, [26] describes a state space model of SVC for a three phase system where the remaining power system was represented by its equivalent network. This model was tested on both symmetrical and unsymmetrical configurations of SVC were done. Both 6 pulse and 12 pulse operations were also discussed.

E.G. Nepomuceno, et al, [27], proposes a model for simulating SVC with the use of Power System Blockset, provided with MATLAB. The proposed model also represents the remaining power system by its equivalent and SVC connected at load bus for voltage control. The simulation was done with resistive load and response of SVC during energization of total system when connected to source was depicted.

D. Jovcic, et al, [28] gives an analytical model of SVC for dynamic purposes. The model proposed was developed in MATLAB and compared with models available in PSCAD/EMTP. Also the influence of PLL gain on SVC control was discussed for a system in which the SVC is connected at the same bus where load is connected.

A.Rahideh, et al, [29] proposes an intelligent fuzzy logic control to reduce losses in power systems by reactive power control. Max-min operator was improved to find a feasible solution for voltage control and min operator for reducing losses. The system was verified on IEEE 30 bus system and FARS electric system. The choice of membership functions for fuzzy control SVC was discussed for control of voltage.

K.L. Lo, et al [30] gives a systematic approach for developing a fuzzy PID controller where the PID controller gains were tuned with the use of fuzzy logic and a better performance was obtained over conventional PID control. The rules were generated based on desired PID response and simulated for a three phase fault in the system considered. Each time with error the PID gains were adjusted so as to obtain desired performance.

Voltage and reactive power control problems, are gaining comparatively more attention now a days. SVC, a first generation reactive power controller was observed as a very good controlling technique is used. Owing to highly non-linear nature of reactive power and voltage control problem, many linear control techniques used to solve this problem could not yield desired responses quickly. Fuzzy Logic, one among the class of Artificial Intelligence (AI) techniques, which does the function of non-linear mapping and has been observed as highly useful in solving such type of problems. In this intelligence of the operator is embedded into the controller in the form of membership functions and the rule which are fired from the responses.

From the reviewed literature, it has been observed that many a time, Fuzzy Control was used for SVC and mostly for solving some other problems, like that of rotor angle stability or reduction of losses or some other. Voltage control problem was seldom attempted by this control technique. So, the driving force for this work is to design and test of an Intelligent Controller based Fuzzy Logic or Fuzzy Control. The designed Intelligent Controller or Fuzzy Logic Controller is to control SVC, so as to attain the desired voltage response at the desired location, i.e. across load.

Chapter 3

Voltage Stability

Voltage stability is the systems' ability to maintain voltage such that, when the load is increased (that is P and Q) making both power and voltage controllable. Voltage instability is associated with relatively slow variations in network and load characteristics. A broad classification of voltage stability problems is shown in Figure 3.1

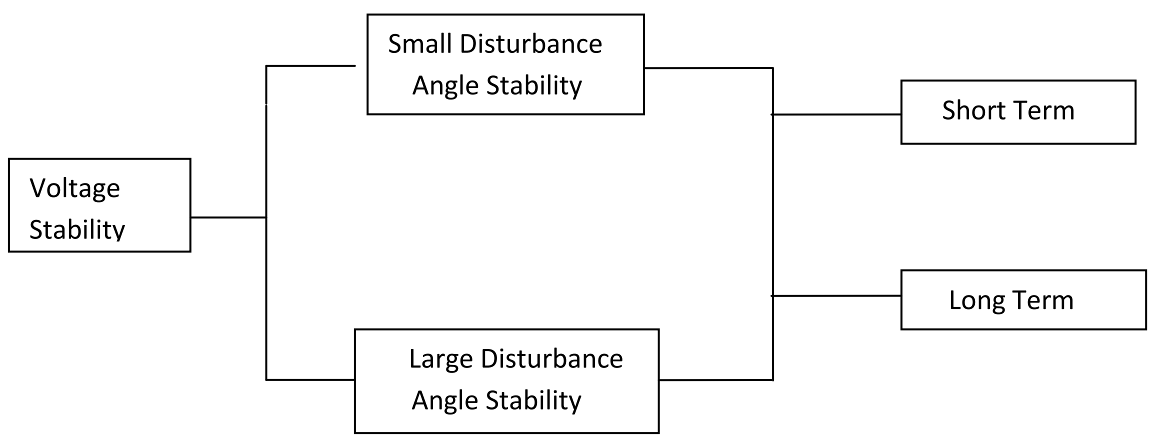


Figure 3-1 Broad Classification of Voltage Stability Problems

Large - Disturbance Voltage stability: Refers to the system ability to maintain voltage within limits following large disturbances like outages or loss of generation, etc. this ability is determined by the system load characteristics, and the interactions of both continuous and non continuous or discrete control and protections.

Small Disturbance voltage stability: Refers to the system ability to maintain the voltage within the permissible limits when a small disturbance like change in load occurs or there is some disturbance in the supply voltage. This form of stability is influenced by characteristics of loads continuous control and discrete controls at a given instant of time.

In the time frame of reference, Voltage stability can be classified as**:**

Short Term Voltage Stability: Involves dynamics of fast acting load components. The study period ranges for several seconds and solution requires appropriate system differential equations. This is similar to analysis done for rotor stability. Here contingencies close to load have greater importance and the term transient voltage stability is not to be used.

Long Term Voltage Stability: Involves slower acting equipment such as tap changing transformer, etc. This study period of interest may extend to several minutes and long term simulations are required for analysis of system dynamic performance.

Loads are the driving force of voltage instability, and for this reason this phenomenon has also been referred as load instability [1]. This limits the transfer capability of the transmission network for power transfer and voltage support. Voltage stability is threatened when a disturbance increases the reactive power demand beyond the sustainable capacity of the available reactive power resources. With the most common form of voltage instability is progressive drop of bus voltages; while the other form is over voltages due to capacitive behaviour of the network [2].

3.1 Single load infinite bus System

One of the primary reasons of power system instability is of transmission of large amounts of power (both active and reactive power) over large distances [3].For the system shown in Figure 3-2, load is connected to an infinite bus [4]. Infinite bus is considered to be at fixed voltage magnitude and fixed frequency under all operating conditions.

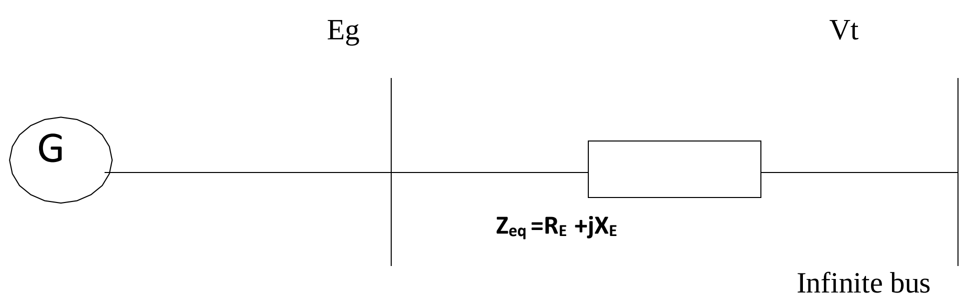


Figure 3-2 Load Connected to an infinite bus

If balanced, steady state operating conditions were assumed then the infinite bus may be represented by simple voltage source and load as constant impedance as shown in Figure 3-3.

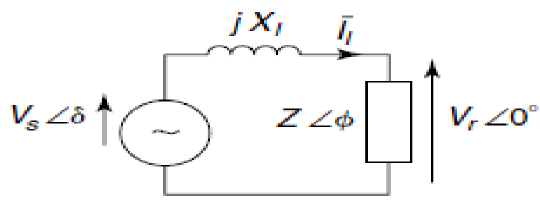


Figure 3-3 Circuit Representation of load connected through transmission line

The voltage magnitude in terms of active and reactive power demand is

$$V = ((E^2/2) - QX + ((E^4/4) - X^2P^2 - XE^2Q)^{1/2})^{1/2} \qquad (3.1)$$

The relation between voltage magnitude and loading (real or reactive) of the bus is highly non-linear. The variations of voltage magnitude with variations in real power demand are such that as power factor increases the voltage increases so it can be said that as the power factor decreases the voltage dips down as well.

For leading power factors at low loadings the voltage magnitude across load may be higher than receiving end owing to Ferranti effect. It may be observed that for increasing the load beyond a particular value leads to instability. This point which is the maximum loading limit is sometimes referred as nose point.

3.2 Voltage Control by Shunt Connected Capacitors

3.2.1 Load connected to infinite bus

For the system shown in Figure 3-2, voltage at load bus can be maintained at a better value by connecting some capacitance across the load then the circuit is as shown in Figure 3-4.

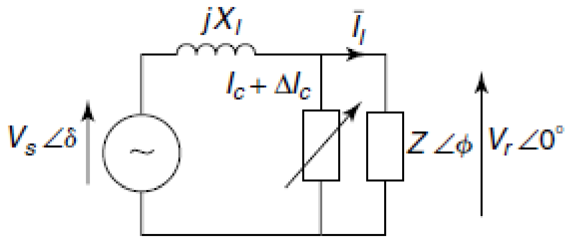


Figure 3-4 Circuit with shunt connected capacitor

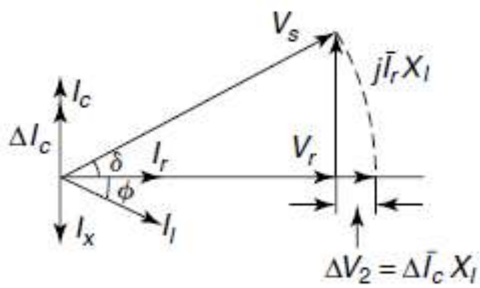


Figure 3-5 Phasor showing the adjustment in Voltage made by shunt compensation

The Phasor showing the adjustment in Voltage made by shunt compensation. At very light loads, owing to the connected shunt capacitances which generate more reactive power than required. This may result in over voltages and hence many undesired changes happenings in the system. So there is a need for variable reactance to be connected across load, so as to maintain the load voltage within desired band.

Switchable capacitors, over excited synchronous machines or many of the emerging FACTS devices may be used for achieving the variable reactive power injection at load.

For a large interconnected system, with injection of reactive power at some selected area not only improves its load carrying ability, voltage stability also. This improvement done to improve local performance, will also improve voltage stability in the whole system [5].

Chapter 4

Voltage Control Using SVC

Static Var Compensator (SVC) is a solid state controller that regulates reactive (VA) power along a power system line i.e. transmission line by switching various combinations of capacitors and inductors in parallel with the line. SVC is a first generation FACTS device, and is used mainly for shunt compensation [6].

SVC is characterized by fast response, high reliability, low cost of operation, and flexibility. With conventional controls the response time is in the range of few cycles, which makes SVC ideally suited for applications requiring fast control of reactive power [7].

SVC is basically a shunt connected static VAR generator/load whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power system variables; typically, the controlled variable is the SVC bus voltage. One of the major reasons for installing a SVC is to improve dynamic voltage control and thus increase system loadability [8].

The two most popular configuration of this type of shunt controller are the fixed capacitor (FC) with a thyristor controlled reactor (TCR), and the thyristor switched capacitor (TSC) with TCR. Of these two setups, the second (TSC-TCR) minimizes stand by losses; however from a steady state point of view this is equivalent to a FC-TCR. The TCR consists of a fixed (usually air core) reactor of inductance L and a bidirectional thyristor valve. The thyristor valves are fired symmetrically in an angle α control range of 90° to 180°, with respect to the capacitor (inductor) voltage. The valves automatically turn OFF at approximately the zero crossings of the ac current [9].

4.1 Static VAR Compensator for Voltage Control

The SVC is basically a shunt connected Static VAR generator/load whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power system variables. In most cases the controlled variable is Voltage [10],[11]. Reactive power changes produced by load variations and line switching can cause adverse effects on system voltage stability and the interconnected system security.[12]

An SVC can be considered as a variable susceptance controlled by the firing angle α of the thyristor controlled reactor of the SVC. Therefore the control limits for this case are represented in form of firing angle α; but it is given that there is one to one correspondence between this firing angle and the corresponding equivalent susceptance value, it can be assumed that these limits directly corresponds to limits on this susceptance which is trivial in most power system analysis tools [13].

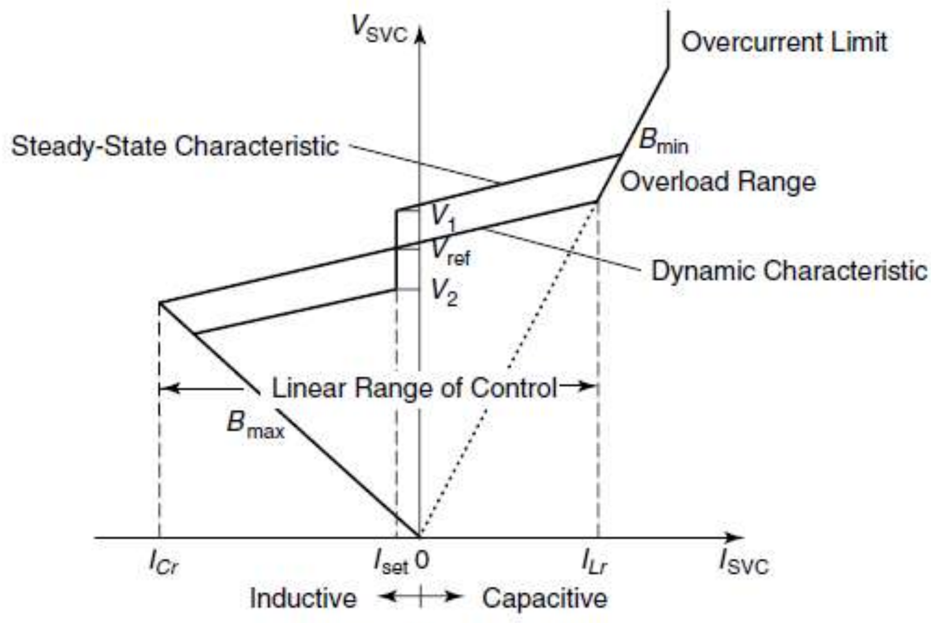


Figure 4-1 Steady State Characteristics of SVC

V_{REF} is the voltage at terminals of SVC during floating condition i.e. when SVC is neither absorbing nor generating reactive power. 'Linear range of control' is the range over which SVC terminal voltage varies linearly with the SVC current.

''Slope or Current Droop'' of VI characteristics is defined as Ratio of magnitude of the **change in voltage** to magnitude of the **change in current**, over linear control range of the compensator

$$K_{SL} = \Delta V / \Delta I \qquad (4.1)$$

Where the ΔV is the change in magnitude of the voltage

ΔI is the change in magnitude of the current

Slope is often defined as reactance $X_S = K_{SL}$ and which is typically 3 to 5 % [14].

For analysis purpose, let the system be represented as shown in Figure 4.2 Simplified Diagram of system and SVC connected. With the system equivalent impedence, Z_{EQ} and equivalent voltage source, V_S corresponding Short Circuit MVA at the SVC bus, and it is obtained as

$$S_C = V_{BUS}^2 / Z_{EQ} \tag{4.2}$$

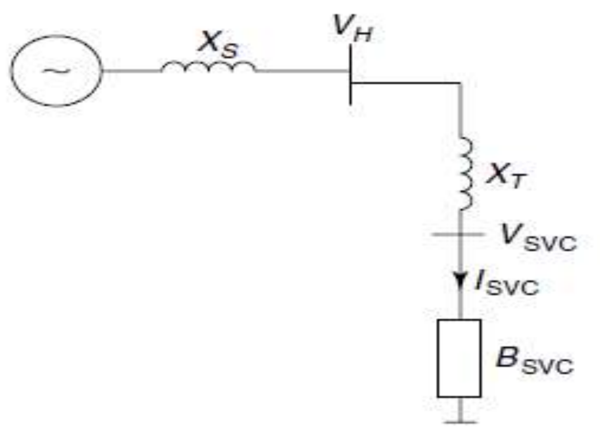


Figure 4-2 Simplified Diagram of power system with SVC connected

If reactive current drawn by SVC is I_{SVC} then in the absence of voltage regulator bus voltage, V_{BUS} is given by

$$V_S = V_{BUS} + I_{SVC} * Z_{EQ} \tag{4.3}$$

As SVC current results in voltage drop of $I_{SVC}Z_{EQ}$ in phase with system voltage with inductive SVC currents and rise with capacitive current.

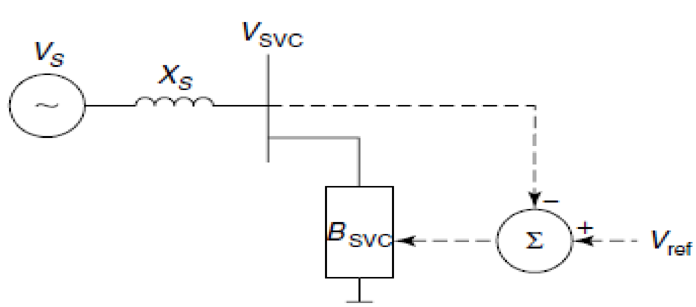


Figure 4-3 Simplified Diagram of power system with SVC control system

The susceptance of SVC and hence the current drawn by SVC can be varied with proper control so as to maintain the desired voltage at the bus SVC is connected. Linearizing the variations of voltage magnitude, V_{BUS} as a function of SVC current magnitude, I_{SVC}, for constant magnitude of equivalent source voltage Vs are obtained as:

$$\Delta V_{SVC} = - Z_S * \Delta I_{SVC} \quad (4.4)$$

The SVC current is related to V_{BUS} through SVC susceptance, Bsvc as

$$I_{SVC} = B_{SVC} * V_{SVC} \quad (4.5)$$

For incremental changes, in (4.4) equation may be linearized to give

$$\Delta I_{SVC} = B_{SVC0}\, \Delta V_{SVC} + \Delta B_{SVC0}\, V_{SVC} \quad (4.6)$$

Where B_{SVC0} is susceptance and V_{SVC0} is voltage magnitudes of SVC at the operating point under consideration.

Substituting ΔI_{SVC} from (4.6) in (4.4)

Where the effective short circuit ratio is defined as

$$ESCR = 1/(\Delta V_{SVC} / \Delta I_{SVC}) = Y_S \quad (4.7)$$

Where Y_S is equivalent system admittance.

The effect of SVC on system voltage can be evaluated using,

$$V_{SVC} = V_S / (1 + B_{SVC} / ESCR) \quad (4.8)$$

For ac systems, generally ESCR >> BSVC and hence above equation becomes

$$V_{SVC} = V_S (1 - B_{SVC} / ESCR) \quad (4.9)$$

The change in SVC bus voltage ΔV is given by

$$\Delta V = V_S - V_{SVC} \quad (4.10)$$

Or

$$\Delta V = K_N * B_{SVC} \qquad (4.11)$$

Where K_N is defined as ‘’system gain’’

System gain relates variation of SVC bus voltage to SVC susceptance. An increase in inductive susceptance, B_{SVC} causes ΔV to become more positive, there by leading to drop in SVC bus voltage.

4.2 Design of Voltage Regulator Based on System Gain

Here the PI controller is a voltage controller which is based on simplistic design method.

This method consist of several assumptions that include

1) The voltage change caused by SVC is small.

2) SVC bus voltage is very close to nominal rate voltage, generally $V_{SVC} \approx 1.0$ p u.

3) Variations in SVC reference voltage are quite small.

4) The inductive current is the only variable considered, which reduces system bus voltage ΔV

The thyristor phase control is denoted by G_Y, is given by

$$G_Y(s) = e^{-sT} / (1+sT_Y) \quad (4.12)$$

Where T is thyristor dead time(approx. = one twelfth cycle time)

T_Y is the thyristor firing delay time caused by sequential switching of thyristors

(approx. = one quarter cycle time)

A PI controller gives the fastest stable response for the weakest system configuration having gain K_{NMAX} is determined by

$$G_R(s) = K_P \{1+(1/s\ T_Y)\} = \{(-1)/(2(K_{SL}+K_{NMAX}))\} * \{1+(1/s\ T_Y)\} \quad (4.13)$$

Comparing (4.13) with the general form of a PI controller

$$G(s) = Kp + Ki/s \quad (4.14)$$

The constants K_P and K_I may be obtained as

$$K_P = -1/(2(K_{SL} + K_{NMAX})) \quad (4.15)$$

$$K_I = K_P / T_Y \quad (4.16)$$

Chapter 5

Fuzzy logic and Fuzzy control

The answer to every statement doesn't always lie in TRUE or FALSE, but rather consist of multilevel answers, therefore a new logic called the *Fuzzy logic* was proposed in which any particular statement can take up any value of the truth.

Fuzzy control is based on this Fuzzy logic and is closer to human thoughts as compared to other traditional logics by which the inexact and imperfect nature of the natural real world can be captured. FL nonlinearly maps the vector data which has been given to it into scalar output. Here with FL an enormous number of mappings can be done through enormous possibilities.

Generally the physical processes are non-linear processes and if they have to be modeled then approximations are the only way out. Though for simple systems mathematical expressions are enough to give description of behavior of the system. But then for the complicated systems mathematical data is not much, rather fuzzy logic give a route to understand the behavioral mode of the system. The key to fuzzy logics is that it makes use of the linguistic variables to represent the imperfect and imprecise data rather than the mathematical variables.

In conclusion Fuzzy logic control or Fuzzy control system is a rule based system in which a set of rules manage a control decision to adjust the causes coming from the system, overall it is a Fuzzy logic controller which consist of the linguistic controls and then this FLC provides algorithm which is capable of converting the this linguistic control strategy to automatic control strategy due to the expertise of this system.

A few advantage of FL over Conventional control [17], [18] :

1) Easy to understand
2) Resolves conflicting objectives by designing weights appropriate to the selected objectives
3) Tolerant to not so precise kind of values and provides with capability of managing ambiguity expressed in diagnostic processes.

5.1 Fuzzy Control

Formation of a knowledge-base, having IF-THEN rules, is the preliminary idea of a fuzzy system. These IF-THEN based rules are obtained from human experts depending upon their domain of knowledge and observations made. Merging these rules into a single system helps in obtaining an output that can achieve assigned goal [19], [20].

In Fig. 5.1 a simple fuzzy logic control system is shown, in which plant's output has to be controlled. Plant's output is compared with a reference value to calculate the error and change in error. Error and their change, if needed by converting them from digital to analog values, to fuzzifier for fuzzification and then these fuzzified values are further given to Inference Engine, with which support of Rule-Base and Data-Base, fuzzy output is calculated. This output is further defuzzified to produce a crisp output that can be used to control the plant to bring the desired change in error [21], [22].

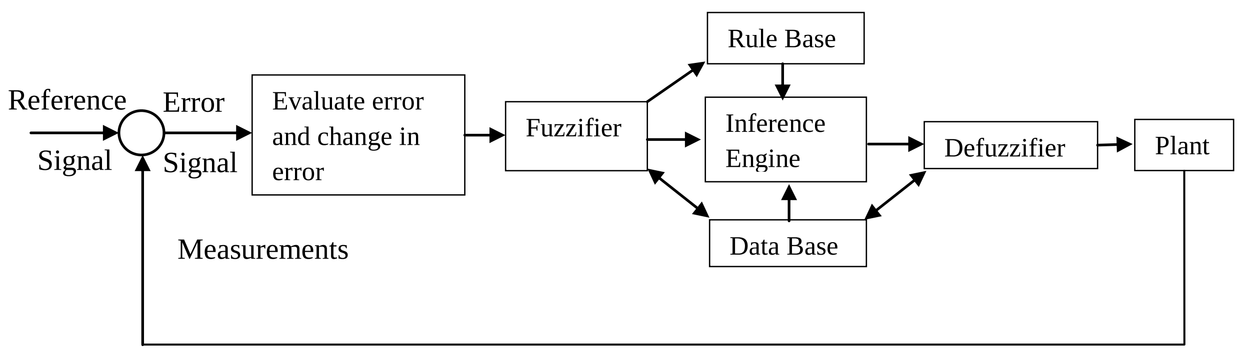


Fig. 5-1 Simple Fuzzy Logic Controller

5.2 Fuzzy Systems

Key point of difference between the classical sets and the fuzzy sets is that in former the transition for an element in the universe between non-membership and membership function for a given set is rapid and well defined that element either belongs to set or not [23]. In disparity, elements in fuzzy sets, membership function can be gradual one. Also allow boundaries for fuzzy sets to be ambiguous and elusive [24].

5.2.1 Membership Function

A fuzzy set is basically characterized by a membership function. Its value ranges from 0 to 1 and consists of members with different degree of membership depending upon the values.

Mathematical expression, showing fuzzy set A in the universe U as a set of ordered pairs of an element X and its membership function, is

$$A = \{(x, \mu A(x)) \mid x \in U\}$$

where U is continuous.

Thus membership function is a continuous function having value in the range of [0, 1]. Commonly, it is decided by human expertise and observation made. Also it can be either linear or non-linear. Thus its choice is critical for performance of fuzzy logic system as it can be used to determine the information contained in the fuzzy set.

5.2.2 Fuzzifier

Fuzzifier do the mapping of real valued point, $x \in U$, to a corresponding fuzzy set A which belongs to U. Certain criteria is needed to justify the fuzzifier use:

1) Input is a crisp point x, so that mapping in U is a fuzzy set A which has a large membership value.
2) It must suppress the noise inherent in real valued inputs.
3) It must be able to simplify the computations in the Inference Engine.

Thus, fuzzifier maps continuous crisp signal of a fuzzy value corresponding to fuzzy membership function.

5.2.3 Defuzzifier

As name implies, defuzzifier has the task opposite to that of fuzzifier. It maps the fuzzy output set, B which belongs to V, from the fuzzy inference engine to a real valued point or a crisp point, $y \in V$. it can also be elaborated as that it provides real points that best describes fuzzy set B. naturally there must be many choices for choosing a real point but certain criterion has to be considered to get a most suitable point. These criterions are:

1) Point y should exhibit a high membership in B i.e. it should represent B from an intuitive point of view.
2) Defuzzifier should have computational simplicity as mostly used in real time.
3) Defuzzifier must have continuity.

5.2.4 Fuzzy Rule-Base:

Fuzzy logic has the subjects or verbs like fuzzy sets and fuzzy operators. The if-then rule statements are used to convey conditional statements that comprised of fuzzy logic. A single fuzzy if-then rule assumes the form

If x is A then y is B

Where A and B are the linguistic values defined by the fuzzy sets on the ranges (universes of the discourse) X and Y, respectively. The if-part of the rule “x is A” is called the antecedent or premise, while the then-part of the rule “y is B” is called the consequent or conclusion. Examples of the linguistic variables may be of any sort, like high, low, fast, slow, warm, cold, etc.

1) Inferring an if-then rule involves distinct parts: Evaluating the antecedent (which involves fuzzifying the input and applying any necessary fuzzy operators)
2) Applying that result to the consequent (known as implication).

If the antecedent is true to some degree of membership, then the consequent is also true to that same degree. If the antecedent has more than one part, then all the parts of antecedent are calculated simultaneously and resolved to a single number using fuzzy operator.

5.2.5 Fuzzy Operators

Fuzzy logic is a superset of Boolean logic and Boolean Logic operators can be obtained by conveying membership function to the Extremis of 1 (completely true) or 0 (completely false) [25].

Couple of such operators are *min ( )*, minimum operator and *max ( )*, maximum operator. The *min ( )* operator results as same as AND operator and max *( )* as OR operator. NOT or complementary operation can be obtained by 1-A, where A is the respective membership function. Table 5.1 represents the use of AND and OR operator for multi-valued logic.

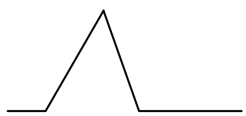
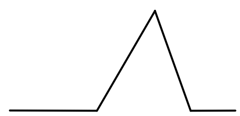
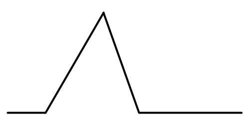
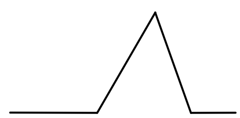
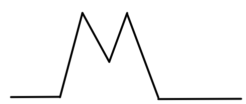
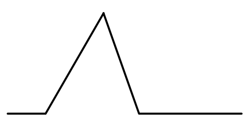
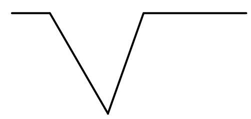
Operator	A	B	Resultant
min()	0	0	0
	0	1	0
	1	0	0
	1	1	1
max()	0	0	0
	0	1	1
	1	0	1
	1	1	1
1-A	0	-	1
	1	-	0
AND			
OR			
NOT			

Table 5-1 Fuzzy operators

5.2.6 Inference Engine

Inference is the process of formulating the mapping from a given input to an desired output using fuzzy logic. This mapping then provides a base depending upon which decisions are mad, or pattern discerned. Inference from a set of fuzzy rules includes fuzzification of condition of the rules (which is done by fuzzifier) and then propagating the membership function, also known as confidence factors, of the conditions to the conclusion of rules. Considering the following rule:

IF <antecedent>THEN<precedent>

Inference for above rule comprises of looking up the membership value (MV) of the condition/s in antecedent and hence calculates precedent. An improvement of this involves having a weight for each rule between 0 and 1 which multiplies MV assigned to the outcome.

A fuzzy rule base has a number of rules with outcome in accord with antecedent will be fired. Thus Inference Engine will allot outcome depending upon precedence, and further MVs from all fired rules.

Thus on summarizing the facts, Inference involves:

1) Defuzzification of each conditions of each rules and their outcomes.
2) Assigning each outcome a MV from its fired rules
3) It results in confidence factors for each outcome in rule base.

Chapter 6

Problem Formulation

6.1 System under consideration

The system under consideration comprises of a programmable voltage source, transmission line impedance, load, a transformer, Static var compensator. The figure 6.1 below is of the system simulated in MATLAB. The Static VAR Compensator is made of a TCR and TSC unit with the TCR varying with the change in alpha and absorbing the reactive power that is lagging reactive power as per the requirement and the TSC is divided in three parts supplying the lagging reactive power in stages. As the TSC is either working or not working it is not varying with the firing angle, it only checks the system suseptance requirement and on the basis of that makes the picture clear as to how many TSC should be ON out of the three in our service so as to make the voltage stable.

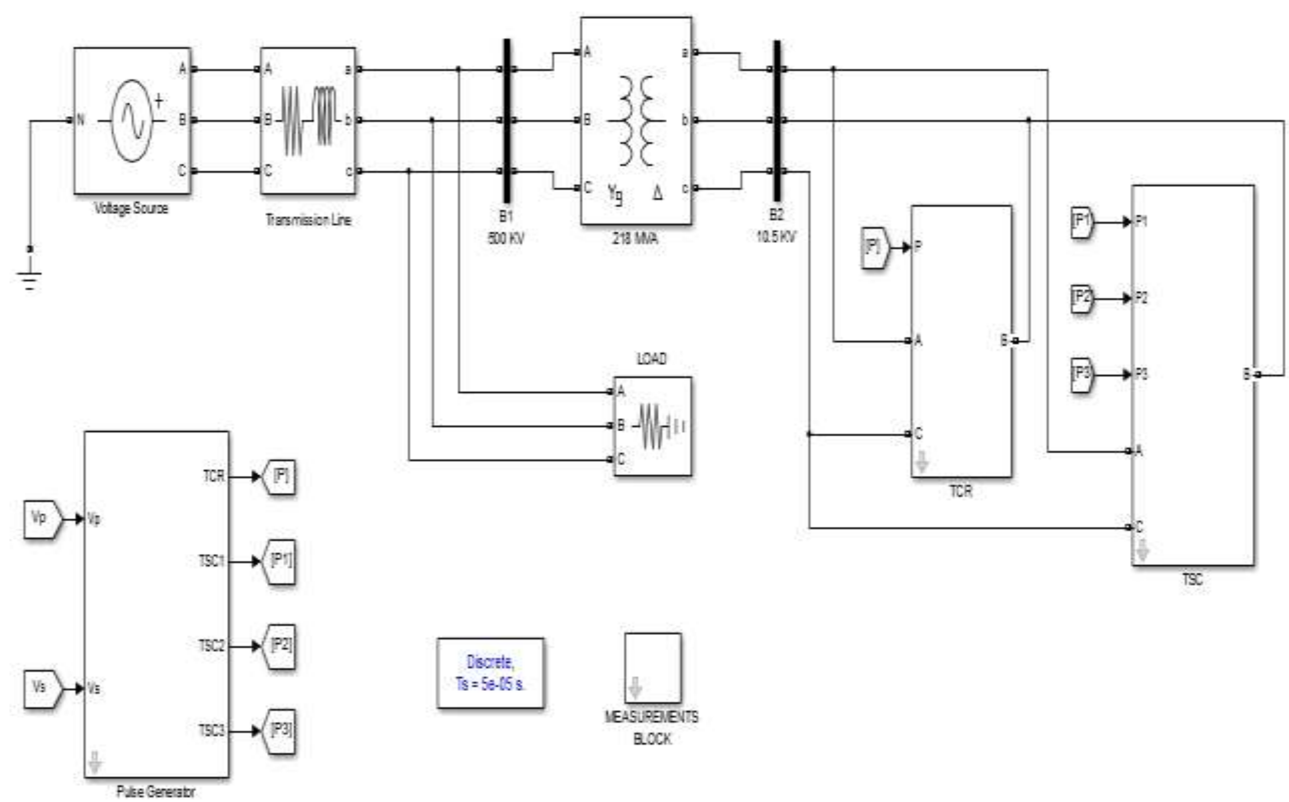


Figure 6-1 Shows the system taken in MATLAB for simulation the SVC is a combination of TCR and TSC taken together

6.1.1 Static VAR Compensator (SVC) Model

The SVC under consideration is having TSC and TCR shown in figure 6.1. The thyristor firing control system gets various signals measured from the system and generates corresponding thyristor firing signals. The simplified diagram of SVC control system is as shown in figure 6.2.

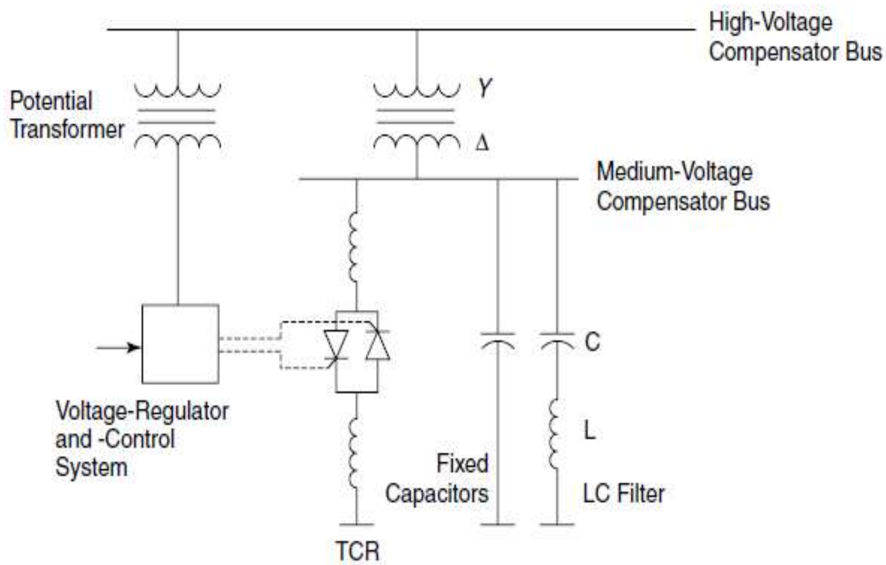


Figure 6-2 Simplified SVC diagram showing a FC-TCR with filters

The thyristor firing control system gets various signals measured from the system and generates corresponding thyristor firing signals. The simplified block diagram of SVC is as shown in Figure 6.3. The figure shows that the control circuitry is related to the error and thus depending on the error at that particular moment we get the value of firing angle and thus the reactive power estimated to bring the voltage back within limits is attained.

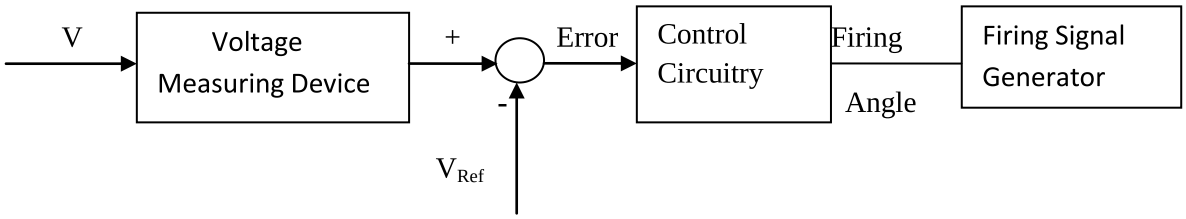


Figure 6-3 Simple Block Diagram of Firing Signal Control System

Two types of control methodologies namely a conventional PI controller and Fuzzy Rule based controller have been modeled and simulated. The conventional PI Controller block diagram is as shown in Figure 6-4

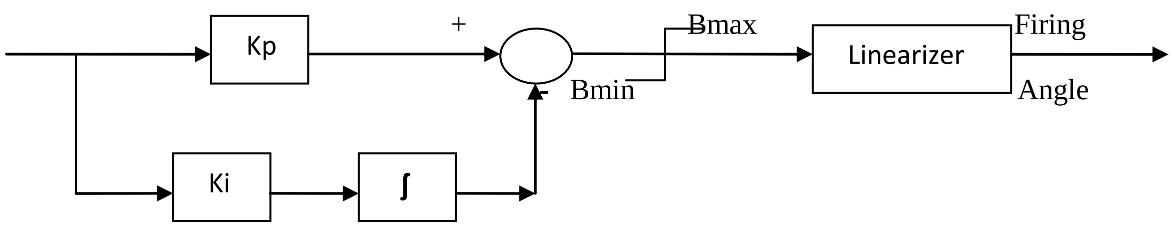


Figure 6-4 Simple Block Diagram of Conventional PI controller

The fuzzy rule based controller is as shown in Figure below. This is just the basic block diagram of FLC.

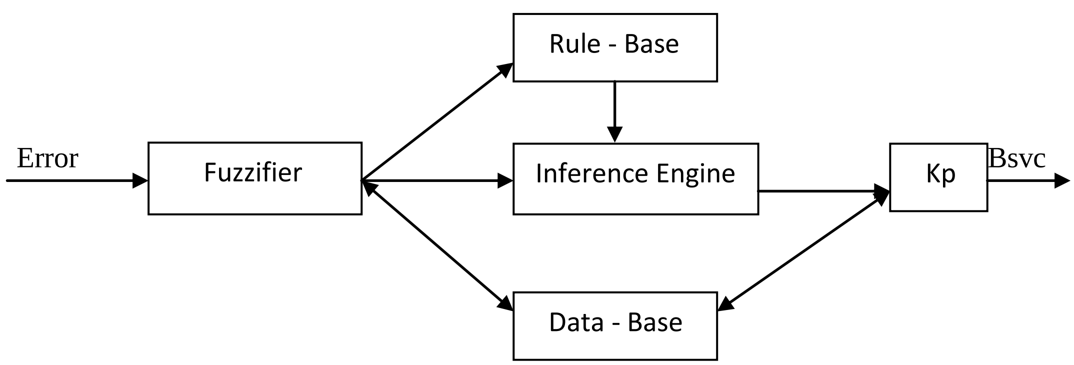


Figure 6-5 Simple Fuzzy Control System

Here the error is given in the fuzzy controller and then the output with value of suseptance (B) comes out. From the B value, alpha is calculated with the help of look up table.

$$B_{TCR} = (2(\pi - \alpha) + \sin 2\alpha) / \pi X_L \quad (6.1)$$

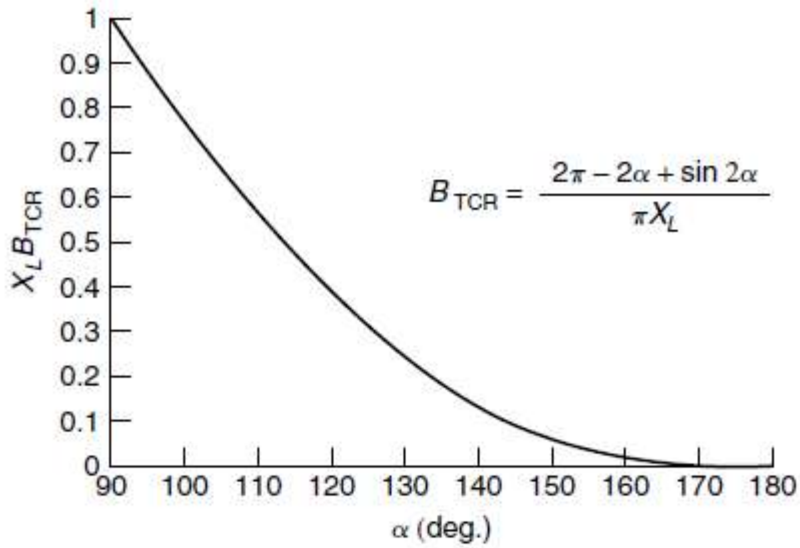


Figure 6-6 Relation of B (Suseptance) v/s α (Firing Angle)

6.1.2 System Values in the Problem

The system under consideration is a 500 KV three phase system, 300 km line supplying the load. The SVC is connected to the system through a step down transformer with secondary voltage of 10.5 KV and the transformer is having 218 MVA rating. On secondary end of the transformer the SVC is connected which is a combination of TCR and TSC.

The TCR is connected in delta configuration with each phase having a reactor which consumes lagging VAR of around 34 MVAR so in total all three phase the total VAR consumed by reactor is 102 MVAR. The value of reactive power absorbed changes with firing angle of the pulse signal. The pulse signal are given to the gate of thyristors connected in antiparallel fashion to each reactor.

The TSC is supplying lagging VAR of around 270 MVAR, but it is divided into three parts. As the capacitor supply of lagging var is not changing with alpha but it is either in circuit or out of circuit. So we have made three parts of 90 MVAR each and depending on the error in voltage the suseptance value is calculated by the control stratergy and then depending on the suseptance value we are able to decide that out of three how many TSC should be in the circuit. The TSC are also connected in delta.

We would be considering two types of changes:

a) *Change in Source Voltage*: When there is change in the supply voltage due to some variations caused by generators then the voltage supplied by them changes. So taking that into consideration we would look into how the system would behave without SVC, with SVC using PI controller and with SVC using Fuzzy controller.

b) *Change in Load*: The load changes frequently in a system so we would like to picture the situation when there is change in load and the impact of load change on the system when no SVC is connected, when SVC with PI controller and when SVC with Fuzzy controller and which gives a better and quicker response in stabilizing the voltage.

The values taken in calculation and graphs also are measured in per unit system.

Base MVA = 100 MVA

Base Voltage = 500 KV (For LV side of transformer it is 16 KV)

Base Current = 115.47 A

Base Impedance = 4330.13 Ohms

Based on these values the calculations are obtained in pu.

The value of TCR reactor and resistance used in series are 8.049 mH and 60.68mΩ respectively.

Similarly the value for TSC capacitance and resistance which are in series are 672.097 µF and 2.5921 mΩ respectively.

The voltage source is also a programmable voltage source which can give the voltage supply in pu system and we can make it to have different values at different times. Basically the main part that we would be focusing on is the controller of SVC and we would be looking into the model to take a closer look as to how the values suseptance varies as the error signal is produced after subtracting the voltage obtained at terminals of the load and reference voltage that we want at the terminals. That suseptance is used to calculate the value of firing angle and thus that firing angle would make the reactor values to change and hence changing the amount of reactive power needed and thus making the voltage to within the prescribed value.

6.2 Design of PI Controller

Design of PI controller is based on the method of system gain as described in section 4.2. the equivalent impedance seen by the capacitor is

$Z_{EPQ} = (Z_{EQ} \parallel Z_{LOAD}) = ((R_{TH} \parallel j\ X_{TH}) \parallel (R_{LOAD} + j\ X_{LOAD})) = (0.00290 + j\ 0.0203)$ pu

Capacitive reactance of TSC in SVC is $X_C = Q_C$ / Base MVA = 250 / 100 = 2.5

System Gain $K_N = (Z_{EQC} \parallel X_C)* Vo = 0.021$

As K_N corresponds to weakest state in system, $K_{NMAX} = K_N = 0.021$, $K_{SL} = 0.01$

The proportional gain of controller, from (4.15)

$$K_P = (1)/(2*(K_{SL} + K_{NMAX})) = 16.13$$

Similarly, ($T_Y = 0.09$)

$$K_I = K_P / T_Y = 222.6$$

The value of $B_{MAX} = 3.23$ where firing angle $\alpha = \pi$ radians and of $B_{MIN} = 0$, where $\alpha = \pi/2$ radians.

6.3 Fuzzy Logic Controller

6.3.1 Inputs and Outputs of Fuzzy Logic Controller

As shown in Figure 6-5 the input to controller is error or deviation of voltage across load from reference value [29], [30].

$$error = V_{RRMS} - V_{REF} \tag{6.2}$$

Output of the controller is B_{SVC} and with this output, firing angle is calculated by Look up table.

The range of error is taken as

$$\text{error} = [-0.4, 0.4]$$

And the range of output variable

$$B_{SVC} = [-1, 3]$$

6.3.2 Choice of Membership Function to Fuzzy Variables

The linguistic values of for the variable ‘error’ considered are having 21 membership functions i.e. MF1, MF2, MF3 up till MF 21. They have values varying from -0.4 to + 0.4.

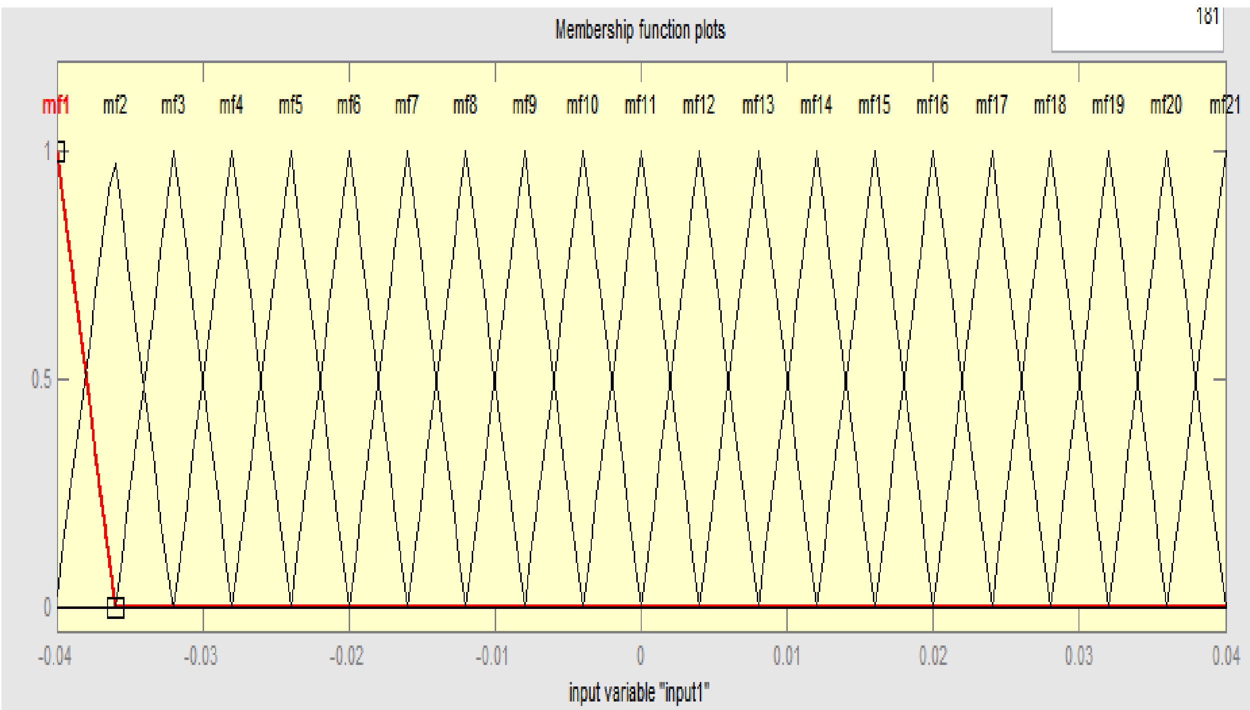


Figure 6-7 Membership Function of fuzzy variable ‘error’

The linguistic output variable ‘B_{SVC}’ varies from -1.04 to 3.23 with 21 Membership fuction from MF1 to MF21.

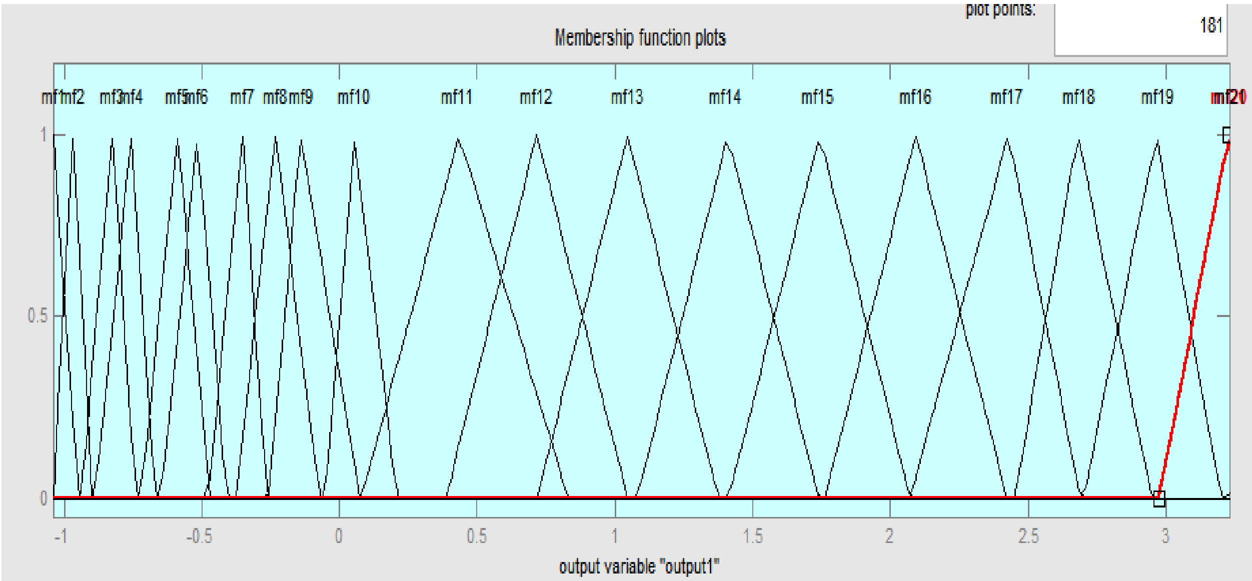


Figure 6-8 Membership function of output variable B_{SVC}

6.3.3 Rules for Fuzzy Control

The rules for the fuzzy control system are based on simple terms of linguistic values of fuzzy membership functions. For example, when the deviation of voltage magnitude of a bus from desired value is negative medium for example -0.03, i.e. for a reference value of 1 pu, nnow voltage magnitude is on the higher side, which is 1.03. Now the reactive power must be absorbed from the system, to bring down the voltage. If this has been from a zero error in previous state, then error is tending to rise and reasonable good reactive power is to be absorbed from the system. Then the B value is adjusted so as to make alpha reduce which in turn makes the reactive power adjusted in a way that it absorbs reactive power. That means change in firing angle should be reduced by reasonable value. In this way all the rules have been constructed and the graph is shown in figure 6.9 and the rules are shown in figure 6.10.

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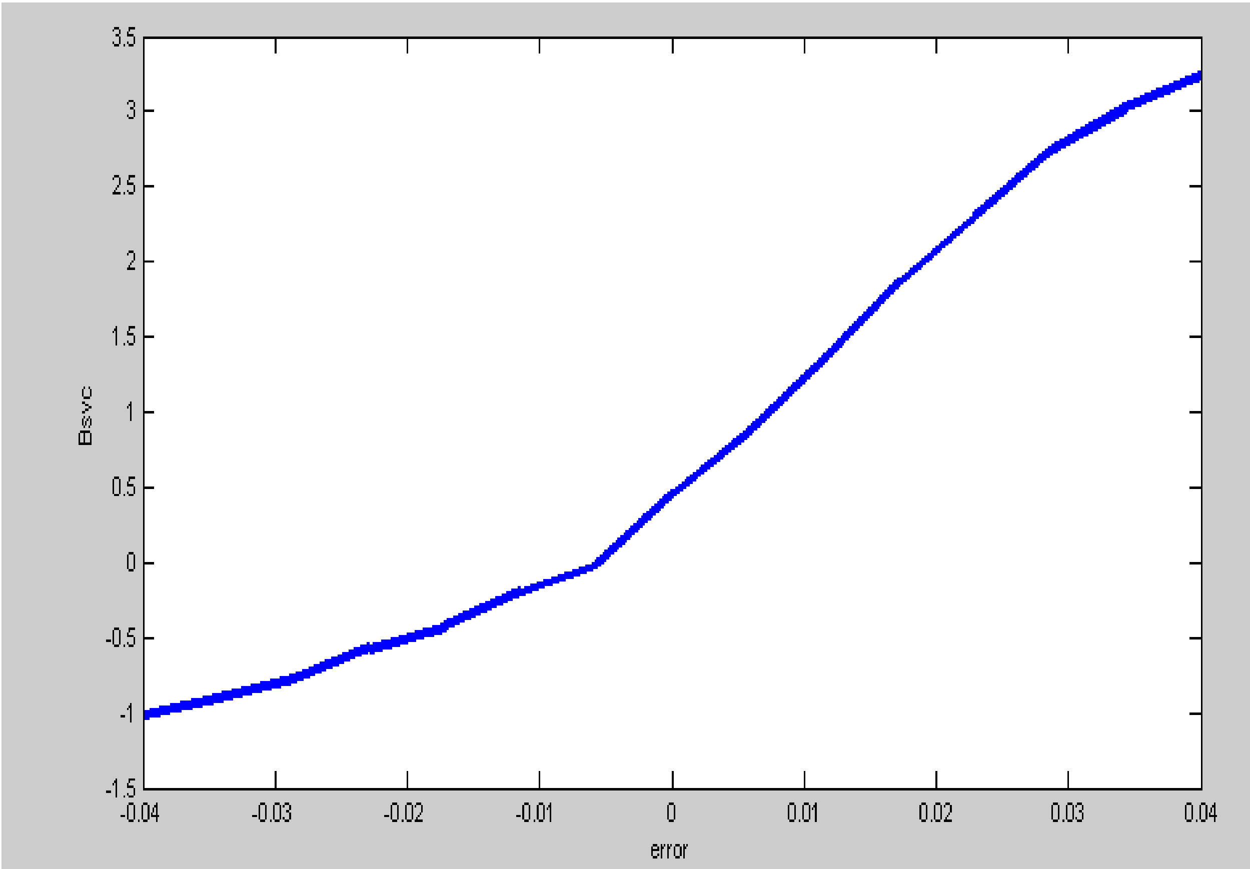

Figure 6-9 Rules surface for fuzzy control system under consideration

The deviation of voltage magnitude i.e. 'error' is fuzzified using triangular fuzzification and the defuzzification method used is Centroid method.

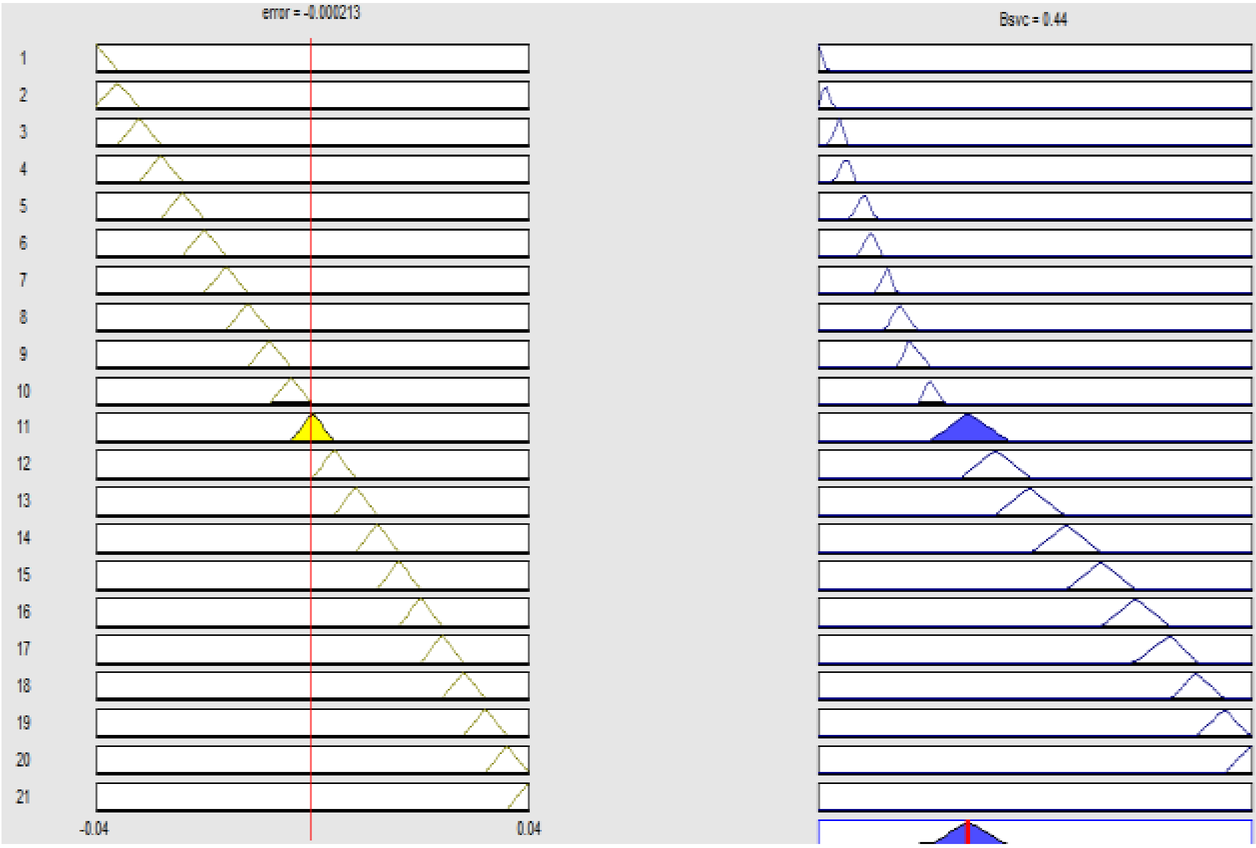

Figure 6-10 Rules for the Fuzzy Controller

6.4 Variations Considered

For observing the performance of system with the fuzzy controller the following variations have been considered and its performance over the conventional PI controller has been observed. The variations are as follows:

Constant Impedance Model

1. Variation in equivalent voltage source

1.1 Step variations

1.1.1 Small step up (4%)

1.1.2 Small step down (4%)

1.1.3 Large step up (30%)

1.1.4 Large step down (30%)

1.2 Small Duration Variation

1.2.1 Swell in Voltage for few seconds

1.2.2 Sag in Voltage for few seconds

1.2.3 Multiple occurrences of sag and swells

2. Variations in Load

2.1 Step Variations

2.1.1 Small step up (5%)

2.1.2 Small step down (5%)

2.1.3 Large step up (50%)

2.1.4 Large step down (50%)

2.2 Sudden Removal of load

Chapter 7

Results and Discussions

7.1 Constant Impedance Load

7.1.1 Variations in Equivalent Source Voltage

7.1.1.1 Small Rise in Voltage Source due to disturbance

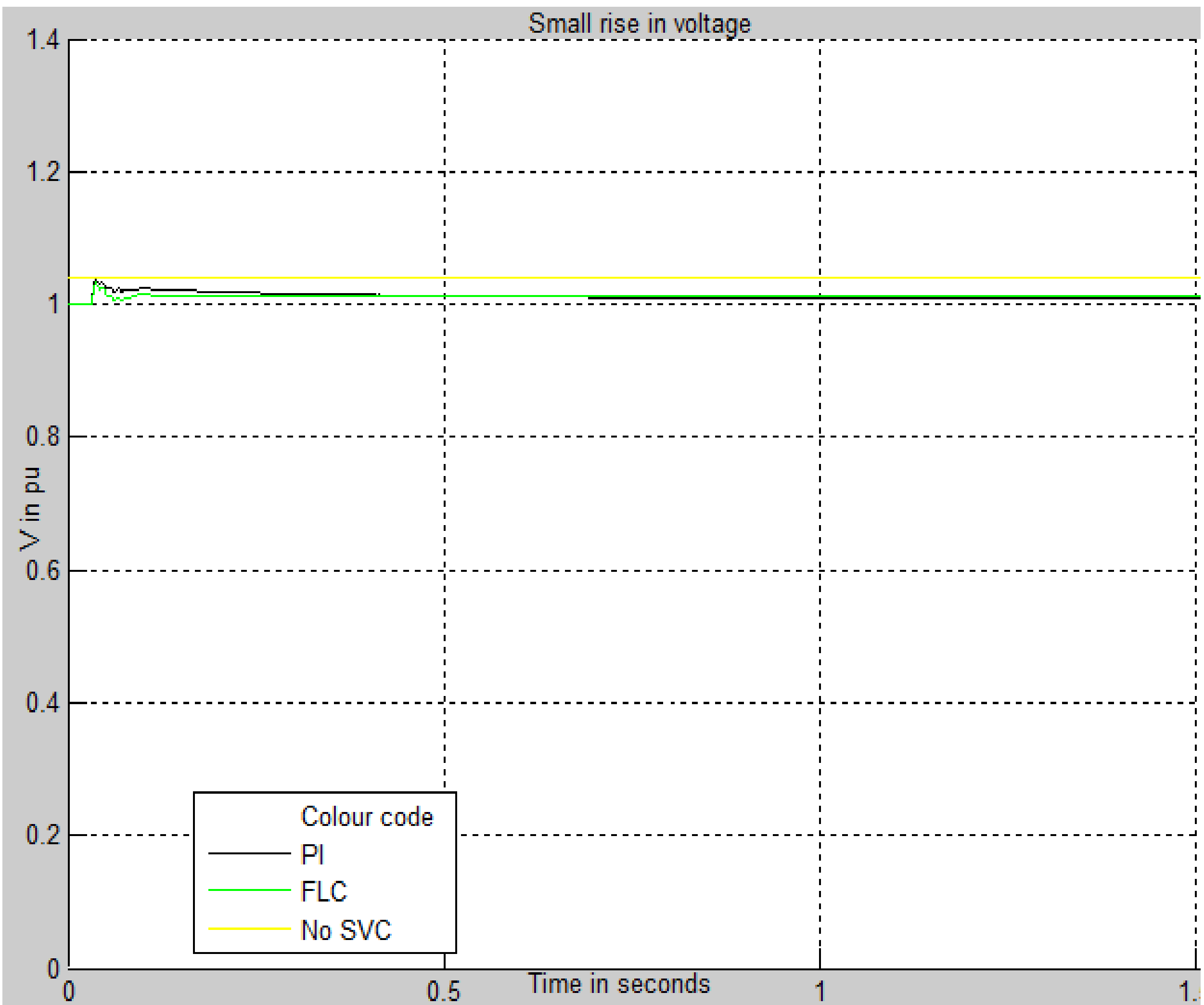

Figure 7-1 Showing the variation at Load Terminals when small rise of 4% in Voltage occurs

The Color code used is *Black* for PI, *Green* for FLC and *Yellow* when no SVC is connected to the system. This color code is used in all the results shown.

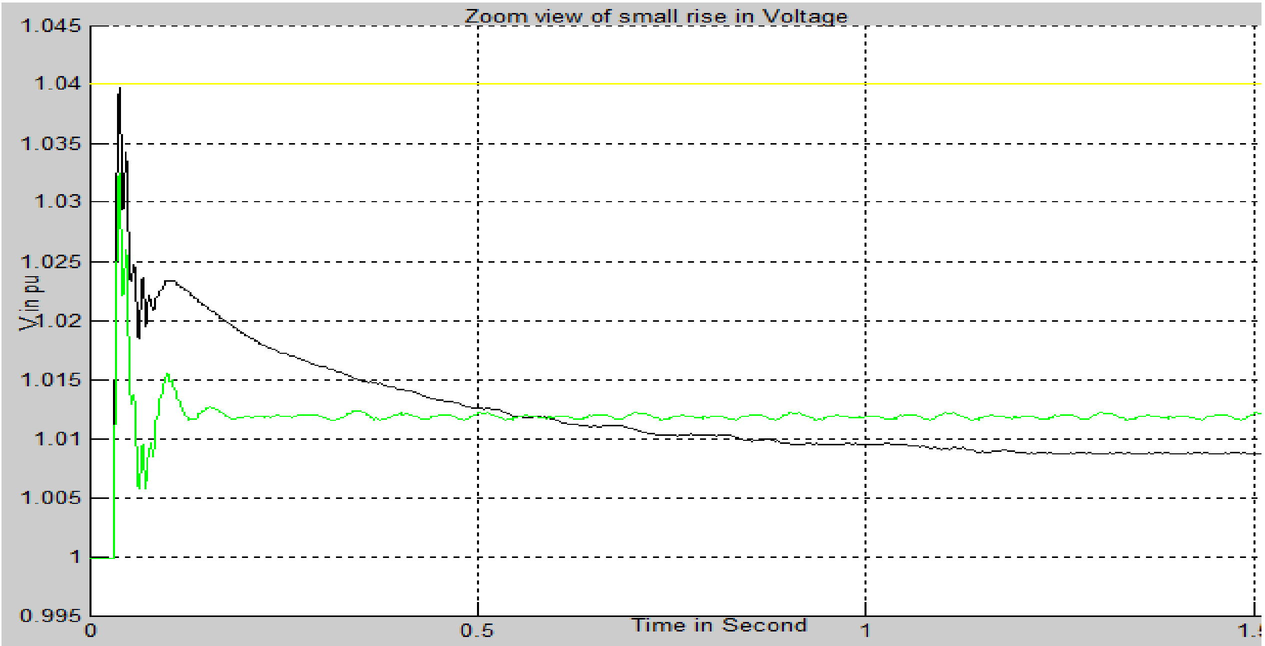

Figure 7-2 Shows zoomed image of the terminal voltage level in pu.

7.1.1.2 Small step down in Source Voltage

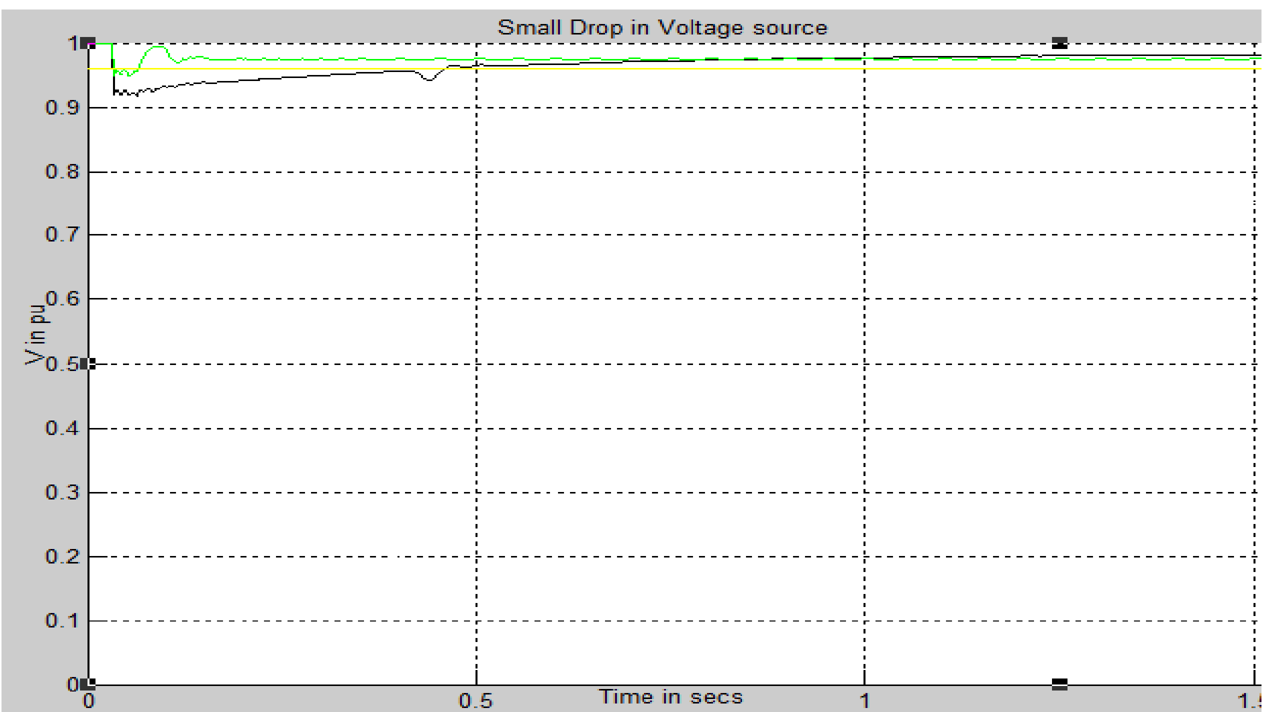

Figure 7-3 Small drop in Voltage source of 4% shows following variations at Load terminals

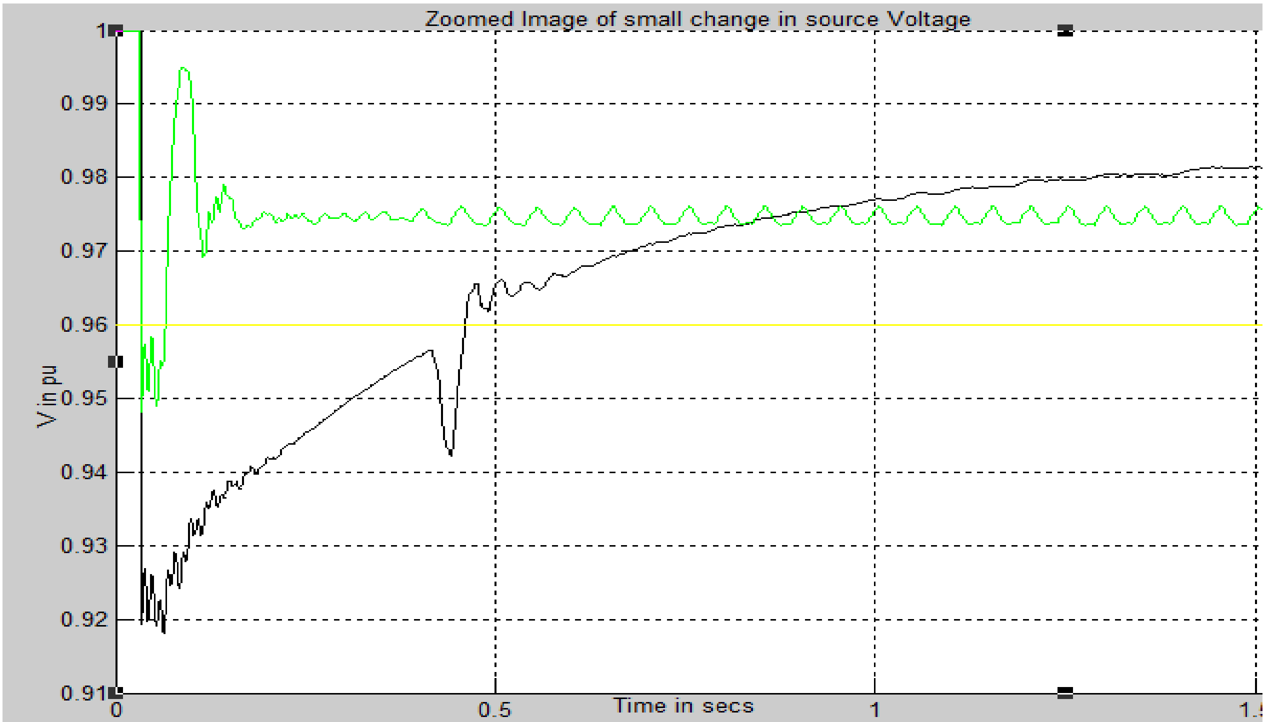

Figure 7-4 Zoomed image of small change in voltage source to show the variations nd which controller is better

7.1.1.3 Large step up in Voltage Source due to disturbance

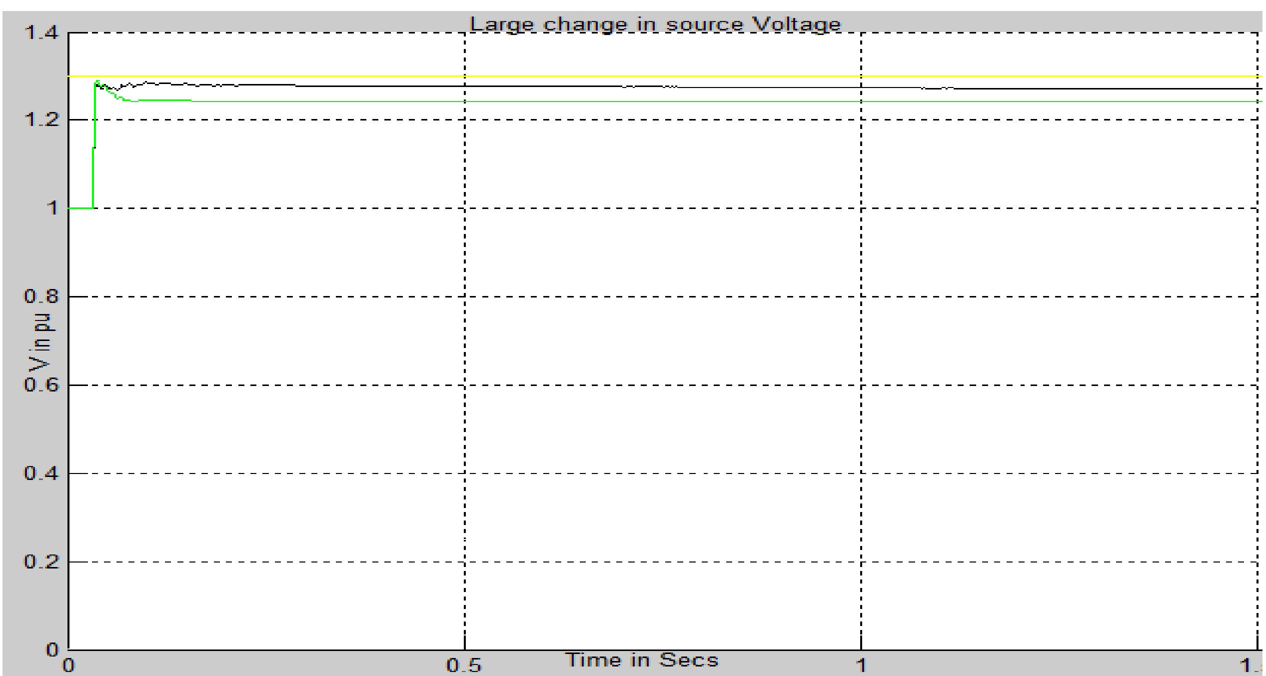

Figure 7-5 Shows the variation of load terminal voltage when large change in source voltage occurs

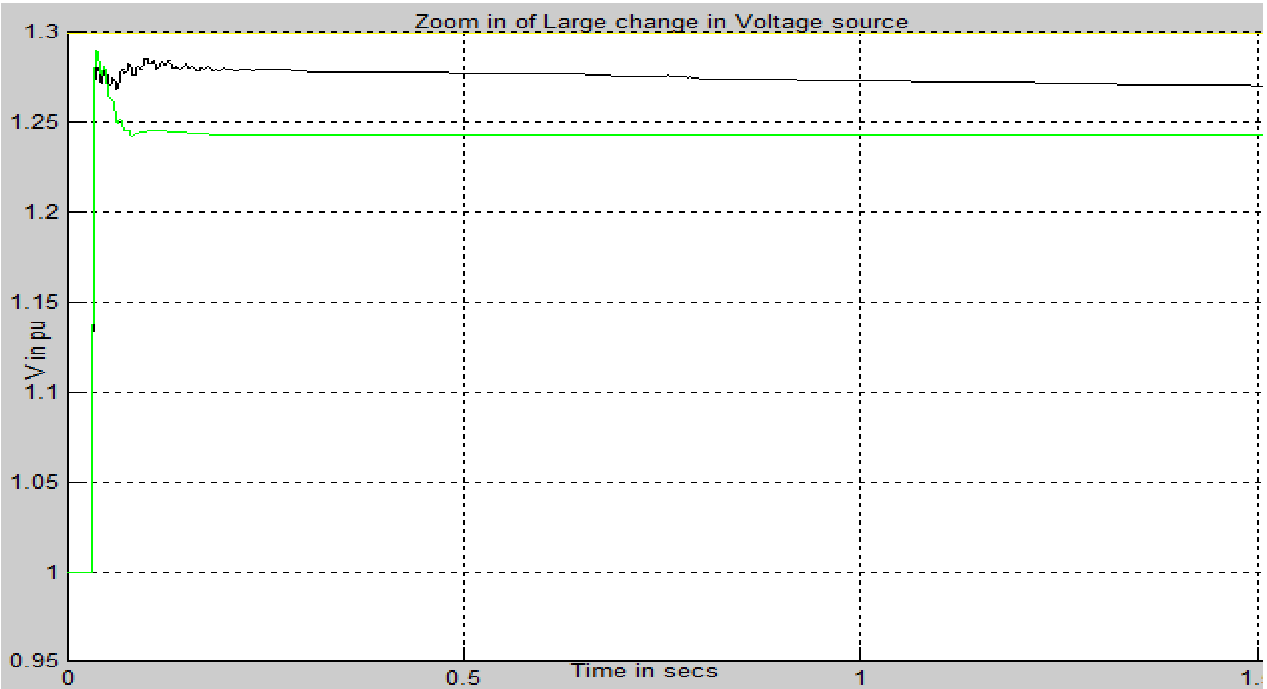

Figure 7-6 Zoomed image of Large Rise in Voltage Source

7.1.1.4 Large Drop in Voltage source

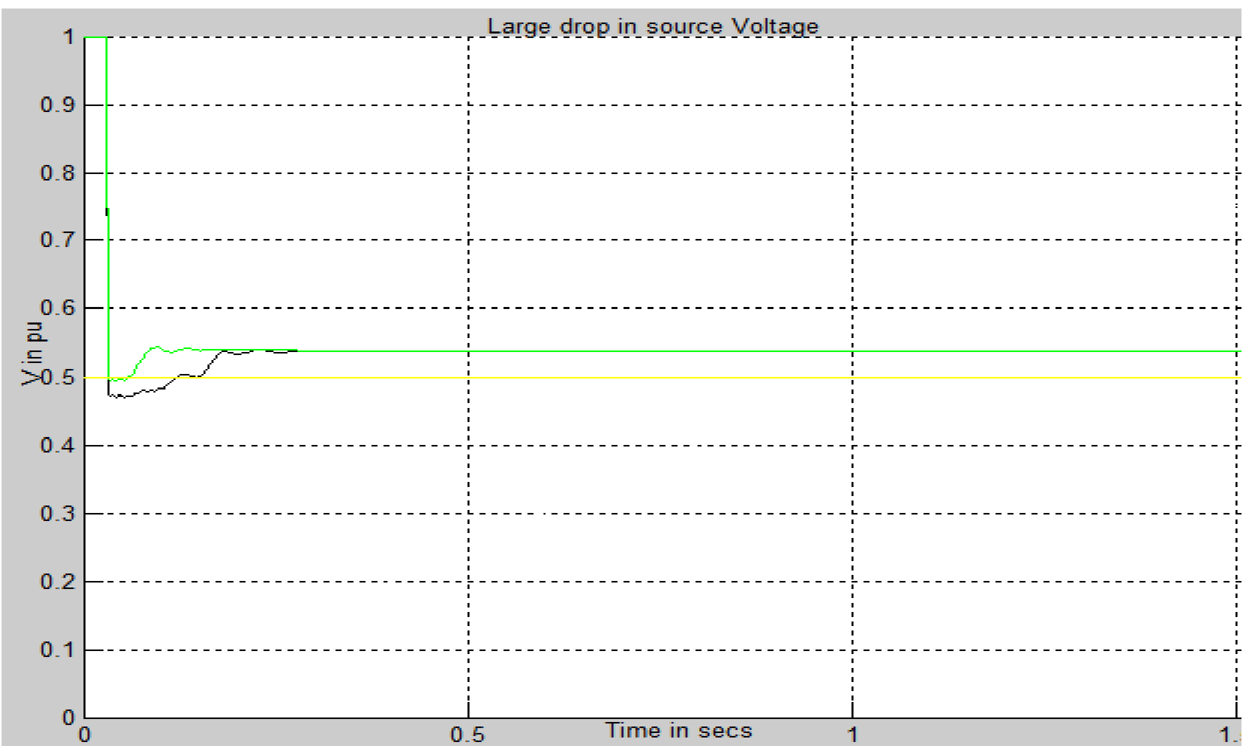

Figure 7-7 Large drop in Voltage Source brings following changes in Terminal Voltage in for PI, FLC and No SVC

7.1.2 Small Duration Variations

7.1.2.1 Small Drop for Short Duration:

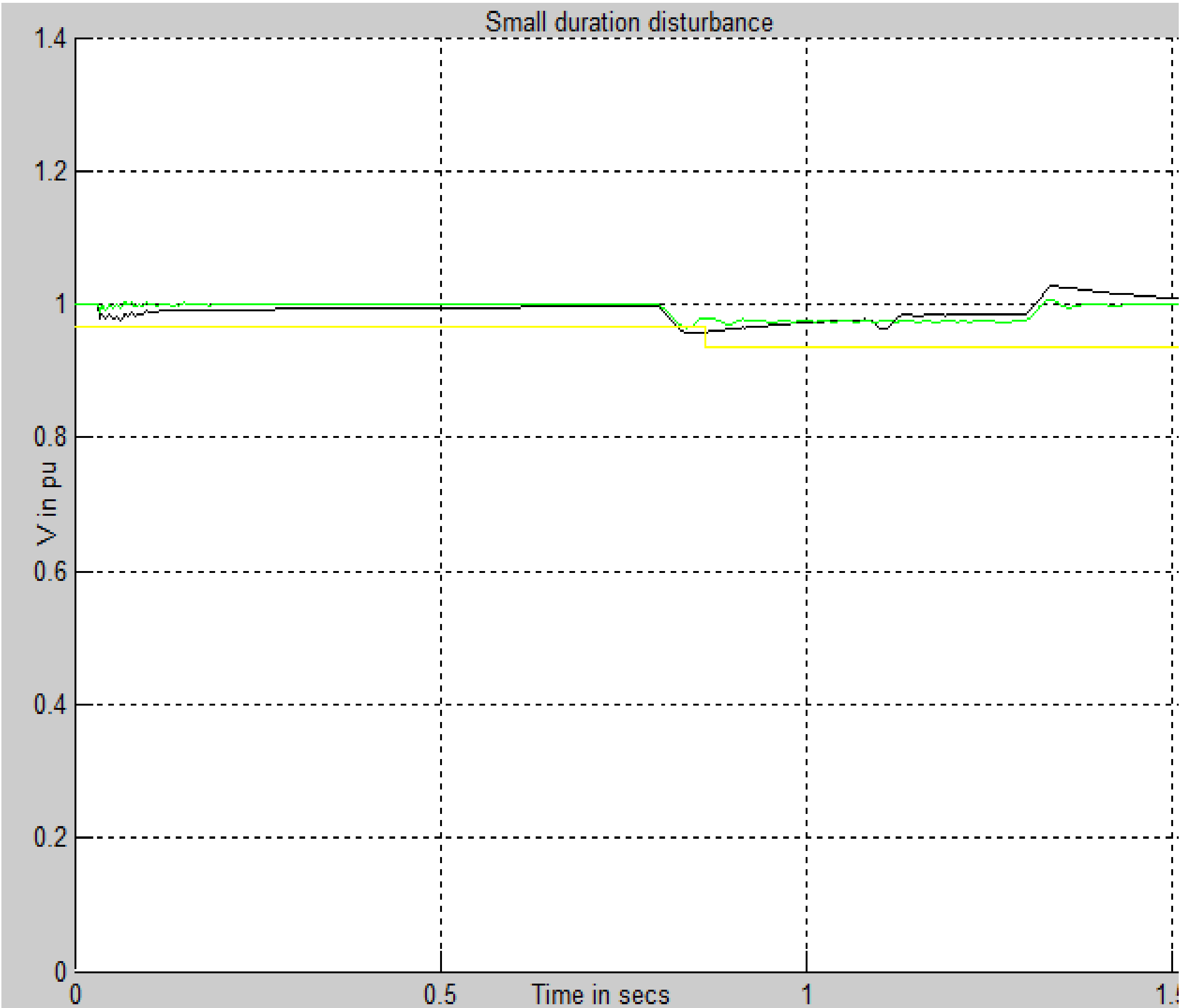

Figure 7-8 Small drop in Voltage Source for a few seconds brings following changes at Load Terminal Voltage as shown above with all three cases

7.1.2.2 Small Rise for Short Duration:

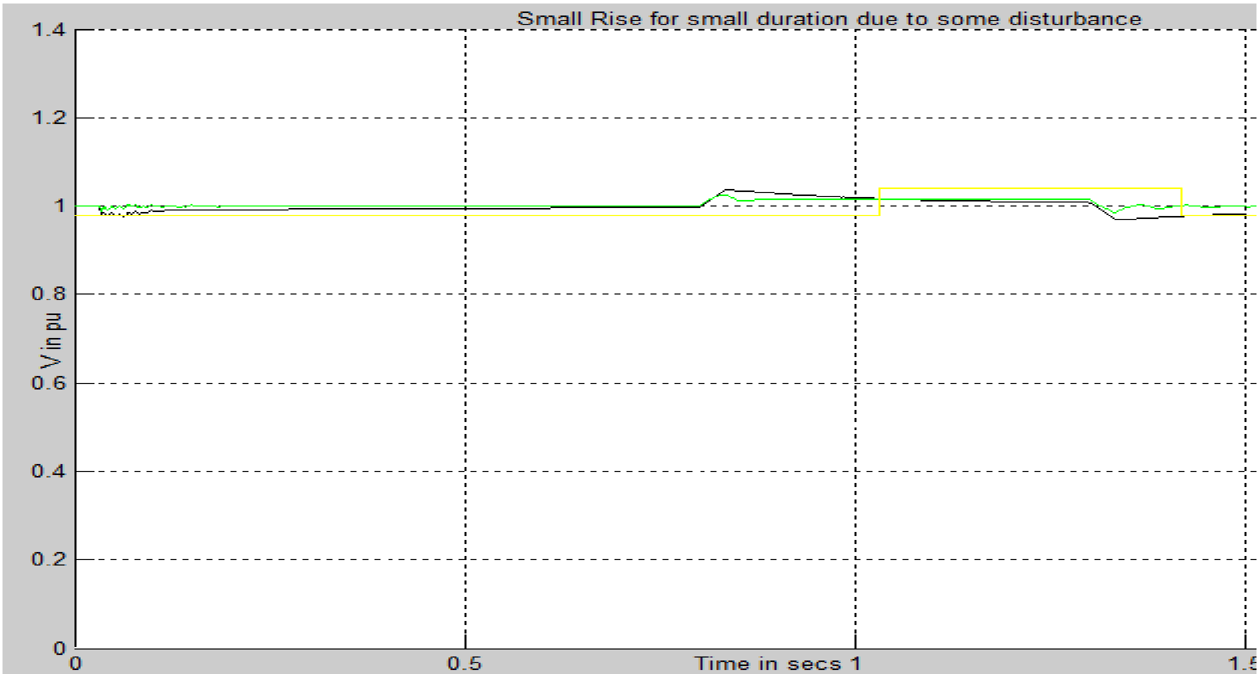

Figure 7-9 Small drop in Voltage Source for a few seconds brings following changes at Load Terminal Voltage as shown above with all three cases

7.1.2.3 Multiple Occurance of Sag and Swell

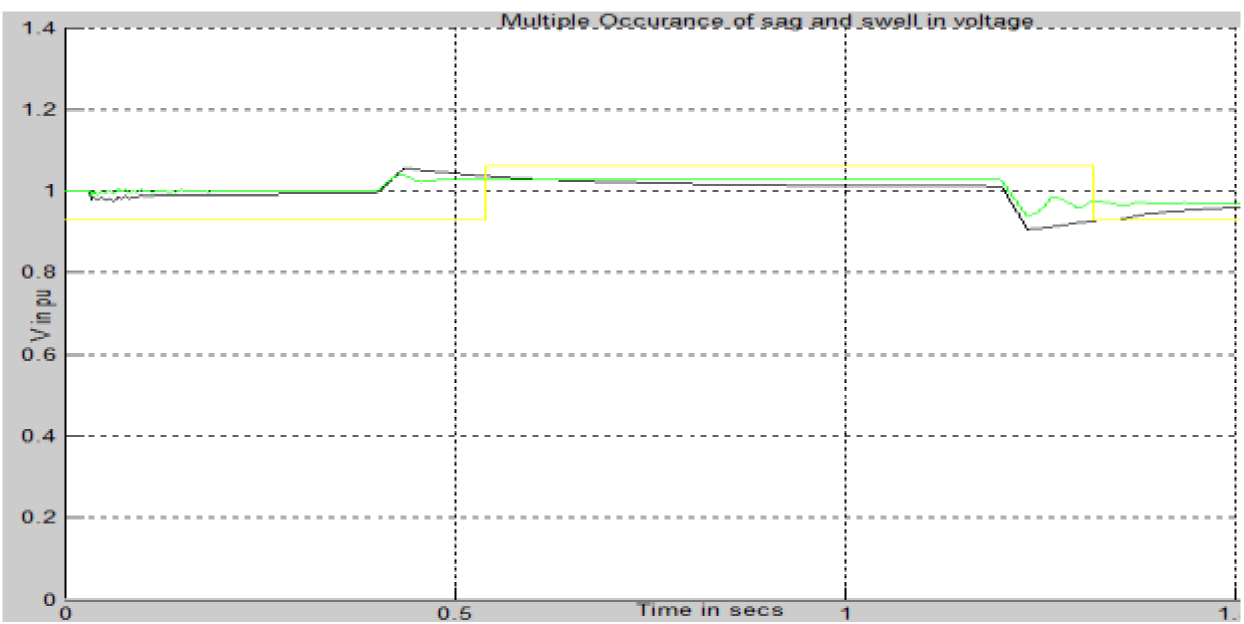

Figure 7-10 Multiple Swell and Sag in Voltage Source brings changes at Terminal Voltage as shown above with all three cases

7.2 Variations in Load

7.2.1 Step Variations

7.2.1.1 Small Raise in Load

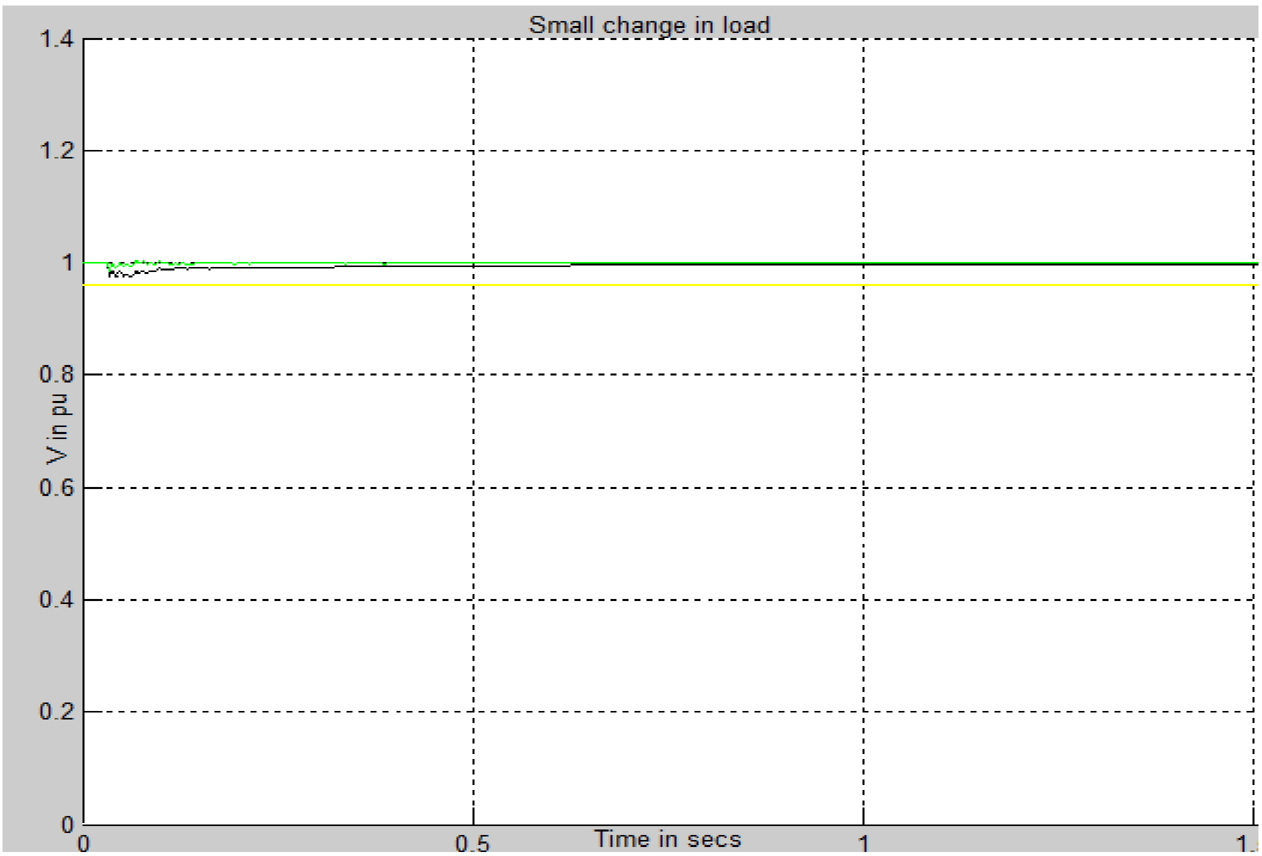

Figure 7-11 Small change in load of around 5% brings following changes to voltage terminals when the SVC is used with controllers PI, FLC and when No SVC is present.

7.2.1.2 Small Drop in Load

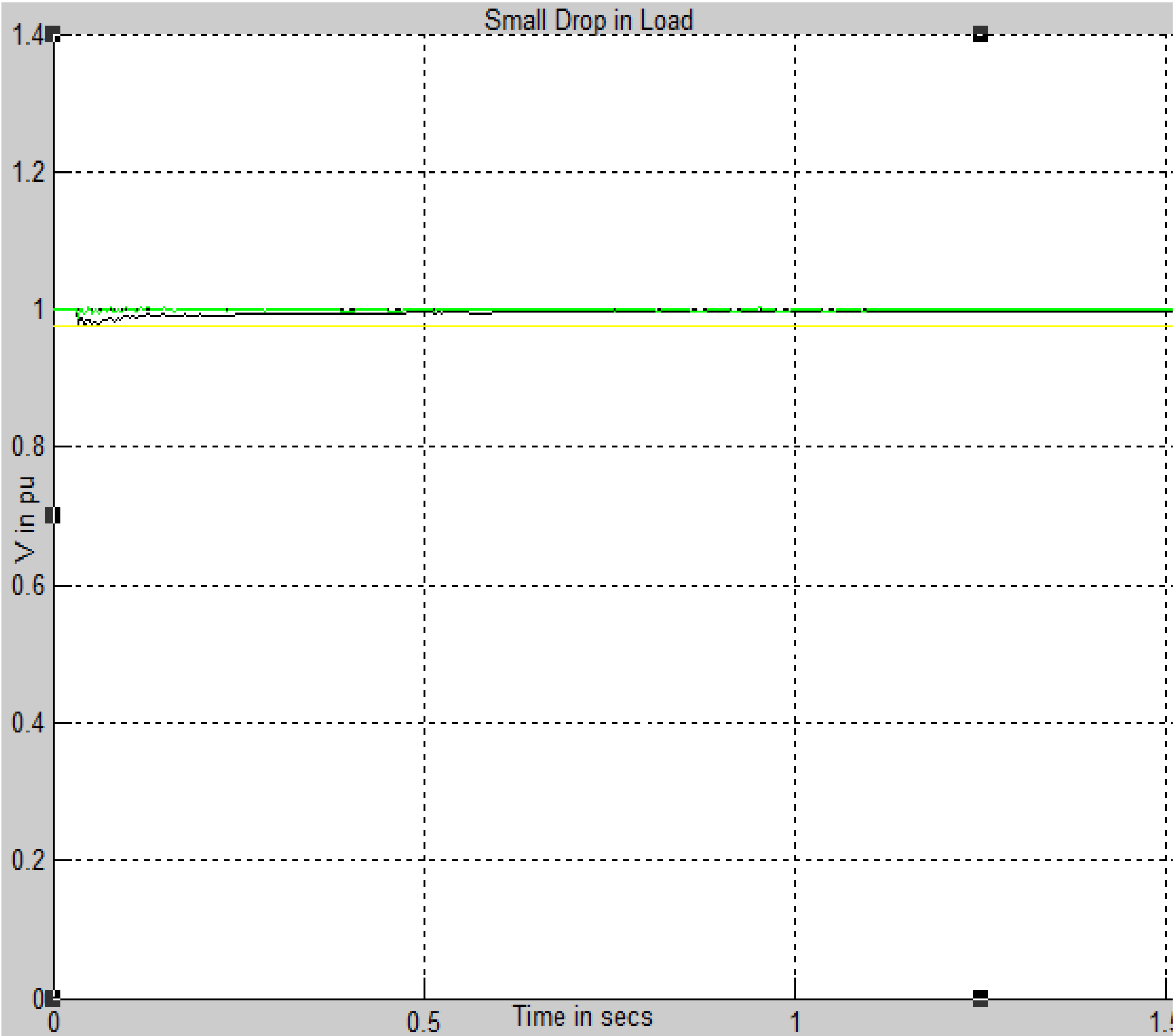

Figure 7-12 Small Drop in Load of around 5% brings following changes to load terminals

7.2.1.3 Large Raise in Load

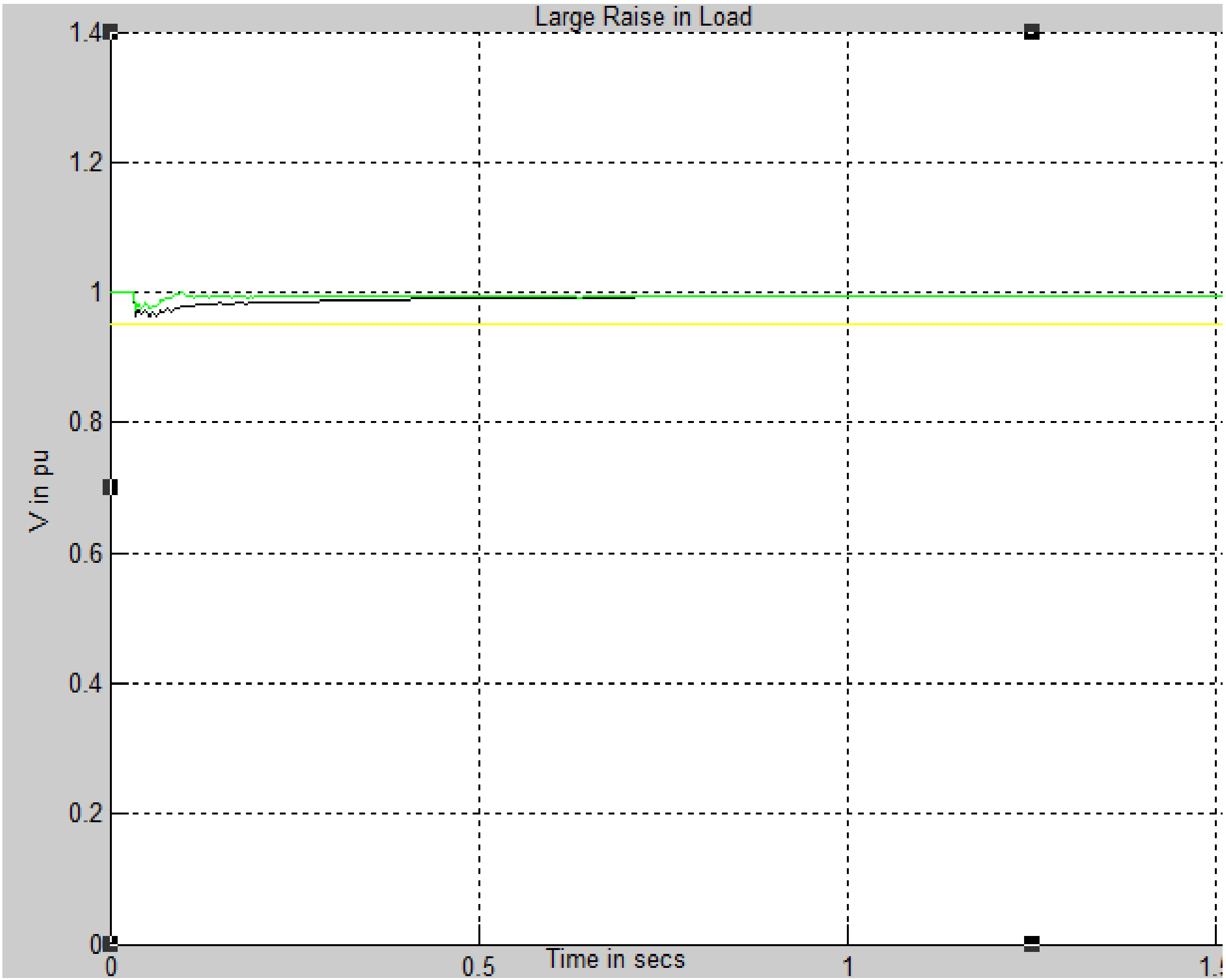

Figure 7-13 Large raise in Load in this case 50% causes Terminal Voltage to behave like shown above in the three cases taken.

7.1.2.4 Large drop in load

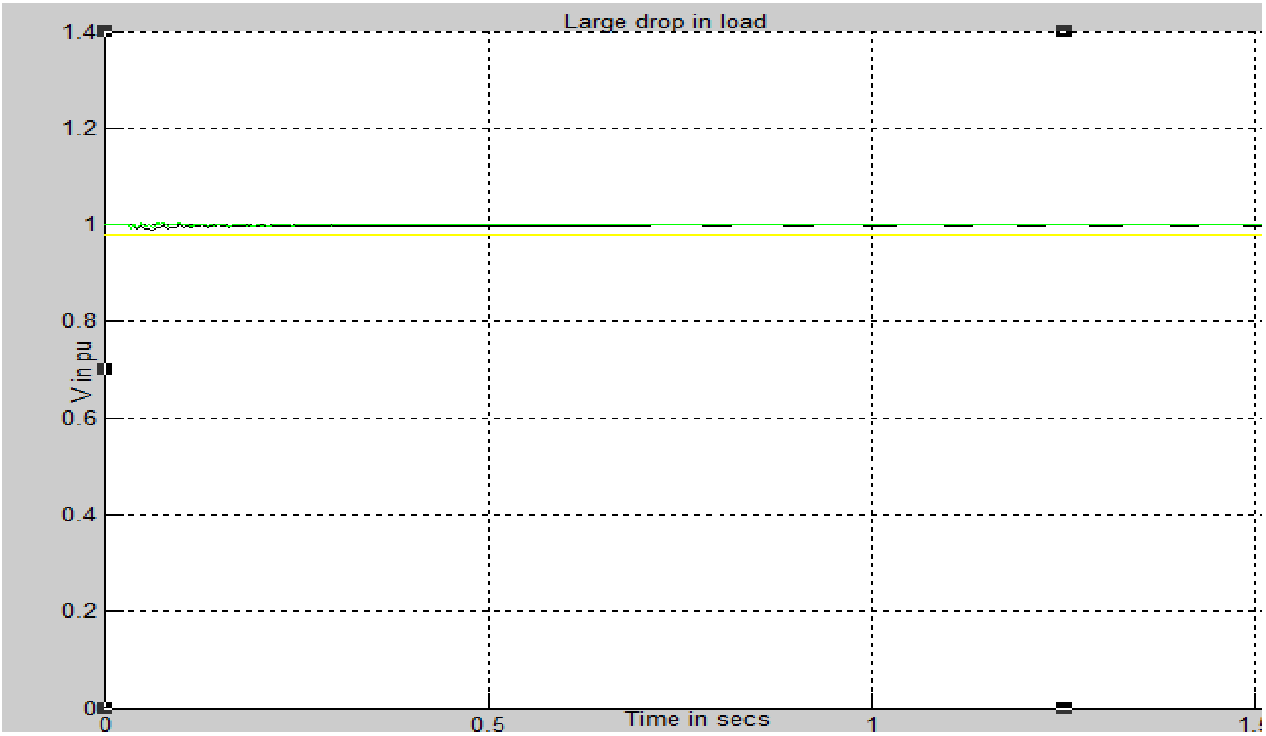

Figure 7-14 When there Large Load shedding of around 50% then following changes in load terminal Voltage take place in the three cases.

7.2.2 Sudden removal of load

The removal of Load suddenly from the system makes it to show lot of hindrance in the system and also causes the voltage to rise at terminals of load due to Ferranti effect but the attachment of SVC clearly shows that the impact of such load removal does not have much impact on it. The FlC shows lower peak and also settles quickly when compared to PI controller.

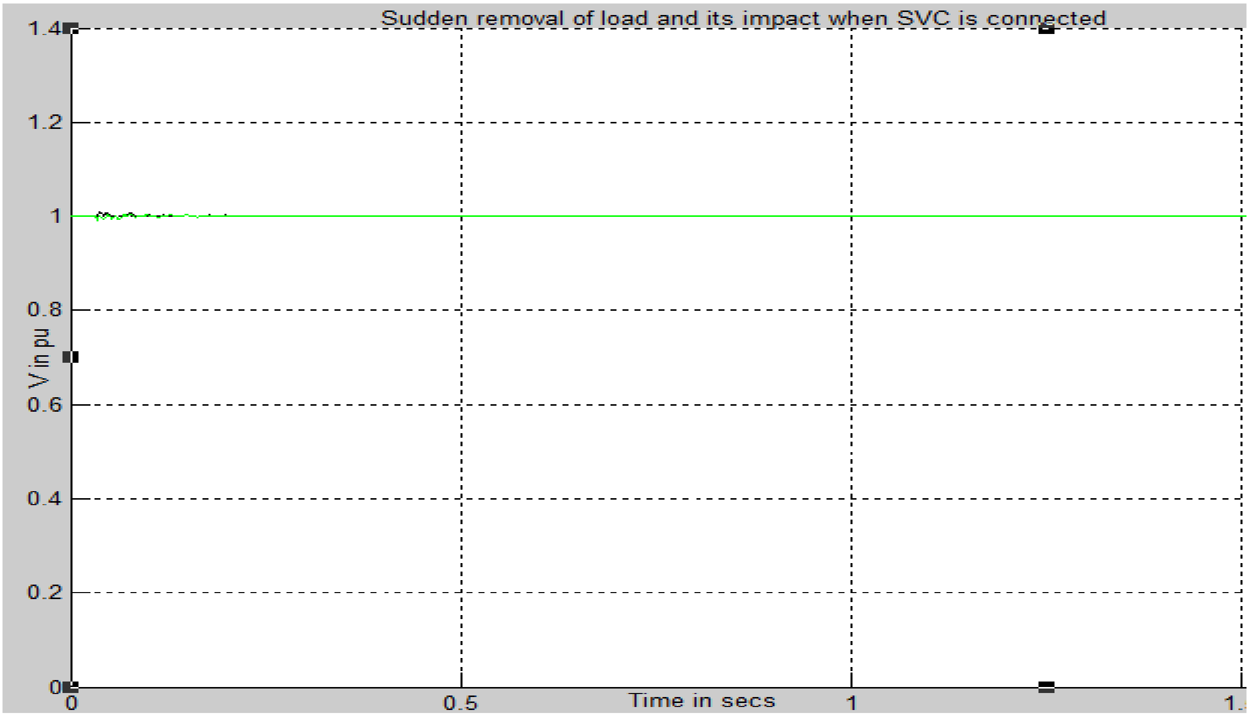

Figure 7.15 Impact on system on sudden removal of load

7.2 Summary of Results

In all the above cases that we have seen we would discuss the cases in details now.

First of all when there is a disturbance in source voltage causing variations of 4% rise in that case it is evident that when there is no SVC then the voltage stays at around 1.038 pu and thus we would have the load terminal voltage of around 519 KV instead of 500 KV but if we include SVC with either of the controller whether PI or FLC the Voltage at terminals is reduced upto 505 KV. But in case of PI the time taken by it is almost 2.5 times that of FLC so FLC proves it is quicker to respond in this case.

When there is a disturbance in source voltage causing variations of 4% drop in that case it is evident that when there is no SVC then the voltage stays at around 0.955 pu and thus we would have the load terminal voltage of around 477 KV instead of 500 KV but if we include SVC with either of the controller whether PI or FLC the Voltage at terminals is increased upto 490 KV. But in case of PI the time taken by it is almost 3 times that of FLC so FLC proves it is quicker to respond in this case also.

When there is a disturbance in source voltage causing large variations of around 50% rise in that case it is evident that when there is no SVC then the voltage stays at around 1.48 pu and thus we would have the load terminal voltage of around 650 KV instead of 500 KV but if we include SVC with either of the controller whether PI or FLC the Voltage at terminals is reduced upto 618 KV. But in case of PI the time taken by it is almost 2 times that of FLC so FLC proves it is quicker to respond in this case.

If there is a disturbance in source voltage causing variations of 50% drop in that case it is evident that when there is no SVC then the voltage stays at around 0.48 pu and thus we would have the load terminal voltage of around 245 KV instead of 500 KV but if we include SVC with either of the controller whether PI or FLC the Voltage at terminals is increased upto 300 KV. But in case of PI the time taken by it is almost 2.5 times that of FLC so FLC proves it is quicker to respond in this case.

In case where there is small drop or rise in voltage source for a small duration we see that if no SVC is present in system then the load terminal voltage stays at around the same voltage even after the voltage duration in which variation occurred has gone so it stays at the dropped voltage or rise voltage but in case of SVC with PI or Fuzzy both are able to recover back to normal stable value that to very quickly and FLC proves its agility in this case also as it had a faster response to come back to normal value i.e. V_{Ref}.

The case of multiple occurance of sag and swell we would show in detail later with all the components of reactive power, No. of TSC working, firing angle and other figures to make the simulation more clear.

In case of variation in load when there is raise in load of small value that is 5% so earlier load was 300 MW now it is 315 MW so the change in Terminal voltage was seen that the voltage at terminals dropped to 0.93. This was case when no SVC was there but when we put SVC in this system then the voltage does not drop that low and it settles at 0.994 pu but the FLC settles faster than PI. Same was the case when load has dropped to 5% that is it became 285 MW. In this case the terminal voltage increased but was nowhere near 1 pu in case when SVC was there but in case of SVC in the system the problem was resolved with terminal voltage becoming 1 pu. But FLC again goes past PI in time as it again proved to be quicker to reach steady state.

Large drop of load and raise of load show clearly that when load is made 150 MW or 450 MW then without SVC the terminal voltage becomes very fragile and is away from our desired results. But in case of the SVC controllers 1 pu desired result was achieved and that too in a small time and here in this case also FLC proved its swiftness.

Chapter 8

Conclusions

For various types of disturbances, FLC has been much faster in settling down and achieving the desired response quickly and accurately. If the disturbance is in linear controllable region then FLC has been much better performer. In other words, if conventional PI control does control voltage after disturbance, then FLC can control the voltage across load even faster. The currents drawn by other parts of system are completely lower than for conventional control.

During initial energization of system the FLC proves to be twice as fast as PI control as the reponse of PI control comprises of oscillations with reducing magnitude. This results in higher rate of change in voltage across the capacitor. This gives in an extra burden on system and extra losses to deal with. With the use of FLC this burden can be lowered because of negligible oscillations in effective value of voltage across load.

The system is quite sensitive to variations in equivalent source voltage. If for a variation in equivalent source voltage is in linear controllable region of SVC, both the controllers tend to control voltage across load. FLC is faster in controlling as compared to PI control. With constant raise and drop of voltage with the use of an SVC with the use of SVC using either equal efficiency.

For changes in load FLC again takes the lead from PI controller and many a time it is twice as fast as the PI controller. The voltage across load may be stiffly maintained close to reference value very quickly with the use of FLC. With PI control low limits of tolerance can be achieved.

So in nutshell it may be said that if with a disturbance voltage across load is controllable with the use of SVC, and then much faster control may be achieved with the use of FLC when compared to PI control.

Chapter 9

Future Perspectives

The membership functions and the fuzzy operator were chosen randomly. A systematic approach for choice of membership function can be considered for future use which can involve the change in error also to come in picture.

The load models namely constant current, arc furnaces, welders, motors etc may be modeled and tested for this control.

The recovery rate after some particular disturbances needs to be improved and the peak overshoot occurring after recovery is to be reduced so as to reduce system burden. And the system can be controlled with less value of peak voltage.

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