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Simulation of Fuzzy Controlled SVC for Transmission Lines

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ABSTRACT: Due to increase in loads during the recent years the transmission lines are subjected to more stress. Thus in order to enhance the performance of these transmission lines, Flexible AC Transmission System (FACTS) devices are considered to be the best acceptable solution. Many FACTS devices are found to be working in power system. Among these devices a shunt connected FACTS device called Static Var Compensator (SVC) is being modelled in this paper. Further, the comparative analysis for improving voltage profile is done using two control techniques such as Artificial Neural Network (ANN) and Fuzzy Logic Control (FLC).

KEYWORDS:FACTS, SVC, ANN, FLC, MATLAB

I.INTRODUCTION

Power system mainly consists of Generation, Transmission and Distribution system. The generated power from the generating station is transmitted through the transmission lines to the distribution system where the power is fed to the loads. Now as the load is increasing day by day, the quality and the quantity of the power being supplied is not up to the mark. This result in voltage instability, increased losses and power system security problems which may damage the loads connected to the system. This increase in load leads to scarcity of both active and reactive power. In order to maintain the terminal voltages at the loads within the prescribed limits,reactive power reserves are essential.

Thus, the main aim of power system planners and researchers is to solve these problems either by establishing new transmission lines in order to meet the increasing demand or to install any compensating devices at the desired load centers. The idea of establishing new transmission lines has various constraints like economic, technical and land use regulations. As a result, the focus of power system planners shifts at installing compensating devices at desired load centers in order improve the transfer capability of existing transmission lines as well as voltage profiles.

With the rapid development in power electronics, these compensating devices commonly known as FACTS controllers are now being used widely to overcome the power system problems. These FACTS devices have quick control characteristics and are also capable of providing compensation continuously. There are many FACTS devices that are operating in power system. Among these, Static VarCompensator (SVC), a shunt connected FACTS device is found to be used widely in resolving dynamic problems like bus voltage violations and reactive power control. Roughly the life span of SVC is about 12-15 years.

II. SVC CONTROL, OPERATION AND MONITORING

SVC is a shunt connected FACTS device whose output can be adjusted in such a way that it can absorb from or inject reactive power into the power system so as to maintain the bus voltages within the prescribed limits. The use of SVC results in following benefits.

1. Improved Voltage Regulations.
2. Increased power transfer capability of existing transmission lines.
3. Reduced line losses.
4. Reduction in power system oscillations.
5. Improves the transient stability of the system.

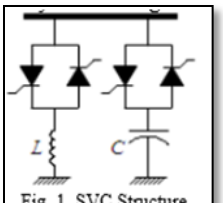

Fig. 1 SVC Structure

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As shown in fig (1), SVC mainly consists of fixed or variable capacitor and reactor banks and the thyristors. The variation in the reactive power is achieved by switching capacitor and reactor banks by thyristors. The capacitors are switched ON and OFF by anti-parallel connected thyristors. The current in the reactor is varied by thyristor firing delay angle control method. To control or to maintain system within specified limits, the output of the SVC is adjusted to exchange the inductive current or capacitive current in the system. Usually SVC may be operated in 2 modes: 1. Voltage regulation 2. VAR control

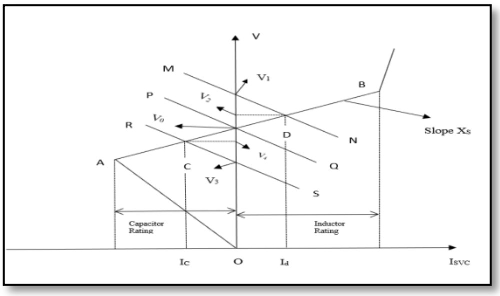


Fig (2): V-I Characteristics of SVC

Mathematically the SVC characteristics can be expressed as,

$$V = V_0 + X_s I_{SVC}$$

Where, V_0 – Nominal voltage (1 p.u) X_s – SVC slope I_{svc} – Compensating current

The V-I characteristics of a high voltage AC system under over loaded, under loaded and normal loaded circumstances are shown correspondingly in lines RS, MN and PQ. When the system voltage increases to V_1 from V_0 i.e., under loaded condition, where SVC works at D point as shown in figure, and brings the system voltage to V_2 by absorbing an inductive current (Id). On the contrary under over loaded condition, decrease in bus voltage from V_0 to V_3 can be bring back to V_4 by operating SVC at point C. X_s normally vary from 1 to 5 percent. The advantage of providing slope is, which considerably eases SVC rating for attaining almost the similar control aims. And also assists for number of compensators operating in parallel to share their reactive power between them.

Further, to analyze the impact of SVC on power system, the basic configuration of SVC control scheme is as shown below in fig (3). This control scheme is referred as Phasor Model of SVC in MATLAB.

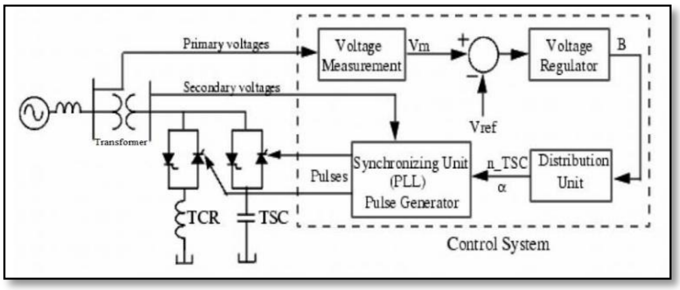


Fig (3): Basic configuration of SVC Control Scheme

The control system consists of

1. Positive sequence voltage is measured using a Voltage Measurement system.
2. The Voltage regulator uses the voltage error to calculate the susceptance (B) of SVC in order to maintain constant system voltage.
3. The distribution unit computes the firing angle (α) for TCRs.
4. The synchronizing unit uses a PLL to synchronize secondary voltage and the pulse generator sends the required pulses to the thyristors.

III.CASE STUDY

In this paper, a standard IEEE 5 bus system is considered to analyze the impact of SVC. The system is simulated in MATLAB and is as shown in figure (4).

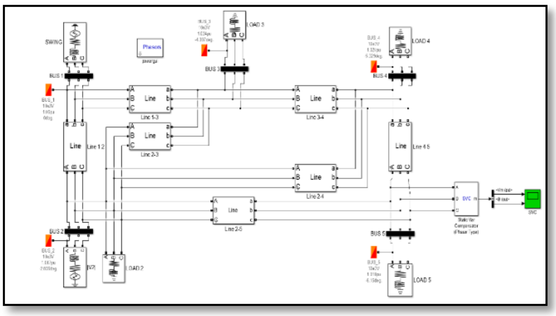


Fig (4): IEEE 5 bus system

Table (1) : Bus Data

Bus number	Bus Voltage	Generation		Load	
		MW	MVar	MW	MVar
1	1.06+j0	0	0	0	0
2	1+j0	40	30	20	10
3	1+j0	0	0	45	15
4	1+j0	0	0	40	5
5	1+j0	0	0	60	10

Table (2) : Line Data

Line number	Line impedance		Line charging admittance
	R (pu)	X (pu)	B/2 (pu)
1-2	0.02	0.06	0+j0.030
1-3	0.08	0.24	0+j0.025
2-3	0.06	0.25	0+j0.020
2-4	0.06	0.18	0+j0.020
2-5	0.04	0.12	0+j0.015
3-4	0.01	0.03	0+j0.010
4-5	0.08	0.24	0+j0.025

The above system is analyzed for various load conditions. At each load condition, load flow analysis is done and the bus voltages for both with and without SVC and the corresponding values of susceptance of SVC are noted down. Now since as the load goes no increasing, one cannot follow the same steps to determine how much susceptance should be provided by the SVC in order to improve the bus voltages and to reduce the losses in the system, the two controllers are proposed in this paper namely Artificial Neural Network and Fuzzy Logic Controller.

IV.ANALYZING USING ANN

The concept of Artificial Neural Network (ANN) is one of the greatest developments of this century. It was proposed by the inventor of first neuro – computers, Dr. ROBERT HECHT-NIELSEN. Neurons are the basic building blocks and the input output relationship solely depends on the interconnection of the nodes and layers. Artificial neural networks are best suitable for nonlinear function approximation, estimation and prediction.

Data set Preparation:

In this paper 150% to 180% load conditions are considered and for each load condition, load flow analysis is done and the bus voltages for both with and without SVC and the corresponding values of susceptance that is required to maintain the bus voltages within prescribed limits were noted down. The matrix consisting of load bus 5 voltage in one column and error in voltage in second column which is of order 51X2 is taken as input to train ANN. And corresponding value of susceptance which is of order 51X1 is considered as target to train ANN.

Training of ANN:

The ANN is trained using ANN toolbox of MATLAB, the starting window of toolbox is shown in figure (5). The fitting tool app in this window is opened and data prepared in excel sheet is imported for training in window shown in figure (6).

Once the data is imported the number of neurons are fixed and data for validation testing and training are fixed as shown in figure (7). The ANN is then trained using Levenberg Marquardt algorithm. Once the ANN is trained, corresponding Simulink diagram is generated and it is used further to determine the value of susceptance that is to be provided by SVC in order to maintain the bus voltages within the prescribed limits and to reduce the losses in the system for any increase in load.

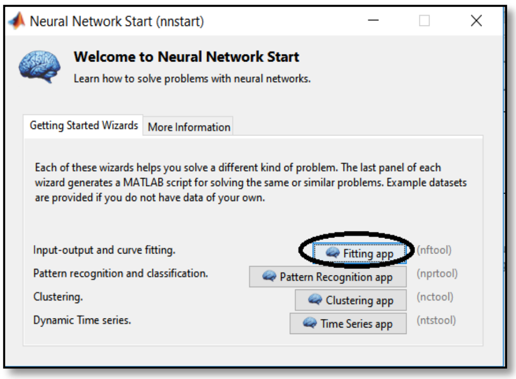
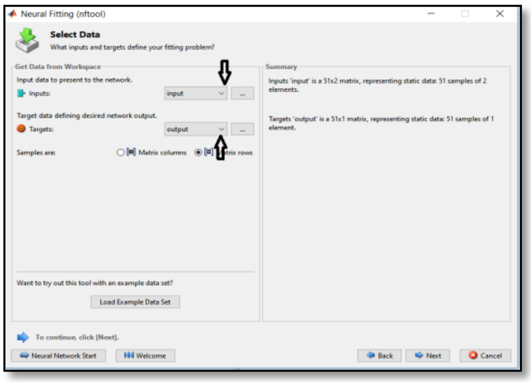
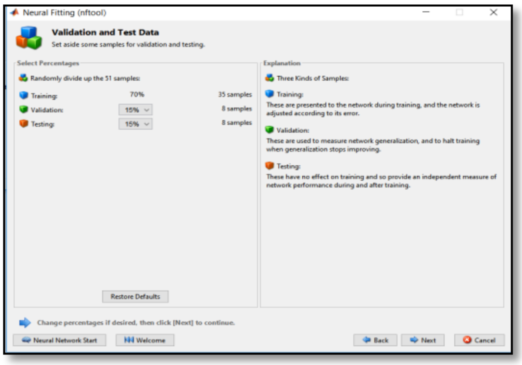


Fig (5): Start to Neural Network



Fig(6): Loading INPUT and OUTPUT variables



Fig(7): Validation and Test Data

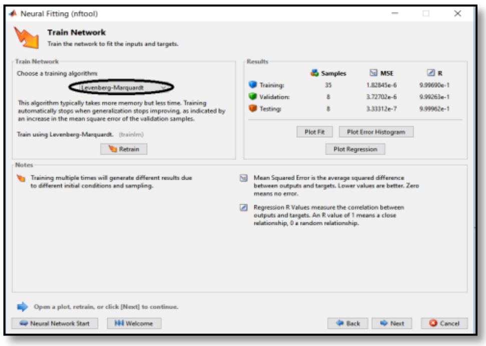
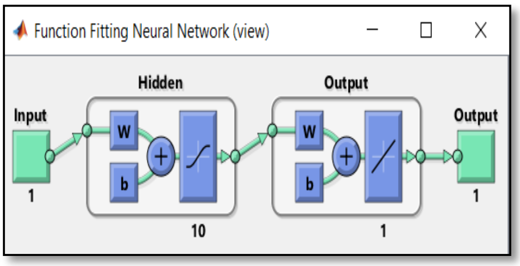


Fig (8): Training of ANN



Fig(9
Fig(9
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Train

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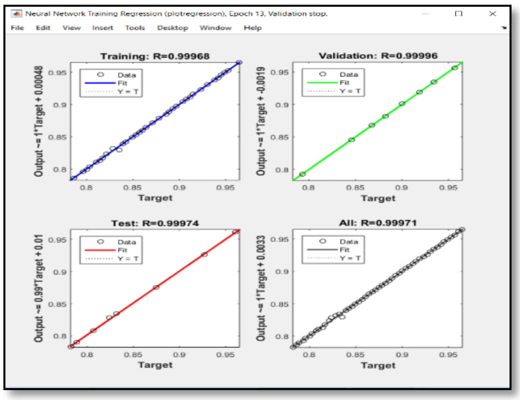

Fig(10): Regression Plots

V. ANALYZING USING FUZZY LOGIC CONTROLLER

Fuzzy Logic is a new control approach for real time applications. The block diagram of Fuzzy Controller is as shown figure 11. Fuzzy Inference System consists of:

- Input variables
- Fuzzification through membership functions
- Rule base
- Defuzzification through membership functions

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• Output variables

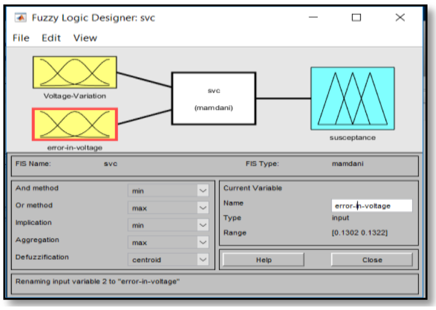

Fig (11): Structure of Fuzzy Logic Controller

Input variables :

The input to the fuzzy system are voltage variation across bus 5 and the change in error voltage (which is the difference between reference voltage i.e., 1.05 and voltage variation across bus 5).

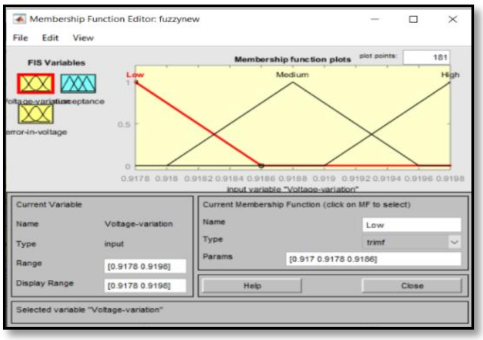

Fig (12): Membership Function of Input 1

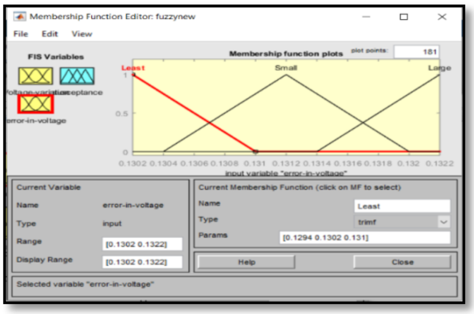

Fig (13): Membership Function of Input 2

Rule base :

The rule base is described as "If Then" format wherein 'IF' side represents the condition and 'Then' side represents the conclusion.

Rule 1 : If voltage variation is low and error in voltage is least, then the output is low.

Rule 2 : If voltage variation is low and error in voltage is small, then the output is low.

Fig (14): Rule Base

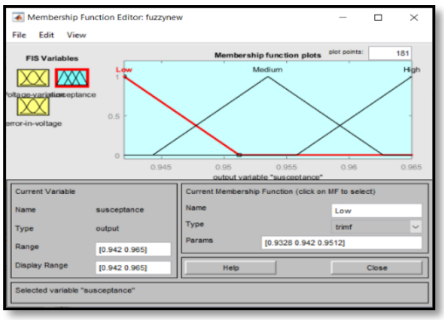

Fig (15): Membership Function for Output

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Table (3) : Rule base for fuzzy controller

Voltage variation	Error in voltage		
	Least	Small	Large
Low	Low	Low	Medium
Medium	Low	Medium	High
high	Medium	High	High

Output variables :The output of fuzzy logic controller is susceptance(B) of SVC which is required to bring the bus voltages to the normal level.

After creating a fuzzy file in fuzzy tool box, the file was saved and the same was used in simulating the IEEE bus 5 bus system to determine the value of susceptance of SVC. The sub system of fuzzy controlled SVC thus used is as shown below:

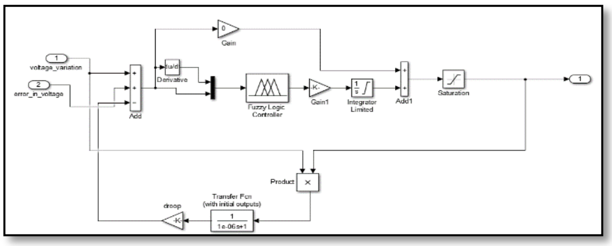

Fig (16): Subsystem for Fuzzy Logic Controller

VI.RESULTS AND DISCUSSIONS

The load on the IEEE 5 bus system is increased from 150% to 180% to investigate the system performance at higher loading condition. The results of bus voltages and the corresponding losses of the system during 100%, 150%, 160%, 170%, 175% and 180% loading condition is as shown below:

Table (4): Bus Voltages for various loading condition

Bus No	Bus Voltages for various loading condition in pu					
	100%	150%	160%	170%	175%	180%
1	1.06	1.06	1.06	1.06	1.06	1.06
2	1.0146	1.0031	1.000	1.00	1.00	1.00
3	0.9915	0.9786	0.975	0.974	0.9739	0.973
4	0.9882	0.9740	0.970	0.969	0.968	0.968
5	0.9622	0.9366	0.931	0.927	0.9258	0.924

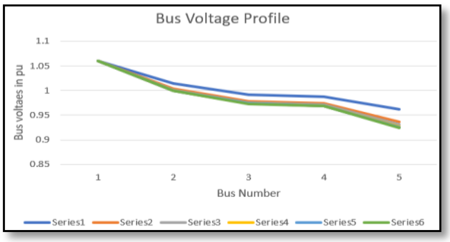

Fig (17): Bus Voltage Profile

Table (5): Active Power Losses for various loading condition

Line No	Active Power Losses for various loading condition in MW					
	100%	150%	160%	170%	175%	180%
1	3.7200	5.4350	5.8360	6.1826	6.3581	6.5248
2	2.4853	3.2574	3.4330	3.5898	3.6665	3.7445
3	0.2727	0.2975	0.3030	0.3085	0.3114	0.3143
4	0.6950	0.8086	0.8337	0.8583	0.8707	0.8833
5	4.0212	6.2700	0.8039	7.3381	7.6107	7.8884
6	0.957	0.1539	0.1679	0.1813	0.1881	0.1950
7	0.4855	0.9862	1.1131	1.2417	1.3080	1.3762

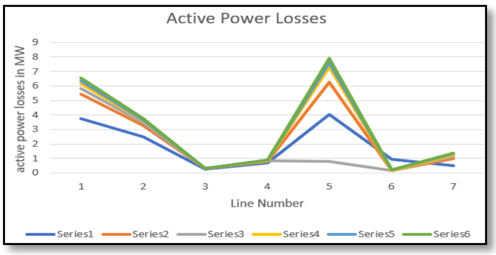

Fig (18): Active power losses in the system

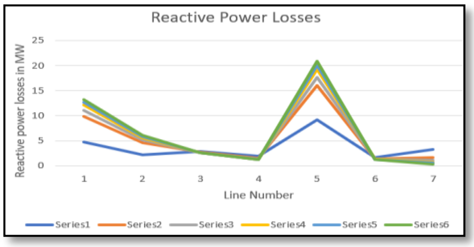

Fig (19): Reactive power losses in the system

Table (6): Reactive Power Losses for various loading condition

Line No	Reactive Power Losses for various loading condition in MW					
	100%	150%	160%	170%	175%	180%
1	4.7007	9.9154	11.1338	12.1770	12.6846	13.203
2	2.1819	4.5690	5.1098	5.5868	5.8193	6.0554
3	2.8893	2.6883	2.6440	2.6133	2.5996	2.5855
4	1.9272	1.4839	1.3858	1.3040	1.2647	1.2248
5	9.1307	15.9847	17.6100	19.2244	20.0462	20.8869
6	1.6727	1.4445	1.3908	1.3448	1.3225	1.2997
7	3.2993	1.6061	1.1836	0.7734	0.5648	0.3501

From the above figures, it is noticed that the growth in loading condition results in decreased bus voltage profiles and increased losses in the system. In such case, the system reliability and security is affected.

Thus in order to enhance the performance of the system, (i.e., in terms of better voltage profile and reduced losses) it is essential to install the compensating devices like SVC. The results of bus voltages and the corresponding losses of the system for 180% loading condition in presence of SVC is as shown below:

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Table (7): Comparision of Bus Voltages

Bus no	Bus voltages in pu	
	Without SVC	With SVC
1	1.06	1.06
2	1.00	1.0388
3	0.9734	1.0193
4	0.9681	1.0202
5	0.9243	1.0415

Table (8): Comparison of Active power losses

Line No	Active Power losses in MW	
	Without SVC	With SVC
1	6.5248	6.0515
2	3.7445	3.3750
3	0.33143	0.2786
4	0.8833	0.7858
5	7.8894	7.5429
6	0.1950	0.1999
7	1.3762	1.4635

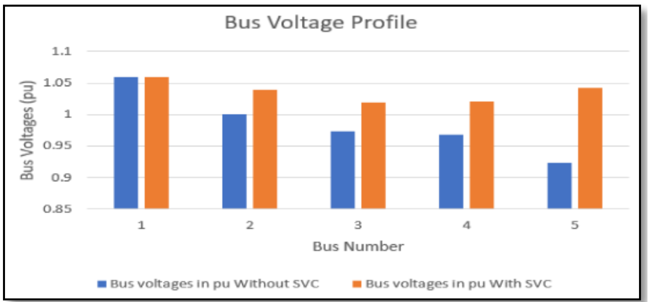

Fig (20): Comparision of Bus Voltages

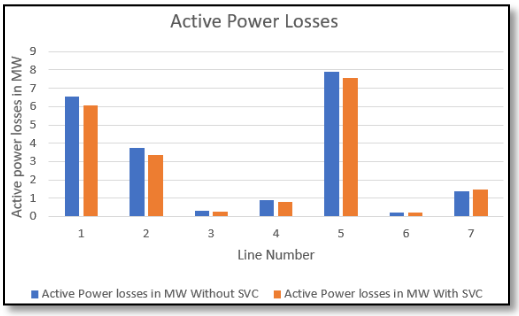

Fig (21): Active power losses in the system with SVC

Table 9: Comparision of Reactive power losses

Line No	Reactive Power losses in MW	
	Without SVC	With SVC
1	13.2036	11.5426
2	6.0554	4.7189
3	2.5855	3.0755
4	1.2248	1.8822
5	20.8869	19.3829
6	1.2997	1.4798
7	0.3501	0.9233

Table (10): Value of Suceptance obtained from ANN And FLC

Random increase in Load (MW)	Value of susceptance in (pu) obtained from	
	ANN	FLC
158.4	0.8297	0.8322
163.8	0.8638	0.8643
168	0.8875	0.8894
172.8	0.9192	0.91910
177.6	0.9491	0.94930
180	0.9638	0.9650

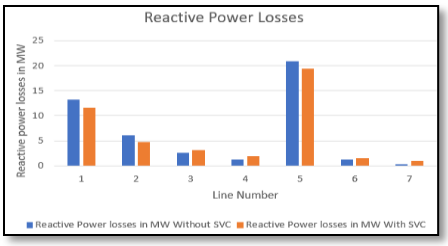

Fig (22): Active power losses in the system with SVC

The above figures show that, due to the placement of SVC the bus voltages are improved and the losses in the system are also reduced even when the load on the system is increased. The similar results are obtained with other increased loading condition.

Now, as and when the load keeps on increasing the same steps cannot be followed as it would be time consuming. Thus, ANN and Fuzzy Logic Controller can be used to determine the value of susceptance that is required to maintain the bus voltages within the prescribed limits and to reduce the losses of the system. The results obtained from these controllers at random increase in load condition are tabulated as shown below:

The results tabulated above, summarizes the value of susceptance that is required by the SVC in order to maintain the bus voltage profile within the standard limits during random increase in load on the system. Further, it can be said that among both the controllers being proposed in this work, the Fuzzy Controller is being superiority because it can be applied to real time power system in managing the specific electrical parameters of the power system under consideration

VII. CONCLUSION

The recent studies made on power system, shows that as there is an increase in population, there has been subsequent increase in the demand of electric power. The most common conventional solution to meet the increased demand is to set up new generating stations or transmission lines. But due to some economic factors these methods are not suitable. Some alternate methods like installing FACTS devices can overcome such problems.

Here is the study which made an attempt to analyze the performance of one of the FACTS devices like SVC, in improving the bus voltage profiles and reducing the losses of a standard IEEE 5 bus system. Further it is noticed that for 150% to 180% increase in load, the bus voltages are seen to be violating and the losses were increasing in the system. To improve the bus voltages and to reduce the losses in the system, a SVC of appropriate MVAR rating is connected to the system. As in the real time the load on the system may increase or decrease, during such situations it may be difficult to implement the above concept. Hence the use of Artificial Neural Network (ANN) and Fuzzy Logic Control (FLC) is proposed in this study to determine the value of the susceptance required by the SVC in improving the bus voltage profiles and reducing the system losses.

FUTURE SCOPE

The controller used for SVC is basic one which has FC-TCR configuration and in large power systems TSC-TCR configuration can be used for better control and voltage profile improvement. And the role of SVC in damping out power system oscillations and to improve the transient stability of the stability of the system can be analyzed further to improve the reliability and stability of the system

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