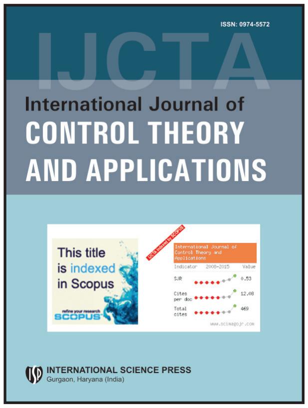

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A Fuzzy based Controller for Series Active Filter used for Mitigation of Voltage Pertubations

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Abstract: A fuzzy based control scheme is proposed here for a series active filter. This controller is used to generate the reference signal for the voltage source inverter which is used as the series active filter to compensate any voltage disturbance. The series active filter compensates for voltage sag, swell and unbalance in the bus voltage. Using fuzzy controller fast response is obtained under all these dynamic changes. The simulation of series active filter with fuzzy controller is done in Matlab/Simulink platform and results are analyzed. Advantages of using a fuzzy based controller are accurate results, fast response and absence of a mathematical modeling requirement.

Keywords: Series active filter, controller.

1. INTRODUCTION

The term power quality ensures the delivery of high grade of power to the consumers. To get high quality, the conditions to be met are the voltage has to be distortion free, within stipulated magnitude, reliability has to be maintained, no unbalance in the voltage and acceptance of dynamic, low power factor nonlinear load without causing any significant effect on terminal voltage [8].

The most prominent sources for poor power quality are non linear load with solid state devices, arcing devices, switching of loads and capacitor banks, staring of large size electrical machines, computers, electromagnetic waves, microcontroller based systems and other environmental factors. These sources creates main power quality issue s like voltage sag, swell, unbalance, distortions, notching, frequency variations and transients etc. These adversely affect the distribution side as well as the generation side. The main symptoms of poor power quality are communication interference, continuous black outs, flickering of lamps, over heated equipments, ground voltage at unexpected locations, frequent drop out of sensitive loads etc.

Before the invention of power electronic devices, the methods used for improving the quality of power are saturable reactors, capacitor banks, tap changing transformers etc. After that once the contraption of power electronic devices, facts deices like TSC-TCR, FC-TCR, DVR, TCSC, TSSR, GCSC and STATCOM have been used to improve the power quality. Passive and filters are other options. Passive filters mainly used to eliminate lower order harmonics. Different Custom power devices such as shunt active filter, series active filter and UPQC can be used to improve the power quality [7]. Shunt Active filters are used to compensate harmonics and reactive power, prevent unbalance, eliminate flicker etc. whereas the series active filter is used to get rid of all voltage turbulence and distortions [2]. Combination of passive and active filters (hybrid filters) [5] are also used. UPQC is the combination of series and shunt active filters [6]. Next cohort is the improved power quality converters in that the design itself is done in such a way that it improves the quality.

Nowadays the deregulated structure ensures the delivery of power with good quality and fast manner. This increases the competition among private companies. The main requirement in deregulated structure is the fast switching devices. That is the response time has to be very less. This can be achieved using fuzzy, neural or AI based controllers instead of usual analog controllers [4].

The main advantages of fuzzy based controllers are fast response, no specific requirement of a mathematical model and transient free switching [3]. Neuro-fuzzy models are also coming up in a big way.

In this paper the performance of a series active filter with IRPT controller [1] is compared with a series active filter based on a fuzzy controller.

2. PROPOSED SYSTEM

The proposed system is shown in Figure 1. The voltage source inverter is used as series active filter. Three phase programmable voltage block represents the source. The voltage source inverter is connected to the line through coupling transformer. The reference compensation voltage is generated by the fuzzy logic controller. The input to fuzzy controller is error (difference between reference and actual voltage) and change in error. The reference voltage is then compared with the actual voltage to get the pulses to the inverter. The inverter output voltage is injected to the line through series coupling transformers. The load used is three phase RL load.

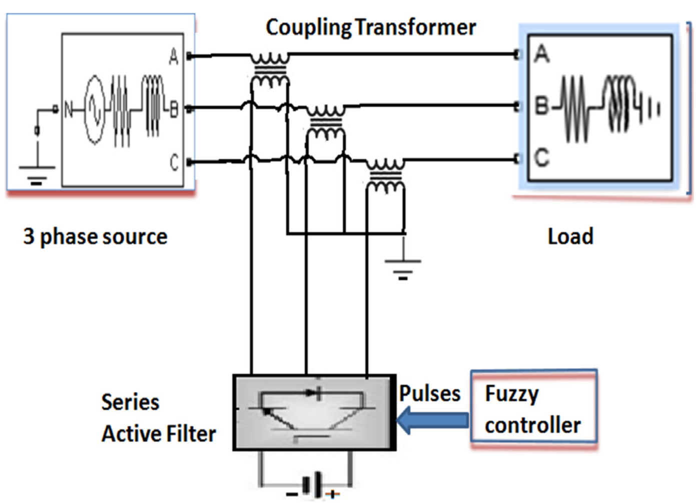

Figure 1: Block diagram representation of the proposed system

3. CONTROL ALGORITHM

The block diagram representation of controller is shown in Figure 2. The control algorithm is based on clarke's transformation. The sensed load voltage is transformed into $\alpha\beta$ plane.

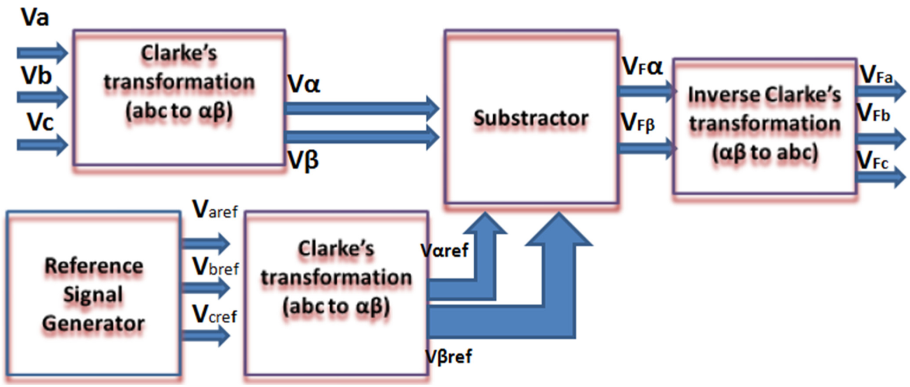

Figure 2: Block diagram representation of controller

The reference source voltage is generated and transformed into αβ plane. The subtractor outputs the reference filter voltage (compensating voltage) by comparing actual and reference voltages. Then filter voltage is obtained by transforming the calculated voltages in αβ plane back to three phase system using inverse clarke's transformation.

4. DESIGN PARAMETERS

A. *kVA rating of VSI:* For a voltage change of +25% or –25%, the voltage injected = $\sqrt{(Vs^2 - Vsag^2}$ = 152V

Current rating = load connected downstream = 7.246A for a load of 5kVA, upf

$$\text{kVA rating} = (3 \times 152 \times 7.246)/1000 = 3.3\text{kVA}$$

B. *kVA rating of Injection transformer:*

$$\text{kVA rating} = (3 \times 152 \times 7.246)/1000 = 3.3\text{kVA}$$

C. *DC Capacitor voltage of VSI:*

$$V_{DC} > 2\sqrt{2}\ V_{SC}$$

where, V_{SC} is the secondary side voltage

D. *DC bus capacitance of VSI:*

$$0.5\ C(V_{dc}^2 - V_{dc\ detla}^2) = 3V_C\ I_s\ \Delta t$$

where, $V_{dc\ detla}$

is the change in the dc bus voltage during transient condition and Δt is the time for which support is required. Here 5% change in DC bus voltage is considered and Δt is taken as 200μs.

E. *Design of Interfacing Inductor:*

$$L = n\left(\frac{\sqrt{3}}{2}\right) mV_{dc}/6af_s\Delta I_s$$

where, n = turns ratio (taken as 1)

m = modulation index (taken as 1)

a = overloading factor (taken as 1.2)

ΔI_s = ripple current in the inductor (taken as 2%)

F. *Design of ripple filter:* The *r* and *c* components of ripple filter is calculated based on the following relation $f_r = \frac{1}{2\Pi RC}$ where the frequency is taken as half of the switching frequency.

The design values are given in Table 1.

Table 1
Design parametrs

Load	5kW upf
KVA rating of Inverter	4 kVA
KVA rating of Transformer	4 kVA
V_{dc}	450V
DC link capacitor	5mF
Interfacing Inductor	12.5mH
Ripple filter	R = 1Ω, C = 500μF

5. FUZZY LOGIC CONTROLLER

Fuzzy control systems are having features like linguistic description, no need of mathematical models, robustness, and universal approximation. A fuzzy logic controller has four phases. The first one is called fuzzification. The second phase is developing a knowledge base. The third is developing an inference mechanism and fourth phase is defuzzification. The development of knowledge base is a process of designing the combination of database and rule base to obtain better dynamic response when process parameters exhibit uncertainty external disturbances. The database is made out of input and output membership functions which provide information for the appropriate fuzzification and defuzzification operations. The inference mechanism uses a set of rules to convert the input conditions into a fuzzified output. Finally, defuzzification is the process to convert the fuzzy outputs into control signals. The designing of a fuzzy control system focuses mainly on the formulation of its rule set because this process is the base for improvement of the system performance. The measured voltage is subtracted from reference voltage and this error is given as one input to the fuzzy controller. Other input is change in the error voltage. There are seven membership functions for each of the inputs and nine membership functions for the output which is the compensating voltage. The rule table contains 49 rule as shown in Table 2 where (N, Z, P) are linguistic codes (N: Negative, Z: Zero, P: Positive).

Table 2
Rule Base

Δe \ e	NL	NM	NS	Z	PS	PM	PL
NL	PL	PL	PL	PM	PS	PVS	Z
NM	PL	PL	PM	PS	PVS	Z	NVS
NS	PL	PM	PS	PVS	Z	NVS	NS
Z	PM	PS	PVS	Z	NVS	NS	NM
PS	PS	PVS	Z	NVS	NS	NM	NL
PM	PVS	Z	NVS	NS	NM	NL	NL
PL	Z	NVS	NS	NM	NL	NL	NL

The relation surface between input and output is represented in Figure 3.

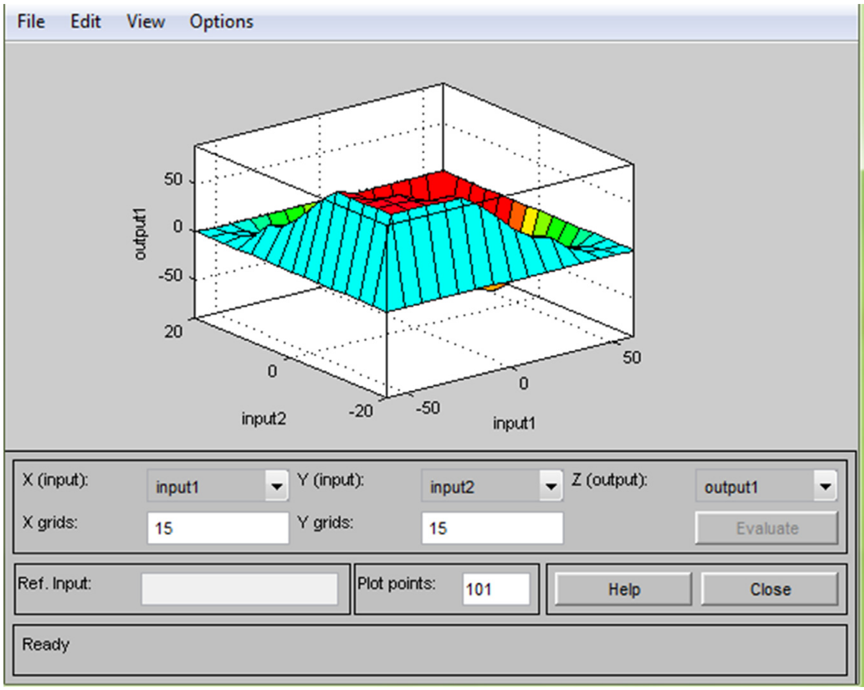

Figure 3: Relation Surface

6. RESULTS AND DISCUSSION

The proposed system is simulated first with IRPT controller to get the idea to develop the rule base for the fuzzy controller. From the results obtained the range for input and output variables are decided and rule base is also formed.

A. *Performance of the system under sag:* Sag of 25% is introduced at 0.1 sec in all the three phases and performance is evaluated.

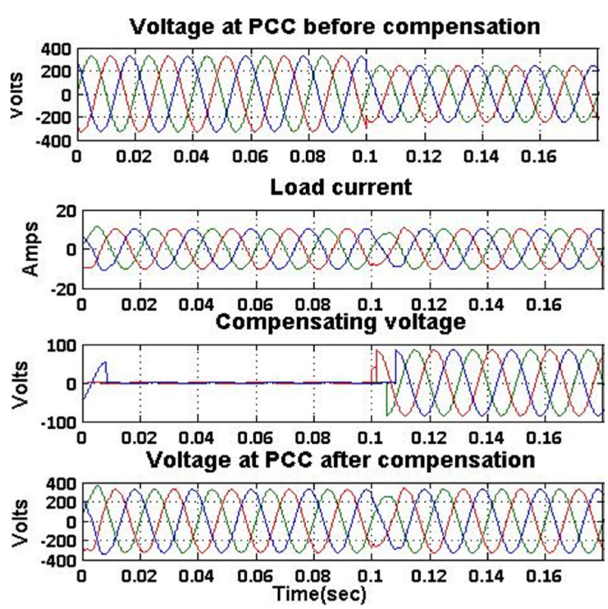

Figure 4. Waveforms at 25% sag condition

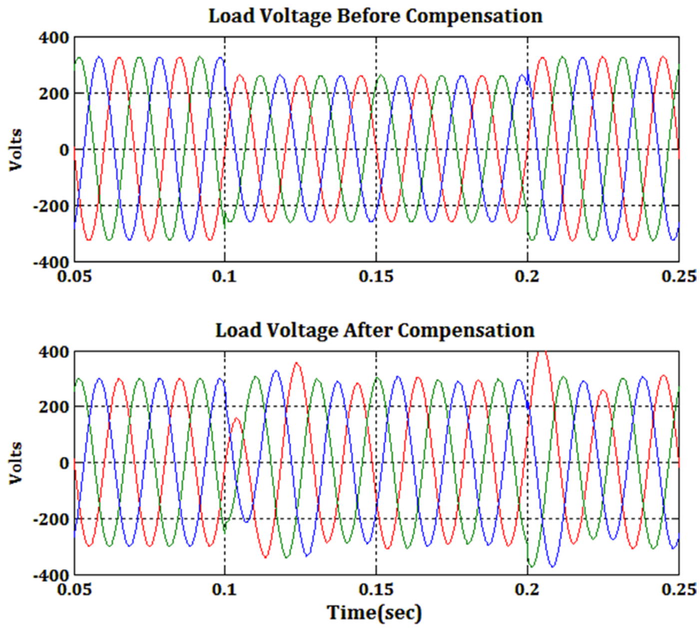

Figure 5. Waveforms at 20% sag condition with IRPT based controller

Figure 4.represents the voltage at PCC(point of common coupling),load current, compensating voltage and voltage at PCC after compensation respectively.It is seen that till 0.1 sec the compensating voltage is zero.Once sag is introduced at 0.1sec the fuzzy controller acts and compensating voltage is generated. By comparing actual and reference voltages pulses to the inverter are generated.This inverter output is injected to the line through the transformer.This voltage is added/subtracted with the line voltage there by maintaining rated voltage at PCC.From the results it is seen that the transition is very smooth and fast.Fig.5 represents the load voltage before and after compensation with IRPT based controller.Sag is introduced at 0.1 sec and it is compensated by the controller.But the response time in this case is high.

B. *Performance of the system under swell:* Figure 6.represents the voltage at PCC(point of common coupling),load current, compensating voltage and voltage at PCC after compensation respectively during swell condition.

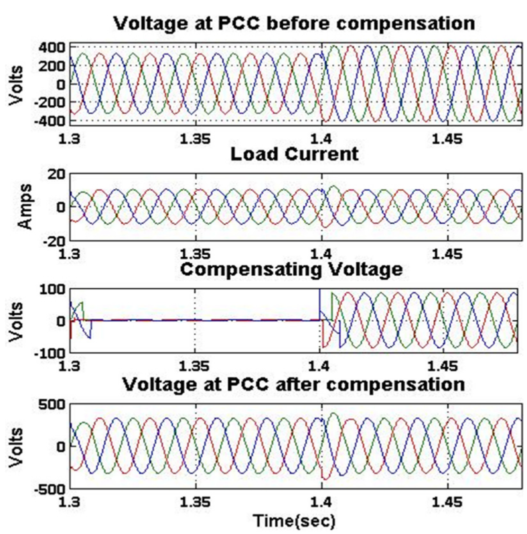

Figure 6: Waveforms at 25% swell condition

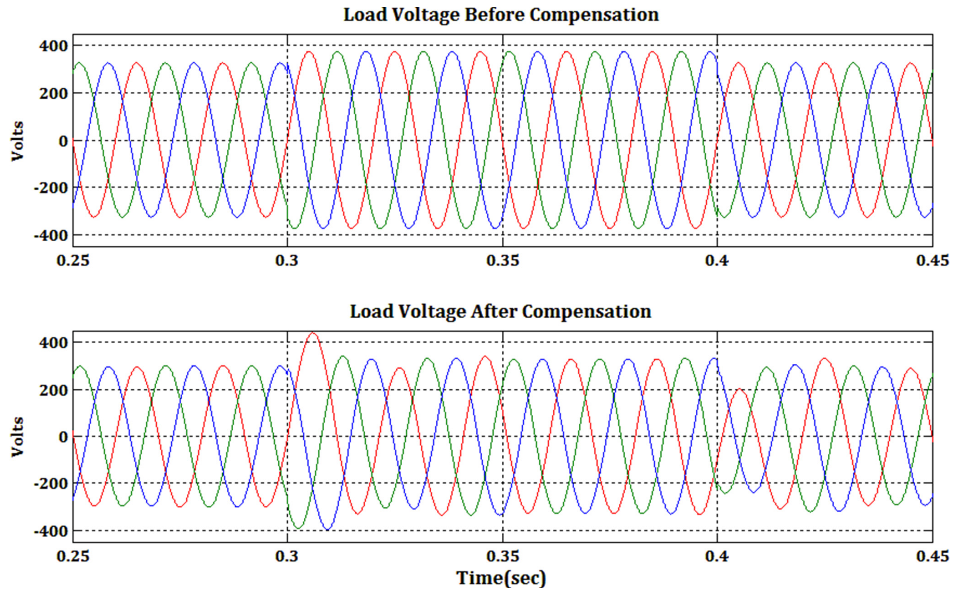

Figure 7: Waveforms at 15% swell condition with IRPT based controller

A swell of 25% is introduced at 1.4sec.From the results it is seen that within less than half a cycle the compensation is done which indicates the response of the fuzzy controller is almost instantaneous.

Figure 7 represents the load voltage before and after compensation with IRPT based controller under swell condition. Swell is introduced at $t = 0.3$ sec. It is seen that the compensation is done, but response time is more.

Even though the IRPT based controller has less number of blocks the response time taken by the controller is nearly one cycle where as the response is almost instataneous in the case of fuzzy controller. Also it is seen that the transtion from one state to other state is smooth in the case of fuzzy controller.

C. *Performance of the system during unbalance:* Figure 8.represents the voltage at PCC(point of common coupling), load current, compensating voltage and voltage at PCC after compensation respectively during unbalnce. That is swell is introduced only in phase A and Phase B and Phase C voltages are maintained at rated value.

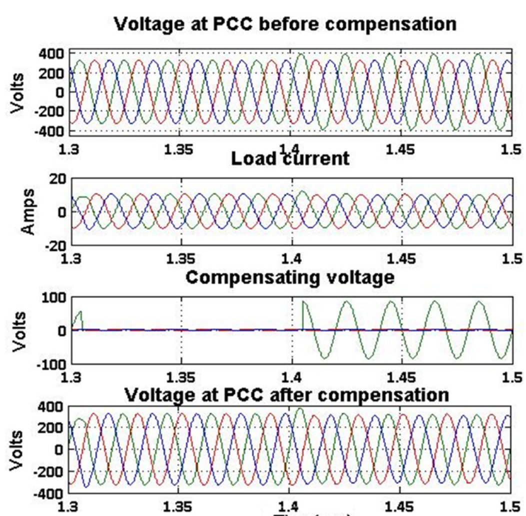

Figure 8: Waveforms at unbalance condition

At 1.4 sec 25% swell is introduced in phase A voltage and almost instantaneously it is corrected to rated voltage by the controller action.

7. CONCLUSION

The simulation of a series active filter with fuzzy controller is carried out in Matlab/Simulink platform. Mamdani maxmin type fuzzy inference and centroid method of defuzzification are used. Voltage perturbations like sag (20%), swell (20%) and unbalance are corrected by the series active filter with fuzzy controller. In all these cases, it is seen that within less than half a cycle effective compensation is done which indicates that the response of the fuzzy controller is almost instantaneous whereas series active filter with simple IRPT based controller takes a response time of nearly one cycle.

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