Study of PI and Fuzzy based PI Controller for Point of Use Voltage Regulation (PUVR) with AC Chopper

Priyanka Pandey[1] Shri S. K. Singh[2]
[1,2]Department of Electronics Design & Technology
[1,2]NIELIT, Gorakhpur, India

Abstract— With ever increase in demand in the urban areas loads, voltage profile at distribution end decreases now a days. So important is given to regulate the domestic customer load voltage and as well as to maintain the power quality. In this work attempt is made to improve the voltage profile at distribution end through point of use voltage regulation (PUVR) based on a power electronics converter at each end-user. An AC-AC converters are mostly used power electronic circuits in industrial areas, where a variable ac voltage is obtained from fixed ac voltage. Power electronics based AC chopper have been investigated in the simulation studies with different controllers such as proportional and integral (PI) controller and fuzzy based PI controller. Performance of the proposed system is studied under different loading as well as different load voltage conditions.
Key words: Component, Formatting, Style, Styling, Insert

I. INTRODUCTION

An AC-AC Converters are mostly used power electronic circuits in industrial areas, where a variable ac voltage is obtained from fixed ac voltage [1], [2]. There are lots of ac controllers are available for industrial application but AC chopper is frequently used as AC voltage regulation circuit to overcome the major disadvantages from other ac voltage controller and power quality is also improved in power system [3]. In this work AC chopper is used with PWM signal and it has an advantages over ac controllers to improve load power factor, low order harmonics are eliminated and wide control range [4]. There are two types of an ac output voltage control methods. These are ON-OFF control method and PHASE control method, in which phase control method has advantage over ON-OFF method and it can be conveniently implemented and exhibits cost effectiveness for large scale applications [5]. There is need of more advanced control methods to meet the real requirement [6]. To obtain a control method which has the best performance under any conditions is always in demand.

Conventionally open loop PI, PID and PD controllers are most popular and used in most power electronics closed loop appliances [7]. The main objective of this work is to study the implementation and performance of fuzzy logic based PI controlled technique over conventional PI control method. Classical methods provide better conditions for working of converters such as fixed switching frequency and zero steady state error [8]. It leads difficulty in analysis and control of nonlinear converters. So there is need of nonlinear and digital stabilizing control methods which can be applied to ensure large signal stability. Recently there are many researchers reported that Fuzzy Logic Controller (FLC) becomes one of intelligent controllers to their appliances [9].

Fuzzy Logic control provides a formal methodology to represent, manipulate and implement human's heuristic knowledge about how to control a system [10]. Fuzzy controllers are represented by if-then rules and thus can provide a user-friendly and understandable knowledge representation. In this paper, the performance of PI controller and fuzzy based PI controller is evaluated under change in load resistance and change in load reference voltages. [11].

The objective of this work is to simulate the methods of voltage regulation using fuzzy logic based PI controller with conventional PI controller. The robustness and feasibility of proposed control techniques is simulated in MATLAB/SIMULINK environment.

II. AC CHOPPER

AC chopper is two switch based power electronics converter that is used to control the AC output voltage from variable AC input voltage. The circuit of AC chopper is shown in Fig.1.

The AC chopper is controlled through the sinusoidal pulse width (SPWM) modulation technique where two modulating sinusoidal signal (1800 phase apart) of same frequency of input voltage is used. Switch S1 and S3 is used to regulate the output voltage at positive half cycle and S2 and S4 used to regulate the output voltage at negative half cycle. The pulse patterns of S1 & S3 and S2 & S4 are complement with each others. The amplitude of modulating signal is used as a controlling parameter to control the output voltage.

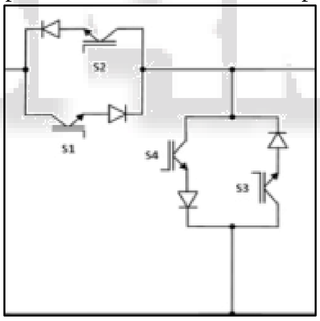

Fig. 1: AC chopper circuit without filter [4]

The load voltage, load current and input current of AC copper are shown in Fig.2 which are pulsating in nature and high in THD due to inherent property of SPWM. To reduce the THD, LC type filter is used at input as well as output in AC chopper as shown in Fig.3. The different voltage and current waveforms are shown in Fig.4 after use the LC filters. The SIMULINK parameters of the AC chopper are shown in Table 1.

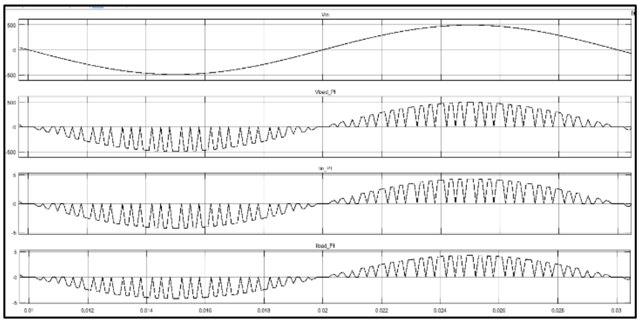

Fig. 2: Voltage and current waveforms without filter

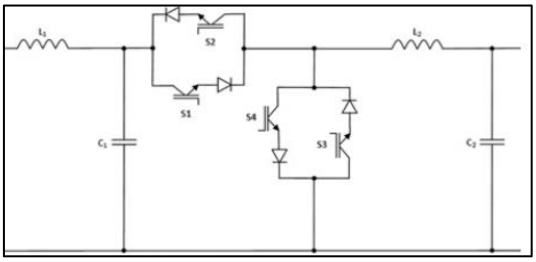

Fig. 3: AC chopper circuit with filter [4]

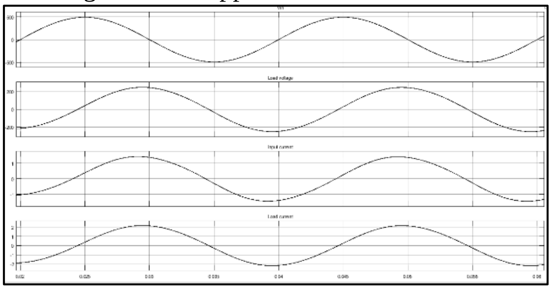

Fig. 4: Voltage and current waveforms with filter

Component	Value
Input inductor (L1)	2mH
Output inductor (L2)	2mH
Input capacitor (C1)	0.6 µF
Output capacitor (C2)	0.6 µF
Switching frequency	33 KHz

Table 1: Simulink Parameters of Simulation Model[]

Proportional integral (PI) and fuzzy based PI controller has been used to control the output voltage of AC chopper. Output of controller is used as modulation index for SPWM.

III. PI CONTROLLER SYNTHESIS FOR VOLTAGE REGULATION

To control the load voltage at reference voltage ($V_{loadref}$) irrespective load change and input voltage change, PI controller is used. Control diagram of PI controller based system is shown in Fig.5.

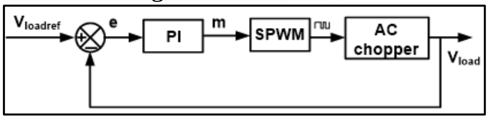

Fig. 5: PI controller based voltage regulation scheme

The difference between reference load voltage ($V_{loadref}$) and actual load voltage (V_{load}) is error signal (e) which is used to control the load voltage. The error signal acts as input of PI controller which produce the appropriate modulating signal (m) for SPWM. The relation between error (e) and modulating signal (m) is given in Eq.1.

$$m = K_p * e + K_i * \int e \, dt \quad (1)$$

Where:

Proportional gain (K_p) = 0.01

Integral gain (K_i) = 1.2

MATLAB/ SIMULINK based PI controller synthesis is shown in Fig.6.

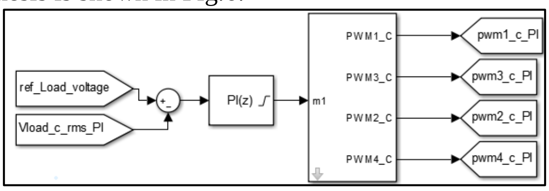

Fig. 6: Simulink model of PI controller based voltage regulation scheme

IV. FUZZY PI CONTROLLER BASED CONTROLLER SYNTHESIS

Fuzzy being a nonlinear controller is in control system due to fast dynamic and steady state response.

In this work fuzzy based PI controller is used to improve the transient and steady state response of conventional PI controller. Mamdani fuzzy controller is used to modify the integral gain of PI controller. The MATLAB implementation of fuzzy based PI controller is shown in Fig. 7.

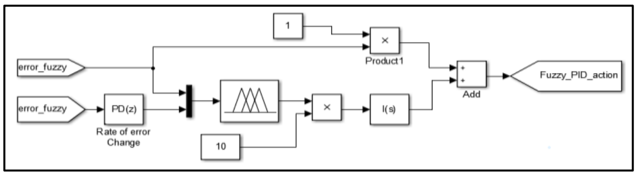

Fig. 7: MATLAB/SIMULINK implementation of fuzzy based PI controller

The input of fuzzy controller is error (e) and change of error. Membership function for error (e) is shown in Fig.8 and membership function of change of error is shown in Fig.9. The rule viewer of fuzzy controller is shown in Fig.10. MATLAB/SIMULINK implementation of fuzzy based PI controller is shown in Fig.11.

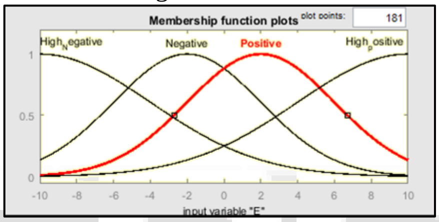

Fig. 8: Membership function of error signal

V. COMPARISON RESULTS BETWEEN PI AND FUZZY PI

The above mentioned AC chopper is simulated in MATLAB/SIMULINK environment. Performance of AC chopper is tested through PI and fuzzy based PI controller. Performances of controllers are tested under different loading conditions as well as different step change in load voltage reference.

Simulation is set to run for 1.5 seconds. Change in load with respect to simulation time is shown in Table 2 and change in load voltage reference is shown in Table 3.

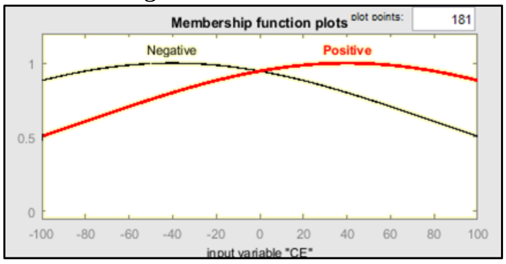

Fig. 9: Membership function of change of error signal

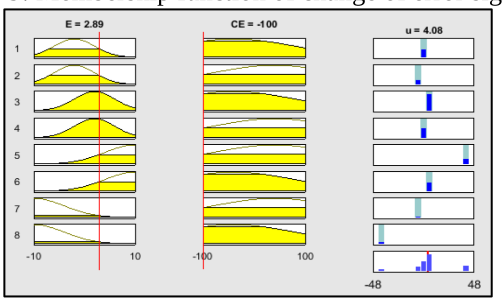

Fig. 10: Rule viewer of fuzzy controller

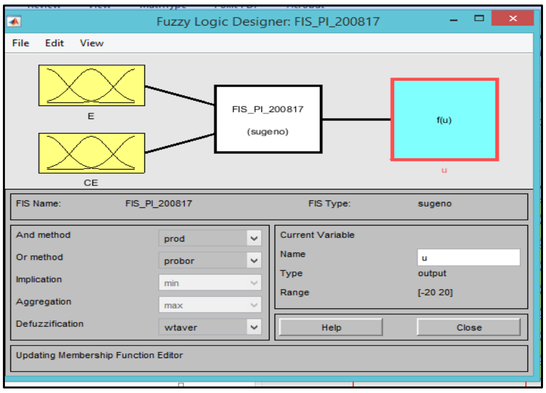

Fig. 11: MATLAB synthesis of fuzzy controller

Simulation time (sec)	Resistive load (at 240 V RMS, 50 Hz)
0-0.2	500 W
0.2-0.4	1000 W
0.4-1.5	2500 W

Table 2: Load Change in Simulation

Simulation time (sec)	Load voltage reference (AC) (RMS) (50 Hz)
0-0.75	240 V RMS
0.75-1	220 V RMS
1-1.5	250 V RMS

Table 3: Load Voltage reference change in simulation

Performance result in PI controller is shown in Fig 12 where first result shows the input voltage, second result shows the load voltage, third results shows the input current and last result shows the load current.

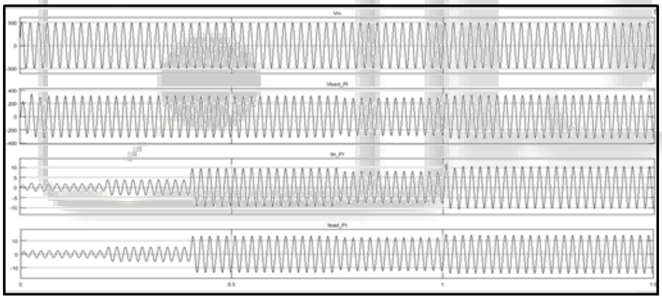

Fig. 12: Performance of PI controller

The tracking performance of PI controller is shown in Fig. 13 where first result shows the reference rms load voltage, second result shows the actual load rms voltage, third results shows the input current, forth result shows the error in tracking and last one shows the PI output.

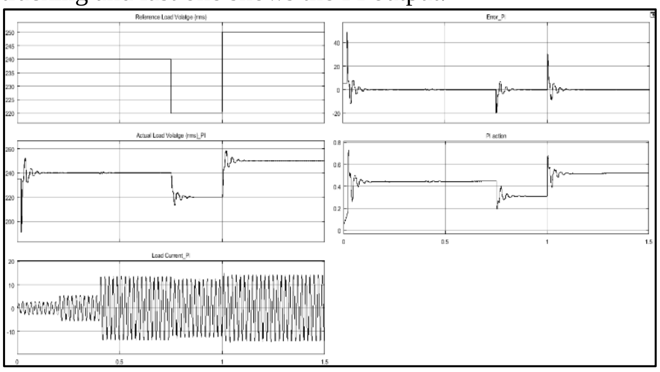

Fig. 13: Tracking performance of PI controller

Performance result in fuzzy based PI controller is shown in Fig 14 where first result shows the input voltage, second result shows the load voltage, third results shows the input current and last result shows the load current.

The tracking performance of fuzzy PI controller is shown in Fig. 15 where first result shows the reference rms load voltage, second result shows the actual load rms voltage, third results shows the input current, forth result shows the error in tracking and last one shows the fuzzy PI output.

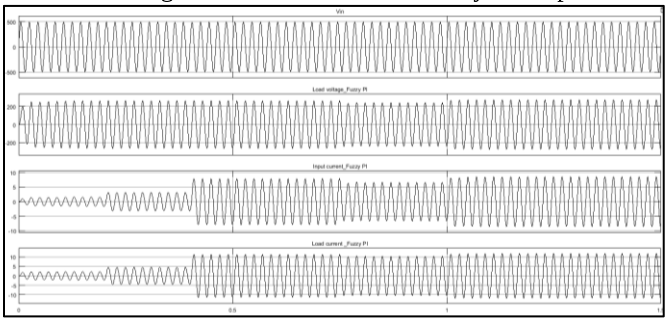

Fig. 14: Performance of fuzzy PI controller

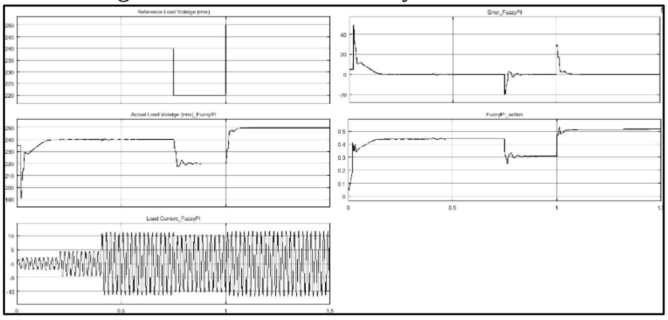

Fig. 15: Tracking performance of PI controller

It is observed from Fig.12-15 that both PI and fuzzy based PI able to track the reference load voltage under different conditions however transient and steady state response is better in fuzzy based PI controller than PI controller. Comparison result between fuzzy based PI and PI controller is shown in Fig.16.

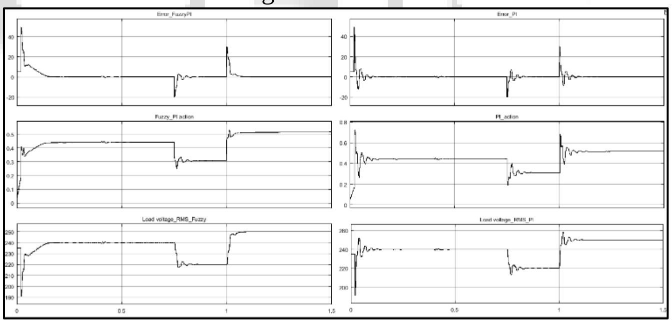

Fig. 16: Comparison between fuzzy based PI and PI controller

VI. Conclusions

In this work AC chopper is studied for voltage regulation purpose. It is found that AC chopper can be suitable for load AC voltage regulation. Implementation studies are done in MATLAB/SIMULINK environment. MATLAB based implementation of PI controller and fuzzy based PI controller is achieved. Performance of both controllers is studies under both varying load conditions and varying load voltage conditions.

It is found that PI and fuzzy based PI controller is suitable for distribution voltage regulation however fuzzy based PI controller gives stiff regulation compare to PI controller.

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