ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 6, June 2014

Power Factor Correction of Three Phase Diode Rectifier at Input Stage Using Artificial Intelligent Techniques for DC Drive Applications

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ABSTRACT: This paper focuses on the power quality improvement of three phase diode rectifier for DC drive applications. The input current harmonics distortion (THD), power factor at input side and voltage regulation of the three phase diode rectifier is investigated for power quality improvement. In this method, bidirectional switches are connected across the front end rectifier to improve the conduction of input current in order to improve the Total Harmonic Distortion (THD). The buck regulator is connected at the output stage of three phase diode rectifier for the voltage regulation. The circuit with buck regulator is simulated for different torque conditions of DC motor using PI current controller, Fuzzy Logic Controller (FLC) and Adaptive Neuro-Fuzzy Inference Systems (ANFIS) and the results are compared for the power factor improvement. Design of Fuzzy controller and Adaptive Neuro-Fuzzy Inference Systems (ANFIS) are based on heuristic knowledge converter behavior. The design of PI control is based on the frequency response of the converter. For the DC drive applications, the performance of the Fuzzy controller and Adaptive Neuro-Fuzzy Inference Systems (ANFIS) are superior in some respects to that of the PI controller.

KEYWORDS: Three phase diode rectifier, Fuzzy Logic Controller, Adaptive Neuro-Fuzzy Inference system, power factor correction, and DC drives.

I. INTRODUCTION

HARMONIC current pollution generated by nonlinear loads is a serious problem in power systems. Numerous harmonic standards have been put forward on this issue, for example, IEEE and IEC standards [1]. Since three-phase diode rectifiers are widely used in industry, such as adjustable speed drives and dc power supplies [2]–[4], the harmonics generated by the diode rectifier in the line current is a main concern in power electronics. To eliminate the harmonic current generated by this type of harmonic source, the shunt active power filter (APF) or series APF has been an effective solution [5]–[11]. However, the rating of APF is normally small because of its partial power processing property. Hence, it generally features with low cost and small volume. Shunt APF's are usually paralleled at the ac side. Therefore, both the voltage and the current processed by APF are with alternating values.

A four-quadrant inverter is commonly used in the power stage of the ac side APF, and an ac side APF always needs complicated harmonic current detection and control. On the other hand, the three-phase power factor correction (PFC), which is a full power processing solution, has been extensively studied [12]–[19]. The most popular topology of the three-phase PFC is a six-switch bridge. This type of PFC has the feature of bidirectional power flowing capability. In some specific applications, unidirectional PFC topologies such as the Vienna converter [15], [16] and the series connected dual boost converter [19], [20] are considered. Both bidirectional and unidirectional three-phase PFCs are required to process all the load power. Thus, most of them suffer from higher silicon cost as compared with the APF solutions which require only partial power processing. Multipulse rectifiers, which employ low frequency phase shift transformer to synthesize reasonable line current waveform, are also reported for the reduction of the silicon cost [17], [18]. Due to the application of low frequency transformer, the volume is a critical limitation. Three phase diode rectifier with bidirectional switches and the buck regulator at the output stage is implemented [21]-[25] with DC and AC drive applications. The performance of diode rectifier is verified with only one controller.

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ISSN: 2319-8753

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In this paper, a simple buck regulator at the output stage of three phase diode rectifier with bidirectional switches is proposed. The buck regulator regulates the voltage at the output stage for speed control applications. The Fuzzy Logic based control method and ANFIS are developed to improving the conduction period of the bidirectional switches. The new technique is simulated with DC drive application by PI current controller, Fuzzy Logic Controller and ANFIS and the results are compared.

II. ANALYSIS OF PROPOSED DIODE RECTIFIER WITH BUCK REGULATOR

The circuit diagram of proposed diode rectifier with buck regulator is shown in Fig. 1. For the circuit analysis, six topological stages are presented in Fig. 2 a to f, corresponding to the 0° to 180° half period. Two main situations can be identified:

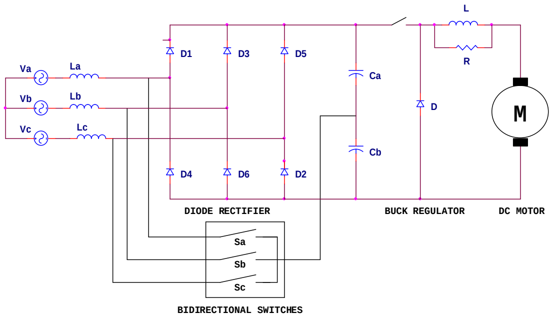
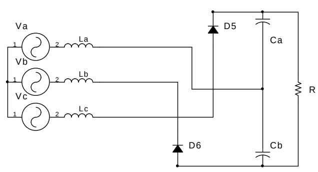


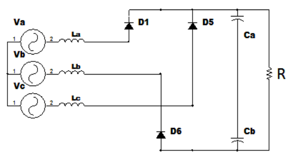
Fig. 1. Proposed diode rectifier with buck regulator

1. In the stage I, III and V, there are only two conducting diodes. As a result, on a conventional three-phase rectifier, the current on the third phase remains null during that interval. In the circuit, the switch associated with the third phase is gated on during that interval. For instance, during the 0° to 30° stage, the bidirectional switch is gated on, so the input current evolves from zero to a maximum value.

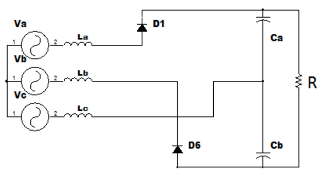
2. In the stage II, IV and VI, there are three conducting diodes, one associated with each phase. The three switches are off, so the converter behaves like a conventional rectifier with input inductors.



(a)



(b)



(c)

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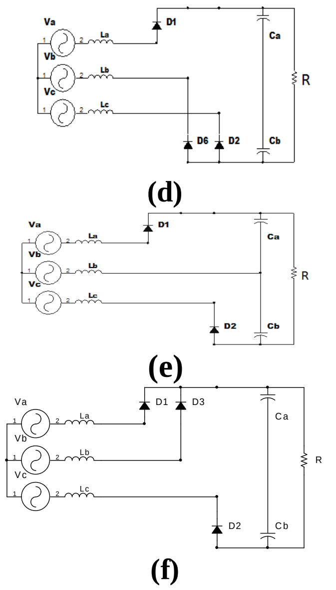

Fig. 2. Conduction of diodes of six topological stages

(a) Stage I – 0°to30° (b) Stage II– 30°to60° (c) Stage III – 60° to 90° (d) Stage IV – 90° to 120° (e) Stage V – 120°to150° (f) Stage I – 150°to180°

A. Bidirectional Switches

When gate circuit is open and Vdd is present, no current flow from drain to source. When gate terminal is made positive with respect to source, current flows from drain to source. The construction of bidirectional switch using four diodes and MOSFET is shown in Fig. 3.

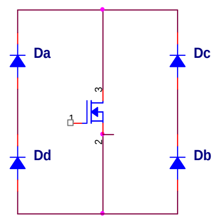

Fig. 3. Bidirectional switch

During positive half cycle of the input voltage, diodes Da and Db are forward biased. When gate signal is applied with respect to source, the input current flows through Da, MOSFET and Db to the load.

During negative half cycle of the input voltage, diodes Dc and Dd are forward biased. When gate signal is applied with respect to source, the input current flows through Dc, MOSFET and Dd to the load.

B. PI Current Controller

Fig. 4 shows the block diagram of PI current controller. It continuously compares the output current with the reference value and generates the signal to control the conduction of the bidirectional switch. The summing point produces the error signal by comparing the output current and reference value. This error signal is given to the integrator through the gain block to Continuous-time integration of the input signal. The output the integrator and error signal is given to another summing point. The output of summing point is given to the saturation block to limit the input signal to the upper and lower saturation values.

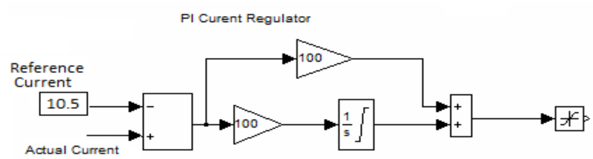

Fig. 4. PI current controller

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C. Fuzzy Logic Controller

The inputs to the fuzzy controller are output current and Error (e) in output current. The output from the fuzzy controller is control signal CS. The fuzzy variables Negative Large (NL), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Large (PL), Positive Medium (PM) and Positive Small (PS). In the simple block diagram of the Fuzzy Logic control system shown in Fig. 5, the reference current is compared with a output current of diode rectifier, and the difference between the reference current and output current is equal to the error (e). The output current and error are both uses as inputs to the FL controller. The FL controller uses the TSK technique to obtain control signal as its output. The control signal is then fed to the bidirectional switches to modify the conduction period and then input current.

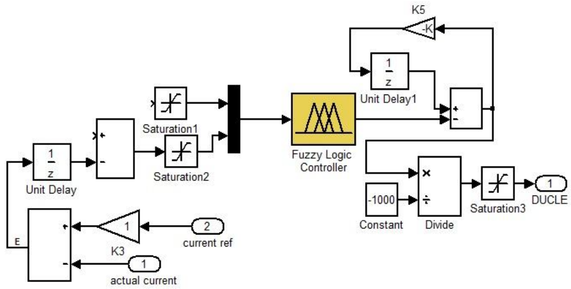

Fig. 5. Fuzzy Controller

D. Adaptive Neuro-Fuzzy Inference Systems (ANFIS)

The objective is to design Adaptive Neuro-Fuzzy Inference Systems (ANFIS) that will improve the input current total harmonic distortion (THD) as well as power factor at the input stage by controlling the conduction period of the bidirectional switches. The ANFIS will use both the output current and output current error of the circuit as input and obtain a control signal as its output. The controls signal will then increase or decrease the conduction period of bidirectional switches that will either achieve the desired power factor at the input stage. The ANFIS Model Structure is shown in Fig. 6.

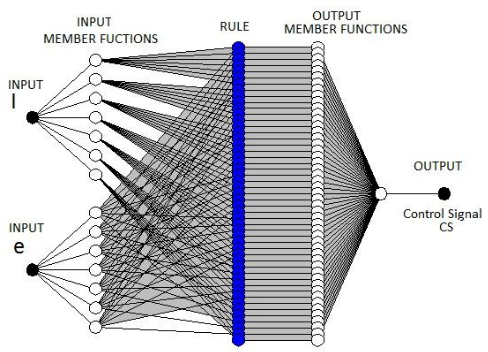

Fig. 6 ANFIS Model Structure

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International Journal of Innovative Research in Science, Engineering and Technology

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III. SIMULATION RESULTS

The closed loop simulation diagram of three phase diode rectifier with bidirectional switch is shown in Fig. 7.

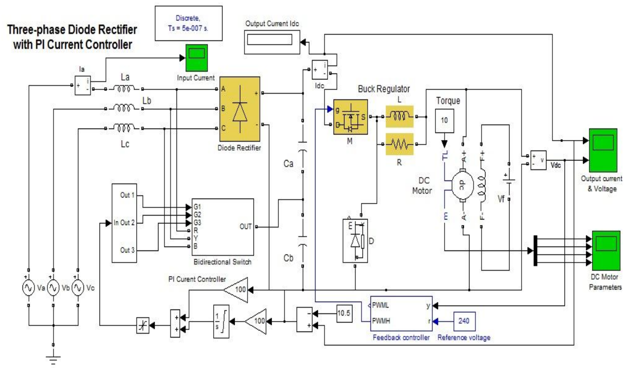

Fig. 7. Closed loop control of three phase diode rectifier with bidirectional switch

The input current waveform and THD of three phase diode rectifier with bi directional switch is shown in Fig. 8. The THD value of input current is 24.94 %.

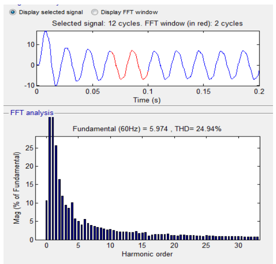

Fig. 8. The input current waveform and THD of three phase diode rectifier with bidirectional switch for closed loop control

The load test on DC motor with closed loop control was performed and reading was tabulated in the table. III. In this closed control, input current value is increased and therefore input power is also increases gradually. So the performance of the DC motor is improved.

TABLE I LOAD TEST ON THREE PHASE DC MOTOR WITH CLOSED LOOP CONTROL

Torque (N-m)	Input Current (Amps)	Input Voltage (Volts)	Speed (RPM)	Input Power (Watts)	Output Power (Watts)	Effi. (%)
1	2.4	223	1730	535.20	181.07	33.83
2	3.1	221	1711	685.10	358.17	52.28
3	4.1	217	1697	889.70	532.86	59.89
4	5	214	1685	1070.00	705.45	65.93
5	6.2	212	1674	1314.40	876.06	66.65
6	7.4	210	1664	1554.00	1044.9	67.25
7	8.5	208	1655	1768.00	1212.5	68.58
8	9.4	206	1647	1936.40	1379.0	71.22
9	9.9	204	1642	2019.60	1546.7	76.59
10	10.2	203	1638	2070.60	1714.4	82.80

The Fuzzy Logic Controller based simulation diagram of three phase diode rectifier is shown in Fig. 9. The input current waveform and THD of three phase diode rectifier with bidirectional switch is shown in Fig. 10. The THD value of input current is improved with 24.20 % when compared with closed loop system of 24.94 %. So the input current waveform is also improved with sinusoidal form.

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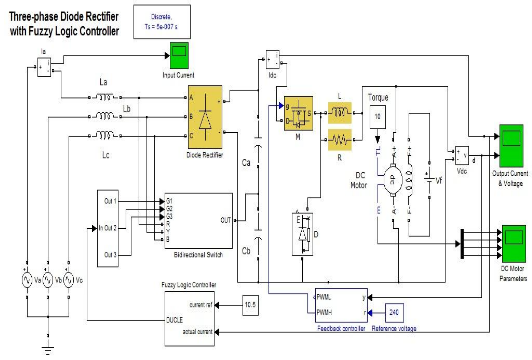

Fig. 9. Fuzzy Logic Controller based simulation diagram of three phase diode rectifier

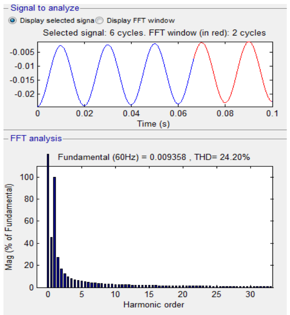

Fig. 10. The input current waveform and THD of three phase diode rectifier with bi directional switch for fuzzy logic control

The load test on DC motor with fuzzy logic control was performed and reading was tabulated in the table. II. In this fuzzy logic control, input current value is further increased when compared with closed loop control and therefore input power is also increases gradually. So the performance of the DC motor is improved.

TABLE II LOAD TEST ON THREE PHASE DC MOTOR WITH FUZZY LOGIC CONTROL

Torque (N-m)	Input Current (Amps)	Input Voltage (Volts)	Speed (RPM)	Input Power (Watts)	Output Power (Watts)	Effi. (%)
1	2.6	218	1756	566.80	183.79	32.43
2	3.2	214	1749	684.80	366.12	53.46
3	4.2	212	1737	890.40	545.42	61.26
4	5.1	210	1726	1071.0	722.62	67.47
5	6.3	209	1719	1316.7	899.61	68.32
6	7.5	207	1707	1552.5	1072.00	69.05
7	8.6	206	1692	1771.6	1239.67	69.97
8	9.5	205	1684	1947.5	1410.07	72.40
9	10.1	203	1672	2050.3	1575.02	76.82
10	10.4	201	1669	2090.4	1746.89	83.57

The Adaptive Neuro-Fuzzy Inference Systems (ANFIS) based simulation diagram of three phase diode rectifier with bi directional switch is shown in Fig. 11.

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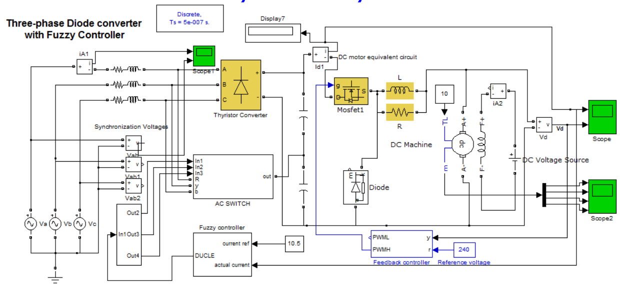

Fig. 11. Adaptive Neuro-Fuzzy Inference Systems based simulation diagram of three phase diode rectifier

The input current waveform and THD of three phase diode rectifier with bi directional switch is shown in Fig. 12. The THD value of input current is improved with 24.18 % when compared with closed loop system of 24.94 %. So the input current waveform is also improved with sinusoidal form.

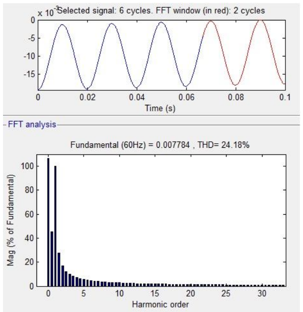

Fig. 12. The input current waveform and THD of three phase diode rectifier with bi directional switch for fuzzy logic control

The load test on DC motor with Adaptive Neuro-Fuzzy Inference Systems (ANFIS) was performed and reading was tabulated in the table. III. In this system, input current value is further increased when compared with closed loop control and therefore input power is also increases gradually. So the performance of the DC motor is improved.

TABLE III LOAD TEST ON THREE PHASE DC MOTOR WITH ADAPTIVE NEURO-FUZZY INFERENCE SYSTEMS (ANFIS)

Torque (N-m)	Input Current (Amps)	Input Voltage (Volts)	Speed (RPM)	Input Power (Watts)	Output Power (Watts)	Effi. (%)
1	2.6	212	1758	551.20	184.00	33.38
2	3.2	210	1752	672.00	366.75	54.58
3	4.3	207	1742	890.10	546.99	61.45
4	5.3	203	1736	1075.90	726.81	67.55
5	6.5	202	1724	1313.00	902.23	68.71
6	7.6	202	1712	1535.20	1075.14	70.03
7	8.7	202	1699	1757.40	1244.80	70.83
8	9.6	196	1689	1881.60	1414.26	75.16
9	10.3	193	1683	1987.90	1585.39	79.75
10	10.6	192	1668	2035.20	1745.84	85.78

The relationship between torque and efficiency for closed loop control, Fuzzy control and Adaptive Neuro-Fuzzy Inference Systems (ANFIS) is shown in Fig. 13. The efficiency of the DC motor is improved in the Adaptive Neuro-Fuzzy Inference Systems (ANFIS). The comparision of simulation results are shown in Table. IV.

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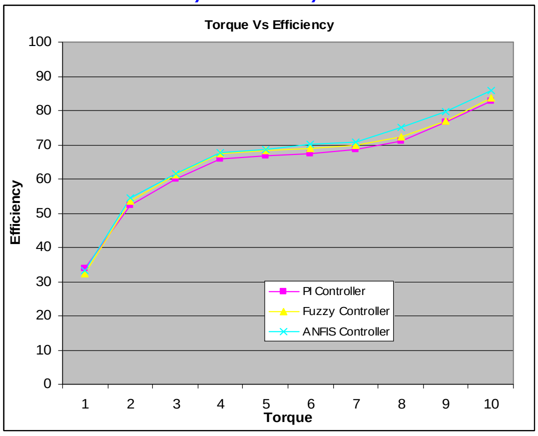

Fig. 13. Variation of efficiency with torque

TABLE IV COMPARISON OF SIMULATION RESULTS

Controller	Max. Efficiency Without Filter at Torque 10 N-m (%)	Improvement in Efficiency (%)
PI Current Controller	82.8	3
Fuzzy Logic Controller	83.57	4
ANFIS	85.78	6.5

IV. CONCLUSION

From the results it is evident that three phase diode rectifier with PI controller, Fuzzy Inference System and Adaptive Neuro-Fuzzy Inference Systems have improved performance in terms of input current harmonics distortion (THD), power factor at input and output side, voltage regulation and switching losses. Good performance is exhibited in recognizing the optimal generation of control signal to the bidirectional switches. The technique has been tested for the three phase diode rectifier with various load torque condition of DC motor. The network is trained by different possible combinations of the output current and its corresponding optimal signal is generated for triggering of bidirectional switches. The test results were compared for ANFIS with FLC. The FLC with neural network makes the solution little bit more efficient only by trains the parameters.

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BIOGRAPHY

G. T. Sundar Rajan was born in 1975. He has received the B.E. (Electrical and Electronics) degree from the Madras University and the M.E. degree in power electronics from the Sathyabama University, Chennai, India, in 1997 and 2007, respectively. He has received the PhD degree from Sathyabama University, Chennai. He has published technical papers in international and national journals and conferences. His areas of interest are power quality improvement, harmonics reduction, AC and DC drives applications.