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Performance Analysis of PI Controller and PR Controller Based Three - Phase AC-DC Boost Converter with Space Vector PWM

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Abstract

Three phase Boost rectifiers are utilized as a part of distributed power generation applications such as micro turbines, windmills, fuel cells etc. The controlled and uncontrolled rectifiers are generally non linear in nature. Thus it causes high harmonic content in the line current, reduced power factor, low efficiency, voltage distortion etc. To overcome these disadvantages, Power converters need control techniques. In this research, PI Controller and PR Controller are used to control the DC output voltage generated using Space Vector Pulse Width Modulation technique (SVPWM) in three phase Boost rectifier. SVPWM is the special switching sequence is given to the boost rectifier. SVPWM having switch utilization and less harmonic component in the Boost rectifier. The parameters characterizing the power quality such as Total Harmonic Distortion

(THD), Power Factor, Total Demand Distortion (TDD) and Efficiency are measured and analyzed in the three phase AC to DC Boost rectifiers using PI controller, PR controller Technique.

***Key Words*:**AC-DC converter, PR Controller, Power Factor, PI controller, Total harmonic distortion.

1 INTRODUCTION

Power electronics equipment's turned out to be all the more generally utilized. Lamentably, the standard diode/thyristor connect rectifiers at the input side reason a few issues as: low input power factor, high estimations of harmonic distortion of AC line currents, and harmonic contamination on the framework [1]. Present days, Pulse Width Modulation (PWM) rectifiers are exceptionally prominent and more appealing. The utilization of PWM control in rectifier dispenses with the issue caused by phase controlled rectifiers [5]. The PWM rectifiers are utilized as a part of numerous applications like dc motor control, electric traction, and so forth. The PWM rectifier is a favored decision for giving a dc voltage source to dc burdens or voltage source bolstered drives, because of its ability of input power factor control, low harmonic distortion of line current, dc voltage control and bi directional power stream, alteration and adjustment of dc interface voltage, diminished dc channel capacitor size[2],[3]. PWM based Single phase AC-DC boost converters have been the wellspring of enthusiasm over late years. A very tight regulations over the harmonics produced by electronic gear, in addition to the lower cost of control circuits and power semiconductors, have made boost rectifiers more appealing. There are a wide range of PWM modulation strategies, for example, sinusoidal PWM, space vector PWM, delta modulation methods. Space vector modulation strategy has favorable position of a use of switch and furthermore lessens harmonic of the output voltage/current. It has been dissected hypothetically and demonstrated that the SVPWM system is possibly the best modulation arrangement in general [4],[5]. Numerous control methods have been received for these rectification devices to enhance the input power factor and shape the input current of the rectifier into sinusoidal waveform, however their standards contrast [6], [7]. Especially, the voltage orientation control (VOC) and virtual flux orientation control (VFOC) and direct power control (DPC) can ensure a high progression and static exhibitions by inside circles of current control[8-12]. The present controlling style has the benefits of quick unique current reaction, great exactness, settled exchanged frequency and less touchy to parameter variety [13-15]. Another approach is Proportional Resonant controller, which is presenting an infinite gain at chose resonant frequency for taking out enduring state blunder at that frequency. With adaptability of tuning resonant frequency, it can specifically repay low request harmonics [16-18]. In this paper, two kinds of controller is utilized to control the DC output voltage utilizing space vector pulse width modulation in three phase PWM rectifier. In the main sort, one will utilize a PI controller whose proportional and integral activities offer to the system an insignificant overshoot and a decent response time. In the second sort of control, PR controller activities offer to the system a less many-sided quality of control and less computational prerequisite and quick transient response.

2 CIRCUIT DESCRIPTION

The circuit outline of the three phase voltage source rectifier structure is indicated Fig.1. So as to setup math show, it is expected that the AC is a balanced three phase supply, the filter reactor is direct IGBT is perfect switch and lossless [5].

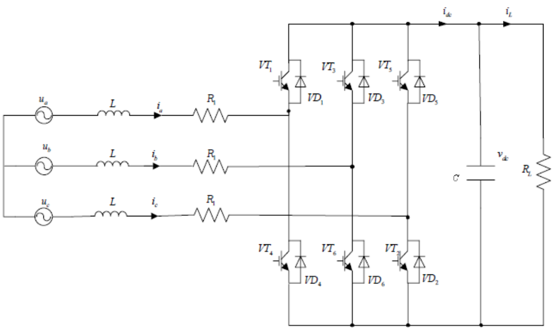

Fig.1 Three phase PWM Rectifier

Where Ua, Ub, Uc → Phase voltages of the three phase balanced voltage source
ia, ib, ic → phase currents
Vdc →DC output voltage,
R1 and L → input resistance and inductance of filter circuit
C →smoothing capacitor over the DC bus
RL → DC side load
Ura, Urb, Urc → input voltage of rectifier
iL →stack current
The accompanying conditions portray the dynamical conduct of the Boost rectifier in Park composed or in d-q as:

$$L\frac{di_d}{dt} = v_d - i_d R_1 + \omega L i_q - U_{rd}$$

$$C\frac{dV_{dc}}{dt} = -\frac{V_{dc}}{R_1} + \frac{3}{2}(S_d i_d + S_q i_q)$$

$$L\frac{di_q}{dt} = v_q - i_q R_1 + \omega L i_d - U_{rq} \tag{1}$$

3 SPACE VECTOR MODULATION

Space Vector PWM (SVPWM) alludes to an exceptional switching sequence of the upper three power transistors of a three-stage power converter. It has been appeared to produce less harmonic distortion in the output voltages or potentially currents and to give more proficient utilization of supply voltage contrasted with sinusoidal modulation system. Contingent upon the switching state on the circuit Fig 1, the bridge rectifier leg voltages can expect 8 conceivable particular states spoke to as voltage vectors (V0 to V7) in the - coordinate. All the vectors are shown in the fig.2 . the six non-zero vectors are named from V1 to V6 and V0 and V7 are two zero vectors. Three phase voltage can be treated as a voltage vector Vs. There is a wide range of techniques for modulation to orchestrate Vs as per the diverse blends eight vectors. Among these strategies, the two phase modulation can influence switching misfortune to limit, in which one switch ought to be constantly determined to ON or OFF in working cycle. To actualize the space vector PWM, the voltage conditions in the abc reference frame can be changed into the stationary dq reference frame that comprises of the horizontal (d) and vertical (q) axes as portrayed in Fig.1. V, V, Vref, and angle () can be determined as follows:

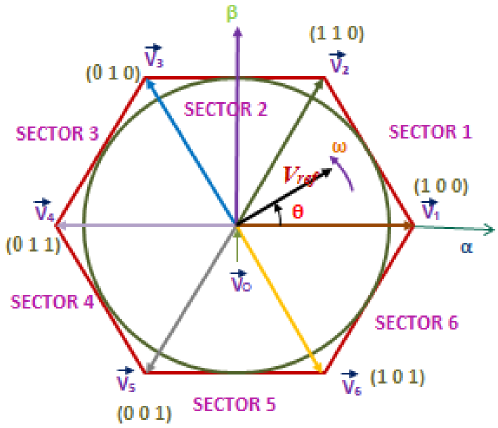

Fig.2 Simple space vector modulation

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \tag{2}$$

$$|\overrightarrow{V}| = \sqrt{V_\alpha^2 + V_\beta^2} \tag{3}$$

$$\Theta = tan^{-1}(\frac{V_\beta}{V_\alpha}) = \omega_s t = 2\pi f_s t \tag{4}$$

The desired reference vector is inspected in each sub cycle Ts and acknowledged by time averaging the three closest space vectors in the space vector stage [5][6] for instance, the reference vector appeared in fig. 3 with magnitude Vs and angle in part 1, is acknowledged by applying the active vector 1, the active vector 2 and the zero vector. The spans T1, T2 and Tz of the three space vectors, individually is computed as:

$$T_1 = T_z.a.\frac{sin(^{\pi}/_{3-\alpha})}{sin(^{\pi}/_{3})} \tag{5}$$

$$T_2 = T_z.a.\frac{sin(\alpha)}{sin(^{\pi}/_{3})} \tag{6}$$

$$T_0 = T_z - (T_1 + T_2) \tag{7}$$

$$T_z = \frac{1}{f_s} \quad anda = \frac{\overrightarrow{(}V)_{ref}}{2/3V_{dc}} \tag{8}$$

This time durations of (T1,T2,T0) are compared with the Triangular waveform ,and gating signals are generated. The gating signal of the upper switches of the three phase rectifier is shown in fig. 6. At the point when an upper transistor is exchanged on, the comparing lower transistor is turned off.

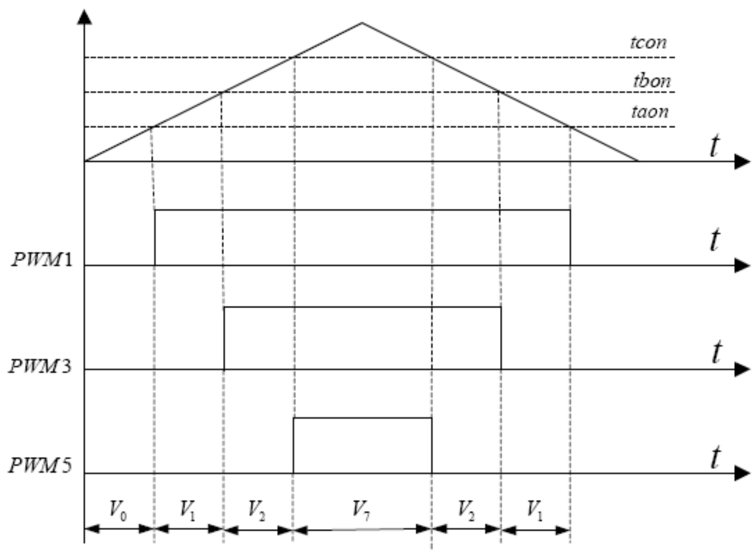

Fig.3. Gating Signals for PWM rectifier

Table: 1 Switching sequence table

Sector	Upper Switches (S_1, S_3, S_5)	Lower Switches (S_4, S_6, S_2)
1	$S_1 = T_1 + T_2 + T_0/2$ $S_3 = T_2 + T_0/2$ $S_5 = T_0/2$	$S_4 = T_0/2$ $S_6 = T_1 + T_0/2$ $S_2 = T_1+T_2+T_0/2$
2	$S_1 = T_1 + T_0/2$ $S_3 = T_1 + T_2 + T_0/2$ $S_5 = T_0/2$	$S_4 = T_2 + T_0/2$ $S_6 = T_0/2$ $S_2 = T_1+T_2+T_0/2$
3	$S_1 = T_0/2$ $S_3 = T_1 + T_2 + T_0/2$ $S_5 = T_2 + T_0/2$	$S_4 = T_1+T_2+T_0/2$ $S_6 = T_0/2$ $S_2 = T_1 + T_0/2$
4	$S_1 = T_0/2$ $S_3 = T_1 + T_0/2$ $S_5 = T_1 + T_2 + T_0/2$	$S_4 = T_1+T_2+T_0/2$ $S_6 = T_2 + T_0/2$ $S_2 = T_0/2$
5	$S_1 = T_2 + T_0/2$ $S_3 = T_0/2$ $S_5 = T_1 + T_2 + T_0/2$	$S_4 = T_1 + T_0/2$ $S_6 = T_1+T_2+T_0/2$ $S_2 = T_0/2$
6	$S_1 = T_1 + T_2 + T_0/2$ $S_3 = T_0/2$ $S_5 = T_1 + T_0/2$	$S_4 = T_0/2$ $S_6 = T_1+T_2+T_0/2$ $S_2 = T_2 + T_0/2$

The switching sequence table for the lower and upper thyristors are appeared in the Table 1. The above development of the symmetrical pulse design for two continuous Tz interims are appeared and Ts = 2Tz = 1/(fs = Switching recurrence) is the examining time. Note that the invalid time has been advantageously appropriated between the V0 and V7 vectors to depict the symmetrical pulse width.

A. PI CONTROLLER Figure 4 demonstrates the closed loop simulink model of three-stage AC to DC boost converter with PI control. In this strategy, both the voltage and current will be detected. The corrected voltage from the diode bridge and the output voltage of the error intensifier are duplicated and it gives the reference current. This is known as the external loop i.e., the voltage loop. In the internal loop i.e., the present loop, inductor current is contrasted and the reference current and the present error intensifier will be prepared. It is compared with the saw tooth ramp. The output pulse created will be given to the switch.

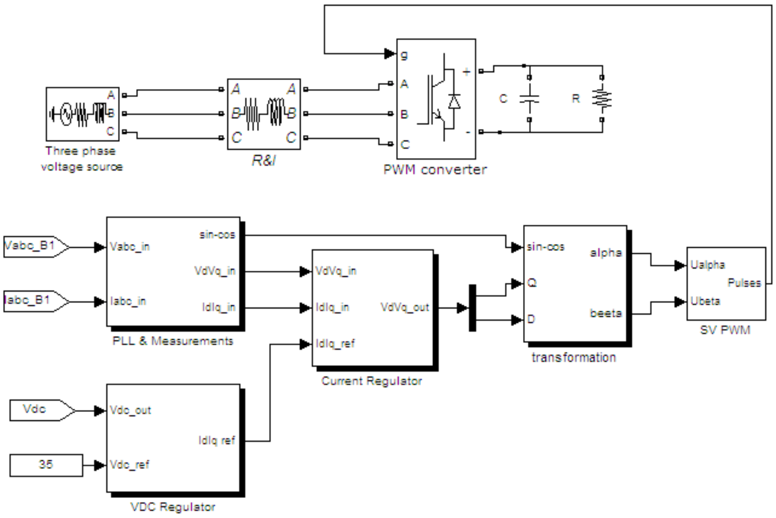

Fig.4. Closed loop simulink model of three-phase AC to DC boost converter with PI controller

Figure.8 shows the input voltage and current waveform of the three-phase AC to DC boost converter in the closed loop analysis. Figure 9 shows the output current and voltage waveform of three- phase AC to DC boost converter with PI controller. Figure 10 shows the harmonic spectrum of three- phase AC to DC boost converter with PI controller.

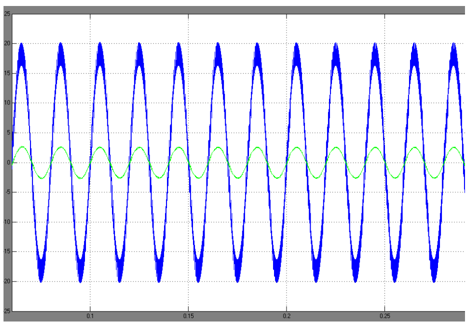

Fig.5. Input current and voltage waveform of three -phase AC to DC boost converter with PI controller

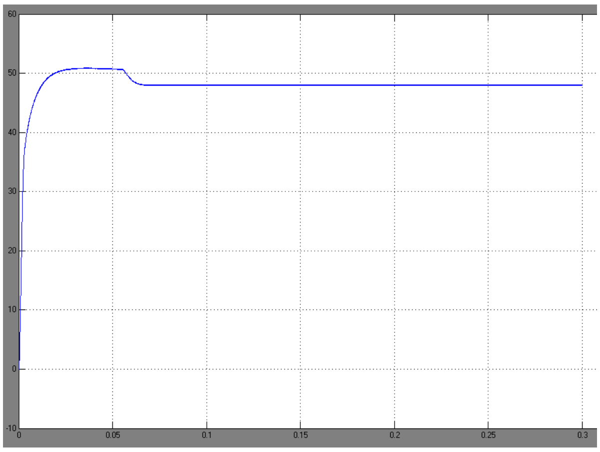

Fig.6. Output voltage waveform of three-phase AC to DC boost converter with PI controller

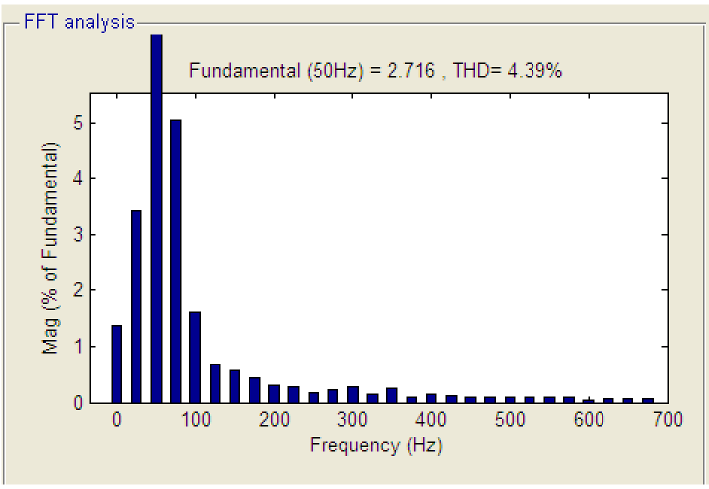

Fig.7. Harmonic spectrum of three phase AC to DC boost converter with PI controller

Using PI control the load and input voltage are varied over certain range, the variations in the parameters such as THD, TDD, and power factor are observed. The table I and II show the variation of load resistance and the input voltage respectively

Table: 2 Performance Analysis Of PWM Rectifier Using PI Controller

Load %	Output Voltage	Power Factor	THD (%)	Efficiency
10	49	0.9222	2.39	93.7%
16	48	0.9268	4.39	97.7%
20	48.22	0.9296	5.88	97.6%
25	49.45	0.9306	7.78	98%
30	49.63	0.9365	8.65	98%

Table I shows, if resistance of the load will varied (increased from 50 to 65) the output voltage almost constant but output power decreased, THD and TDD increased. Power factor will increased from 0.9587 to 0.9969.

B. PR CONTROLLER

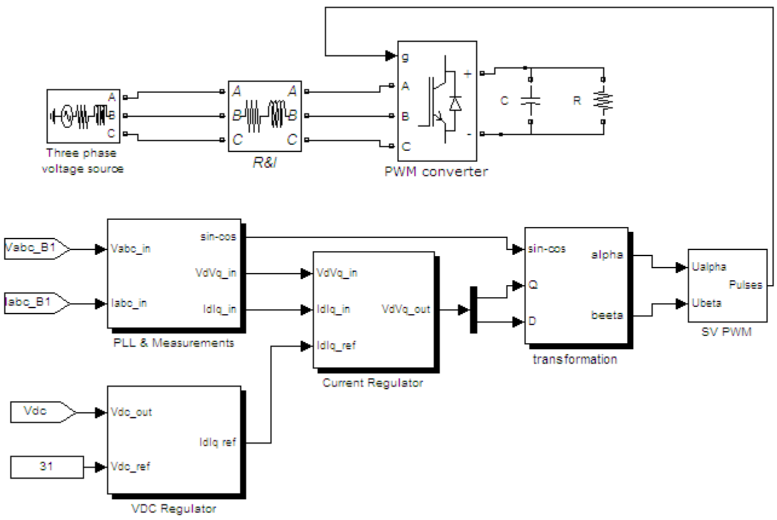

Fig.8. Closed loop simulink model of three-phase AC to DC boost converter with PI controller

The decoupled double close-loop controller has been reproduced utilizing MATLAB/SIMULINK to test the execution of PWM rectifier depicted by the proposed work. The entire system conduct is reproduced as a discrete control system. Fig.5 shows the developed simulation model of the PWM rectifier with PR controller. The PR controller is applied to obtain a fast transient and steady state to reduce oscillation and improve the system stability. The switching frequency of PI controller is 20 kHz. In the circuits, the AC source is a perfect adjusted three-stage voltage source with frequency of 50Hz. In this work, the Proportional Resonant controller whose transfer function is,

$$G_c(s) = K_p + \frac{2K_i\omega_c S}{S^2 + 2\omega_c S + \omega_1^2} \tag{9}$$

Where kp and ki are proportional gain and integral gain. c is the cut off frequency. And 1 is the fundamental frequency. In this way with the resonant control technique one can track the high frequency sinusoidal current order without expanding the exchanging frequency nor receiving a greatly huge control gain that may bring about a danger of system's unsteadiness.

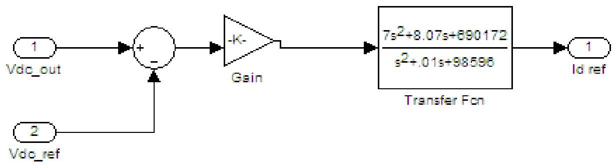

Fig.9. Voltage Regulator Circuit

In Fig.6 the actual output voltage is compared with the desired output voltage and the error is controlled by the voltage regulator. The output voltage regulator is given to the current regulator unit. The current regulator unit compares the voltage regulator output and input current. Output of the current regulator unit is given to the transformation block which generates the - component. This two phase quantity is given to the space vector modulation. The space vector modulation generates the pulses for the PWM rectifier. Three Phase input voltage and input current quantities are converted into the two phase quantities by using the clarkes transformation eqn(6).

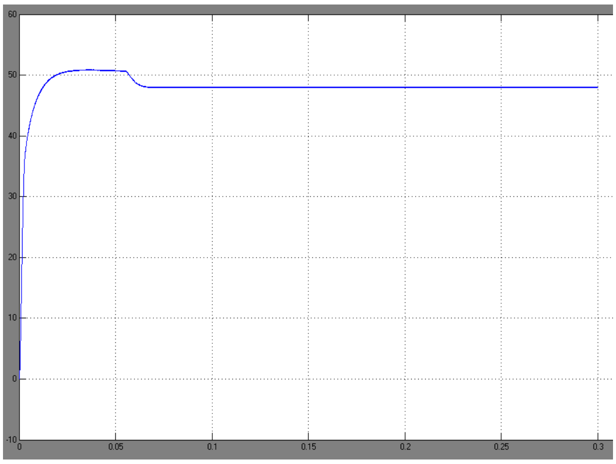

Fig.10. Output voltage waveform of three-phase AC to DC boost converter with PR controller

The output voltage is regulated using PR controller. The supply side voltage and current are measured, which is shown in figure 11. The value of the input power factor is 0.9309.

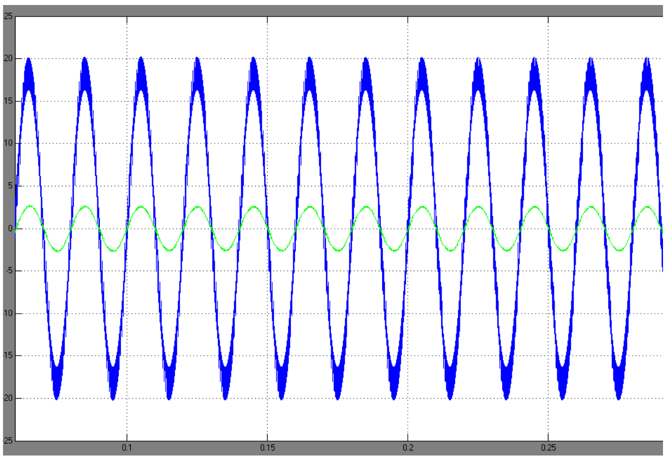

Fig.11. Input current and voltage waveform of three -phase AC to DC boost converter with PR controller

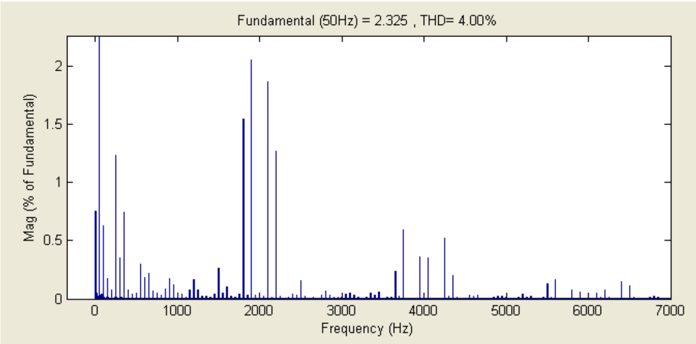

Fig.12. Harmonic spectrum of three phase AC to DC boost converter with PI controller

Table: 3 Performance Analysis Of PWM Rectifier Using PR Controller

Load %	Output Voltage	Power Factor	THD (%)	Efficiency
10	49	0.9208	3.83	95%
16	47.99	0.9310	4	99%
20	48.32	0.9324	4.67	99%
25	48.45	0.9457	5.27	98.2%
30	48.63	0.9435	6.78	98%

4 CONCLUSION

The three phase AC-DC boost converter was examined in various conditions These tests were finished utilizing diverse control systems, with PI controller and PR controller. The overall performance for PR controller is great when contrasted with other control and very robust against load variations. Using the proposed converter the obtained value of THD is less than 5% as prescribed by IEEE as the minimum limits of THD. Power factor is also nearby unity comparing with other techniques.

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