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Three Phase Twelve Pulse Controlled Rectifier with Reduced Output Current Harmonics Using PI Controller

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Abstract: **The power conversion from AC to DC and vice versa is basic need for several industrial applications, single phase or three phase controlled or uncontrolled convertor is used for this purpose. In these types of convertors large lower order harmonics are present. A twelve pulse three phase rectifier is used for reducing harmonics in high power applications, but the (12m±1) order harmonics are still present in the system. For further reduction of harmonics this paper proposes a PI controller based synchronous twelve pulse generator used for gate triggering of controlled twelve pulse rectifier with DC motor as a load.**

Keywords: **power conversion, controlled or uncontrolled convertors, PI controller, harmonics.**

1. INTRODUCTION

Most commonly used power conversion devices are consists on the diodes and thyristors for single phase and three phase power conversion from AC to DC or DC to AC. Due to commutation or turn off of these rectifiers occur at zero crossing of current, hence these are called as line commutated rectifiers. Since the commutation circuit is absent in these circuits hence these are economical but draw reactive power from the source so the power quality of the system becomes poor. To improve the power quality of the system and reduce the harmonics in the system passive linear filters can be employed [1-3]. The three phase multi pulse rectifiers are used to overcome these issues by using different connection combination of the three phase transformers [4-5]. The diode rectifiers are simplest and reliable but due to these filters they become large and unwieldy.

Three phase pulse width modulated rectifiers are used for low and medium power drive applications where the requirement of international standards should be satisfied [6-9]. These types of rectifiers are the most promising rectifiers from a power quality viewpoint [10- 12] since they can present low harmonic distortion and unity power factor.

The series and /or parallel combination of a line commutated rectifier and a self commutated rectifier are used for the rectification of three phase power in high power conversion system and is known as hybrid rectifiers. The line-commutated rectifier operates at low frequency and has a higher output power rating. The active rectifier is designed to operate with a small power rating and at a high switching frequency [13-16].

The circulation of current harmonics into the source impedance yields in harmonic polluted voltages at the point of common coupling (PCC) and consequently resulting in undesired supply voltage conditions for costumers in the vicinity. The value of current harmonic components which are injected into the grid by nonlinear loads such as DTCIMDs should be confined within the standard limitations. The most prominent standards in this field are IEEE standard 519 [2] and the International Electro technical Commission (IEC) 61000-3-2 [17].

A convertor of 12-pulse [1], [5], [13]–[15] consisting of two sets of six-pulse rectifiers is used for high-power applications. This convertor diminishes the effect of fifth and seventh harmonic components produced by each of the two

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rectifiers, but the (12m±1) th (*m*: integer) harmonics still remain in the resultant input currents. It is usual to use passive power filters tuned to harmonics 11 and 13, and an additional high-pass filter to eliminate the remaining harmonics.

2. PROPOSED 12-PULSE AC TO DC CONVERTOR

A 12-pulse rectified voltage can be made with two paralleled six-pulse three-phase (three-leg) controlled/uncontrolled-bridge rectifiers. The phase shift between two supplying voltages should be 30 degrees which is provided through two transformers of connections star-star and star-delta. The proposed 12-pulse convertor is shown in fig1.

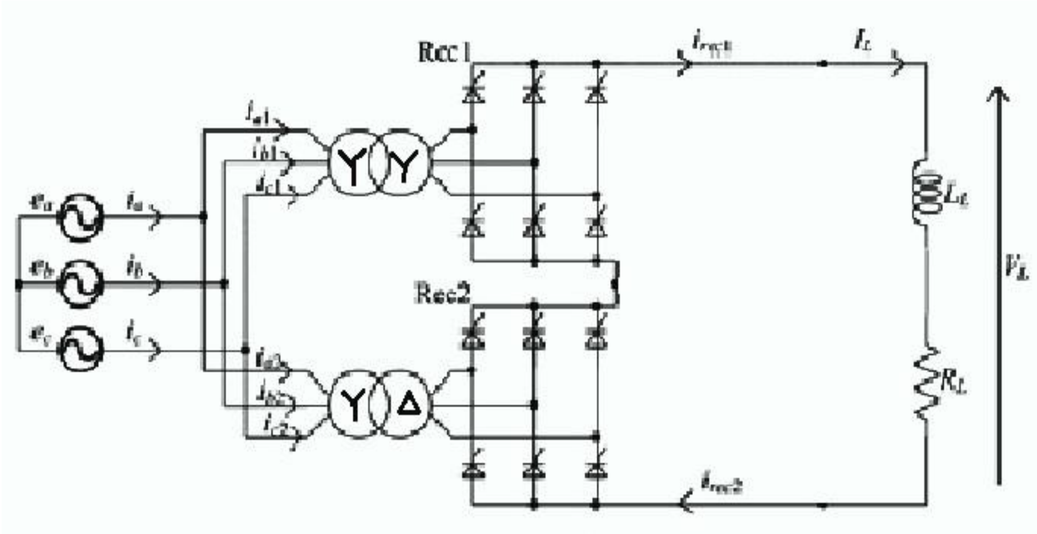

Fig.1. Circuit configuration for 12 pulse convertor

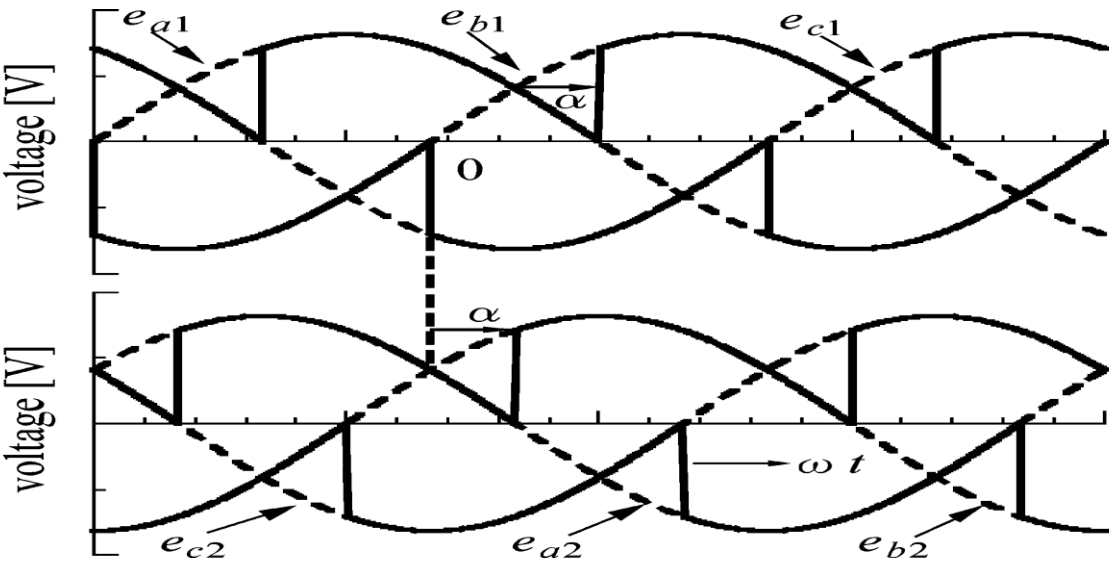

Fig.*2.* Two sets of three-*phase* mains voltage supplied to two convertors

The following two sets of three-phase main voltage systems, *e*1 and *e*2, defines the two rectifier systems Rec1 and Rec2, respectively. These are illustrated in Fig. 2.

$e_{a1} = E\,sin(\omega t + \frac{2\pi}{3})$ $\qquad e_{a2} = E\,sin(\omega t + \frac{5\pi}{3})$

$e_{b1} = E \sin \omega t$ $\qquad e_{b2} = E \sin\left(\omega t + \frac{\pi}{6}\right)$

$$e_{c1} = E\,sin\left(\omega t - \frac{2\pi}{3}\right) \quad e_{c2} = E\,sin\left(\omega t - \frac{\pi}{2}\right)$$

Consider a time period, $\theta = \alpha$ *to* $\theta = \alpha + \pi/6$ with $\theta = \omega t$. The commutation in Rec2 starts at $\theta = \alpha$ from phase-*a*2 to phase-*b*2, and it finishes instantaneously. Similarly other thyristors start conduction when the phase voltages of positive group thyristors are maximum positive and negative group thyristors are maximum negative. The firings of thyristors are controlled through PI controller.

CHARACTERISTICS OF PROPOSED RECTIFIER: The average dc output voltage *VL*0 and output power out of the rectifier will be

$$V_{L0} = \left(\frac{3\sqrt{3}}{\pi}\right) E \cos\alpha \qquad Pout = \left(\frac{3\sqrt{3}}{\pi}\right) EI_L \cos\alpha$$

If PI controller is not used, at light load, either Rec1 or Rec2 having a higher instantaneous dc voltage provides the dc current to the load for a 30◦-period and the rest stops conducting the dc current, but at heavy load, both Rec1 and Rec2 provide the dc current simultaneously. If PI controller is used, Rec1 and Rec2 provide the dc current simultaneously, but the current of extinguishing thyristor is reduced to zero at every commutation instant. The average dc voltage *VL*0 is exactly proportional to $\cos\alpha$ because no current overlap occurs at thyristor commutation. Accordingly, the proposed rectifier provides a slightly lower dc average voltage than a conventional 12-pulse rectifier.

3. SIMULATION DIAGRAM AND WORKING

The matlab simulation diagram of the proposed convertor is shown in fig.3. The two six pulse controlled convertors are connected in cascade and the input given to both rectifiers from identical two sets of three phase voltage source and phase displaced by 30^0 to each other. Assume that the dc output current of the rectifier circuit were triangular with a frequency twelve times that of the utility having a dc component I_L.

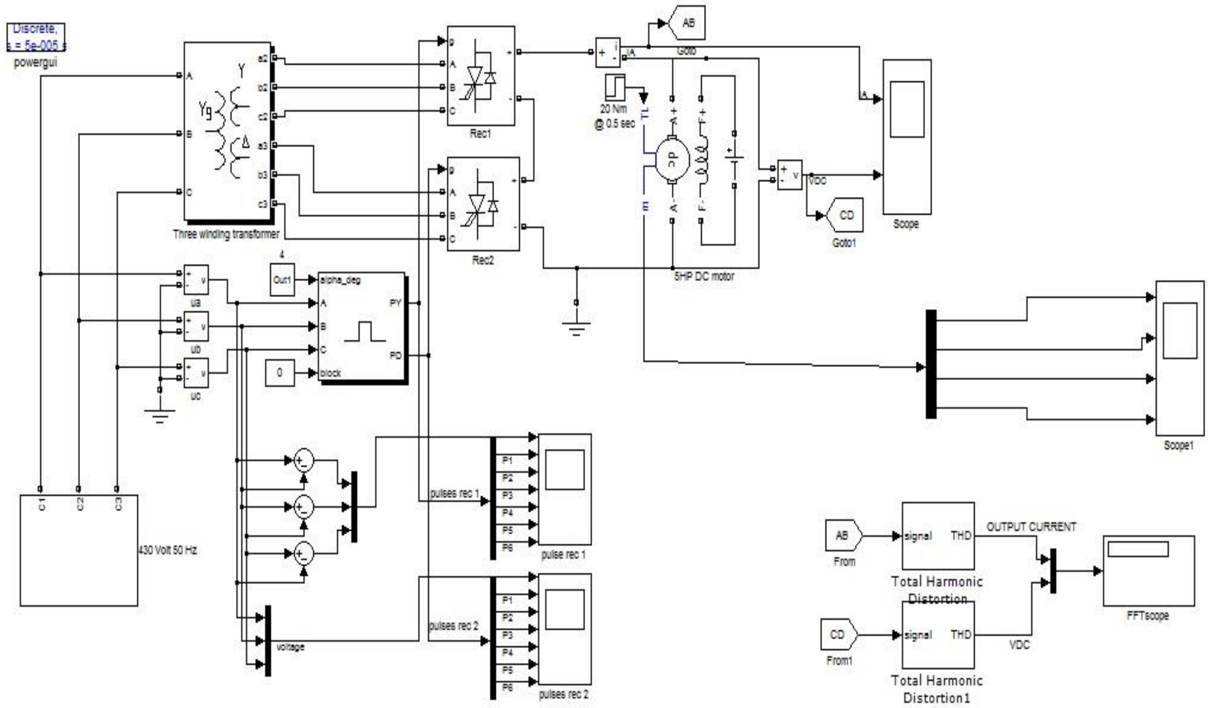

Fig.3. Simulation diagram of 12pulse controlled rectifier

A twelve pulse synchronized pulse generator is used to generate the twelve synchronized gate pulses for triggering the 12 thyristors used in 12- pulse convertor. The pulse generator is synchronized with the load current and the firing angle of the thyristors. For this purpose a PI controller is used and the Transfer function of PI controller is given by

$$G = \mathrm{Kp} + \frac{\mathrm{Ki}}{\mathrm{s}}$$

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Where K_p is the proportional constant and K_i is the integral constant.

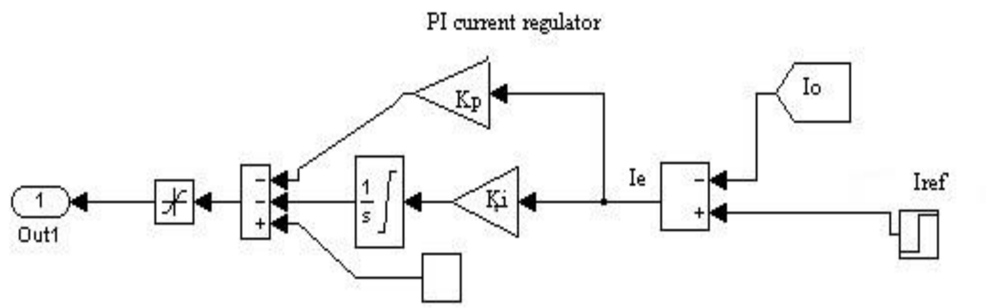

Fig.4. Conventional PI controller

Imperfect adjustment of the delay angles in the two phase-shifted 6 pulse converters results in dc current imbalance. The output current of the converter is compared with the reference current and is amplified by PI controller for obtaining $\Delta\alpha$ and then $\Delta\alpha$ is added to or subtracted from its original reference value α^*.The reference value α_1^* : for converter 1 is $\alpha^* \pm \Delta\alpha$ while $\alpha_2^* = \alpha^* \mp \Delta\alpha$. The constants of the PI controller therefore can be determined by applying the Ziegler-Nichols method. A proportional gain of K_P= 5 and an integration time constant of K_i = 1ms are chosen. Waveform and the FFT analysis for output of the fig1 are shown in fig5. The 12-pulse thyristor converter with PI controller based synchronized pulse generator contains less harmonic currents than that of a 36pulse thyristor converter.

4. SIMULATION RESULTS AND DISCUSSION

In this chapter we carried out the simulation studies with the parameter listed in table no.1. The load of this simulation is kept constant during the simulation study that is a DC motor at which load of 20N-m is applied.

Table1 PARAMETERS USED FOR SIMULATION

Rectifier output (DC motor load)	5HP
Line to line voltage in RMS	220volts
Frequency(Hz)	50
Transformer rating	1200VA, 50Hz
Transformer voltage ratio	400/100
DC motor	5HP,240volts,1750rpm and field 300volts
THD	5.7%

Matlab simulation is performed to confirm the validity of the novel PI controller design concept.Fig5 shows the output current of the twelve pulse rectifier with PI controller. Fig.6 shows simulation result under the following conditions: DC motor of rating 5HP, 240volts, 1750rpm and field of 300volts with mechanical load of torque 20N-m. Fig 6 shows the FFT analysis of the output current of the rectifier. It is clearly seen that the 9^{th}, 11^{th} and 13^{th} and other odd harmonics are reduced to negligible amount and the THD of the system reduced to 5.7%.The simulation result concludes that the use of the PI controller based synchronized 12 pulse generator is extremely effective in reducing the current harmonics produced by the parallel connected 12-pulse thyristor converter.Fig7 shows the current drawn by the DC motor. Although the proposed method cannot perfectly cancel the 11th and 13th order harmonic currents, it is effective in reducing the output current harmonics in a wide range up to the 37th harmonic current. However, the 12-pulse thyristor with the PI controller does not always achieve the similar harmonic reduction to an ideal 36-pulse converter, when the operating and load

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conditions vary widely. The authors, however, realize that this is practically not problematic, because the proposed method is the simplest way of providing a clean power utility interface under the normal operating and load conditions.

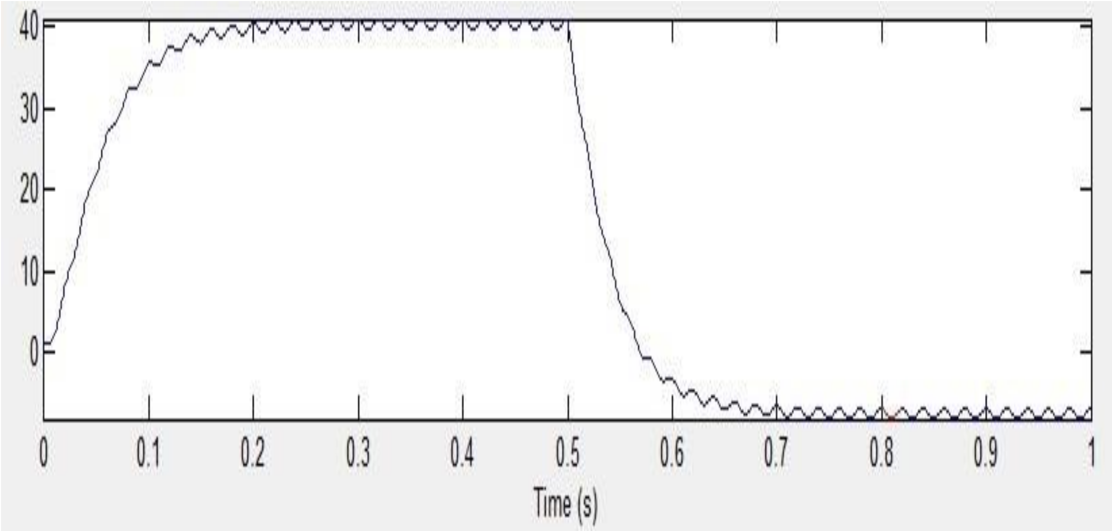

Fig.5. Output current waveform of the 12 pulse converter

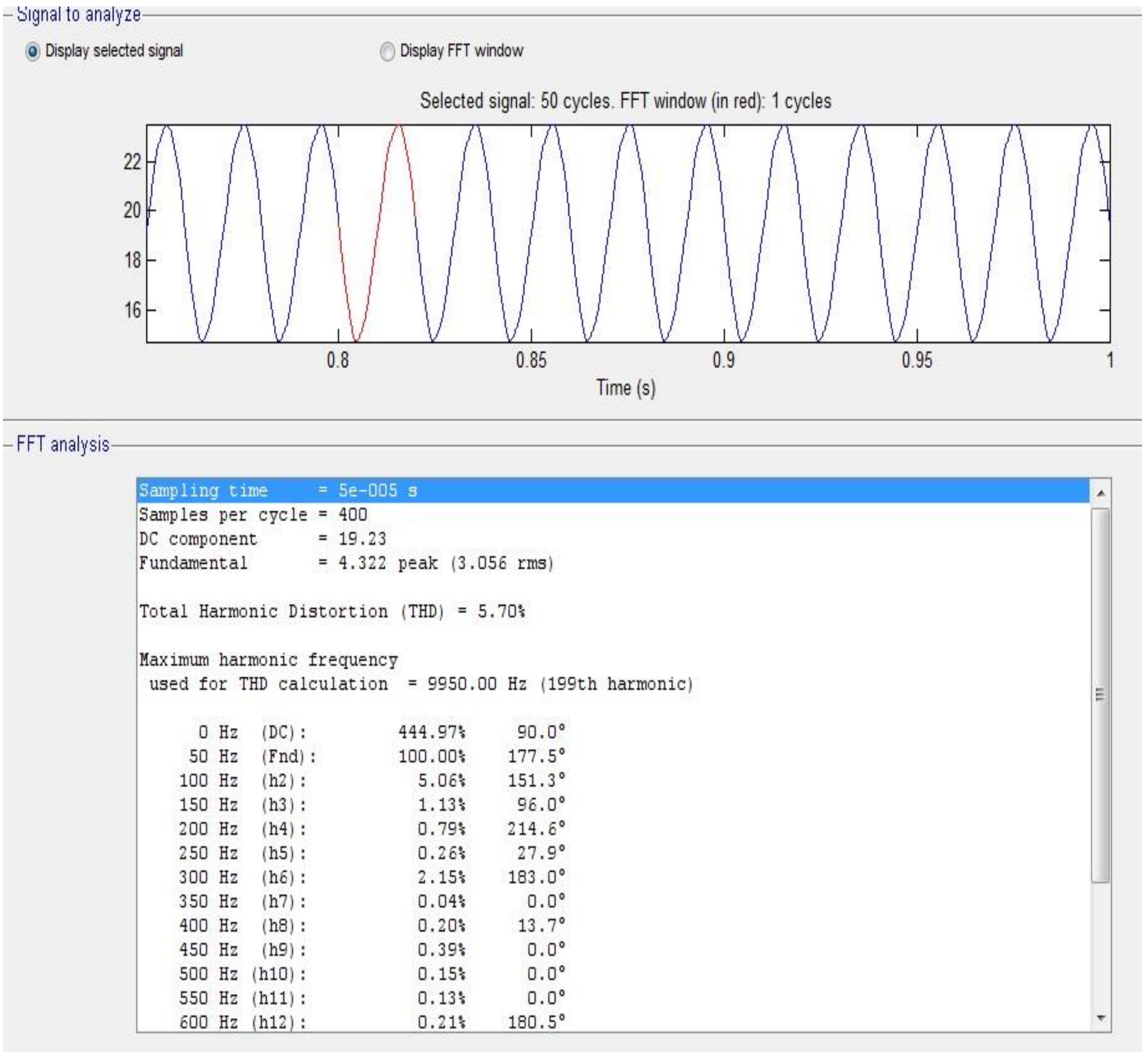

Fig.6. FFT analysis of the output current waveform

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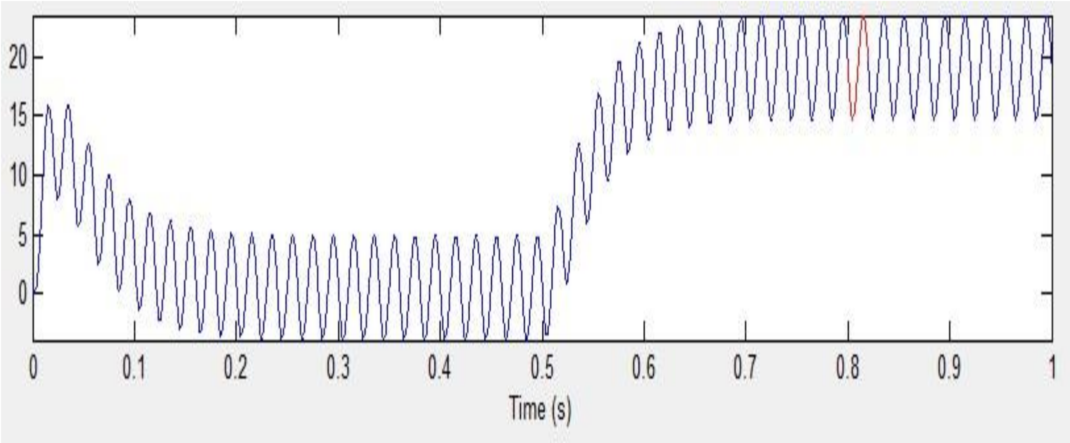

Fig.7. Current drawn by the dc motor

5. CONCLUSION

A 12-pulse phase controlled thyristor rectifier with PI controller is used for the reduction of current harmonics in this paper. The PI controller used in this method of harmonic reduction is used to synchronize the gate pulses with load current and firing for 12 pulse thyristor rectifier. This method of harmonic reduction is useful to reduce the 7^{th} and 11^{th} harmonics. This configuration enables one to reduce the harmonic distortion of the rectifier resultant input currents almost equivalent to that of a phase-controlled 24-pulse rectifier.

The most important application of this above proposed method is that it can be used as a drive to operate an electrical machine with reduced current harmonics. As a result with the help of reduction in current harmonics the efficiency and performance of our electric drives is improved to much better as compared to other methods.

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