Power Factor Improvement of a Permanent Magnet Synchronous Motor Load Using Vienna Rectifier and a Higly Efiicient Pure Sine-Wave Inverter

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Abstract— **Power factor improvement is an intensive study of power electronic system for reducing line losses and cost effective. In this study, a new circuit with Vienna Rectifier and a three-phase highly efficient Sine-wave inverter is introduced for improving the power factor. The simulation work has been performed using PSIM. The new technique revealed that the power factor has been improved from 0.75 to above 0.9 providing high efficiency above 97%, low switching loss, reduced harmonic distortion, low cost, small size and simple control.**

***Keywords*— Power electronics, Permanent Magnet Synchronous Motor, Vienna Rectifier, Pure Sine Wave Inverter, Power Factor.**

I. INTRODUCTION

Synchronous Motors are operated at a low lagging power factor. A low power factor at the loads means higher line losses in the system [1]. The process of increasing the power factor without changing the loads or altering the voltage or the current to the original load is known as power factor improvement [2]. Among the three-phase rectifier topologies, three-phase three-switch three-level rectifier (VIENNA rectifier) [3]-[5] is an attractive choice for power factor improvement because its switch voltage stress is one half of the total output voltage so that fast switches such as MOSFETs can be used. Vienna rectifier and Buck-Boost converter can improve the power factor of a three phase circuit [6]. The output current of the Buck-Boost converter contains harmonics. Harmonics have a negative effect in the operation of the electrical system and therefore, an increasing attention is paid to their generation and control [7-8]. A Pure Sine Wave Inverter provides low harmonics, low cost, high efficiency and simple control [9]. In this paper, a new circuit with combination of a 3-phase Vienna rectifier and a highly efficient pure sine wave inverter is studied to improve power factor.

II. VIENNA RECTIFIER

VIENNA rectifier is a three-switch rectifier which gives the DC output given in Fig. 1. For controlling the rectifier it only need three switches rather five floating switches of other rectifiers. This switching system gives it more convenience to implement. However, in comparing this with single switch controlling is still complex. The input current distortion of this rectifier is about 8.2% which is significantly less than the single switching and also than H-bridge and two switch implementation [10]. Basically the VIENNA rectifier works as a two-switch boost rectifier. One of the switches works at line frequency and two switches switched at high frequency. In 60° control block one switch is permanently on.

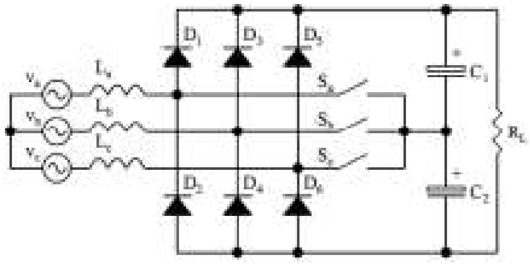

Fig.1. Vienna Rectifier [11]

VIENNA rectifier can be explained as two independent boost rectifiers, one for boosting C1 and the other for boosting C2. Thus it can be seen that the minimum boost voltage over C1and C2 will be the maximum line-to-line voltage of the input.

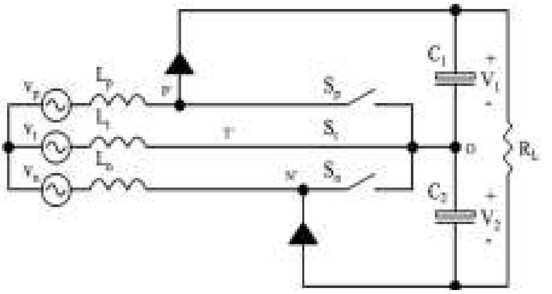

Fig.2. Equivalent circuit of VIENNA rectifier (60° control block) [11]

The equivalent representation of VIENNA rectifier for a 60° control block in one switch "on" condition is shown in Fig. 2. VIENNA rectifier has lower switch and diode currents than all of the other dual-boost rectifiers [12]. For switch losses and diode losses it has the same harmonic distortion like others. But an extra convenience of the VIENNA rectifier is that modules are available having all the power stage bridge leg p, n and t-subscript denotes parts associated with the positive rail, parts associated with the negative rail and parts associated with a transitional period respectively. The small-signal model is derived for a negative duty cycle which is larger than the positive duty cycle, dN> dP. Then the process is repeated for the positive duty cycle which is larger than the negative duty cycle, dP > dN. The common parts of two switch cycle off periods (1-dN) and (1-dP) can be associated.

III. PAGE STYLE

In the Inverter design Sinusoidal Pulse Width Modulation (SPWM) is used to generate sine wave output from DC input. SPWM technique is implemented by constant amplitude pulse with varying duty cycle for each period. To generate SPWM signals a high frequency triangular wave is used as carrier signal (*V*c), which is compared with sinusoidal wave that is called reference signal (*V*r) [13], [14]. The most important parameter of designing the switching strategy is amplitude modulation (*M*A) that will influence the performance of the inverter. *M*A is defined as the ratio between sine waveform also termed as reference signal and the triangular waveform also termed as carrier signal. The amplitude modulation is determined by the following equation:

$$M_A = \frac{\mathrm{Vr}}{\mathrm{Vc}} \qquad (1)$$

MA plays a crucial role to determine the output voltage of the inverter. However, theoretically if MA value increases, the AC output voltage of the inverter will be increased.

Based on the (1), MA value should be less than 1, in order to achieve a high voltage gain with fewer harmonics. So filter designing is getting easier if the MA value choose between 0.8 and 0.9. The harmonics at MA greater than 1 will also increase. This condition is known as over modulation [9].

IV. SYSTEM MODEL

Fig.3 represents the model of power factor improvement circuit of a permanent magnet synchronous motor by using Vienna rectifier and 3-phase highly efficient pure sine wave inverter. The first part of the circuit is the Vienna Rectifier in which the input 30V p-p ac voltage is rectified to almost 60V dc voltage. The MOSFET are triggered using a Square pulse of 30V. Then for the inverter, six MOSFETs are used. At any instant, only two MOSFETs conduct at the same time. The third and final part of the circuit is Permanent magnet induction motor. A duty cycle is the percentage of one period in which a signal is active. It is important because it relates to peak and average power in the determination of total energy output. This, in turn, ultimately affects the strength of the reflected signal as well as the required power supply capacity and power factor.A period is the time it takes for a signal to complete an on and off cycle. As a formula, a duty cycle may be expressed as:

$$D = \frac{t_{on}}{T} \times 100\% \qquad (2)$$

And again, $D = \frac{\mathrm{Ppeak}}{\mathrm{Paverage}}$ (3)

V. SIMULATION RESULT

MOSFET’s triggering pulses of pure sine wave Inverter and Vienna rectifier are shown in Fig. 4 and Fig. 5 respectively. Fig.6 shows the output of Vienna rectifier. It revealed that the output is distorted and is difficult to measure the voltage. Fig. 7 shows the simulated voltage waveform of the inverter which is non sinusoidal, distorted and contains excessive harmonics. Thus a low pass L-C filter is employed at the output terminal of the inverter to reduce the harmonics. L-C filter is available in market at low cost. So, it is cost effective. L-C filter can be handled easily. So, it also provides simple control of the circuit. Fig.8 is the output voltage waveform of the inverter after filtering.

A non sinusoidal and distorted current wave form of the inverter’s output before filtering is shown in Fig.9. A pure sine wave output current waveform of the inverter is depicted in Fig.10. Equation (4) can also reveal that the efficiency is above 97%.

Efficiency, $\eta = \frac{\mathrm{Pout}}{\mathrm{Pin}} \times 100\%$ (4)

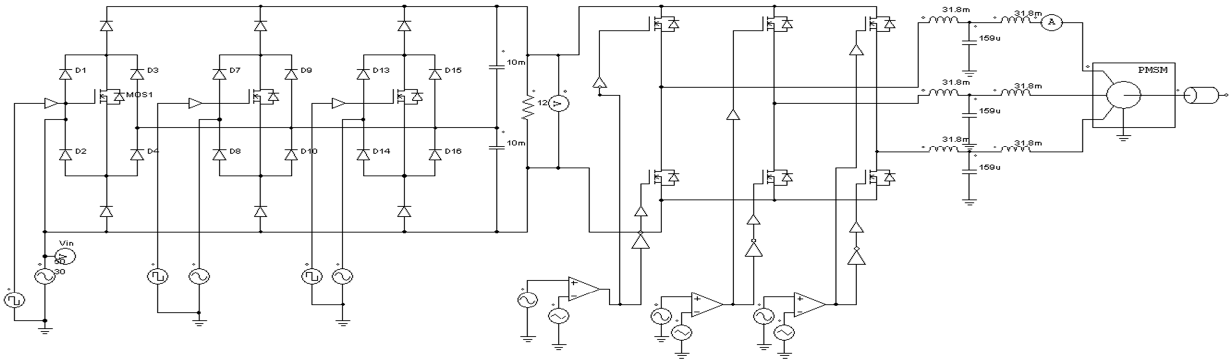

Fig.3. Schematic diagram of proposed combined circuit of Vienna rectifier and a pure sine wave inverter

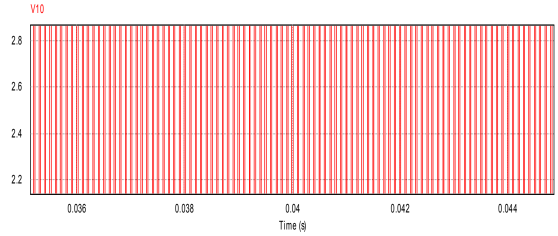

Fig.4. MOSFET's triggering pulse of Sine wave Inverter

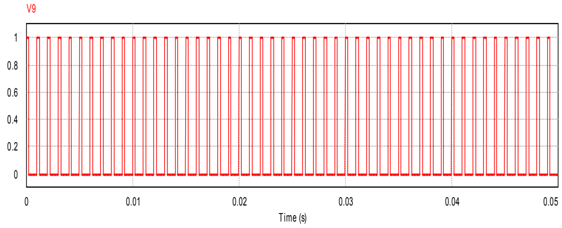

Fig.5. MOSFET's triggering pulse of Vienna rectifier

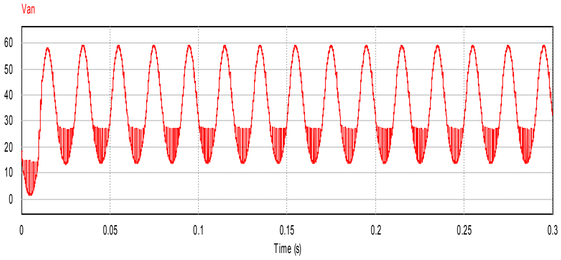

Fig.6. Output of Vienna rectifier

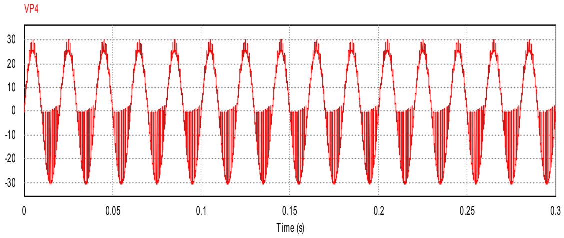

Fig.7. Output voltage of the pure sine wave inverter before using filter

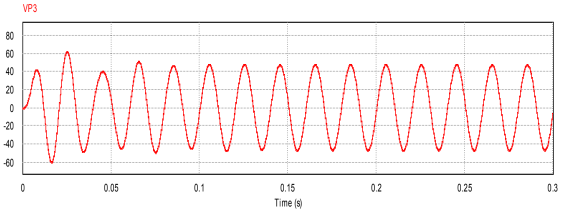

Fig.8. Output voltage of highly efficient pure sine wave inverter after filtering

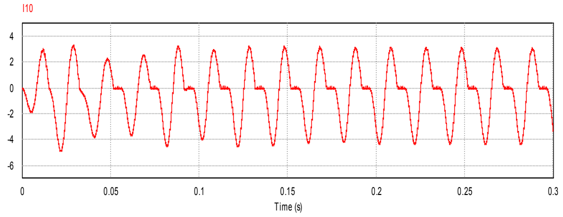

Fig.9. Output current of pure sine wave Inverter before using filter

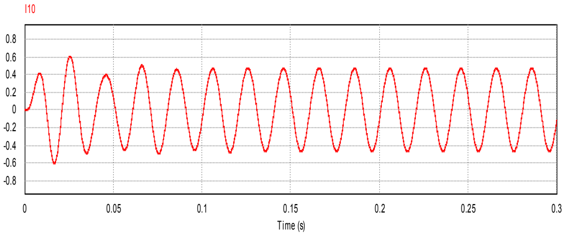

Fig.10. Output current of highly efficient pure sine wave inverter after filtering

VI. PERFORMANCE ANALYSIS

We have taken the data of power factor in between the duty cycles of 0.25 and 0.75. It is mentioned that the received data will not be feasible if we further increase the duty cycle because a very little increase in power factor is achieved after the duty cycle of 0.75.

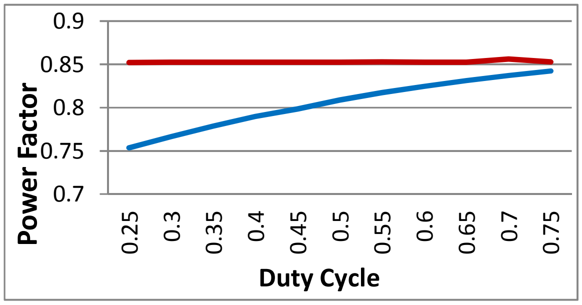

Fig.11. Power factor vs Duty cycle graph for without using Vienna rectifier (blue curve) and using Vienna rectifier (red curve) when the Inverter's duty cycle is fixed at 0.25.

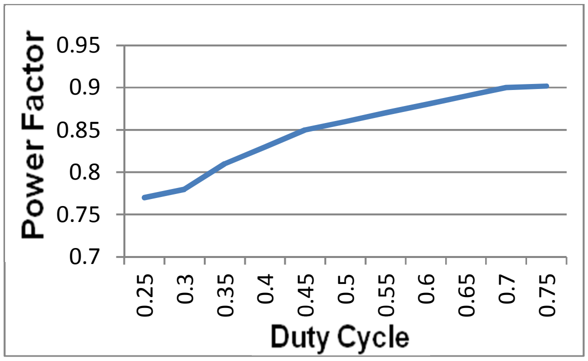

Fig.12. Power factor vs Duty cycle for pure Sine wave Inverter's gate pulse when the Vienna rectifier's duty cycle is fixed at 0.25.

Fig. 11 shows how the power factor changes before (blue curve) and after (red curve) using Vienna rectifier. Before using Vienna rectifier, it is revealed that the power factor was increasing gradually with the increasing of the duty cycle up to 0.65. After 0.65, the change was very little. However, when we use Vienna rectifier then we get approximately a straight line of power factor experiencing a little increase at duty cycle 0.7, which might be the saturation point. It is clearly seen that using Vienna rectifier gives the initial value of power factor 0.86 while it was only 0.75 without Vienna rectifier at the same duty cycle 0.25. Fig. 12 shows the power factor vs duty cycle when applied the MOSFET's triggering pulses of the highly efficient pure sine wave inverter. It is further revealed that the power factor is improved up to above 0.9 after using the MOSFET's triggering pulses of the highly efficient pure sine wave inverter.

VII. CONCLUSION

Power factor improvement of a permanent magnet motor load by using a combined study of Vienna rectifier and a pure sine wave inverter has been studied. The simulation result showed that the power factor improved above 0.85 by using only Vienna rectifier. However, the power factor improved above 0.9 when we use a combined Vienna rectifier and a highly efficient pure sine wave inverter. This new circuit providing higher power factor, high efficiency above 97%, low switching loss, reduced harmonic distortion, low cost, small size and simple control might be the application of modern power electronic systems.

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