IJAREEIE

e-ISSN: 2278-8875
p-ISSN: 2320-3765

International Journal of Advanced Research

in Electrical, Electronics and Instrumentation Engineering

Volume 10, Issue 1, January 2021

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 7.122

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE)

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

||Volume 10, Issue 1, January 2021||

DOI:10.15662/IJAREEIE.2021.1001006

A High Power Factor Flux-Weakening Strategy for PMSMs without Electrolytic Capacitors

Seyit Yıldırım[1]

M.Sc Student, Electrical and Electronics Engineering Department, Özyeğin University, Istanbul, Turkey[1]

ABSTRACT: Nowadays, large electrolytic capacitors are being replaced with small film capacitors in single phase to three phase motor drive inverters. The inverter is easy to control as the large electrolytic capacitor keeps the dc bus voltage almost constant. However, this particular electrolytic capacitor is expensive, large and it is the device with the shortest lifetime in the overall inverter system. Also, the use of electrolytic capacitors requires additional PFC circuit and pre-charging circuit. If a small film capacity is to be used instead, cost and overall size are reduced, and the product life time is increased significantly. However, in the case of smaller capacitors the dc-link voltage fluctuates at a rate twice of the source frequency and this in return causes control difficulties. In order to handle this issue, many methods have been proposed in the literature. This paper introduces a somehow different flux-weakening strategy to solve the mentioned problem. Also the proposed method provides power factor improvement and input current harmonic reduction in comparison to available traditional methods.

KEYWORDS: PMSM, capacitorless system, power factor correction, motor drive, film capacitor.

I.INTRODUCTION

In recent years, permanent magnet synchronous motors (PMSM) have been widely used in many different applications due to their wide speed operation range, low audible noise, high efficiency and high power density. Besides these features, driving a PMSM is not simple as other motors. It requires an inverter board and complex control system. In a traditional single phase to three phase inverter for motor control, large electrolytic capacitors are used to keep dc-link voltage flat for high quality supply and hence better motor performance.

Using a large electrolytic capacitor poses some challenges, most notably its much shorter lifetime. Hence, this huge input capacitor in most cases determines the overall lifespan of the inverter board. Also, it can’t be ignored that this large dc-link electrolytic capacitor has a quite reputable weakness in reliability [1]. Other important issues about electrolytic capacitor can be cited as its large volume and high cost. Moreover, large electrolytic capacitors cause low input power factor and high inrush current. In conventional method shown Fig.1, active or passive PFC circuit is used to solve low input power factor problem and pre-charging circuit is used to overcome high inrush current issue. This extra circuit relating to electrolytic capacitor has also high cost and takes up big space.

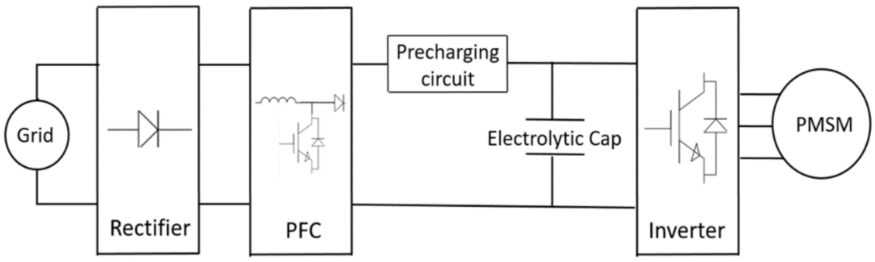

Fig. 1 Conventional single phase to three phase inverter

In order to overcome all these problems mentioned, many different techniques have been proposed. Studies in the literature can be divided into two main groups depending onwhether or not any capacitor is used. The first is the matrix converter topology, which does not contain a dc link capacitor. However, since this method contains a large number of

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switches, it is both very difficult to control and unfavourable in terms of space and cost [2]. Therefore, this topology was not preferred in industrial applications. Other method is using several microfarad film capacitor instead of several hundred microfarad electrolytic capacitor as dc link capacitor [3-9]. This method is called as "capacitorless system" in literature. In this system, since the PFC circuit and the pre-charging circuit are not needed, the system volume is significantly reduced, and cost is also reduced. Moreover, due to switchover to a film capacitor, reliability weakness is also eliminated. This method can be utilized into two groups as single phase and three phase AC supply. There are fewer studies in the literature about single phase systems compared to three phase system. In this work, a new control strategy is proposed for a small film capacitor PMSM drive fed by single phase AC input source which is shown in Fig. 2.

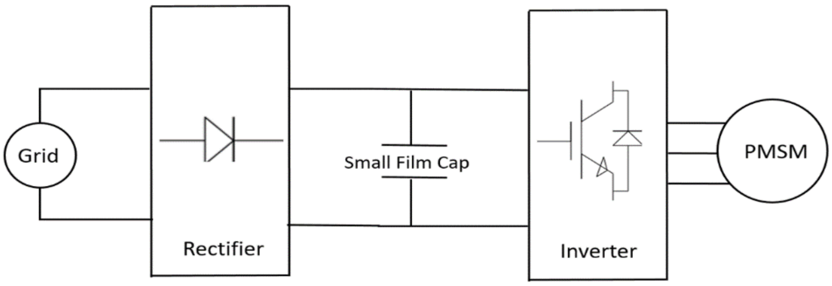

Fig. 2 Electrolytic capacitorless single phase to three phase inverter

If small film capacitor is used in single phase system, the rectified dc-link voltage fluctuates at twice frequency of the ac source voltage source frequency [3]. As the output power increases, the dc link voltage waveform will be similar to the rectified ac signal waveform. Fluctuating Dc-link voltage causes torque fluctuations and a speed control difficulties. In order to overcome these problems various correction techniques are proposed in literature. Many researches overcome this problem by modifying the d-axis and q-axis current references of the inverter.

In field oriented control, there are two axis current components which are commonly described as d axis current and q axis current. For q axis current, there are two main approaches in the literature. The first approach is that the shape of the q-axis current reference is modified as the square of sinusoidal wave synchronized with AC source voltage angle. Also in some research outcomes, in order to reduce input current harmonics using the power spent in the capacitor andinverter, synchronized sinusoidal q-axis current reference is also modified. Another approach is whereby the q-axis current reference is shaped as a trapezoidal waveform. However, trapezoidal q-axis current reference causes high levels of input current harmonics compared to sinusoidal q-axis current reference. Therefore, the sinusoidal current q-axis reference method is the most commonly used technique [3]. Hence, synchronized sinusoidal q-axis current reference is also utilized in this paper.

As regard to d-axis current reference [4, 5, 9] current reference is calculated through a formula which is related to motor parameters. In [6], d-axis current reference is a constant value according to the desired torque and speed. In [3], d-axis current reference changes very slowly according to average voltage constraint concept. In [8], the d-axis current reference is set at a negative constant value by trial-and-error after changing operating point. In [7], a slightly different method is proposed, but, d-axis current reference waveform ends up to be too sharp. In order to achieve control loop with such a sharp reference, a PR controller is used as a current control which is difficult to implement in comparison to a standard PI controller.

II.PROPOSED METHOD

The method investigated in this control system proposal is shown in Fig.3. Q-axis current reference is modified as the square of sinusoidal wave synchronized with AC source voltage angle just like most studies in the literature. Unlike other methods in literature however, the d-axis current reference is modified as the square of cosinusoidal wave synchronized again with ac source voltage angle. The basic motivation behind the proposed method is to apply d current only when needed. As mentioned before, dc-link voltage fluctuates at twice the frequency of the grid due to rather small capacitor allocation. At the peak of the dc-link voltage, it can be considered as a large capacity system. So, there is no need for d-axis current around at peak value of dc-link voltage under nominal speed. Similarly, there is much more need to d-axis current around lower value of dc-link voltage. As a result, d-axis current waveform should be square of cosinusoidal which is synchronized with ac source voltage angle. This method is illustrated in Fig. 4.

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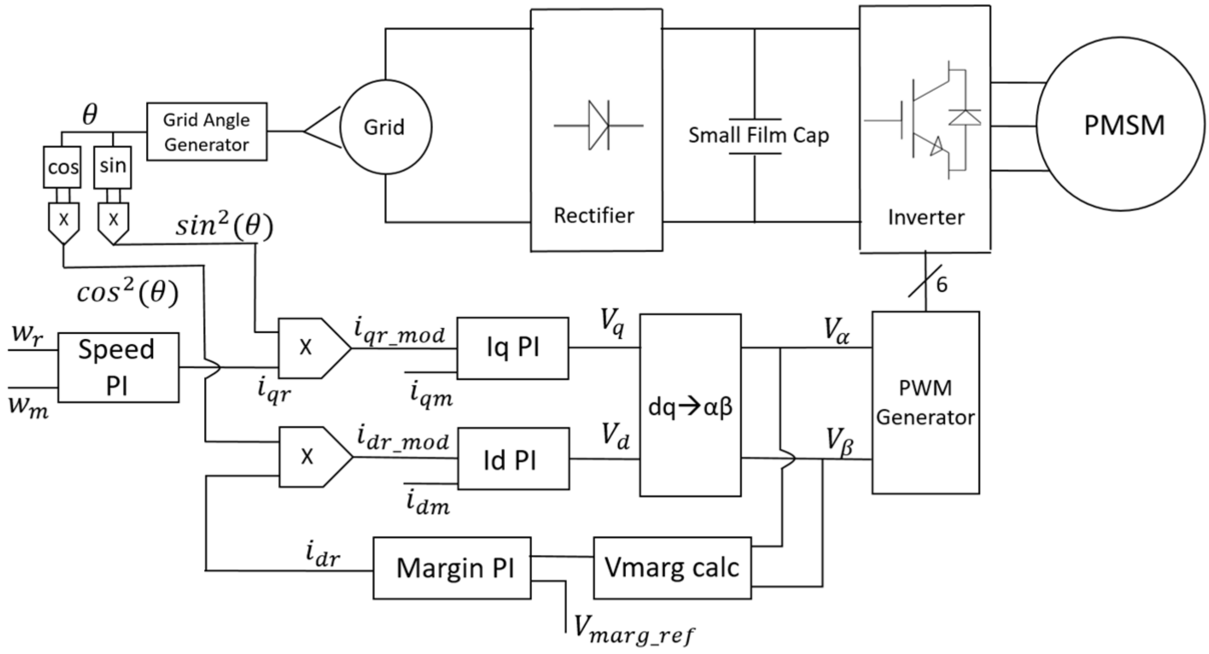

Fig. 3 Overall proposed system

Amplitude of d-axis current is adjusted with voltage margin in PI controller. If voltage margin reference value is too high, unnecessary extra d current is applied and it causes the power factor to drop.Similarly, if voltage margin reference value is too low, there will be disruptions in torque control since enough d current cannot be applied. Therefore, the voltage margin reference value is obtained with fine tuning at working conditions with load. In order not to disturb sinusoidal waveform of i_{dr_mod} and i_{qr_mod} currents, i_{dr} and i_{qr} are determined at every zero crossing event.

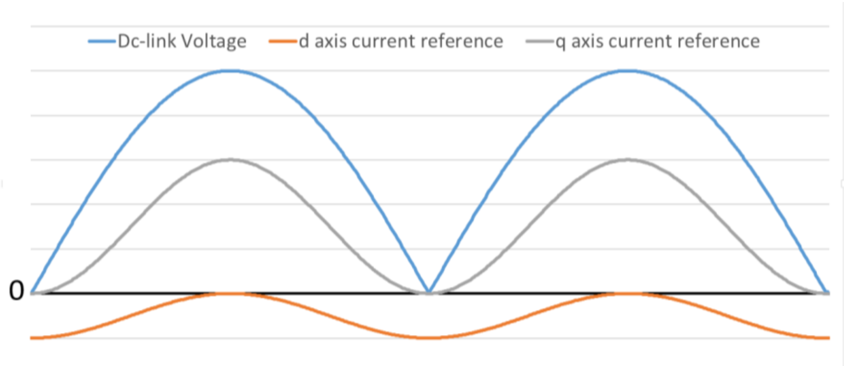

Fig. 4 Current references waveform of the proposed system

III. SIMULATION RESULTS

In order to verify the validity of proposed technique, as well the performance and stability improvements that can be attained, a detailed computer simulation has been performed by MATLAB/SIMULINK. The motor parameters shown in Table-1 are used in the simulations. The same design parameters were employed in experimental setup, too. Also, 10μF film capacitor is used as a dc-link capacitor and no additional inductor is used. Most commonly used d-axis method was also simulated to compare the performance with respect to the performance of the proposed technique.

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Fig.5 and Fig.6 shows the speed performance at nominal speed and rated torque with traditional method and this work, respectively. In proposed method, speed oscillation levels are slightly higher than traditional one. However, input power factor is improved with proposed method.

Pole	3 Phase 6 Pole
Rated Output	790 Watts
Rated Speed	3600 rpm
Winding Resistances (phase-phase) at 75°C	2.790 ± 7% Ohms
Inductance (Ld)	6.9 mH
Inductance (Lq)	10.8 mH
BEMF	42.5 Vrms / krpm (Line-to-Line) at 25°C

Table 1. Motor Parameters

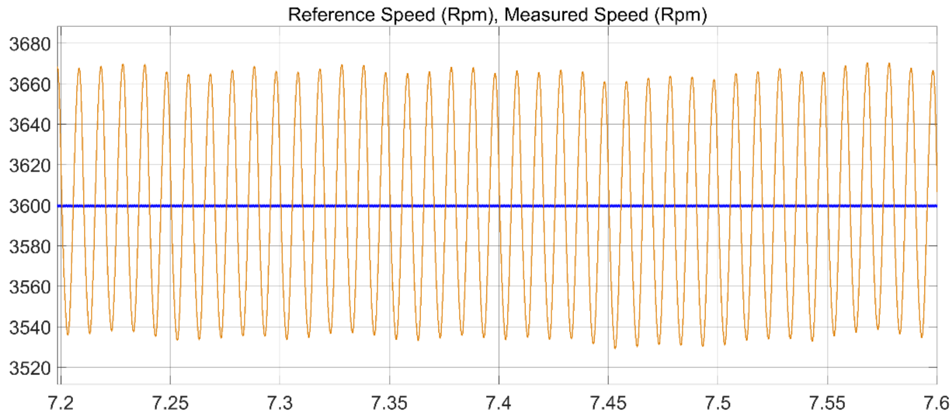

Fig. 5 Speed performance at nominal speed and rated torque with traditional method

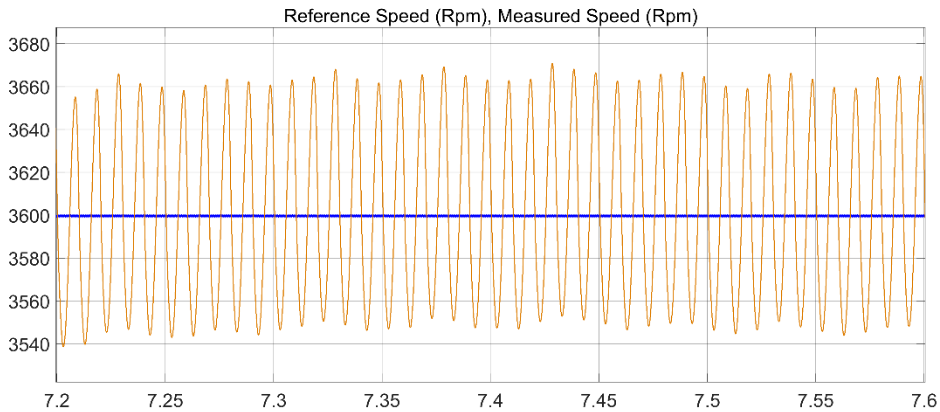

Fig. 6 Speed performance at nominal speed and rated torque with proposed method

Fig. 7 and Fig. 8 shows grid voltage (230V AC 50Hz) and input current waveform at nominal speed and rated torque with traditional method and proposed technique, respectively. Also, Fig. 9 and Fig. 10 shows modified d-axis currents and q-axis currents waveforms at nominal speed and rated torque with respect to both cases. In simulation results, proposed method power factor is 0.97 while traditional method power factor is 0.95

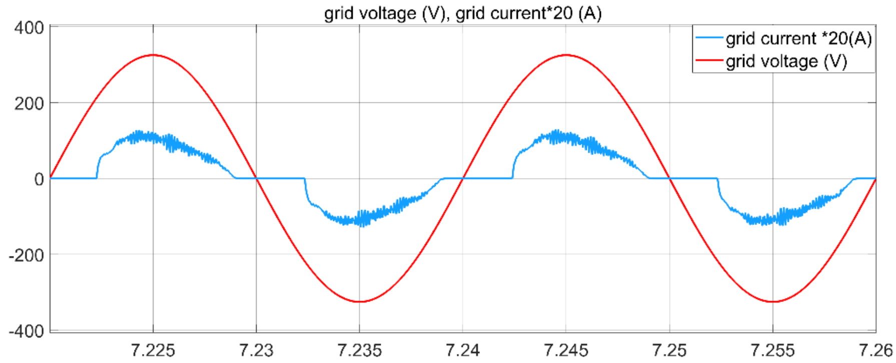

Fig. 7 Grid voltage and input current waveform with traditional method.

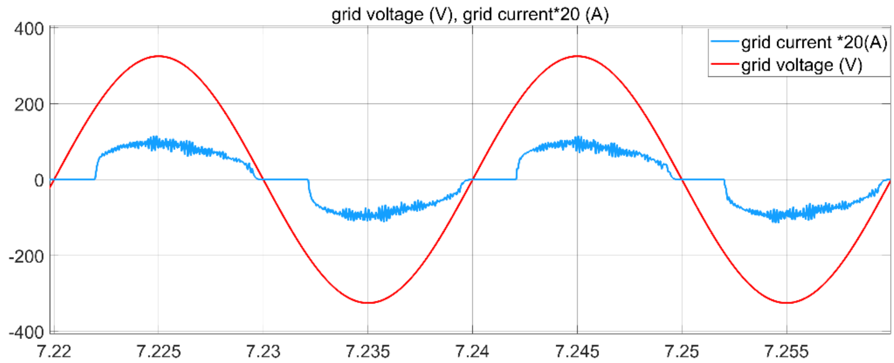

Fig. 8 Grid voltage and input current waveform with proposed method.

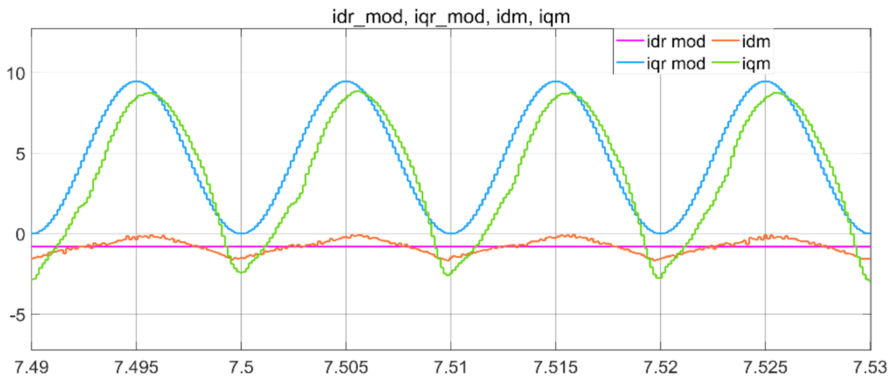

Fig. 9 Modified d-axis and q-axis currents with traditional method

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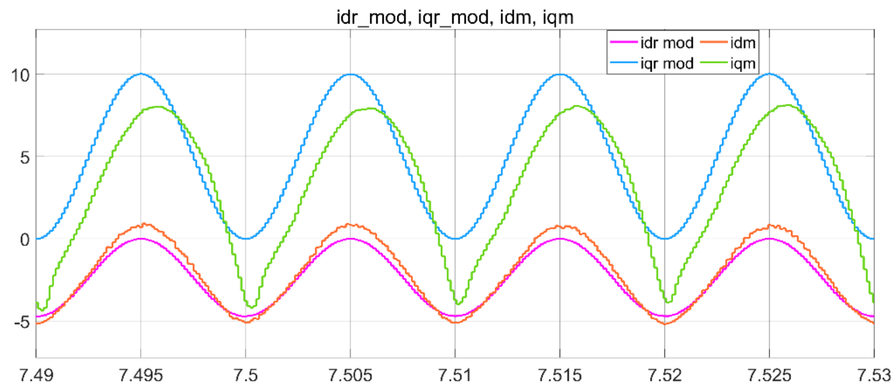

Fig. 10 Modified d-axis and q-axis currents with proposed method

IV. EXPERIMENTAL RESULTS

The standard techniques and this particular method were compared in terms of power factor and input current harmonic performance during experimental work. For input current harmonics, IEC6 1000-3-2 Class A regulation defines the harmonics limit which is very important criteria especially for air conditioning applications. Hence, the experimental work is done at an air conditioner setup which is shown Fig. 11. In the experiment, the supply voltage is 230Vac and 50 Hz. The inverter board in the figure is designed with electrolytic capacitor. The card was prepared for testing by removing the electrolytic capacitors and installing two 5uF film capacitors from the outside.

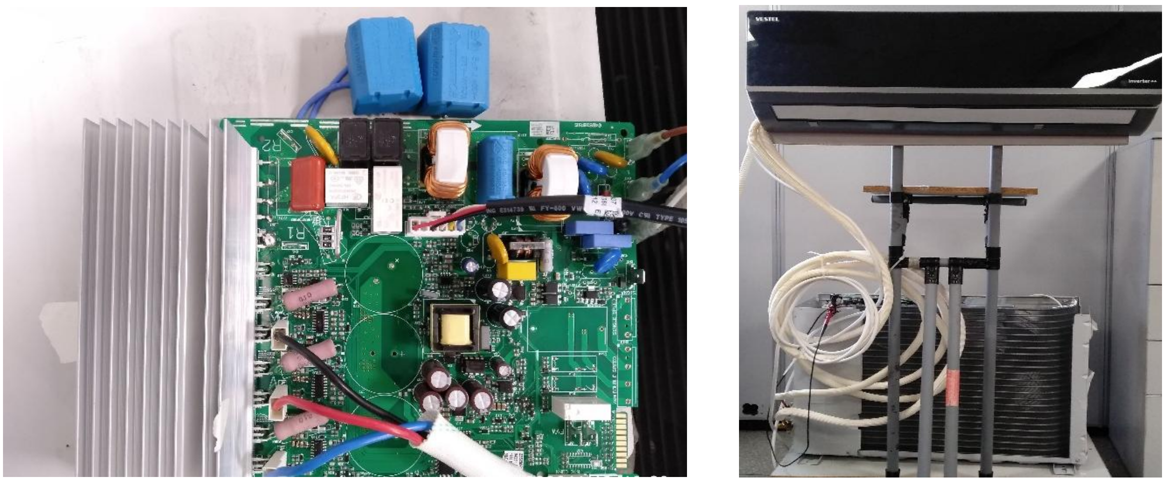

Fig. 11 Experimental air conditioner inverter setup with 10 uF film capacitor

Fig. 12 and Fig. 13 show grid voltage and input current waveform at nominal speed and rated torque with traditional method and proposed method respectively. In experimental results, in the work proposed power factor is 0.924 while traditional method power factor is 0.96. Fig.14 and Fig.15 shows input current harmonic results with traditional method and proposed method respectively in terms of IEC6 1000-3-2 Class A regulation. According to test results, the study has provided better input current harmonic performance.

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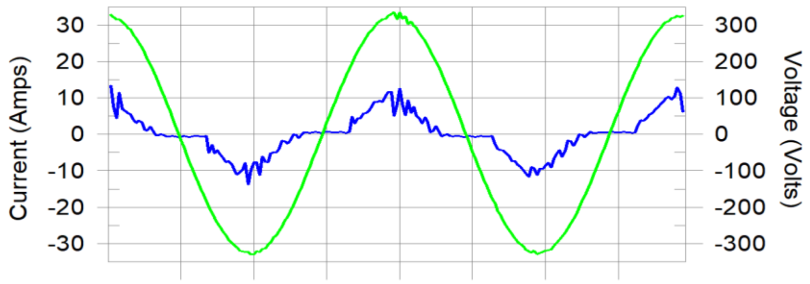

Fig. 12 Supply voltage and input current waveform with traditional method

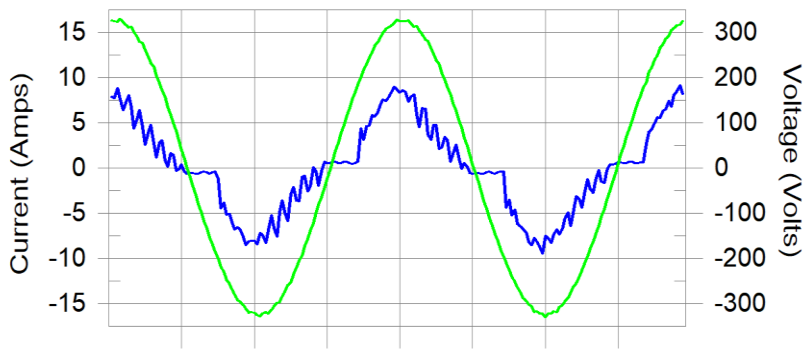

Fig. 13 Supply voltage and input current waveform with proposed method

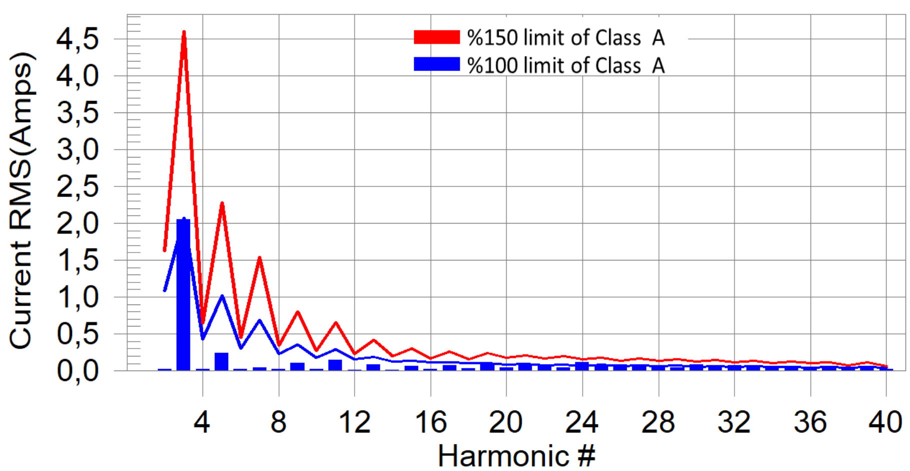

Fig. 14 Input current harmonic performance with traditional method in terms of Class A

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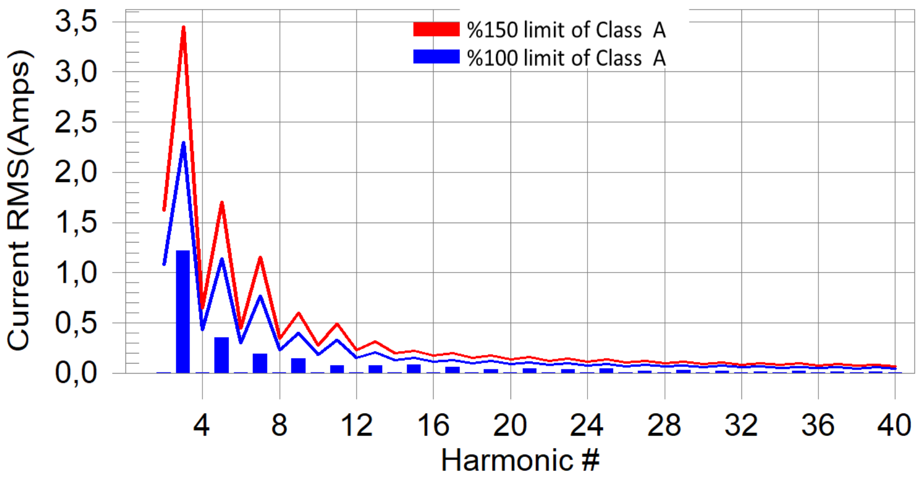

Fig. 15 Input current harmonic performance with proposed method in terms of Class A

V. CONCLUSIONS

This paper proposes a new flux weakening strategy by a different d-axis current waveform injection than the ones introduced in prior literature. The method has provided a better input current harmonics performance and hence, provides high power factor compared to traditional methods at nominal speed conditions. For future work, above the nominal speed levels, this method must be modified by adding dc offset to cosinusoidal d-axis current waveform. Performance improvements and validity of the proposed method is verified experimentally by comparison with respect to the traditional harmonic cancellation methods.

REFERENCES

[1] K.-D. Kim, Y.-H. Kim, J.-G. Kim, Y.-C. Jung, and C.-Y. Won, “A new active power decoupling technique for three-port flyback inverter,” Proceedings of The 7th International Power Electronics and Motion Control Conference, 2012.

[2] Y. Yoon and S. Sul, "Carrier-Based Modulation Technique for Matrix Converter," in IEEE Transactions on Power Electronics, vol. 21, no. 6, pp. 1691-1703, Nov. 2006.

[3] H. Jung, S. Chee, S. Sul, Y. Park, H. Park and W. Kim, "Control of Three-Phase Inverter for AC Motor Drive With Small DC-Link Capacitor Fed by Single-Phase AC Source," in IEEE Transactions on Industry Applications, vol. 50, no. 2, pp. 1074-1081, March-April 2014.

[4] I. Takahashi and H. Haga, "Power factor improvement of single-phase diode rectifier by fast field-weakening of inverter driven IPM motor," 4th IEEE International Conference on Power Electronics and Drive Systems. IEEE PEDS 2001-Indonesia. Proceedings (Cat. No.01TH8594), Denpasar, Indonesia, 2001, pp. 241-246 vol.1.

[5] H. Lamsahel and P. Mutschler, "Permanent magnet drives with reduced dc-link capacitor for home appliances," 2009 35th Annual Conference of IEEE Industrial Electronics, Porto, 2009, pp. 725-730.

[6] K. Inazuma, K. Ohishi and H. Haga, "High-power-factor control for inverter output power of IPM motor driven by inverter system without electrolytic capacitor," 2011 IEEE International Symposium on Industrial Electronics, Gdansk, 2011, pp. 619-624.

[7] Hui Luo, Genping Wu and Quan Yin, "Proportional-resonant control of a single-phase to three-phase converter without electrolytic capacitor," 2015 Chinese Automation Congress (CAC), Wuhan, 2015, pp. 1798-1803.

[8] K. Abe, H. Haga, K. Ohishi and Y. Yokokura, "Fine Current Harmonics Reduction Method for Electrolytic Capacitor-Less and Inductor-Less Inverter Based on Motor Torque Control and Fast Voltage Feedforward Control for IPMSM," in IEEE Transactions on Industrial Electronics, vol. 64, no. 2, pp. 1071-1080, Feb. 2017.

[9] A. Yoo, S. Sul, S. Kim and K. Kim, "Flux weakening strategy of an induction machine driven by an electrolytic capacitor-less inverter," 2009 IEEE Energy Conversion Congress and Exposition, San Jose, CA, 2009, pp. 147-154.