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Computer Simulation Model of Single Stage Direct Control of Dc Machines Fed AC Voltage Source Using Single-Phase Matrix Converter (SPMC)

Nur Hidayah Abdullah, Rahimi Baharom, Muhammad Shawwal Mohamad Rawi and Mohd Shukri Mohd Ghazali

Abstract— This paper aims to present a new model of the single-stage direct control of DC machines fed with an AC voltage source using a Single-Phase Matrix Converter (SPMC). The proposed system uses a single circuit topology to perform four-quadrant control operations. Besides, enabling four quadrants control operation, the proposed circuit topology can be controlled to provide almost unity power factor operation using the supply current wave shaping technique. It features low power losses resulting in high power density. The theoretical model of the switching algorithms of the SPMC is utilized to control the desired output according to the characteristics of quadrant I, II, III, and IV operations. The simulation model of the proposed converter is developed using MATLAB/Simulink to investigate the circuit behaviors. The selected results are presented to verify the proposed converter.

Index Terms **— Single-Phase Matrix Converter (SPMC), AC-DC Converter and Active Power Filter (APF) Function.**

I. INTRODUCTION

THE power electronics community has heard for decades about the power electronics technological roadmap. Furthermore, a lower capital outlay in the building infrastructure and greater design freedom can be achieved with a small volume [1]. This is in line with the recent development of power electronic converters that are moving to the embedded in the final application. As a result, it can reduce the installation cost and enhance their electromagnetic compatibility [1]. The typical permanent magnet DC motor control uses two different converters (dual converter) as shown in Fig. 1 to perform four quadrants operation and requires additional devices for input current wave shaping to compensate the supply current to operate at almost unity power factor [1]. The use of separate converters circuit contributes to the increase of the number of semiconductor devices [2], which leads to the bulky size. Also, resulting in high power semiconductor losses and low power density [3-5]. Hence, this is not in line with the power electronic converter technological roadmap that focuses on reducing the power losses, size, and volume, thus, increase the power density [6] of the power converter system.

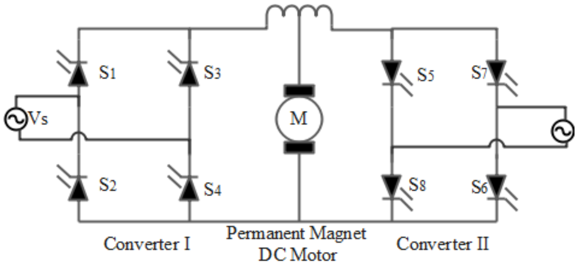

Fig. 1. Typical Dual Converter

This paper, therefore, proposes a single SPMC circuit topology to operate as a direct AC-AC converter to control four quadrants operation of a permanent magnet DC motor as shown in Fig. 2, which employs an Insulated-Gate Bipolar Transistor (IGBTs) for the main power switching devices [7]. Besides, the conversion of AC to DC, the SPMC circuit topology can also be used to uphold the supply current waveform of unity power factor operation through a proper switching arrangement [8-9]. The safe-commutation technique as presented in [10-12] is used to prevent the commutation problem due to the inductive load with regards to the voltage spikes during switch transitions. To verify the performance and viability of the proposed switching algorithms, a computer simulation model using MATLAB/Simulink is developed.

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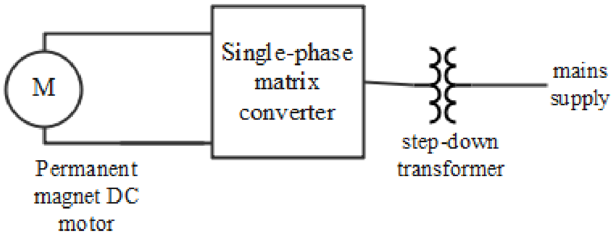


Fig. 2. The proposed control of four quadrant PMDC motor

II. SINGLE-PHASE MATRIX CONVERTER (SPMC)

Fig. 3 shows the SPMC circuit configuration. The SPMC has great potential in offering direct AC-AC conversion without energy storage elements [13]. An important practical issue to consider with the application of matrix converters is the switching transitions problem [14] – [16]. Therefore, a systemic switching sequence is required to decay the energy flowing in the IGBTs. For this reason, freewheeling diodes are used in traditional-operated rectifiers. But, there is no need for this in SPMC so that a switching sequence can be established to allow energy dissipation.

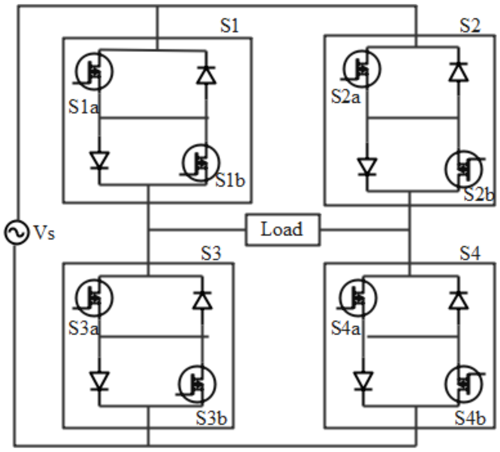


Fig. 3. SPMC circuit configuration

III. THE NEED FOR HIGH POWER DENSITY AC TO DC CONVERTER TO CONTROL OF FOUR QUADRANT PERMANENT MAGNET DC MOTOR

High efficiency and high power density of power supply are important for the rapidly changing global manufacturing environment. The current trend in power electronics is to increase the power density of conversion voltage, particularly for information technology applications in which the rapid development of integrated circuit technology had led to the higher power consumption of more compact systems [20]. Every 10 years since 1970, the power density of power electronic converters has almost doubled in various applications. Lower capital expenditure on the construction infrastructure and greater flexibility of design can be achieved with a small volume. This is consistent with the recent development of power electronic converters and drive systems which move to the integrated part of the final application [21]-[22]. The Matrix Converter (MC) is an emerging converter and currently has a significant interest in both academic and commercial matters [23]. The probability of higher power density due to a shortage of a DC link [24] in direct AC conversion is one of the major advantages claimed for the MC. Moreover, MC can function in all four quadrants operations. These characteristics make the MC a great alternative to the conventional inverter voltage source [25].

IV. THE PROPOSED AC TO DC CONVERTER FOR CONTROL OF FOUR QUADRANT PERMANENT MAGNET DC MOTOR

A new AC to DC converter for control of four quadrants permanent magnet DC motor is developed using the SPMC circuit topology. The SPMC will perform the dual converter operation of the conventional circuit topology. By suitable control, the added features could be implemented in the form of supply-side unity power factor operation, active filter, and reactive compensation [26]. The limitation of the typical DC chopper circuit to control the four-quadrant operation of DC machines could also be solved using the proposed converter without any additional circuits [27]. The proposed system features low power losses resulting in high power density. The switching operations of the SPMC for the AC-DC conversion are only appropriate for the unidirectional flow of the current through the load in a time, both in the positive and negative cycles as shown in Fig. 4 [28]. The operations for quadrants II and IV are carried out with AC sources, and DC voltage sources are performed as an induced voltage at load side instead of inductor for easier simulation convergence [29]. The input frequency of the power supply is set to 50Hz. Four quadrant operations based on voltage and current profiles for quadrant I, quadrant II, quadrant III, and quadrant IV respectively is shown in Figs. 4 as stated in Table1. Both torque and speed characteristics for quadrants I and III move in the same forward and opposite direction respectively. Thus, quadrant I operate as forward motoring, and quadrant III is reverse motoring. As for quadrant II and IV, either speed or torque is moving in the opposite direction in each quadrant and causes the torque produced by the motor to 'brake' the speed rotation of the motor.

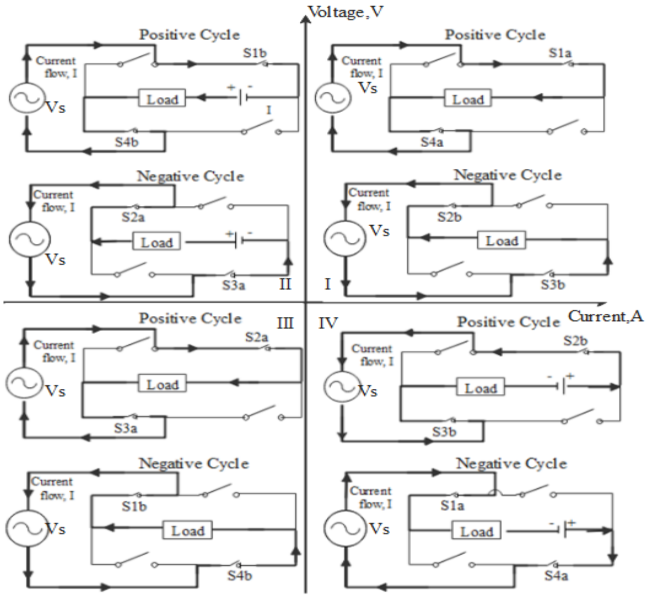


Fig. 4. Schematic circuit for the operation of four quadrants control

TABLE I
SWITCHING ALGORITHMS OF FOUR QUADRANTS OPERATIONS

Quadrants	Positive Cycle	Negative Cycle	Operations
1	S1a, S4a	S3b, S2b	Forward Motoring
2	S1b, S2b	S3a, S2b	Forward Braking
3	S2a, S3a	S4b, S1b	Reverse Motoring
4	S2b, S3b	S4a, S1a	Reverse Braking

V. COMPUTER SIMULATION

The proposed converter has been investigated using MATLAB/Simulink (MLS) in terms of circuit operation for controlling of four quadrants operation of a DC motor as shown in Fig. 5 to Fig. 13. The SPMC is modeled using eight reverse-blocking IGBTs, which have been connected to the common-emitter configuration by the combination of the two IGBTs and two power diodes as shown in Figs. 5 and 6 respectively. The control block set is designed to control the SPMC. It consists of the PWM generator as shown in Fig. 7, and the phase detector circuit to detect the phase sequence of AC voltage waveform as shown in Fig. 8. The SPMC circuit model with APF function is as shown in Fig. 9. The additional circuit of the Current Control Loop (CCL) is used to generate an Active Pulse Width Modulation (APWM) signal to control the SPMC circuit topology. An AC voltage source of 100V (p-p) has been used to supply the proposed regulated rectifier operation. The investigations of the behavior of the proposed converter involving the use of inductive (RL) load as shown in Fig. 10 with the suitable safe-commutation strategy to solve the commutation problem in SPMC circuit topology. The simulation model of the SPMC circuit integrated with the active power filter (APF) function is shown in Fig. 11. The capacitive load with the resistor, R of 300 Ω and DC capacitor filter of 1000μF are used with the switching frequency of 50 kHz. Further investigations are carried out with the advanced SPMC circuit topology to control four quadrants of DC machines operation as shown in Figs. 12 and 13.

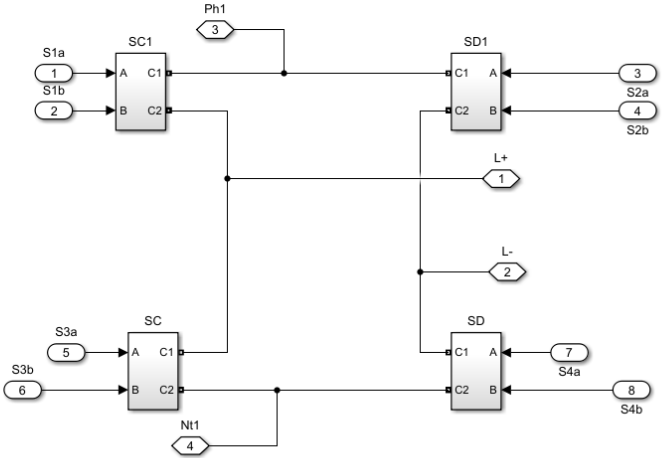


Fig. 5. The SPMC circuit model

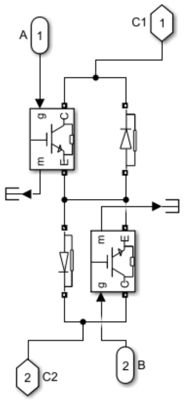


Fig. 6. Bidirectional Switch Model

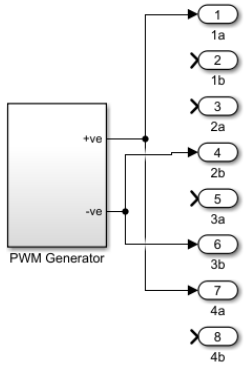


Fig. 7. PWM Generator using MLS

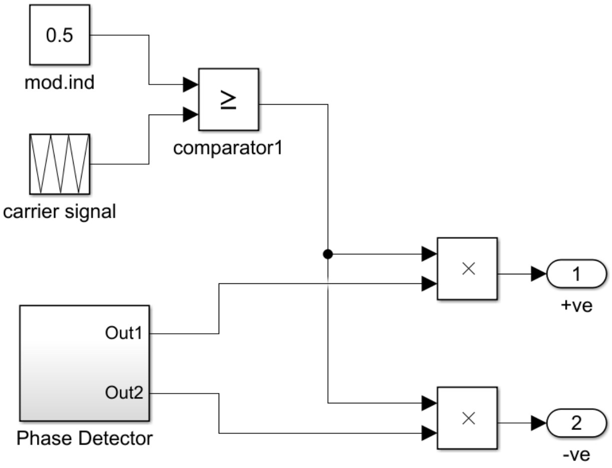


Fig. 8. Controller Circuit using MLS

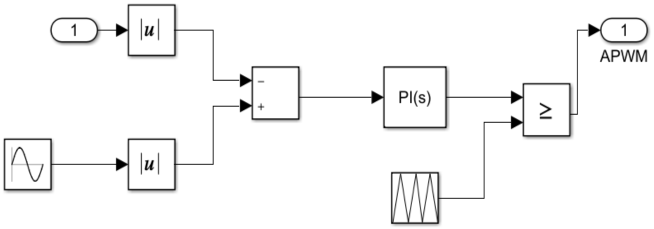


Fig. 9. Current controller

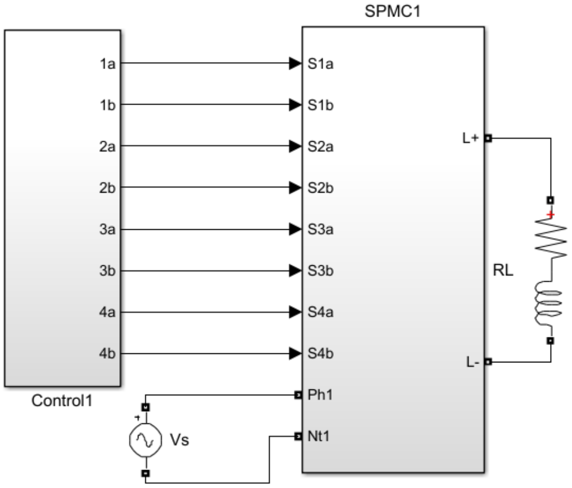


Fig. 10. SPMC with inductive (RL) loads

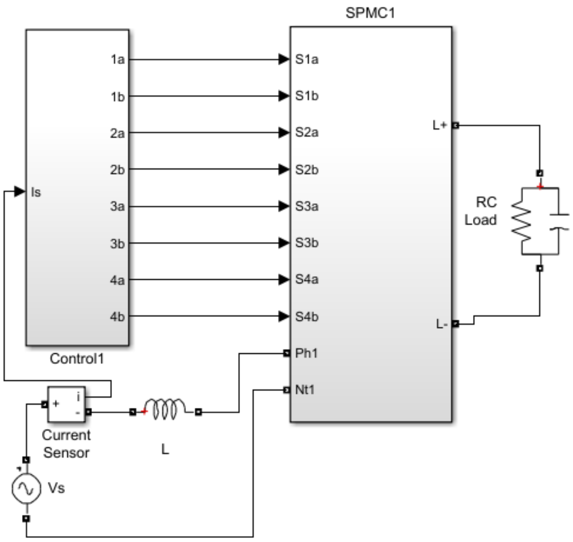


Fig. 11. SPMC incorporating with Active Power Filter (APF)

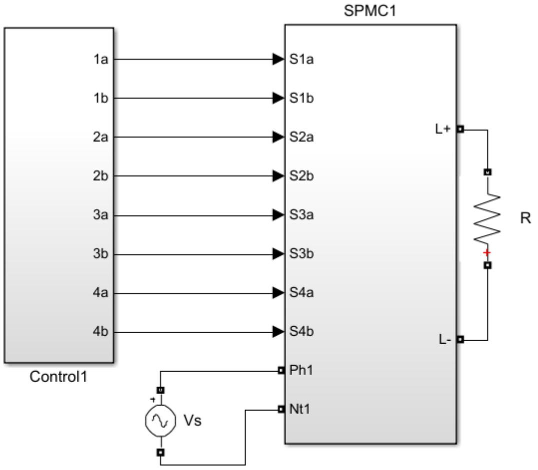


Fig. 12. SPMC with R Load for Quadrant I and III

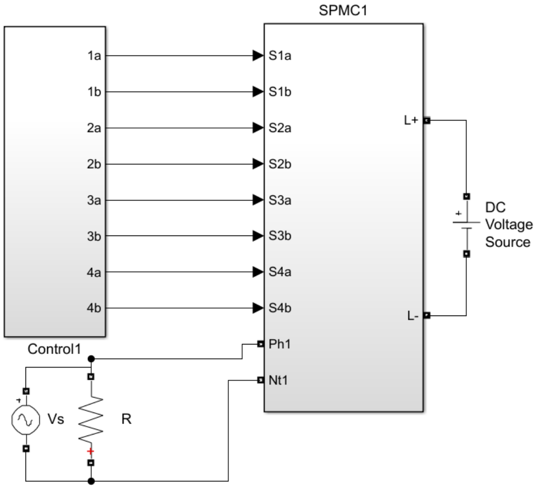


Fig. 13. SPMC with R Load for Quadrant II and IV

VI. RESULTS AND DISCUSSION

Figs. 14 to 18 show the results obtained for the operation of SPMC as a controlled rectifier including the effect of inductive load and the safe-commutation strategy. Fig. 14 shows the results of the output voltage and current waveforms of a controlled AC-DC converter using a purely resistive load. Damaging spikes were observed with the presence of inductive load as shown in Fig. 15. The implementation of the safe-commutations strategy led to the removal of voltage spikes as shown in Fig. 16. This result can be used to prove that the proposed safe-commutation technique is effective. The non-sinusoidal supply current waveform of the non-linear load is shown in Fig. 17. The inclusion of the APF function indicates that the supply current waveform is significantly improved, where the waveform becomes continuous, sinusoidal, and in phase with the supply voltage waveform as shown in Fig. 18.

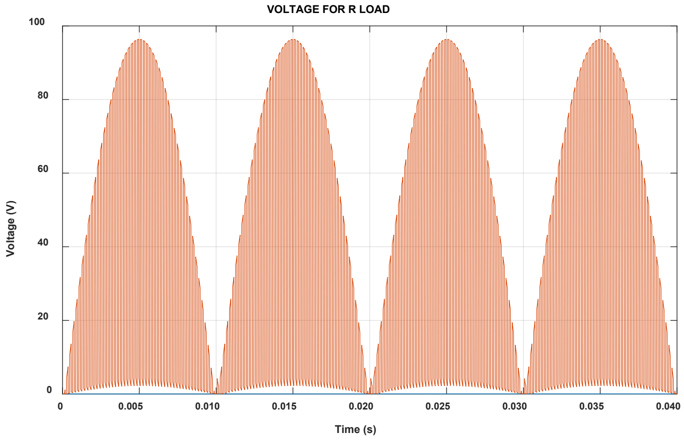


Fig. 14. Output voltage of R load from MLS

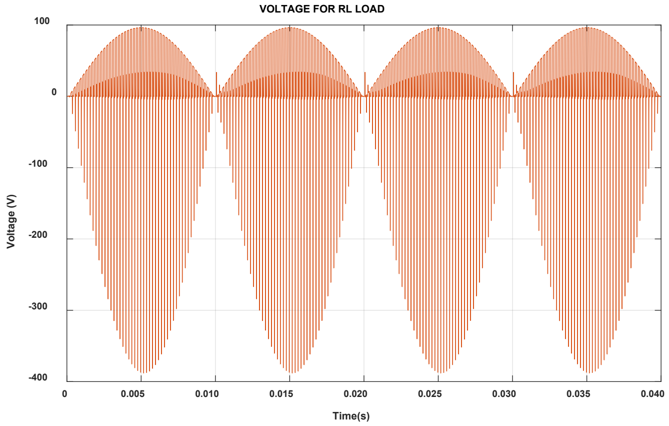


Fig. 15. Output voltage of RL load without commutation

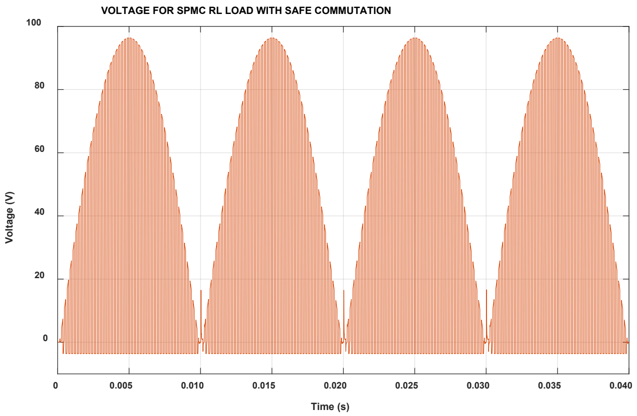


Fig. 16. Output voltage for RL load with safe commutation

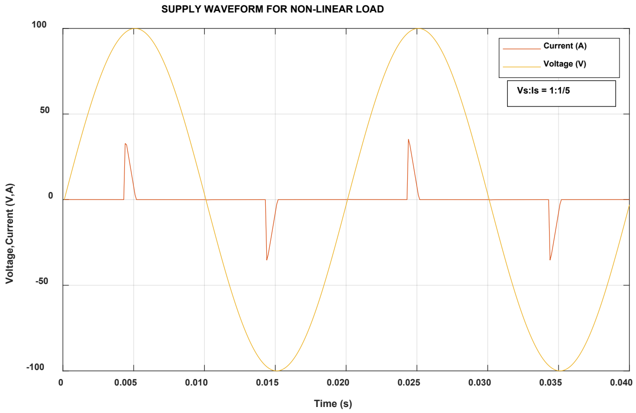


Fig. 17. Rectifier input signal of RL load without APF

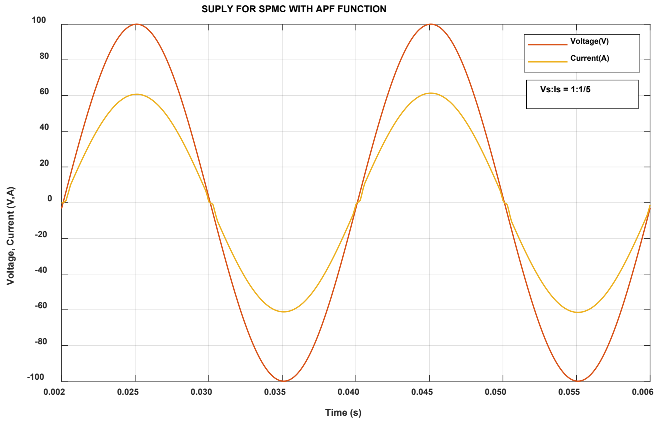
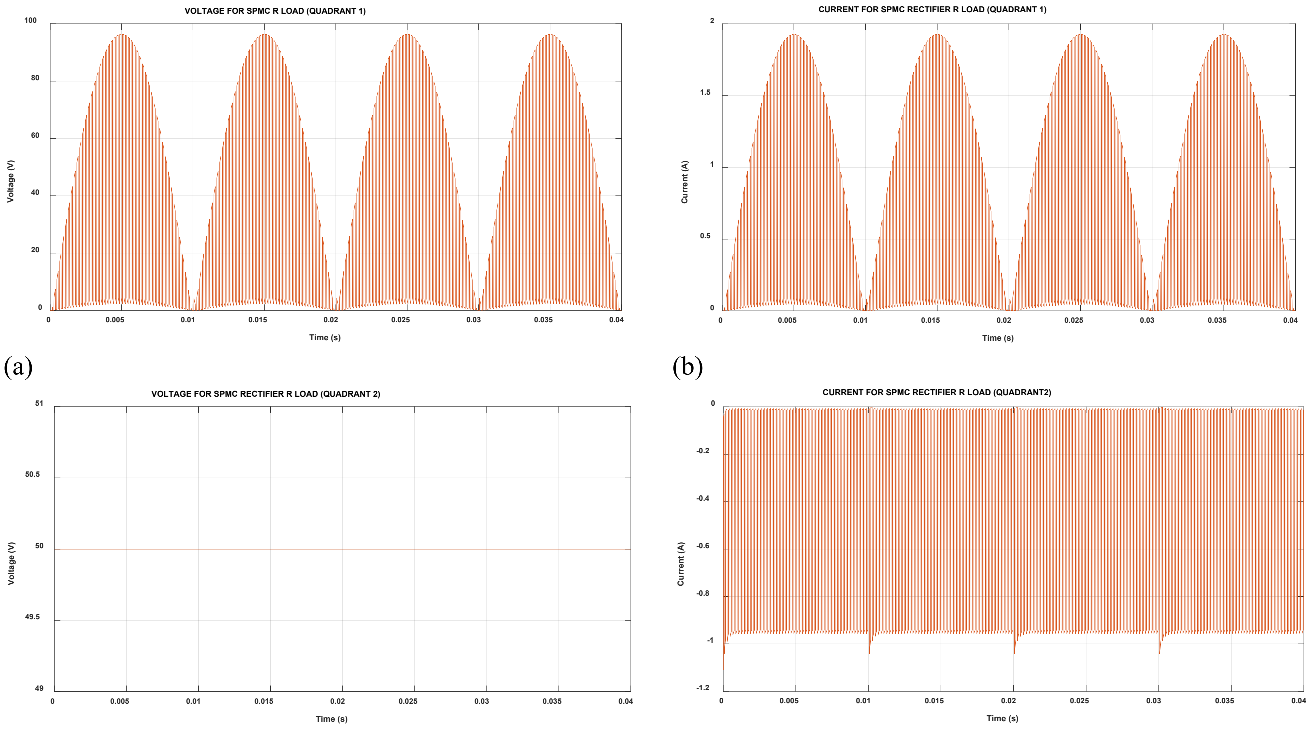


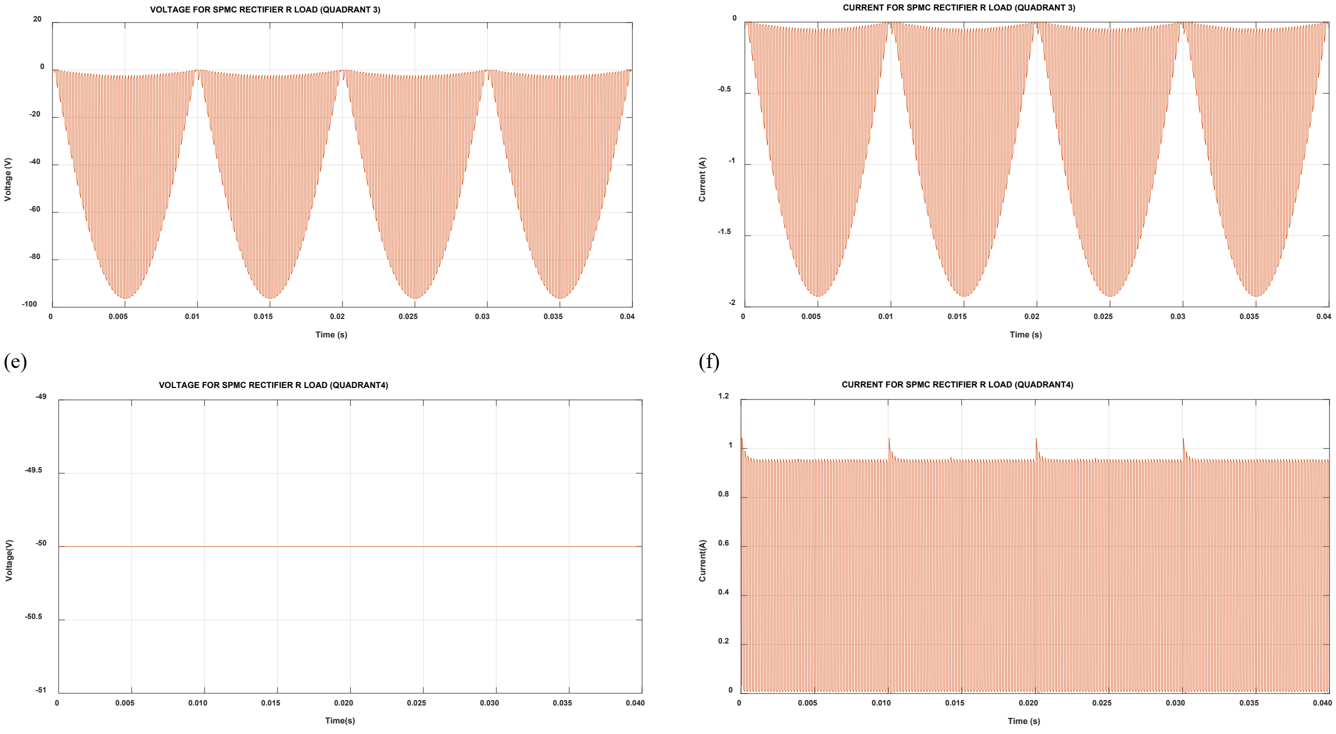
Fig. 18. Rectifier input signal of RL load with APF

Fig. 19 shows the results of four-quadrant operations of the DC drive system. Figs. 19 (a) and 19 (b) indicate the output voltage and current waveforms for Quadrant I operation. Both positive values of voltage and current waveforms verify the forward motor operation of the DC drive. Figs. 19 (c) and 19 (d) show the output voltage and current waveforms for Quadrant II operation where the voltage waveform is positive while the current waveform is negative. Figs. 19 (e) and 19 (f) demonstrate both voltage and current waveforms for Quadrant III operation. For Quadrant III operation, both output voltage and current waveforms are negative values, thus, verify the operation of the DC machine in the reverse motoring mode. Figs. 19 (g) and 19 (h) show the results for the Quadrant IV operation, where the current waveform is positive, and the voltage waveform is negative. The voltage and current profile for Quadrant IV verify the operation of the DC machine to operate in the reverse braking mode.



(a) (b)

(c) (d)



(e) (f)

(g) (h)

Figure 19 . Four quadrants operations, (a) Output voltage waveform for Quadrant I, (b) Output current waveform for Quadrant I, (c) Output voltage waveform for Quadrant II, (d) Output current waveform for Quadrant II, (e) Output voltage waveform for Quadrant III, (f) Output current waveform for Quadrant III, (g) Output voltage waveform for Quadrant IV, (h) Output current waveform for Quadrant IV

VII. CONCLUSION

The proposed new model of the AC-DC converter to control all four quadrant operations of the PMDC motor system has been presented. The limitation of the typical circuit topology to control four quadrant operations of the DC motor can be solved resulting in improving the power density of the electrical power converters. Despite improving the power density, the proposed system also has the capability to maintain a unity power factor operation of the supply current waveform by integrating with the APF function. Inherent commutation problems that lead to switching spikes are also investigated with a suitable safe-commutation algorithm. As a result, such new enhancements can be used as a good foundation of future power electronic converters systems. Therefore, it could be expected that the developed AC-DC converter for control the four quadrants of the PMDC motor system with compact and high power density could help to minimize losses due to the multiple power conversion stages of the conventional power converters.

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