International Journal of Electrical Engineering & Emerging Technology, Vol. 02, No. 02, Dec 2019, pp 9-13

A New UPS System Employing SPMC

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[**Received on:** 29-08-2019 **Accepted on**: 02-10-2019 **Published on:** 03-12-2019]

***Abstract*— This paper presents an Uninterruptible Power Supply (UPS) system using a Single-Phase Matrix Converter (SPMC) topology. The proposed UPS system is called UPS-SPMC. In this work, the conversion of AC to DC and vice versa using the proposed UPS-SPMC is investigated. This work proposes to simplify the circuit topology of the UPS system. The SPMC is opted to replace both rectifier and inverter circuits that typically used in UPS systems. Integrated switching algorithms for the proposed UPS-SPMC to work in rectifier-mode (during normal operation) or inverter-mode (during interruption) have been developed. Selected simulation results are presented to verify the proposed system.**

***Index Terms*—Single-Phase Matrix Converter (SPMC), Uninterruptible Power Supply (UPS), Pulse Width Modulation (PWM), AC-DC converter, DC-AC converter.**

I. INTRODUCTION

UPS is known as a device that can be connected to any electrical device to act as a temporary electric supply in a case of electrical power interruption [1]. The UPS will supply electrical power from a battery to the device whenever the main power supply collapse. Hence, it provides additional safety to the device from power disruption.

All components of a conventional static UPS system are shown in Fig. 1. It comprises of three main components: a rectifier unit for Alternating Current (AC) to Direct Current (DC) conversion during normal operation, an inverter unit for DC to AC conversion during interruption, and [6] a physical bypass switch (like push button) for maintenance and repairment activities.

As shown in Fig. 1, the conventional UPS system consists of 2 different converters (which are rectifier and inverter) that are connected in parallel to each other, to perform UPS operation. The use of both converters has become a weakness to the UPS topology [7]. The complexity of the UPS topology could increase the construction cost as the UPS needs 2 different converters for 2 difference modes of operation, and the UPS size as it requires additional space for many components.

A matrix converter is an emerging circuit topology that bargain many benefits with unrestricted switching control. The topology was first proposed by Gyugyi in 1976 [2], whilst, the single-phase topology called a Single-Phase Matrix Converter (SPMC) was realized by Zuckerberger [3][4]. The SPMC circuit topology offers many advantages such as regenerative ability, reactive element alleviation, and power quality improvement [5]. By using the SPMC as a UPS, power conversions that normally performed by the rectifier and the inverter (in a conventional UPS system) can be realized using a single unit of converter. As a result, the size, cost and weight of the UPS system can be reduced. Also, it improves power density of the UPS system.

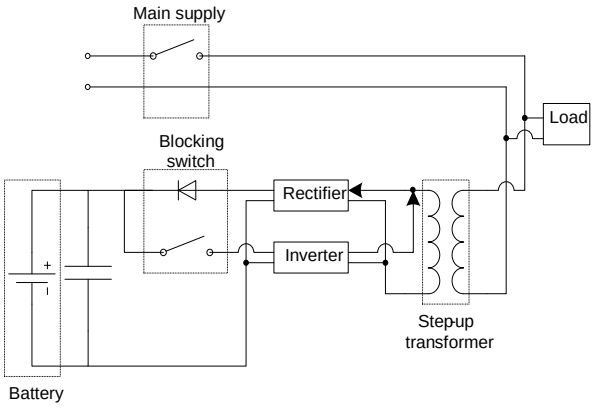


Fig. 1. Conventional static UPS system

II. THE SPMC

The topology of a SPMC is shown in Fig. 2. Based on the figure, four bi-directional switches are needed for constructing a single unit of SPMC [8][9][10]. Fig. 3 shows bi-directional current flows in the SPMC; each switch is capable to block voltage and leading current in both directions [11].

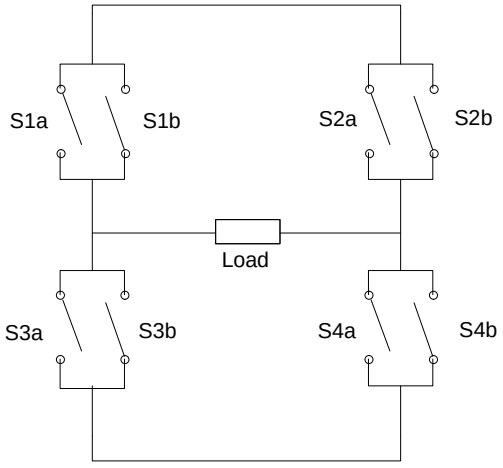


Fig. 2. SPMC topology

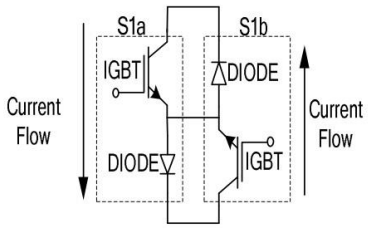


Fig. 3. Bi-directional switch

III. THE PROPOSED UPS SYSTEM

The topology of the proposed UPS system called UPS-SPMC is depicted in Fig. 4. As shown in the figure, the system only consists 1 converter (which is the SPMC). Hence, it provides a simple UPS topology as compared to the conventional UPS system. The SPMC is controlled to operate as a rectifier (during normal operation) and inverter (during interruption), thus remove the need of 2 separate circuits of rectifier and inverter. In this work, the proposed UPS-SPMC is connected to an inductive load.

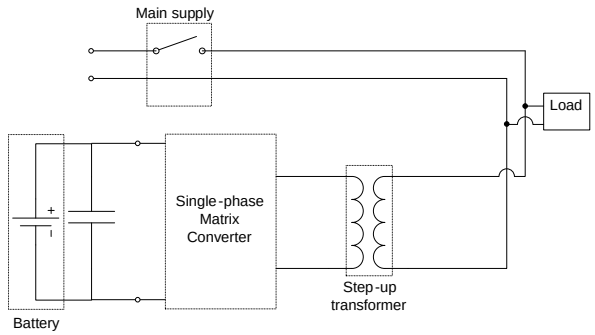


Fig. 4. Proposed UPS-SPMC

A. AC to DC Conversion with safe-commutation function (rectifier operation)

The operation of the UPS-SPMC in AC to DC conversion with safe-commutation function can be divided into 2 modes of operation; Mode 1 (positive cycle) and Mode 2 (negative cycle) operations. The safe-commutation technique is developed to reduce voltage and current spikes produced by the inductive load. Detail operation of AC to DC conversion with safe-commutation function is illustrated in Fig. 5. Meanwhile, Table 1 and Fig. 6 show the switching algorithm and Pulse Width Modulation (PWM) switching pattern respectively.

For mode 1 operation, switch S1a is controlled by the PWM signal whilst both switches S3b and S4a operate as commutation switches as shown in Fig. 5(a), to allow current stored in the inductor to freewheel and dissipates in the load resistor.

For mode 2 operation, switch S3b is controlled by the PWM signal, whilst, both switches S2b and S1a operate as commutation switches during the negative half-cycle operation as shown in Fig. 5(b)

B. DC to AC conversion with safe-commutation function (inverter operation)

An inverter is used in a UPS system to convert DC voltage from a backup battery to AC voltage required by the load [12][15]. Detail operation of DC to AC conversion with safe-commutation function is illustrated in Fig. 7. The switching algorithm and PWM switching pattern are presented in Table II and Fig. 8 respectively. As similar as the rectifier operation, the operation of DC to AC conversion with safe-commutation function can also be divided into 2 modes of operation; mode 1 for positive cycle and mode 2 for negative cycle operations.

Mode 1: During positive cycle operation, switch S1a is controlled by the PWM signal. At the same time, both switches S3b and S4a operate as commutation switches as illustrated in Fig. 7(a).

Mode 2: Switch S2a is controlled by the PWM signal, whilst, both switches S3a and S4b operate as commutation switches during the negative half-cycle operation as illustrated in Fig. 7(b).

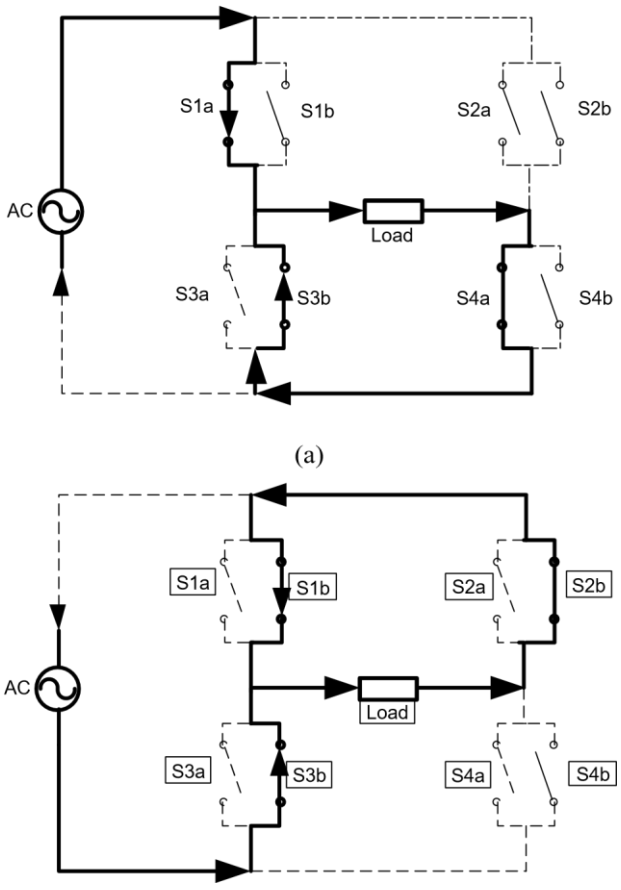


Fig. 5. Rectifier operation using SPMC (a) Positive cycle operation, (b) Negative cycle operation.

TABLE I: Switching algorithm for AC-DC with safe-commutation function.

	PWM switch	**Commutation switch**
Mode 1	S1a	S3b, S4a
Mode 2	S3b	S1a, S2b

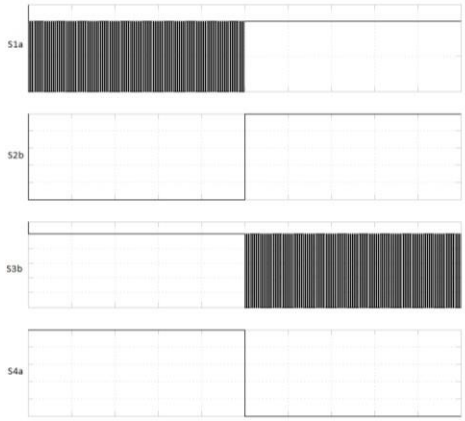
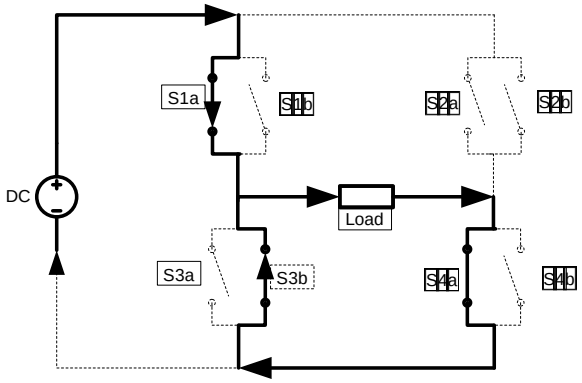
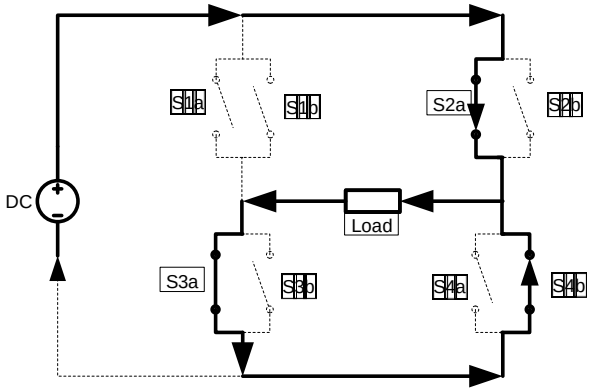


Fig. 6. Proposed UPS-SPMC



(a)



(b)

Fig. 7. Proposed UPS-SPMC

TABLE II: Switching algorithm for DC to AC converter with safe-commutation technique.

	PWM switch	Commutation switch
Mode 1	S1a	S3b, S4a
Mode 2	S2a	S3a, S4b

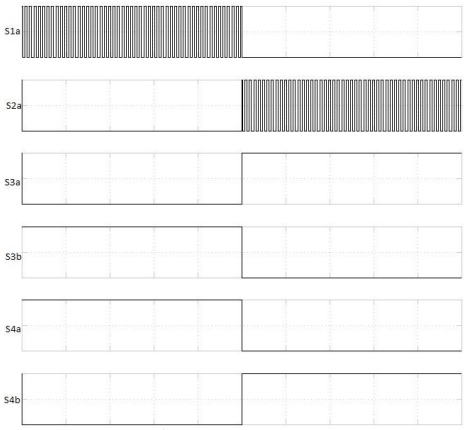


Fig. 8. Switching signal for DC to AC converter with safe commutation technique

IV. COMPUTER SIMULATION MODEL

In this work, the proposed UPS-SPMC model is simulated using MATLAB/Simulink; to investigate the operation of the proposed UPS-SPMC system. As explained in previous section, a new switching algorithm is required to integrate both rectifier and inverter functions in the proposed UPS-SPMC operation. Table III shows the switching algorithm for the proposed UPSSPMC system.

TABLE III: The switching scheme of UPS system.

Operation	Modes	PWM switch	Commutation switch
AC-DC operation	Mode 1	S1b	S2b, S4b
	Mode 2	S2b	S1b, S3b
DC-AC operation	Mode 1	S1a	S3b, S4a
	Mode 2	S2a	S3a, S4b

Fig. 9 shows the schematic circuit of the proposed UPSSPMC system. In this work, a step response is used to simulate the transition time between rectifier and inverter operations. Figs. 10 and 11 show simulation models of circuit controller for both rectifier and inverter operations respectively. For the rectifier operation, the sample time of the step response is set to 0 to 0.04 s, whilst, for the inverter operation is set to 0.04 to 0.08 s.

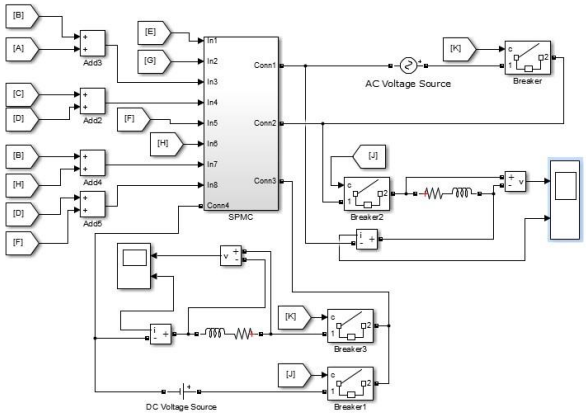


Fig. 9. Circuit integration of rectifier and inverter

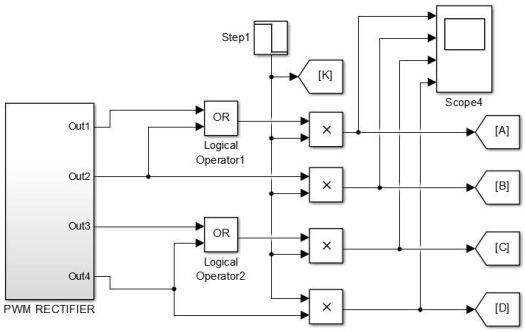


Fig. 10. PWM configuration for rectifier operation

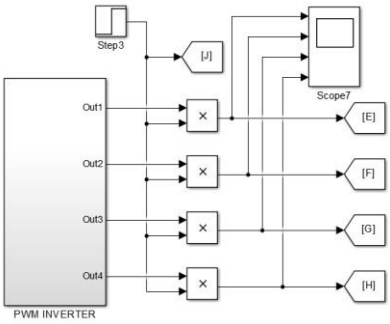


Fig. 11. PWM configuration for inverter operation

V. Results and Discussions

Fig. 12 shows waveforms of output voltage and output current of the proposed UPS-SPMC during rectifier mode of operation. As shown in the figure, the amplitude of the output voltage and the output current are approximately 48 V and 0.7 A respectively. Both voltage and current waveforms are in DC form, and the voltage and current spikes have been reduced using the proposed safe-commutation technique. Fig. 13 shows the output voltage and current waveforms of the proposed UPS-SPMC during inverter mode of operation. The output voltage is 48 V and both voltage and current waveforms are in AC form, and the voltage and current spikes have also been reduced.

Fig. 14(a) shows voltage and current waveform of the inductive load when the proposed UPS-SPMC when it works in rectifier mode triggered by the step response, whilst, Fig. 14(b) shows output voltage and current waveforms of the proposed UPS-SPMC when it operated in inverter mode. Based on Fig. 14, it clearly shown that the step response is able to switch the mode operation of the proposed UPS-SPMC, from rectifier mode to inverter mode and vice versa. Between of 0 to 0.04 s, the proposed UPS-SPMC system operates as rectifier or AC-DC converter. During this time, the standby battery is charging. At 0.04 s to 0.08 s, the AC supply is disconnected and the proposed UPS-SPMC system operates as an inverter or DC-AC converter. Within this period, the battery is discharging to supply the inductive load.

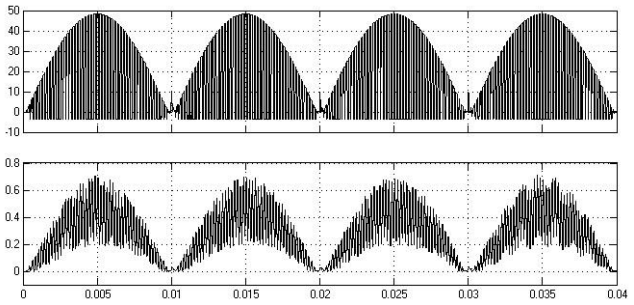


Fig. 12. Output voltage and current waveforms of the proposed UPS-SPMC during rectifier mode.

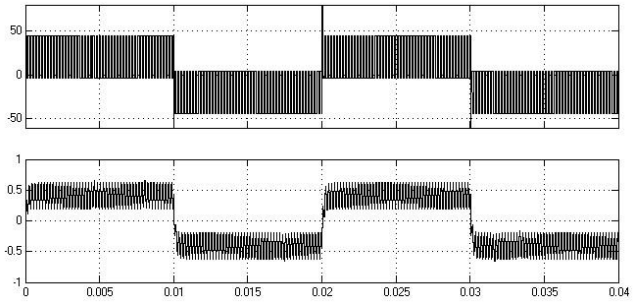
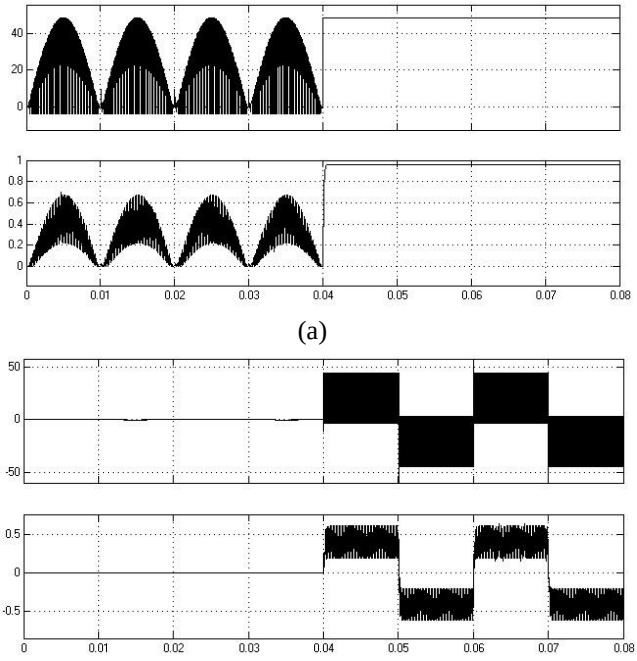


Fig. 13. Output voltage and current waveforms of RL-load.



(a)

(b)

Fig. 14. Output of voltage and current waveforms (a) For AC-DC operation. (b) For DC-AC operation.

Acknowledgment

Authors gratefully acknowledge the financial support from Ministries of Higher Education Malaysia and Institute of Research Management and Innovation (IRMI) Universiti Teknologi MARA Grant No: 600-IRMI/MyRA 5/3/BESTARI (029/2017).

VI. CONCLUSION

This paper briefly describes the successful implementation of a UPS system using a SPMC circuit topology. By using the proposed UPS-SPMC system, both rectifier and inverter circuits used in a conventional UPS can be replaced by a single unit of SPMC. The proposed UPS-SPMC system can operate as a rectifier or inverter using the proposed switching algorithm. All simulations results have proven that the proposed UPSSPMC system is capable to work as similar as the conventional UPS system. For future recommendation, a closed-loop current control should be developed for the proposed UPS-SPMC system; to improve the Total Harmonic Distortion (THD) level of the proposed UPS-SPWC system

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