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Analysis of suitable converter for the implementation of drive system in solar photovoltaic panels

Introduction. *Photovoltaic (PV) systems gained immense attraction in the recent years since it produces electricity without causing environmental pollution through direct conversion of solar irradiance into electricity. Solar PV panels produce DC power. The magnitude of this DC power varies with temperature and irradiance of the sun rays. The DC supply from solar panels can be regulated using DC-DC converter and then can further be converted into the desired AC voltage by means of a voltage source inverter before being fed to an induction motor (IM). The speed and torque of an IM, fed from PV arrays, can vary due to the variation in the output power of the panels.* ***Goal*** *of this work is to improve the dynamic performance and reduce the torque ripple of Cuk converter-inverter fed IM drive system. The* ***novelty*** *of the current work proposes interleaved Cuk converter between solar PV DC source and the inverter.* ***Purpose.*** *To provide continuous current using an interleaved Cuk converter to the IM drive and in turn to reduce the torque ripple in IM.* ***Methodology****. Introduced an interleaved Cuk converter which is a blend of Cuk converters connected in parallel with each other between solar PV arrays and IM drive system.* ***Originality.*** *Simulation results are obtained for Cuk converter and interleaved Cuk converter fed IM drive by means of MATLAB. The hardware setup for the same IM systems is developed.* ***Practical value.*** *Simulation and hardware results are coincided with each other and it is subject from the simulation and hardware results that the interleaved Cuk converter-inverter fed IM system produced results superior than the Cuk converter inverter fed IM drive system.* References 25, table 2, figures 22.
Key words: **induction motor drive, interleaved Cuk converter, voltage source inverter.**

Вступ*. Фотоелектричні (ФЕ) системи набули величезної привабливості в останні роки, оскільки вони виробляють електроенергію, не викликаючи забруднення навколишнього середовища, за рахунок прямого перетворення сонячного випромінювання на електрику. Сонячні ФЕ панелі виробляють енергію постійного струму. Значення цієї потужності постійного струму залежить від температури та освітленості сонячних променів. Подача постійного струму від сонячних панелей може регулюватися за допомогою DC-DC перетворювача, а потім може бути перетворена в бажану змінну напругу за допомогою інвертора джерела напруги перед подачею на асинхронний двигун. Швидкість та обертаючий момент асинхронного двигуна, що живиться від ФЕ батарей, можуть змінюватися через зміну вихідної потужності панелей.* ***Метою*** *даної роботи є покращення динамічних характеристик та зменшення пульсацій обертаючого моменту системи приводу асинхронного двигуна з живленням від Cuk перетворювача-інвертора.* ***Новизна*** *цієї роботи пропонує Cuk перетворювач, що чергується, між сонячним ФЕ джерелом постійного струму та інвертором.* ***Мета****. Забезпечення безперервності струму за допомогою Cuk перетворювача, що чергується, для приводу асинхронного двигуна і, у свою чергу, зменшення пульсації обертаючого моменту в асинхронному двигуні.* ***Методологія****. Представлений Cuk перетворювач, що чергується, який являє собою суміш Cuk перетворювачів, підключених паралельно один до одного між сонячними ФЕ батареями і системою приводу асинхронного двигуна.* ***Оригінальність****. Результати моделювання отримані для Cuk перетворювача і приводу асинхронного двигуна з живленням Cuk перетворювача, що чергується, за допомогою MATLAB. Розроблено апаратну частину цих же асинхронних двигунів.* ***Практична цінність****. Результати моделювання та апаратного забезпечення збігаються один з одним, і з результатів моделювання та апаратного забезпечення випливає, що система асинхронного двигуна з живленням від Cuk перетворювача-інвертора, що чергується, дає результати, які перевищують результати, ніж система приводу асинхронного двигуна з живленням від Cuk перетворювача.* Бібл. 25, табл. 2, рис. 22.
Ключові слова: **привід асинхронного двигуна, Cuk перетворювач, що чергується, інвертор джерела напруги.**

1. Introduction. Photovoltaic (PV) systems gained immense attraction in the recent years since it produces electricity without causing environmental pollution through direct conversion of solar irradiance into electricity. This reality, together with constant decline in the cost incurred for PV arrays and increased efficiency which makes the next generation PV systems a preferable one. The capacity of PV cells relies upon a number of elements, for example, temperature, solar irradiance, daylight timings, soil condition, shadow timings and types of PV panels etc. The magnitude of this DC power varies with temperature and irradiance of the sun rays. DC supply from solar panels can be regulated using DC-DC converter and then can further be converted into the desired AC using a Voltage Source Inverter (VSI) before being feed to an induction motor (IM) for controlling its velocity and modes of operation.

The output from the PV system gets increased when utilizing a Cuk converter. With the help of a 3-phase VSI, the Cuk converter's output is upturned and pragmatically feed into a 3-phase IM. PV fed Cuk converter is permitted to make DC voltage as the input of inverter. In this way, the PV system's output is improved by using a Cuk converter. In general, the yield of the Cuk converter is reversed in an inverter-fed 3-phase IM.

By presenting a novel active clamper circuit, a converter circuit for electric vehicles (EVs) that achieves high efficiency and constant input current is demonstrated [1]. A modular multilevel inverter was designed using fuzzy logic technique for marine water pumping applications. A systematic method to attain Maximum Power Point Tracking (MPPT) for a PV fed IM support water pumping system was proposed [2]. Cuk converters were not employed in PV array-based water pumping systems prior to this study, despite the fact that they have various advantages and are a viable choice for utilisation when compared to other DC-DC converters. This study also proposed low-esteemed DC interface capacitor of VSI [3].

In order to eliminate the input current ripple at the selected duty cycle, two Cuk converters with positive and negative output voltage polarity are interleaved to create a buck-boost converter [4]. By calculating the quantity of inductors on the input side of both converters, the selective duty ratio can be calculated. The buck-boost converter uses output inductors to achieve low output current ripple and zero input current ripple. The converter's maximum voltage gain is straightforward and easy controlled [5].

A novel MPPT procedure for solar panels utilizing a SEPIC or Cuk converter was proposed. This study proposed a novel method to leverage the highest result power from solar panels under differing environmental conditions. The study followed a methodology in which a pulse-width-modulated DC-DC SEPIC or Cuk converter was connected with a solar panel along with load or the battery bus [6]. The converter functions in a manner under discontinuous capacitor voltage mode, whereas the input current-fed switched inverter having single-stage, high boost inverter with buck-boost capability is reported for better electromagnetic interference noise immunity, wide input and output voltage range of operation, etc. A hybrid converter has been also developed to suit both AC and DC loads [7]. To enhance the robustness of a robotic system, a fractional PID control system is identified and analyzed. Control system parameters are obtained by employing recursive least-squares method [8]. Given attention on a 5 horse power, 110 V, 80 Hz IM that is appropriate for EV applications. High base frequency is utilised for uphill driving in order to maintain steady torque over a wider range. When developing the IM for an EV application, efficiency, power factor, and breakdown torque are taken into account [9]. It is said that an IM with four active and reactive power quadrants, a variable speed operation range, excellent energy efficiency, and better power quality. Because of its unique functions, this IM was specifically created for high-power wind energy conversion systems. Additionally, a three phase matrix converter is offered to lower the big harmonics [10].

Bridgeless Power Factor Correction (PFC), SEPIC and Cuk rectifiers were introduced that resulted in fewer amounts of conduction and switching losses). The study proposed novel bridgeless single-stage AC-DC PFC rectifiers in line with SEPIC and Cuk topologies. Due to the lack of input diode connect and since the two semiconductor switches are close proximity to the current streaming way, during each switching cycle, it ensures that the conduction losses get reduced while the thermal management is also increased in comparison with general SEPIC converter and Cuk PFC converter. The recommended topologies were proposed to exertion in DC motor to finish a next solitary control aspect in a flourishing method [11]. Model predictive control based field weakening algorithm is insisted to eliminate the DC-link disturbance in traction EV using a low-voltage IM [12]. A dynamic snubber zero voltage exchanging Cuk converter was planned, designed and executed [13]. The primary windings seemed to be series-connected in two transformers of the converter proposed in the study, while parallel connection was established between two half-wave rectifiers at output end in order to diminish the power stretches that occur in the transformer's secondary winding. The design and control of a single stage power controller used in a solar fed standalone application is given in [14]. A DC synchronous reference frame based controller is designed for the converter to normalize the yield voltage as per the requirement of the load [15]. Robust analysis on a non-linear system controlled by PID controller and FOPID controller were performed and compared their performance based on their ability to reject external disturbance. The performance of the controllers was done on the system based on their response for a step input [16-18]. There is a requirement to normalize the speed of IM while the guidelines for open loop Interleaved Cuk Converter-Inverter fed IM (ILCCIIM) seem impressive.

The review of literature is evident that the works conducted earlier missed to deal with ILCCIIM [19-25]. There is a requirement to regulate the speed of ILCCIIM system.

The goal of the article. The current work proposes interleaved Cuk converter between solar PV DC source and the inverter to regulate the speed and torque of the IM.

2. Selection of Cuk converter for IM drive system.

DC-DC Cuk converter. In general, DC-DC Cuk converter can work in both boost and buck modes. It further ensures the energy is flown in both directions i.e., between source and the load. Based on input voltage, the output voltage from Cuk converter remains negative. The converter can handle nonstop input voltage and persistent output current. The inductor, on the output side, is used for better output current. Likewise, on input side, it is used to support the voltage level. It is possible to make the Cuk converter function in either continuous conduction mode or in discontinuous conduction mode based on load requirements. Since the output current of the converter is discontinuous, in order to make it continuous and to meet the load current requirement of the IM, the Cuk converter can be interleaved. Here the *interleaving* means the parallel connection of Cuk converters by retaining the rating of the components like inductors and capacitors. This work concentrated on two stages of interleaved Cuk converter. If the number of stages is increased that will lead to increase in complexity and more switching loss. Hence two stages of interleaved Cuk converter are preferred here for the decide speed control of IM drive.

3. Proposed interleaved Cuk converter.

Output of Cuk converter. The production of all the Cuk converters is available as output for the load. The course of action of two converters makes the output in such a way that an interleaved Cuk converter turns into a single controlled device topology. The benefit of the proposed interleaved Cuk converter is the mitigation of torque ripples in the output.

The turn-around stream of current that emerges from load side to input side gets inhibited by the input side inductor. Figure 1 shows the proposed interleaved Cuk converter in which two Cuk converters are connected in parallel. Figure 2 shows the circuit diagram of converter-inverter fed IM system.

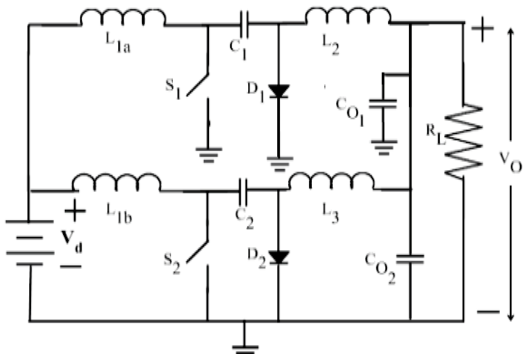

Fig. 1. Proposed interleaved Cuk converter

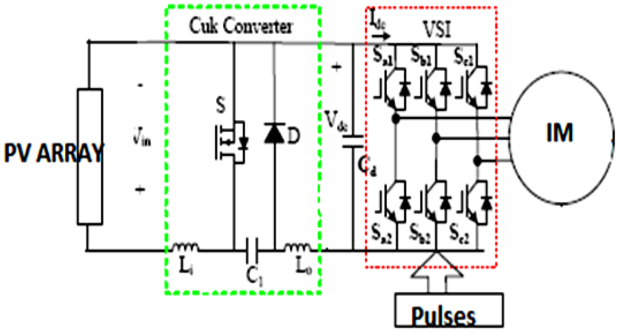

Fig. 2.Circuit diagram of Cuk converter-inverter fed IM

4. Simulation results of Cuk converter-inverter fed IM. The MATLAB/Simulink model is used to investigate the performance of the Cuk converter and interleaved converter circuit. The high gain interleaved Cuk converter has a 100 V input voltage and a 400 V output voltage. The switching frequency is held constant at 10 kHz.

The Cuk converter fed IM system created in MATLAB/Simulink is shown in Fig. 3. Figures 4, 5 illustrate the applied input voltage and the voltage across the Cuk converter, respectively. The applied input voltage is 150 V DC. The voltage across the Cuk converter is shown in Fig. 6. The Cuk converter's output voltage is 60 V. Figure 7 depicts the Cuk converter's voltage ripple.

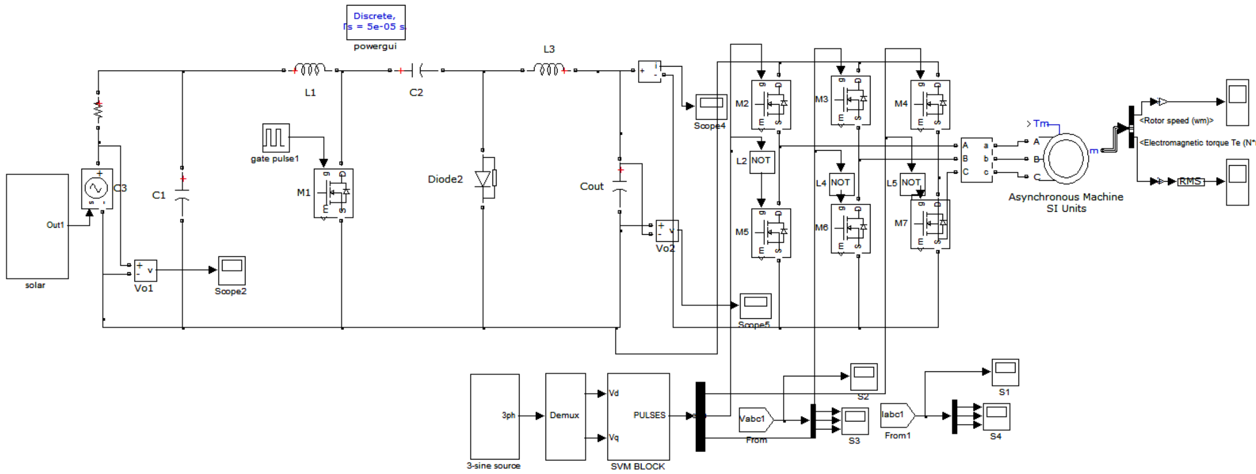

Fig. 3. Cuk converter fed IM system

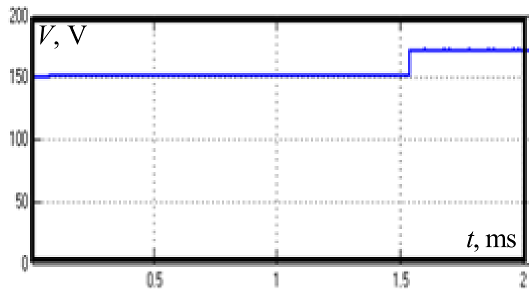

Fig. 4. Input voltage applied to the Cuk converter in open loop ILCCIIM

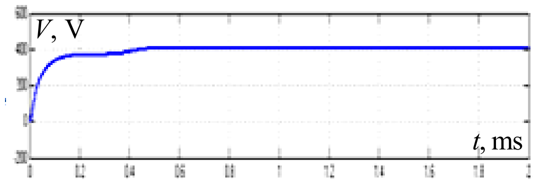

Fig. 5. Voltage across Cuk converter

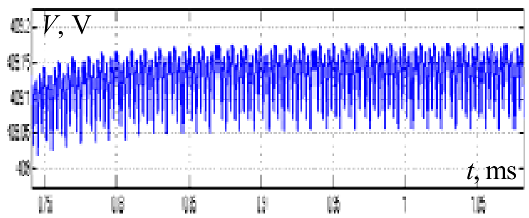

Fig. 6. Voltage ripple of CUK converter

Figures 7, 8 show the inverter's output voltage and current, respectively. The output current (peak to peak) is 50 A, and the output voltage is 500 V.

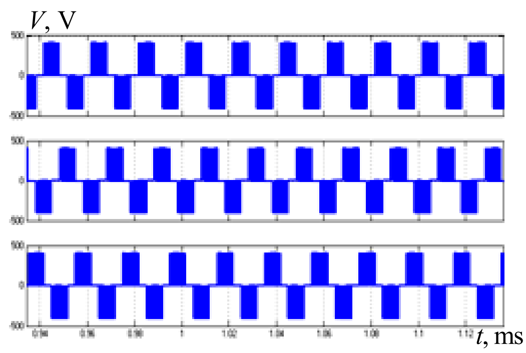

Fig. 7. Output voltage of the inverter

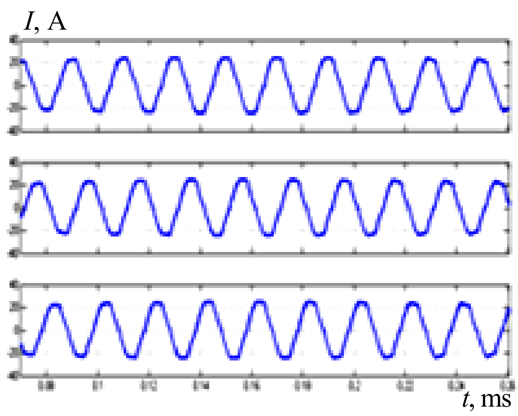

Fig. 8. Output current of the inverter

Figures 9, 10, respectively, display the motor speed and motor wave forms. According to the findings, the motor torque stabilizes about 0.5 s.

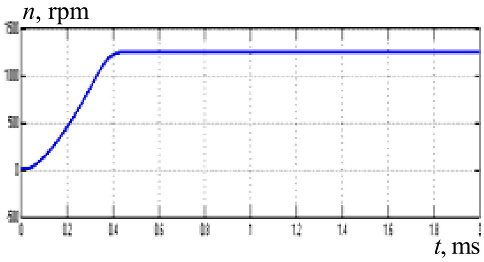

Fig. 9. Motor speed

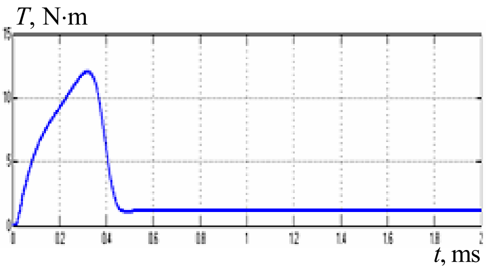

Fig. 10. Motor torque

5. Simulation of ILCCIIM system. The MATLAB Simulink is used to build the ILCCIIM system. Similar outcomes are also attained with this system. ILCCIIM system circuit is depicted in Fig. 11. Figure 12 depicts the output torque ripple of a single Cuk converter as well as the superimposed waveform of a two-stage interleaved Cuk converter.

In order to lessen the input current ripple, two Cuk converters were assigned in tandem. The speed response established by ILCCIIM is depicted in Fig. 13, and it had a value of 0.48 N·m. Due to improved insulation, the ILCCIIM's torque and speed were both stabilized at higher values.

6. Implementation results of ILCCIIM. A hardware setup for an inverted-fed, interleaved Cuk converter motor was created and put into practice in a lab environment (Table 1). Figure 14 shows the hardware setup of ILCCIIM system. Figure 15 shows the output voltage of solar panel whereas. Figure 16 shows the Cuk converter's output voltage.

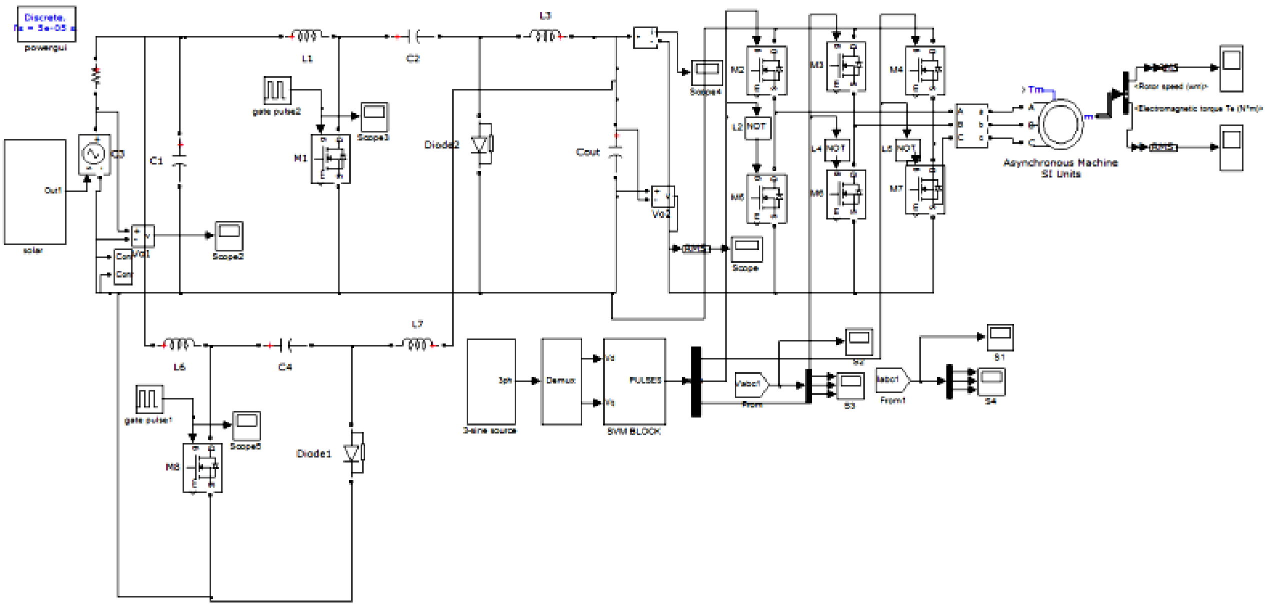

Fig. 11. Interleaved Cuk converter-inverter fed IM

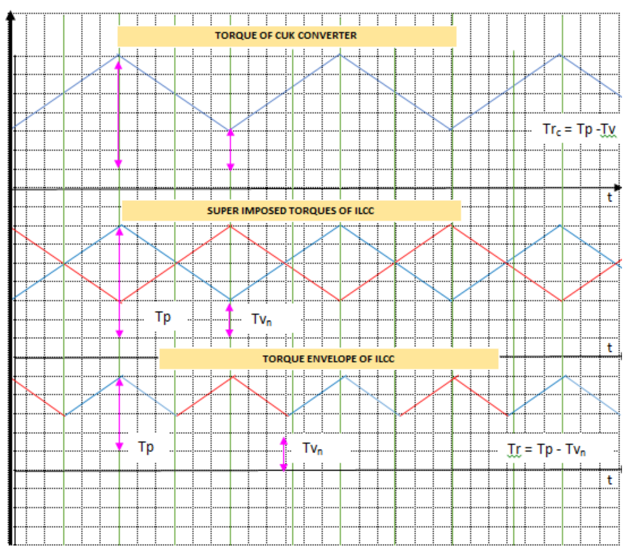

Fig. 12. Torque wave form of the interleaved CUK converter

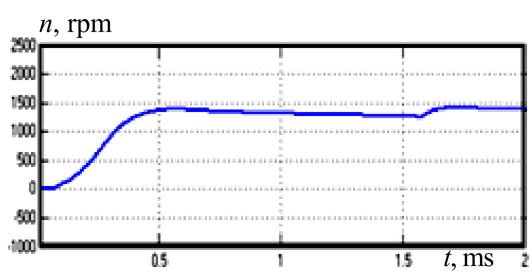

Fig. 13. Motor speed

Table 1

Hardware parameters of Cuk converter-inverter fed IM

Parameter	Value
L_1,L_3	0.5 mH
C_2,C_4	1000 μF
MOSFET(IRF840)	500 V / 8 A
Diode	230 V / 1 A
Controller	PIC16F84A
Driver IC	IR2110

Fig. 14. Hardware setup of solar based IRCCIIM

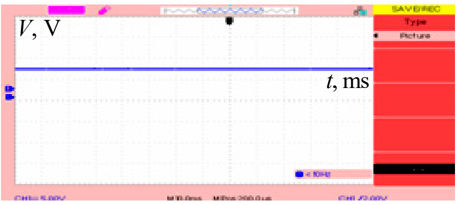

Fig. 15. Output voltage of the solar panel

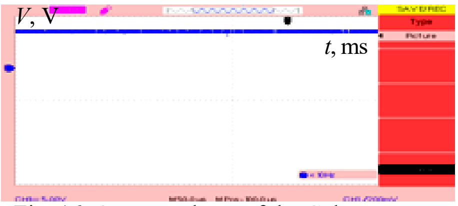

Fig. 16. Output voltage of the Cuk converter

Figure 17 shows the switching pulses for M1, M4 and Fig. 18 shows the switching pulses for M5, M2. Figure 19 shows the voltage across the motor load. The inverter's output spiked because the switching order was changed at intervals of 600.

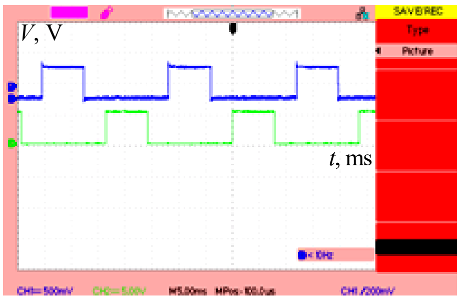

Fig. 17. Switching pulse for M1, M4

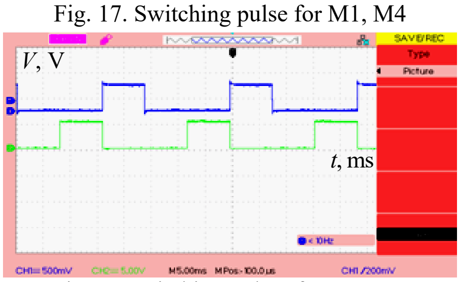

Fig. 18 Switching pulses for M5, M2

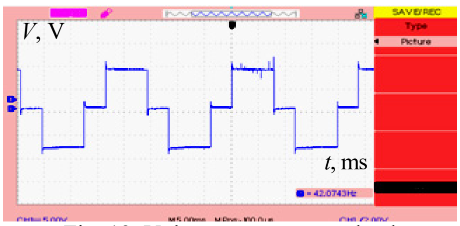

Fig. 19. Voltage across motor load

The output voltage contains reverse polarity nature in case if it is attached with input voltage. Cuk converter's output is then applied on to 3-phase inverter. The balanced voltage, which is actually developed with the help of 3-phase inverter, is then applied onto IM.

The hardware setup for ILCCIIM is checked and verified. The structure suggested in this study is shown in Fig. 20 in terms of hardware setup and it is composed of PV panel, inverter board, Cuk converter board, control board and transformer board.

Figure 21 shows the input voltage from solar PV system further. Figure 22 shows the voltage across Cuk converter.

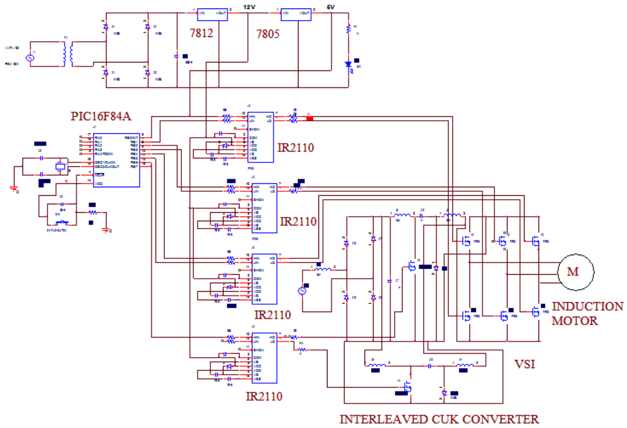

Fig. 20. Hardware circuit of IRCCIIM

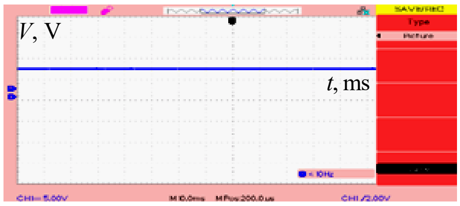

Fig. 21. Input voltage from solar panel to Cuk converter

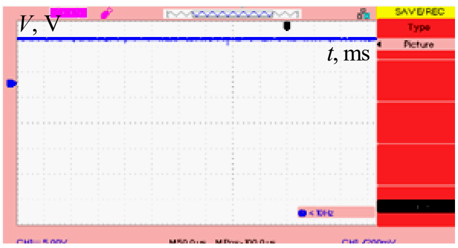

Fig. 22. Voltage across Cuk converter

The comparison between Cuk converter based system and interleaved Cuk converter based system is given in Table 2.

Table 2

Comparison between CCIM and ILCCIIM

Parameters	CCIM	ILCCIIM
Input voltage V_{in}, V	150	150
Output voltage V_o, V	400	475
Frequency, kHz	5	5
Speed n, rpm	1200	1250

7. Conclusions.

1. An interleaved Cuk converter compared to other conventional converters, inverter-fed induction motor systems offer greater voltage transformation and a reduction in input and output current ripple.

2. In continuous conduction mode, a traditional Cuk converter creates enormous input side current ripples, which then inject harmonics into the source. The interleaved Cuk converter is used to reduce the undesired input current ripple.

3. The output voltage of an interleaved Cuk converter is 75 V higher than that of a regular Cuk converter,

according to simulation data. Cuk converter with interleave inverter designed is also suitable for high power applications, such as electric car systems.

Conflict of interest. The authors declare that they have no conflicts of interest.

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