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System for a Solar Power High-Frequency Converter Operation in Electric Vehicle Application

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A solar power system is the most reliable and environmentally-friendly form of energy because it is non-polluting, inexhaustible, and non-toxic. Because of the rapid advancement of semiconductor devices and the application of power electronics methods, it is required to maintain the DC maximum power and high output efficiency of solar arrays. The solar power converter operates as a single-stage and single-phase converter on both the transmitter and receiver sides with some parameter configurations. This proposed system mostly utilizes the PV array with the high-frequency inverter integrating the DC-DC converter, which minimizes the converter losses and the current ripple. A high-frequency rectifier can be used on the receiver side of the proposed output circuit to rectify it. By reducing switching and conduction losses, it is possible to increase the output power. This circuit diagram uses a prescribed level of solar irradiance, suitable DC optimal voltage, and optimal AC RMS current to simulate an entire AC cycle. MATLAB/SIMULINK is used to design and simulate the system. Using an irradiance value of 1000 W/m^2, and a temperature of 20 °C, the optimal output values have been obtained and evaluated as 342V DC and 20.05A AC. Thus, the main objective of this paper is to create a highly efficient energy converter to charge EVs with a DC input voltage of 12 V. This converter will have a high-efficiency range of 96 %.

Keywords: DC-DC converter, Electric Vehicle, Solar photovoltaic array, Wireless power transfer.

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1. INTRODUCTION

Nowadays, power generators based on Renewable energy resources are increasing. Because renewable energy is alternative energy for already using a non-renewable type of resources [1, 2] such as coal, petroleum, natural gas, etc., some Renewable energy resources are solar, wind, Hydro, Geothermal, Ocean, etc. [3] Among the discussed renewable energy resources, the solar energy is most commonly used all over the world. Further, they are clean, highly abundant, and emission-free resources. Solar energy-based power generation uses Photovoltaic (PV) cells. Multiple PV cells are connected in series to give the maximum output power as a single PV cell produces low power output [4, 5]. Also, the PV cell arrangement is sometimes affected by changing environmental conditions, because generally renewable energy resources are based on seasonal parameters such as temperature, wind velocity, irradiation, etc., [6].

Due to these environmental changes, the output power generated also changes often leading to fluctuations. Thus, the maximum output power produced using the MPPT process is to be stored in the batteries for further use. Further, it is not suitable for direct use, because of some unavoidable fluctuations in the power output (as a result of environmental change) [7]. As a result, power converters like DC-DC converters are employed to convert low (or) fluctuating DC output power to the appropriate power rating [8]. DC-DC converters use semiconductor devices such as MOSFETs, IGBTs, and BJTs to increase or decrease the DC output power [9]. DC-DC converters are also employed in a variety of applications, including automotive transportation, switched-mode DC power supplies, electric motor drives, aerospace, smart grids, and other traction applications [10]. Several researchers have recently created fuzzy model DC-DC converters, interleaved DC-DC converters, multi-input independent step-up DC-DC converters, burst mode DC-DC converters, and other DC-DC converters [11].

In recent years, several researchers have proposed various single-stage inverters to achieve maximum efficiency [12]. Chen and Xu [13] 2021 have discussed various soft-switching single-phase inverter topologies used for residential applications. Khan and Gupta [14] 2021 have proposed a small-scale wind energy conversion system for residential applications at remote locations [15]. The objective of this paper is to create a solar power converter for residential PV applications that includes a high-frequency rectifier as well as an inverter [15].

Section I includes the introduction of the solar power converter and the advantages of using renewable energy. Section II includes a description of the proposed methodology of the simulation circuit diagram. Section III includes the results and discussion of the proposed system. The result and discussion section contains the waveform of the voltage, current, total losses, power losses, and efficiency. Section IV includes the conclusion part and which contains the advantages and

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disadvantages of the suggested system when compared to the existing system.

2. METHODOLOGY

The proposed simulation circuit diagram is depicted in Figure 1. The proposed system contains a PV array, a high-frequency inverter with a DC-DC converter, and a controller unit. Further, the high-frequency inverter side is made up of an input PV array and four MOSFET semiconductor switches such as MOS1, MOS2, MOS3, and MOS4. The grid and the receiver side are also fed the output of the high-frequency inverter.

The receiver side consists of a 1:1:1 linear transformer with a high-frequency rectifier circuit. The controller unit is responsible for generating switching pulses for all the MOSFET switches. Furthermore, the four different feedbacks such as DC voltage (v_dc), AC voltage (v_ac), AC current (i_ac), and AC current reference value (i_ac_ref) are given to the controller and the controller generates the switching pulses for the respective switches.

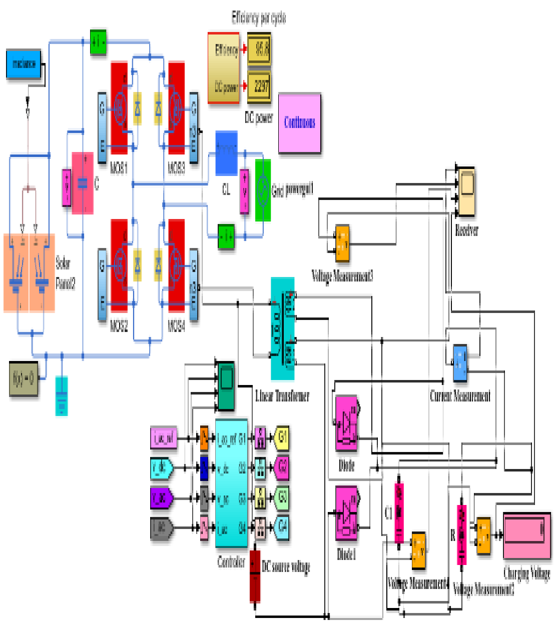

Fig. 1 – Simulation Circuit Diagram

The switching pulses are applied to the gate terminals G1, G2, G3, and G4 of the MOSFET's MOS1, MOS2, MOS3, and MOS4 respectively. In this work, the solar irradiance given to the PV array is set as 1000 W/m^2 and the temperature of the panel is set as 20 degrees Celsius. With the presented input parameters, the output of the proposed high-frequency rectifier as well as the inverter circuit is analyzed and the efficiency of the proposed system is evaluated. Also, the proposed topology is a single-phase and single-stage topology in which both AC and DC power is generated in a single stage resulting in the reduction of converter losses, less current ripple, and high efficiency.

3. RESULTS AND DISCUSSION

The entire circuit configuration is simulated in this research study using MATLAB/Simulink. In addition, the output parameters for the suggested system are represented as waveforms in Figures 2-8. Figure 2 depicts the suggested system's output DC voltage.

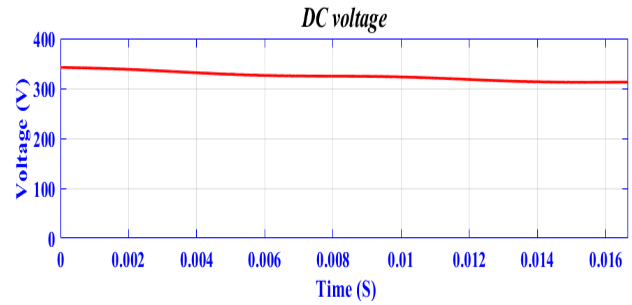

Fig. 2 – DC output voltage of the proposed system

It is seen that the optimal output value for the given solar irradiance is 342 V DC. Also, the demanded AC RMS current is shown in Figure 3 and it is observed that the AC RMS current value is 20 A.

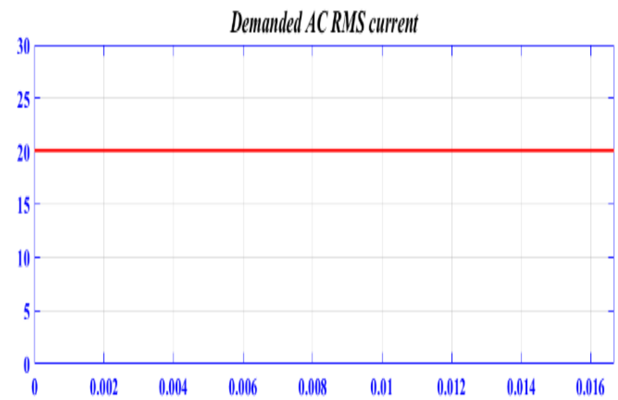

Fig. 3 – AC RMS current of the proposed system

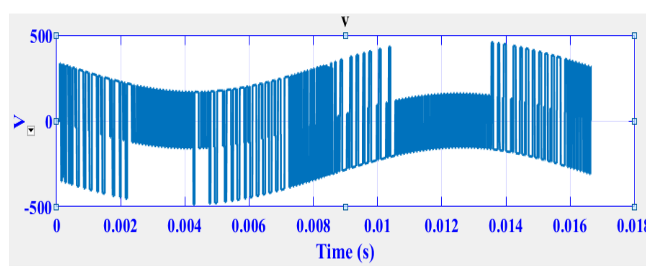

Fig. 4 – Output AC voltage before filtering

Figure 4 depicts the suggested system's voltage output before the filtering operation. The *L* and *C* filter is employed to smooth the AC voltage output of the suggested system. The output voltage of the proposed system after the filtering operation is depicted in Figure 5. Figure 5 shows an *LC* filter flattening the AC output voltage, and Figure 6 shows the flattened output voltage waveform.

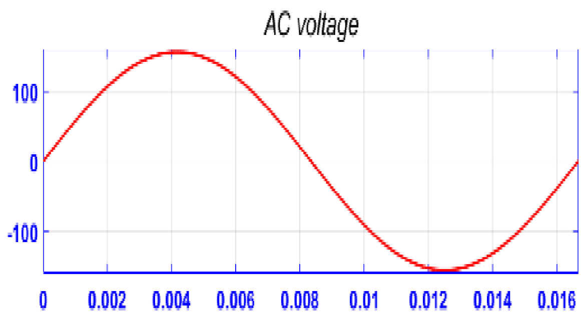

Fig. 5 – Output AC voltage after filtering

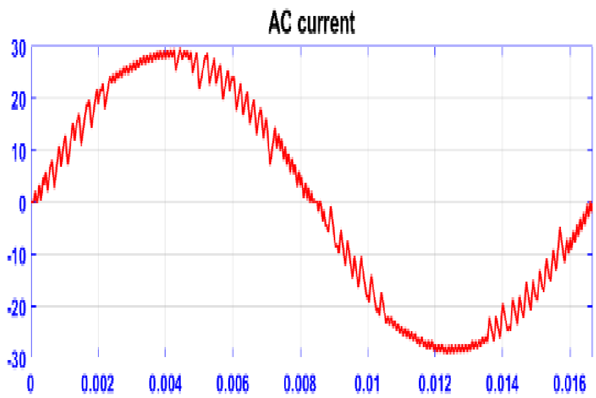

Fig. 6 – Output AC current of the proposed system

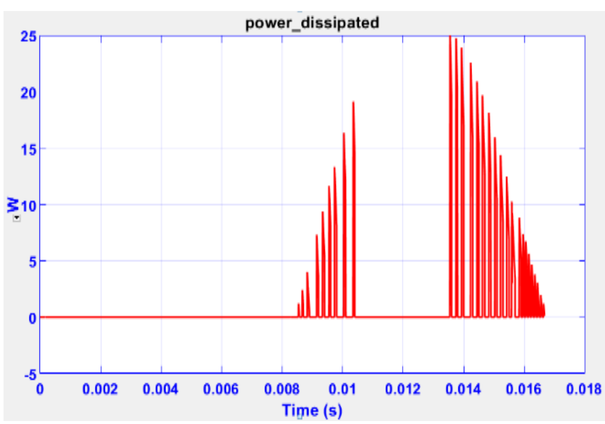

Fig. 7 – Output Power of the suggested system

Figure 6 illustrates the proposed system's output AC current waveform. The suggested system's output AC current is 29 A, as can be observed. In addition, Figure 7 depicts the output power of the suggested system.

Figure 8 and 9 shows the output waveform of the converter and power dissipation graph for mosfet 1 and 2 present in the proposed system. In the simulation proposed diagram, separate DC-DC converters are used and the waveform is plotted above.

3.1 Energy Losses and Overall System Efficiency

Table 1 illustrates the expected primary implementation losses, which are mostly determined by

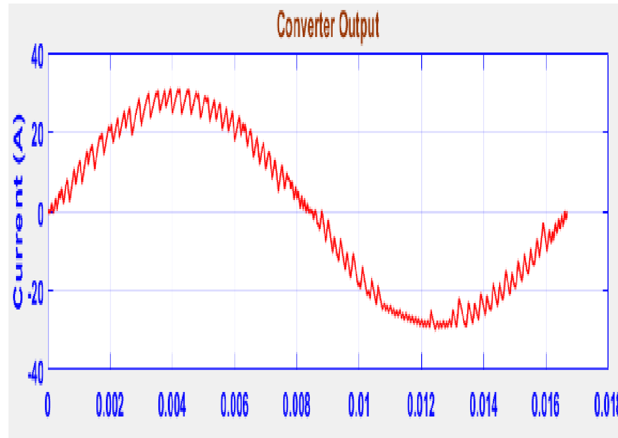

Fig. 8 – Converter Output of the suggested system

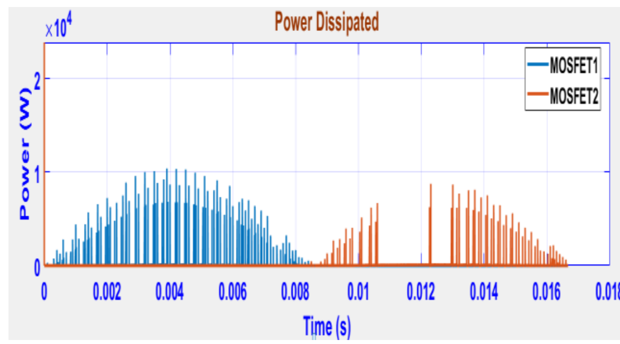

Fig. 9 – Output Power dissipation of the simulation diagram

the highest possible power output and the selected expansion voltage (12-15 V). This obtained output depends on manufacturer requirements (for inverters block system efficiency) and even some operational factors (for controller efficiency and switching losses, such as Voltages/currents/dimension size of the capacitor). If all of the components are taken into account, the overall power loss is predicted to be around (13-15) W. Thus, the commercial usage inverter utilized by the solar energy converter has a 96.6 % efficiency of approximate rating. The DC power source block and the efficiency diagram are presented in Figure 10 and the waveform of the efficiency is shown in Figure 11 as follows.

Table 1 – Study of the Suggested System Loss Factors

Loss Factor	**Loss factor Representation**	**Estimati Value**
1	Conduction losses caused by the MOSFET mostly on the transmission end	8.09W
2	Conduction losses as a result of the diode inside solar energy converter circuit design	5.87W
3	Dynamic losses are caused while switching	≈0.1 W
4	The logical and sequential capacitors with varying voltages cause power losses	2.1 mW

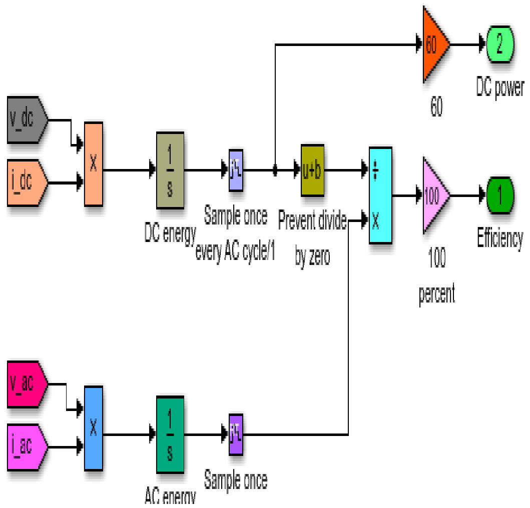

Fig. 10 – DC Power Source and the Efficiency Block Diagram Representation

DC Output Power Source
= 60×trapz (t,vDC.×iDC)
= 60×trapz (1.2801, 342.9×5.231
= 2298 V

System Efficiency
= 100× (DC Power source-overall Losses)/DC Power source
= 100×(2298 – 13.94)/2298 = 96.6 %
Overall system Losses = Total (DC Losses in Power)
= 13.8 V

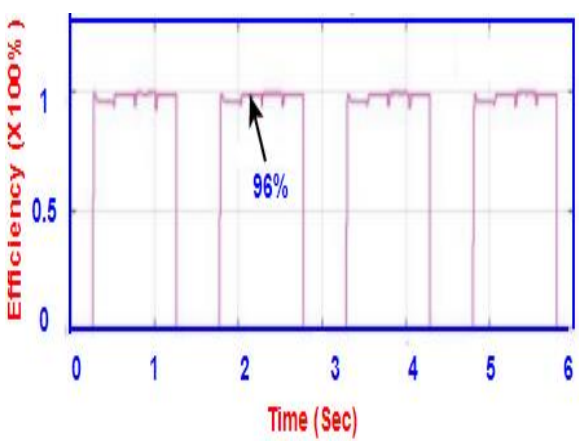

Fig. 11 – Efficiency of the proposed system

To create high-input inverters, Increased input source voltage MOSFET switches having higher RDS (on) resistances are necessary. Therefore as result, optimum system designs have a lot of power losses and have the minimum amount of efficiency. Inverters designed for low input voltage commonly use low on-resistance MOSFETs as input side switching transistors, contributing to enhanced efficiency. Table 2 compares the (12-15) V input value of the commercial inverter associated with the solar power converter used in the proposed system design layout is evaluated by comparing it with the (24-27) V input inverter.

Table 2 – Comparing the parameters for the suggested system with the existing system

Parameter Specification	**Suggested system**	**Existing (Current) System**
DC source voltage input (V_{in})	(12-15) V	(24-27) V
DC source voltage output (V_0)	12.12 V	24.9 V
DC input source Power (P_{in})	2298 kw	1516 kw
The input Switching frequency (F_{sw})	86 kHz	66 kHz
Input Turns Ratio value (N_{tr})	1:1:1	1:1
Equivalent resistance load value (*RL*)	41 ~ 801 Ω	41 ~ 801 Ω
Range of the Duty Cycle (*D*)	50 %	50 %
Capacitor value (*C*)	2 μf	12 μf
AC input source voltage (V_{in})	230 V	230 V
Efficiency range (η)	96.6 %	87 %
Overall Loss factor in Watts (*P*)	13.5 w	25 w

From the obtained results, it is noted that the proposed topology is energy efficient and can be used for residential and Electric Vehicle charging applications since the efficiency is around 96 % with an input DC voltage of 12 V and the noted DC Power is 2298 for the suggested system when compared to the existing(current) system. Table 2 shows the comparative analysis of suggested and existing system.

CONCLUSION

In this paper, a solar power converter is designed for residential PV applications. Further, the solar power converter operates in two different modes namely High-Frequency inverter and High-Frequency rectifier operation in a single-stage conversion. The simulation work is mainly carried out using MATLAB/Simulink. The proposed solar power converter's results show that it is capable of producing both AC and DC power. Further, the output DC voltage is 342 V and the AC RMS current is 20.05 A for a given 1000W/m^2 irradiance and 20 degrees Celsius panel temperature. This work appears to be highly reliable since the proposed topology has minimal losses when compared to conventional multistage converters.

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Система для експлуатації сонячної енергії високочастотного перетворювача для електричної установки в електромобілі

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Сонячна енергетична система є найнадійнішим і екологічно чистим видом енергії. Через швидкий розвиток напівпровідникових пристроїв і застосування методів силової електроніки необхідно підтримувати максимальну потужність постійного струму та високу вихідну ефективність сонячних батарей. Перетворювач сонячної енергії працює як одноступінчастий і однофазний перетворювач як на стороні передавача, так і на стороні приймача з деякими конфігураціями параметрів. Ця запропонована система здебільшого використовує фотоелектричну матрицю з високочастотним інвертором, який інтегрує перетворювач DC-DC, що мінімізує втрати перетворювача та пульсації струму. Для його випрямлення на стороні приймача запропонованої вихідної схеми можна використовувати високочастотний випрямляч. Зменшуючи втрати на комутацію та провідність, можна збільшити вихідну потужність. В електричній схемі використовується заданий рівень сонячного випромінювання, відповідна оптимальна напруга постійного струму та оптимальний середньоквадратичний струм змінного струму для імітації всього циклу змінного струму. MATLAB/SIMULINK використовується для проектування та моделювання системи. Значення опромінення 1000 Вт/м^2 і температуру 20 °С, оптимальні вихідні значення були отримані та оцінені як 342 В постійного струму та 20,05 А змінного струму. Таким чином, основною метою цієї статті є створення високоефективного перетворювача енергії (ККД до 96 %) для зарядки електромобілів із вхідною напругою постійного струму 12 В.

Ключові слова: DC-DC конвертер, Електромобіль, Сонячна фотоелектрична батарея, Бездротова передача енергії.