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A novel multi-port SEPIC converter with grid-tie system for hybrid power generation

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ABSTRACT

As the load demand continues to rise on a daily basis, there will be an increased requirement for sources of renewable energy. When compared to the building of an entire power system, the cost of distributed generation, also known as DG, is significantly lower, which makes it a useful tool for fulfilling the demand for electricity. However, these DG are built utilizing renewable energy, which by their very nature is intermittent in its output. As a result, hybrid power generation, which draws power from a variety of sources, is employed to meet the demand for electricity. There are many multiport converters available but they use more number of components which causes complexity and increase in size. And as there are many devices there are possibility stability in the power generation may take time. A brand-new multi-port single ended primary inductor converter (MP-SEPIC), sometimes known as an MP-SEPIC, is proposed in this article. Connecting the photovoltaic (PV), wind, and fuel cell systems is done in order to evaluate the performance of the MP-SEPIC converter. A comparison is made between the standard multi-port boost converter and the suggested MP-SEPIC, the MATLAB simulation is carried out for the purpose of validating the proposed system.

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1. INTRODUCTION

The daily increase in load demand drives up the need for renewable energy supply, which in turn drives up prices. The current electricity system cannot achieve its full potential without the implementation of new technology. Distributed generation (DG) is helpful in meeting the demand for energy because it is less expensive than building a comprehensive power infrastructure. However, because they are made from renewable resources, which are by their very nature variable, these DG are subject to fluctuations. As a result of this, hybrid power generation, which utilizes a combination of several sources, is utilized in order to meet the demand for electricity. In this paper, the multi-port single ended primary inductor converter (MP-SEPIC) is suggested as an input controller for multi-input power systems. The evaluations of the pertinent articles are broken down into the following categories: Renewable power generation control, Intelligent controls and various converters.

The renewable power generation is discussed in this paragraph. In the field of photovoltaic power generation, the concept of big data analysis has been carried out in [1], and [2] carries out a full literature review for PV power plant modeling. Parra *et al.* [3] does PV performance modeling in order to address the issue of huge power generation. In control of photovoltaic (PV) power [4] the large-scale power generating system that is more penetrated by renewable energy generation is explored. A conceptualization of virtual energy storage is presented in [5]. Its primary function is to compensate for power consumption so that voltage control may be maintained. A description of the dynamic voltage stability of the grid with PV can be found in [6]. Comparative study of the performances of several maximum power point tracking (MPPT) methods [7].

The intelligent control over renewable power generation is discussed in this part. The use of fuzzy logic is discussed in relation to the PV-based grid connection control implemented by the Z-source inverter in [8]. You should find that doing so helps raise the voltage. Adjustments to the PI based on fuzzy logic are carried out in [9], [10], and [11], while [12] presents a literature analysis on ambiguous implementations. In this study, we investigate the power oscillation stability, disturbance reduction, and total harmonic distortion improvement of PV systems that are coupled to the grid. In addition to this, it explores ways to improve the functionality of the proportional integral (PI) controller, which is being phased out in favor of fuzzy-PI [13] and the adaptive neuro fuzzy inference system proportional integral (ANFIS-PI) that is now in the works. Some multi-input converters (MICs) have been suggested, and that is discussed in the following paragraphs. MICs have been suggested for improving the stability. In the following paragraphs the literatures related to MICs are studied.

Liu and Chen [14] presented a comprehensive plan for the construction of MICs. By examining the topologies of converters, a method for the synthesis of MICs was developed. And by connecting a suitable source of pulse current or voltage to a converter, one can further improve the performance of the device. Dobbs and Chapman [15] suggests the use of a multi-input DC/DC converter that is capable of functioning in three different converter topologies (boost, buck, and buck–boost). This converter has positive input and power flow in both directions, making it a bidirectional device. In [16], a hybrid fuel cell/photovoltaic/battery power system that makes advantage of a multi-input DC boost converter is discussed. Wai *et al.* [17] suggests a bidirectional MIC that has a high step-up ratio and a high level of efficiency. The converter may function in three different modes: united power supply, standalone, and discharge and charge respectively. Hu *et al.* [18] suggested a DC/DC converter with three ports that is built on an enhanced flyback-forward architecture for use in freestanding solar power systems. The goal of this proposal is to improve the system's efficiency and cost effectiveness. The article [19] presented a novel MIC buck and boost converter that can be used for the application of street lights. Nejabatkhah *et al.* [20] explained outlines a multi-input boost type converter that is unitary in construction and has two unidirectional input power ports as well as a bidirectional port for a storage element. In the system that is being suggested, there are only four power switches total, and each of those switches is controlled by four distinct duty cycles. Nahavandi *et al.* [21] presented a boost converter that is not inverted, has many inputs, multiple outputs, and is not isolated from the rest of the circuit. In this converter, the load power can be distributed in any way the user sees fit across the input sources. Dehghan *et al.* [22] introduced an idea for a z-source converter MIC property that utilized the same number of inductors and capacitors. Another method of hybrid energy conversion using MICs is presented in [23]–[25].

The literature survey on the above specified topics show that reduced there are not much efforts in reducing the power stability issues. Within the scope of this investigation the MP-SEPIC is the proposal. The new circuit on multi-input is proposed in this paper. It reduces the power oscillations and makes the circuit simple. Within the scope of this investigation, the MP-SEPIC is the proposal. The performance of the MP-SEPIC converter is investigated by connecting photovoltaic cells, fuel cells, and wind turbines. When the suggested system is linked to the grid, power transients are analyzed to see how they behave. The investigation on settling time is also compared.

2. METHOD

The new MP-SEPIC converter is proposed here and the operation of the same is explained. The DQ control is used for grid-tie operation and the PI controller is replaced with PI to improve the transient performance. The conventional and proposed systems are shown in Figure 1 and Figure 2.

2.1. Proposed MP-SEPIC converter operation

The proposed MP-SEPIC converter is based on the conventional SEPIC converter and the input of the SEPIC converter is changed according to the required input number. It can be done for n number of sources. Here it is used for three inputs. This converter is made for this hybrid power generation. The coupled inductor is used here to make the circuit simpler. Figure 3 shows the proposed MP-SEPIC converter for n-number of inputs.

In conventional methods, the converters are connected in parallel to get the combined power. If the SEPIC converter is used then there are 2n number of inductors needed. And n number of capacitors needed. The proposed MP-SEPIC converter reduced these two needs. This makes the circuit simpler, easy, cost-effective and reduces the size of the circuit. Figure 4 shows the proposed MP-SEPIC converter for three inputs.

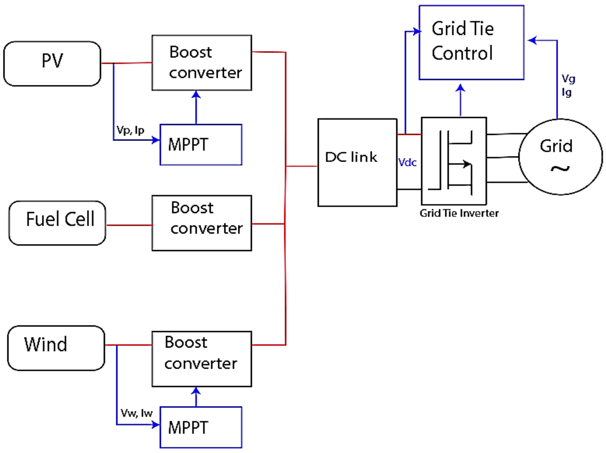


Figure 1. Conventional hybrid power generation [11], [13]

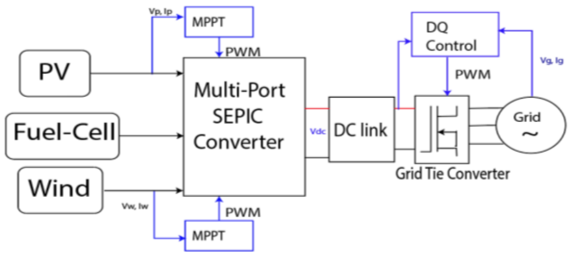
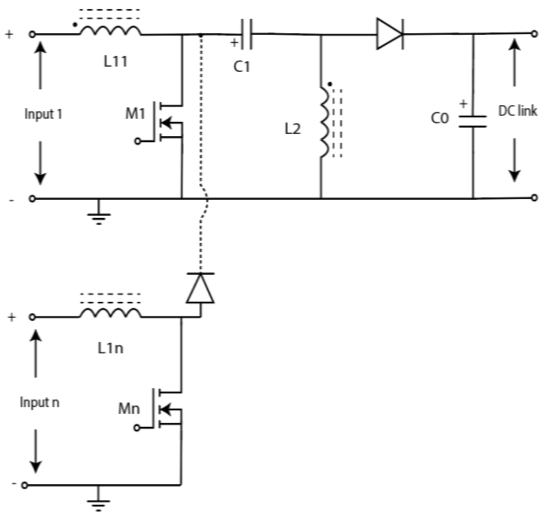


Figure 2. Proposed MP-SEPIC hybrid power generation system using PI



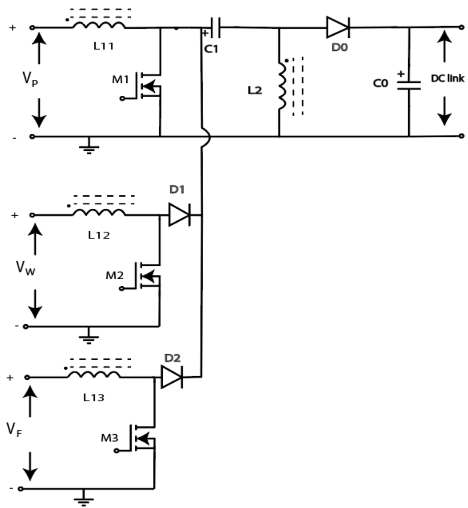


Figure 3. Proposed MP-SEPIC converters for n-number of inputs

Figure 4. Proposed MP-SEPIC converters for three inputs

The operation of the converter is explained as follows:

i) Mode 1: when switch M1, M2 and M3 are ON

When the switches M1, M2 and M3 are ON, the inductors L11, L12 and L13 get charged. At the same time, the Co is supplying the load/DC link. According to KVL for the first input the current path V_{pv}, V_{L11}, V_{C1} and V_{L2},

$$-V_P + V_{L11} + V_{C1} - V_{L2} = 0 \tag{1}$$

for wind,

$$-V_W + V_{L12} + V_{C1} - V_{L2} = 0 \tag{2}$$

for fuel cell,

$$-V_F + V_{L12} + V_{C1} - V_{L2} = 0 \tag{3}$$

using the average of the voltages the voltages $V_{L11}, V_{L12}, V_{L13}$ *and* V_{L2}, becomes zero.

$$-V_W - V_P - V_F + 0 + V_{C1} - 0 = 0 \tag{4}$$

So, the voltage of average across the capacitor C_1 can be represented by,

$$V_{c1} = V_p + V_W + V_F \tag{5}$$

when the M1 switch is ON the diode is OFF as shown in Figure 5. The voltage across L11, L12 and L13 for the interval DT is given by,

$$V_{L11} = V_p \tag{6}$$

$$V_{L12} = V_W \tag{7}$$

$$V_{L13} = V_F \tag{8}$$

Figure 6 shows the operation mode of 2.

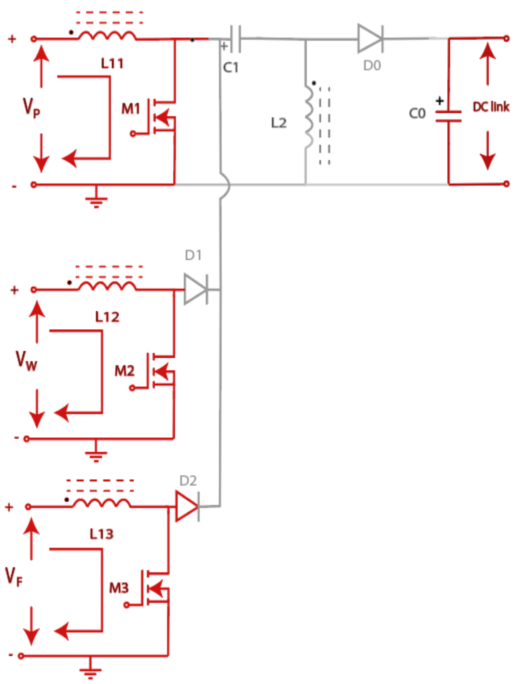


Figure 5. Operation of mode 1

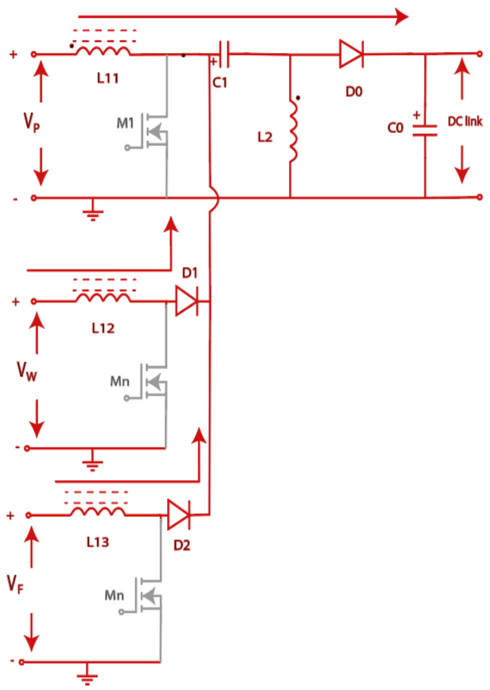


Figure 6. Operation of mode 2

ii) Mode 2: when switch M1, M2 and M3 are OFF

When the switch M1, M2 and M3 are OFF, the inductors L11, L12 and L13 gets discharge. The diodes D1, D2 and D0 are ON. At the same time the Co is supplying the load/DC link.

According to KVL for the first input the current path V_p, V_{L11}, V_{C1} and V_{L2},

$$-V_P + V_{L11} + V_{C1} + V_{DC\,LINK} = 0 \quad (9)$$

assuming the voltage across C1 remains constant at its average value of V_{PV},

$$-V_P + V_{L11} + V_{PV} - V_{DC\,LINK} = 0 \quad (10)$$

$$V_{L11} = -V_{DC\,LINK} \quad (11)$$

for the interval of $(1-D)T$, the average voltage of the inductor is zero for each periodic operation.

$$V_{L11}\,(when\ switch\ M1\ closed)\,(DT) + V_{L11}\,(when\ switch\ M1\ open)\,(1-D)T = 0 \quad (12)$$

$$V_P(DT) - V_{DC\,LINK}(1-D)T = 0 \quad (13)$$

Solving for only duty cycle of PV input,

$$D_P = \frac{V_{DC\,LINK}}{V_{DC\,LINK} + V_P} \quad (14)$$

same can be repeated for wind and fuel cell.

$$D_W = \frac{V_{DC\,LINK}}{V_{DC\,LINK} + V_W} \quad (15)$$

$$D_F = \frac{V_{DC\,LINK}}{V_{DC\,LINK} + V_W} \quad (16)$$

2.2. DQ controlled grid tie controller

The DC reference voltage ($V_{dc\,ref}$) is compared with measured voltage ($V_{dc\,meas}$) and the error is given to PI controller. This produces the $I_{d\,ref}$ as it is shown in Figure 7. Figure 8 shows the PI regulator which converts the current error taken from the comparison of $I_{dq\,ref}$ and $I_{dq\,meas}$ to voltage of $V_{dq\,conv}$.

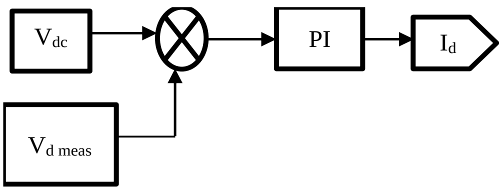


Figure 7. DC voltage regulation using PI controller

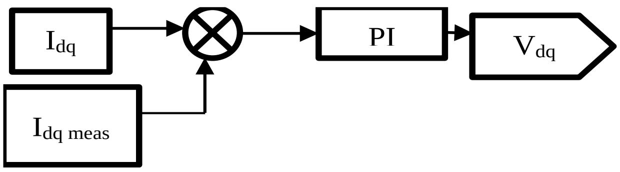


Figure 8. PI based current regulation

2.3. Current Regulator designed with PI

In general, PI or PID controllers are used in the current regulation of electrical systems. The output of the conventional current regulator is expressed in (17).

$$Out(t) = K_p\left(I_{dq}{}^{*} - I_{dq}\right) + K_i \int (I_{dq}{}^{*} - I_{dq})dt \quad (17)$$

Where, I_{dq}* is reference current and I_{dq} is the measured current; and the discrepancy between them causes an error, which the PI controller should try to reduce. The recommended signal with the least amount of errors (out(t)) is the output. The proportional constant is Kp, while the integral constant is Ki. Manual tuning procedures are used to adjust the parameters Kp and Ki. The block diagram of PI based current regulation is shown in Figure 9. Both the outputs are added and given as output.

3. RESULTS AND DISCUSSION

PV power, wind power generation, and fuel cell power generation are used as sources. Here, PV and fuel cell power generation are DC power. Wind power generation is made from PMSM power generators, which create high frequency AC power. This is converted to DC using the diode rectifier bridge. These powers are given to the traditional boost converter according to Figure 1. Figure 2, it uses the proposed converter. This conventional or proposed converter converts direct current to boosted direct current voltage. While boosting, the MPPT is applied to the converter switch. This is done for only PV and wind. The MPPT technique used is the traditional perturb and observe (P&O) method. Then from the DC link, the inverter is connected, and the output of the inverter is connected to the power grid. The inverter is controlled by the DQ technique. The DQ controller here controls the direct current (Id) and quadrature current (Iq). The power grid is connected to a 10 kW load of utility. After supplying this demand, the grid takes the power that is available in excess. Table 1 shows the parameters used in the simulation. Current regulation is shown in the Figure 9.

Figure 10 shows the proposed method in MATLAB simulation. The real power on the grid is depicted in Figure 11. It shows that the real power spikes take place in the conventional method using a PI controller with a conventional boost converter. But the spikes are fewer and the power is settling faster in the proposed method. Figure 12 shows the voltage at the DC link. In this voltage also, there are lots of spikes in the conventional method. The initial spikes are reduced in the proposed method. Figure 13 shows the solar power from PV. It can be seen that PV power starts the power sooner compared to the proposed method. The same is happening in the wind shown in Figure 14 and fuel cell shown in Figure 15 power inputs. The power observed from the fuel cell is more in the proposed method compared to the conventional method. Figure 16 shows more spikes of AC current in the conventional method. Grid voltage is shown in Figure 17. The current is depicted in Figure 18. The proposed method reduced the spikes compared to conventional methods. Table 2 shows the performance comparison of the conventional and proposed method. It can be seen that the rise time, setting time and peak over shoot is less in proposed method compared to conventional technique.

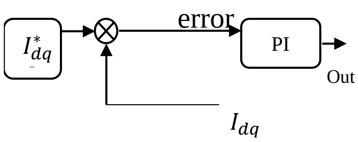


Figure 9. Current regulation

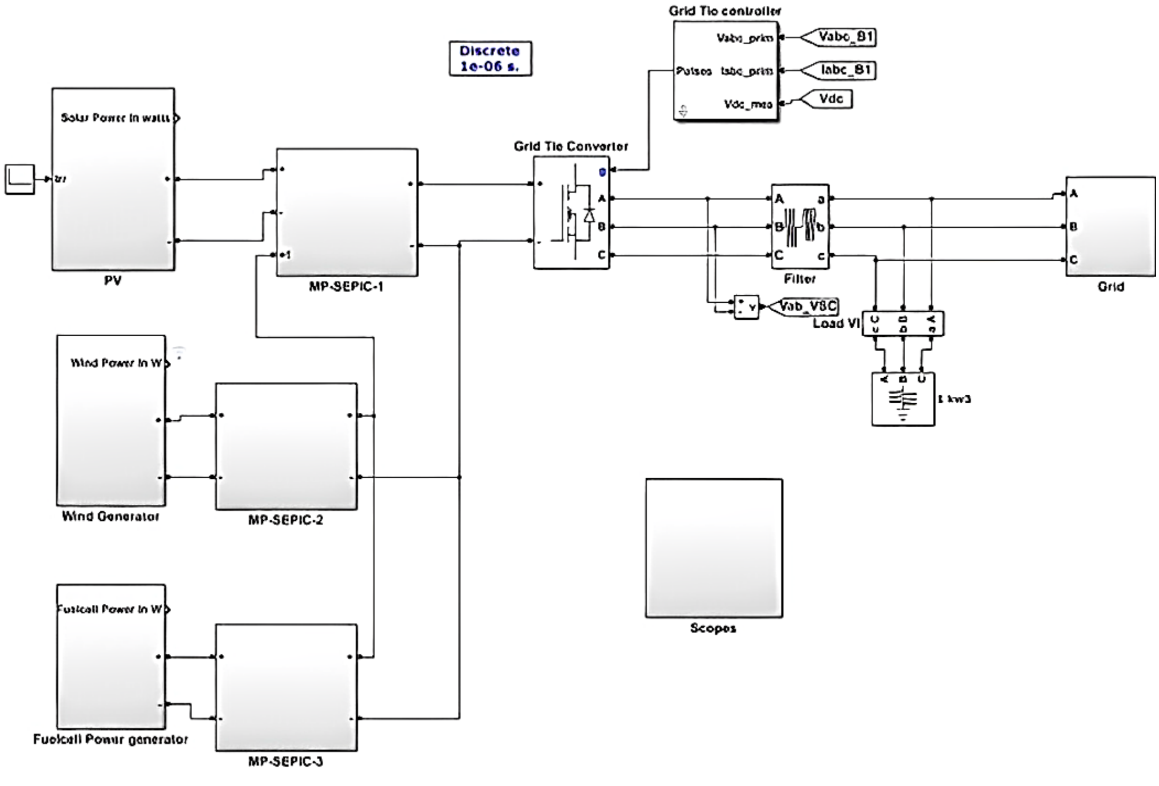


Figure 10. Proposed method in MATLAB simulation

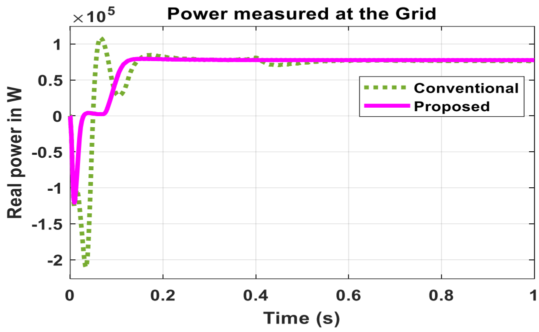


Figure 11. Power measurement at the grid

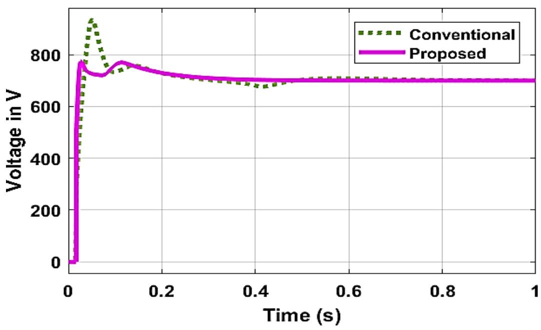


Figure 12. Voltage at DC link

Table 1. Simulation parameters

PV power plant		Fuel cell	
Module type	SunPower SPR-305-WHT	Type	PEMFC
Number of series	5	Power (W)	6
Connected modules per string		Voltage (V)	45
Number of parallel	34	Series connected fuel cells	4
Connected modules per string		Nominal power in W	24 kW
Open circuit voltage (V)	64.2	Grid:	
Short circuit current (A)	5.96	- Voltage (V)	0.4 kV
Maximum power point voltage (V)	54.7	- Frequency (Hz)	50 Hz
Maximum power point current (A)	5.58	Transformer:	
Nominal power in W	51.8 kW	- Nominal power in W	100 kW
Wind power plant:		- Primary voltage	0.4 kV
- Nominal mechanical power (W)	20 kW	- Secondary voltage	11 kV
- Base wind speed (m/s)	12	Filter:	
- Maximum power at base wind speed	0.73	- R	2 ohm
- Number of turbines	3	- L	1.5 mH
- Torque in Nm	6	MP-SEPIC:	
- DC voltage rating (V)	600	- L11, L12, L13	5 mH
- Speed in RPM	4500	- C1	12 uF
		- L2	5 mH
		- Co	12000 uF

Table 2. Performance comparison of conventional and proposed methods

Parameters		DC link voltage	Current
Rise time (s)	Conventional method	0.06	0.06
	Proposed method	0.02	0.02
Settling time (s)	Conventional method	0.5	0.15
	Proposed method	0.2	0.1
Peak overshoot %	Conventional method	133	182
	Proposed method	99	99.5

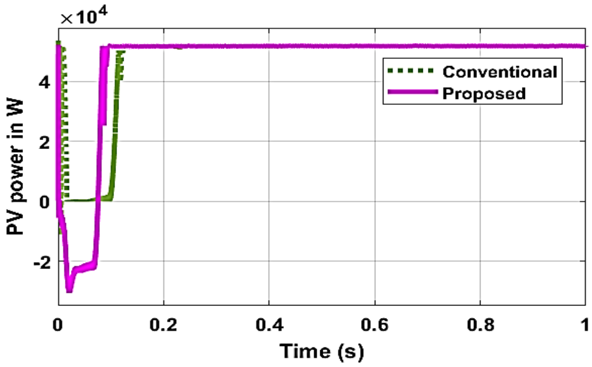


Figure 13. Solar power from PV

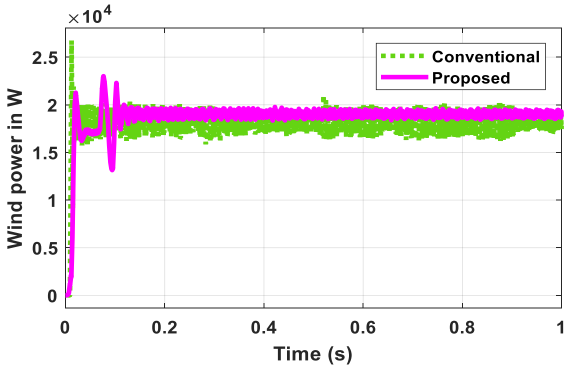


Figure 14. Wind power from the input

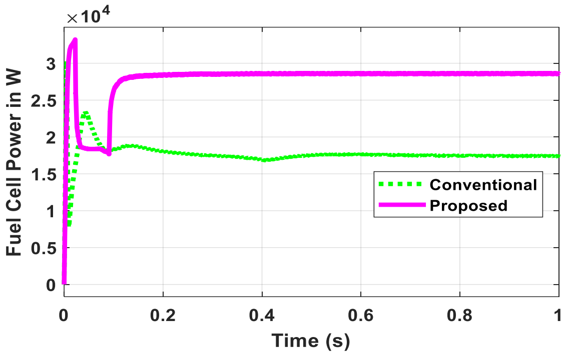


Figure 15. Fuel cell power measured at the input

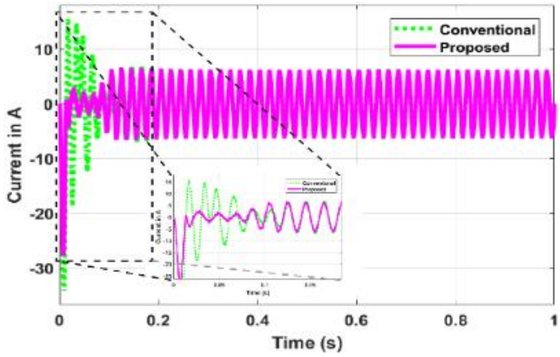


Figure 16. Current at the AC grid

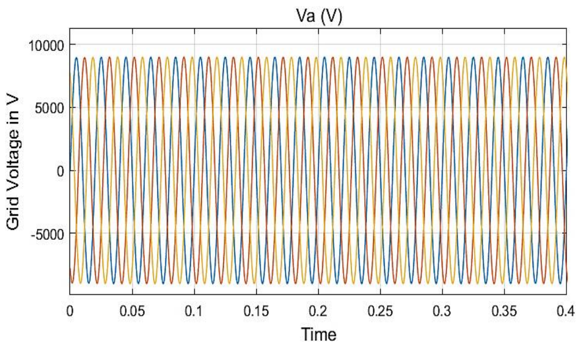


Figure 17. Grid voltage

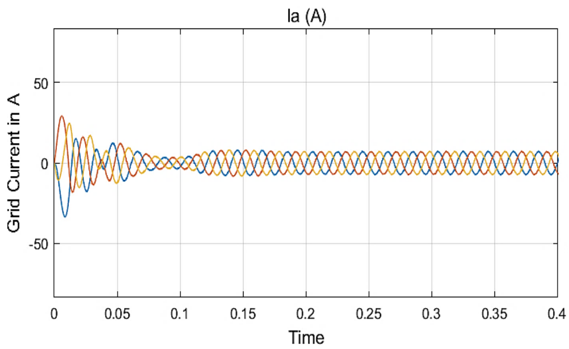


Figure 18. Grid current

4. CONCLUSION

The MP-SEPIC (multi-input single ended primary inductor converter) is proposed in this study. The MP-SEPIC converter's performance is evaluated by connecting PV, wind, and fuel cells. Power transients are examined when the proposed system is connected to the grid. This work deals with grid synchronization control in direct and quadrature (DQ) mode. The results are compared when a standard boost is substituted with a MP-SEPIC. For the purpose of verifying the proposed system, a MATLAB simulation is run. The results shows that the proposed method is superior to the conventional method.

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