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A High Gain DC-DC Converter with Maximum Power Point Tracking System for PV Applications

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Abstract

This study proposes a PV fed grid tied high gain converter. Recently, the growth of sustainable energy resource is noticeable. Among that, the solar system plays a prominent role as it has plenty of advantages such as simple, eco-friendly, cost-effective, and requires less maintenance. The voltage gain of solar system is influenced by temperature, irradiance, and several other environmental factors. To enhance the output voltage magnitude of solar system, a transformer less high gain DC-DC converter is presented.It has fewer switches and passive components in order to handles the switching stress and losses created during conversion. Moreover, the Incremental Conductance (INC) MPPT algorithm used in this technique fine tune the switching cycle of the converter. The proposed converter coupled with solar system can obtain desired output voltage while employing this MPPT controller. The simple structure of single phase inverter converts the voltage magnitude of converter into AC waveform. Experimental results show that this system obtained the higher efficiency of 98.58%.

Keywords: Solar System, High Gain Converter, Incremental Conductance (INC) MPPT algorithm, Single Phase Inverter, Pulse Width Modulation

1. Introduction

Recently, the usage of renewable resources is quite increasing. It is the promising solution for the replacement of the fossil fuel and several other non-renewable resource based power generation.The conventional approaches emit harmful gases on the atmosphere and pollute the environment which endangers the life of humans and living beings on the earth. To control the environmental degradation, the renewable resources take part in generation and transmission of that power to remote areas where power transmission is impossible. Numerous renewable resource based power generations are still under development, but the solar system has a tremendous growth and it is one of the leading power generating system in our planet. Globally, it is expected to reach 593 GW within this year, 2024.The contribution of solar power to meet the energy crisis in future is indispensable.Even though, the power generation from solar panel is uncommon as it is impacted by various environmental factors and the designing of conversion circuit coupled with. To track peak power from the solar system is mandatory to reach desired voltage gain.For this purpose, Maximum Power Point Tracking (MPPT) system is introduced. The purpose of it is tracking peak power from the panel under change in temperature and irradiance or any other climatic change. At the beginning, Perturb and Observe method (P&O) technique is employed to track peak power from the panel [1]. Later, Incremental Conductance (INC) [2], parasitic capacitance

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[3], constant voltage [4], and constant current methods [5] are developed. These are very basic MPPT techniques. The operation of it is comparing the voltage and current gain of the respective DC-DC converter coupled with it and control the switching cycle of the converter. This in turn enhances the output voltage magnitude of the converter. The DC-DC converters are widely used to increment or decrement the input voltage based on the demand[6]-[7].It is carried out through the arrangement of active and passive components with respective duty ratio.In simple, the most commonly used converters are buck, boost, buck-boost, CUK, SEPIC, and Zeta converter.At present, there are plenty of converters were introduced by interchanging the position of components and feasible to operate under various conditions without magnifying the loss and switching stress applied on the switches.If a DC output voltage at desired rate is attained, it is converted into sinusoidal AC voltage using inverter. The single half bridge and full bridge, three phase half bridge and full bridge inverter are the basic types of inverters. Based on the need, any one of them is chosen and implemented.

This proposed study using solar panel as a source and it is coupled with a transformerless high gain converter. The purpose of this converter is to regulate the voltage gain to reach desired voltage range. To lower the switching frequency of the converter and to track the peak power from panel, a simple INC MPPT technique is introduced. Any change in voltage magnitude of converter is understood by the MPPT controller and alter the switching cycle of the converter. Also, the single phase inverter coupled with the circuit convert the variable DC voltage into AC voltage. The contribution of PWM technique turn ON/OFF the switches present in the inverter.

The remaining of this study is explained as follows: The following section 2 explainingthe circuit configuration and techniques employed in this study. Following this, the result obtained and the comparative study of proposed technique with others are explained. The section 4 concludes the performance of the model.

2. Methodology

The detailed study proposed circuit is discussed in this section. Here, the solar panel acts as a voltage source. The voltage gain of solar panel may not be continuous; to regulate the gain of it, a high gain converter is integrated with it. The converter uplift the voltage gain based on the switching cycle. As controlling of switches present in the converter is crucial. By regulating the switching cycle based on the output of the converter can possibly improves the voltage gain of model under any circumstances. To achieve this, INC MPPT technique is proposed. Depending on the output voltage of the converter, it tracks peak power from the solar panel and regulate it to obtain high gain. Later, the DC voltage magnitude is converted into AC using the inverter integrated with it. The PWM technique is used to obtain sinusoidal AC voltage. The circuit configuration of proposed work is represented in figure 1. The brief study of the techniques employed in this study is discussed below.

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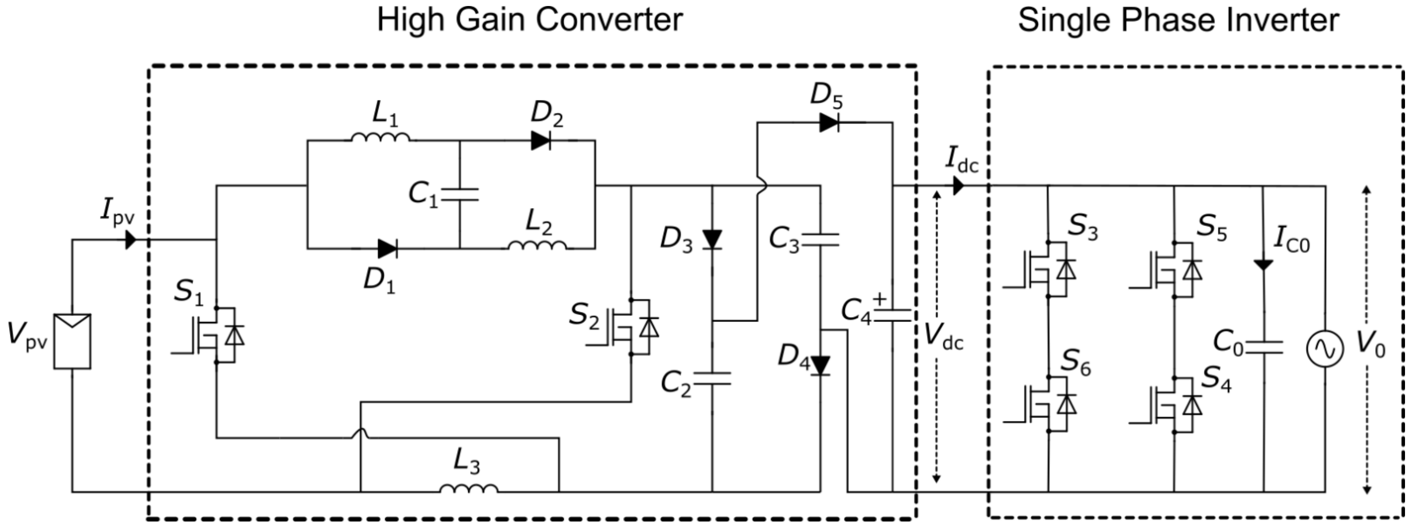

Fig.1.Cicrcuit configuration of proposed study

A. High Gain Converter

This high gain converter consist of 3 inductors such as L_1, L_2, and L_3, 5 Diodes namely D_1, D_2, D_3, D_4, and D_5, 3 capacitors C_1, C_2, and C_3, and a pair of MOSFET switches S_1 and S_2. Among that, the passive components including L_1, L_2, D_1, D_2, and C_1 that constitutes the first voltage multiplier cell [1]. Also, C_2 and C_3 are switched capacitors that constituteanothervoltage multiplier cells in addition with the diodes such as D_3 and D_4. The operation of this converter is studied through continuous and discontinuous conduction mode and the detailed study of it are discussed below:

Continuous Conduction Mode (CCM)

Mode 1:The switches S_1 and S_2 are in closed condition; the diodes D_3 and D_4 are reverse biased, which is shown in figure 1 (a). The rest of the diodes are forward biased.All of the inductors are energised uniformly through the input voltage. The input capacitor C_1 alone is energisedby I_{pv}in this mode; C_2 and C_3 are de-energised, andenergising the output capacitor C_4. The voltage across capacitors and inductors are denoted by,

$$V_{L1} = V_{L2} = V_{L3} = V_{pv} \qquad (1)$$

$$V_{C1} = V_{pv} \qquad (2)$$

$$V_{C2} = V_{C3} = \frac{V_{dc} - V_{pv}}{2} \qquad (3)$$

$$V_{D3} = V_{D4} = V_{C2} + V_{dc} \qquad (4)$$

The average value of I_{pv} is written as,

$$i_{pv_{ON}} = I_{L1} + I_{L2} + I_{L3} + I_{D1} \qquad (5)$$

$$I_{D1} = I_{D2} = 2I_{L1} \quad (6)$$

$$I_{L1} = I_{L2} = I_{L3} \quad (7)$$

$$I_{pv_{ON}} = 5I_{L1} \quad (8)$$

Mode 2: All of the switches are in open condition; the diodes D_1, D_2, D_5 are reverse biased. The remaining diodes namely D_3 and D_4 are forward biased, which is shown in figure 1(b). The passive components such as C_1, L_1, L_2, and L_3de-energised entirely to energise C_2 and C_3.The voltage again across output capacitor C_4 is written as,

$$V_{L1} = V_{L2} = V_{L3} = \frac{(2V_{pv} - V_{C2})}{3} = \frac{(5V_{pv} - V_{dc})}{6} \quad (9)$$

$$V_{C2} = V_{C3} \quad (10)$$

$$V_{C4} = V_{pv} \quad (11)$$

In this mode, the value of I_{pv} and current across diodes D_3 and D_4 is written as,

$$I_{pv_{OFF}} = I_{L1} \quad (12)$$

$$I_{D3_{OFF}} = I_{D4_{OFF}} = \frac{I_{L1}}{2} \quad (13)$$

By applying the voltage second balance principal, the ideal voltage in CCM is derived by,

$$\frac{1}{Ts}\left(\int_0^{DTs} V_{pv}dt + \int_{DTs}^{T_s} \frac{(5V_{pv} - V_{dc})}{6}dt\right) = 0 \quad (14)$$

$$M_{CMM} = \frac{V_{dc}}{V_{pv}} = \frac{5 + D}{1 - D}$$

whereas, D represents duty ratio. The voltage across the capacitors are represented as,

$$V_{C1} = V_{pv} \quad (15)$$

$$V_{C2} = V_{C3} = \frac{(2 + D)}{1 - D}V_{pv} \quad (16)$$

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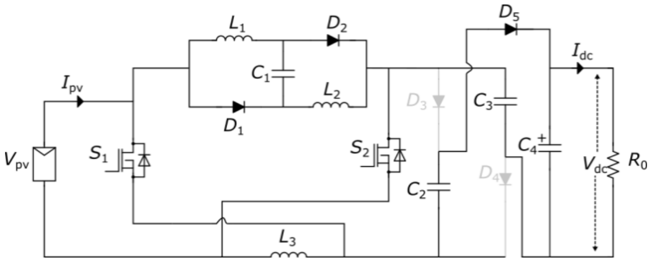
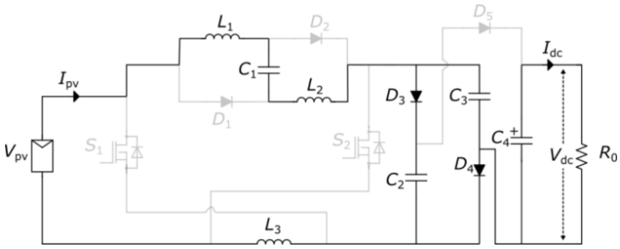
$$V_{c4}=\frac{5+D}{1-D}V_{pv} \tag{17}$$

It is observed that, the voltage across input capacitors such as C_1, C_2, and C_3 is lower than V_{dc}.



(a)Mode 1



(b)Mode 2

Fig.2.Operation of converter under CCM

Discontinuous Conduction Mode (DCM):

The mode 1 operation of converter under DCM is similar toCCM. In mode 2, all of the inductors de-energised and the value of I_{D3} and I_{D4} tends to be zero.Furthermore, the all of the diodes are reverse biased in mode 3, the output capacitor C_4alone contributing in energise the load terminal. The addition of average of I_{D3} and I_{D4} is equivalent to I_{dc} and it is equivalent to half of I_{L1} assuming that the average inductors current are identical.

$$I_{D3_{avg}}+I_{D4_{avg}}=\frac{1}{2}I_{L1}=\frac{1}{2}\left(I_{Dpk}\right)D' \tag{18}$$

whereas,$I_{D3_{avg}}$ and $I_{D4_{avg}}$ represents average of diode current. The term I_{Dpk} is the addition of peak value of I_{D3} and I_{D4}.

$$I_{Dpk}=\frac{DTV_{pv}}{L_{eq}} \tag{19}$$

Since, the value of L_{eq} is $1/L_1$. When applying voltage second balance principal cross L1, the value of D' is determined.

$$D' = \frac{6DV_{pv}}{V_{dc} - 5V_{pv}} \tag{20}$$

Substituting equation (19) and (20) in (18), we get,

$$M_{DCM}^2 - 5M_{DCM} - \frac{3D^2RT}{L} = 0 \tag{21}$$

$$M_{DCM} = \frac{\sqrt[5]{1 + \frac{D^2}{K_e}}}{2} \tag{22}$$

whereas, $M_{DCM} = V_{dc}/V_{pv}$is the voltage gain of converter under DCM.

B. Incremental Conductance (INC) MPPT technique

The fundamental structure unit of a solar system is the PV module that comprised of multiple solar cells arranged in series and parallel combination. The solar panel converting photons of sunlight into electrical energy as per the photoelectric phenomenon present in several kinds of semiconducting materials such as silicon and selenium. A single cell can produce only a certain amount of power. To maximise the output power, the cells are organised in series and parallel combination [2]. More number of cells connected in series results in high voltage gain and vice versa a high current gain is obtained by the parallel connection. Moreover, the factors such as temperature, irradiance, dust accumulation, and shading also take part in determining the output power of the panel. Also, the output voltage is non-linear and when subjecting to previously mentioned factors it cannot produce the desired voltage magnitude. To limit these difficulties and enhance the output power of solar panel a MPPT is required, which decrease the power failure caused by environmental condition. This study employed INC MPPT technique to regulate the switching cycle of the high gain converter integrated with the solar panel.

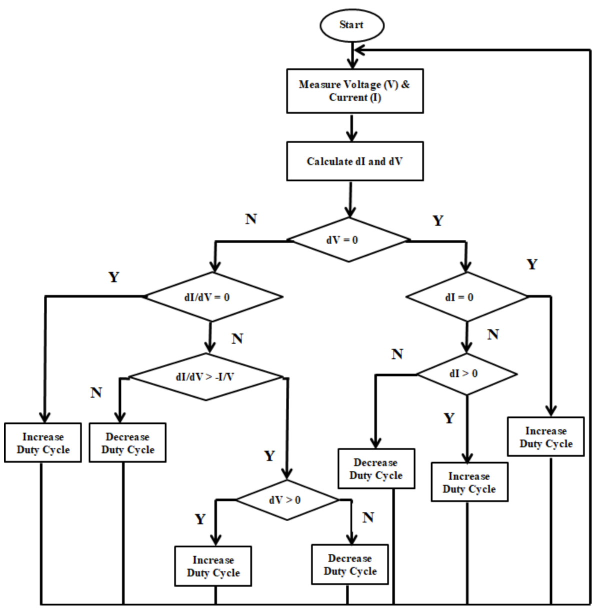


Fig.3.Flowchart of INC method

The figure 3 shows flowchart of INC method. It was designed on the observation of P-V characteristics curve.This method is especially designed to overcome the difficulties of P&Otechnique [3] and they are introducing an oscillation on the steady state, high voltage difference [3], time consuming, and delayed response to the environmental changes. It enhances the tracking time and generates a high output voltage corresponding with a change in irradiance.The MPP has been determined by using the relationship between dI/dV and –I/V. When dP/dV is negative, the MPPT lies on the right side of the latest position, and if the MPP is positive, the MPPT lies on the left side [5]. It is derived by,

$$\frac{dP}{dV} = \frac{d(V.I)}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} = I + V\frac{dI}{dV} \qquad (23)$$

MPP is attained when $\frac{dP}{dV} = 0$

$$\frac{dI}{dV} = -\frac{I}{V} \qquad (24)$$

$$\frac{dP}{dV} > 0 \text{ then } V_p < V_{mpp}$$

$$\frac{dP}{dV} = 0 \text{ then } V_p = V_{mpp}$$

$$\frac{dP}{dV} < 0 \text{ then } V_p > V_{mpp}$$

WhenMPP lie on the right side, dI/dV<-I/V, V_{pv} is minimised to acquire the MPP. It can greatly improve the prediction of MPP; enhance the efficiency of solar panel, decrease power loss, and cost effective.

C. Inverter

The DC output voltage of converter is fed to the single phase inverter and the circuit topology of it is represented in figure 4. The principle of inverter is to convert DC voltage into sinusoidal AC voltage [6]. It consists of switches S_3, S_4, S_5, and S_6 and a filtering capacitor C_0. The switches S_3 and S_4 are kept ON for a half cycle and inversely S_5 and S_6 are kept ON for another half cycle. The PWM is employed here to control the switching cycle of the inverter. When S_3 and S_4 is switches ON, the input current I_{dc} reach the output capacitor C_0 and energise it. Next, the switches are inversely operated to energise the output capacitor. The output capacitor C_0 stores the energy and produces a pure sinusoidal AC voltage at load terminal, V_0.

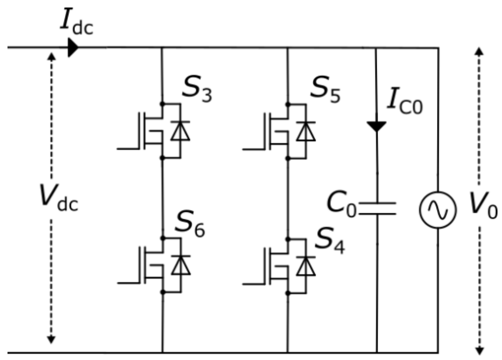
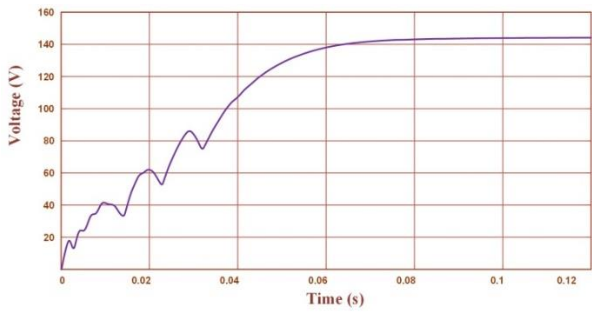


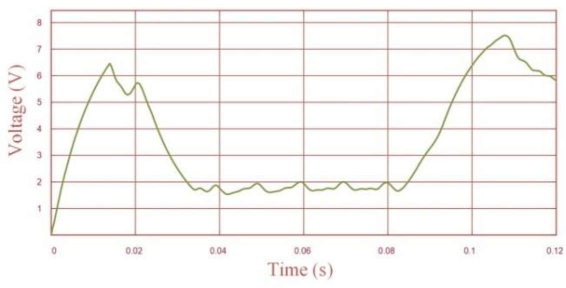
Fig.4.Single Phase Inverter

3. Result & Discussion

In this study, the solar panel is operated at temperature and irradiance of 25° Celsius and 1000W/m^2. The voltage gain of it is not enough to obtain the desired voltage at load terminal. The voltage and current obtained at the output terminals of PV array is 145.07V and 4.28A. Thus, the power rating of it is 622.08W which is represented in figure 5.



(a) Voltage



(b)Current

Fig.5.Ouput voltage and Current of solar panel

To maximise the voltage gain of converter, the proposed MPPT technique adjust the switching angle of converter by comparing the voltage observed at load terminal of converter with the output voltage of solar panel.By comparing this, the duty ratio of the switches

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S_1 and S_2 are regulated. The Simulink modelling of the proposed MPPT technique is represented in figure 6. The output voltage and current gain of converter is 298.03V and 2.06A which is represented in figure 7. The output power is observed as 614W. The table 1 compares the performance of proposed converter with several other converters. Here, the types of MPPT and converter, components, input and output voltage are discussed.The DC voltage is converted into AC voltage using the single phase inverter which is represented in figure 8. It is cleared that, the proposed converter outperformed several other converters. Relatively, the proposed technique obtained higher efficiency of 98.58%.

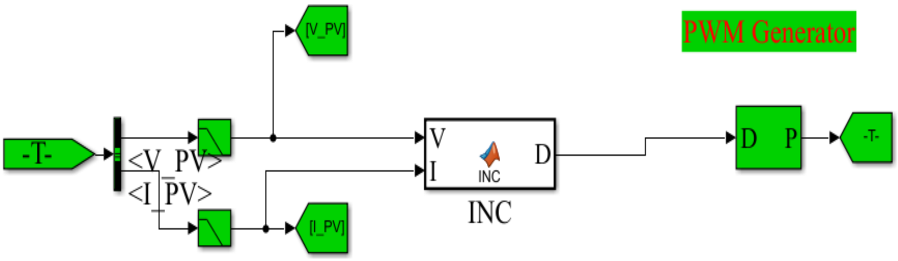
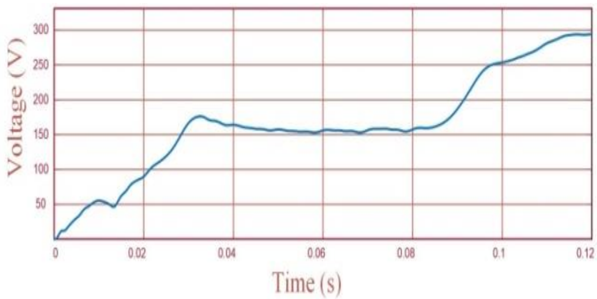
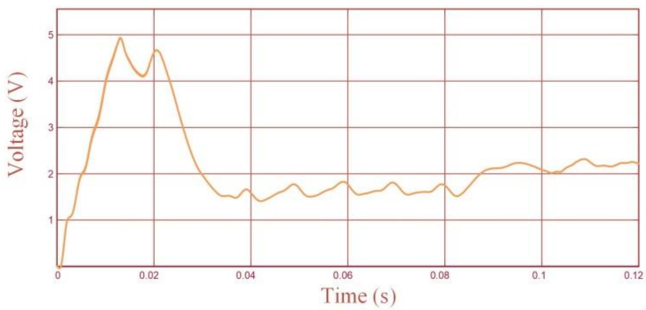


Fig.6.Simulink model of INC MPPT



(a)Voltage



(b)Current

Fig.7.Voltage and current gain of high gain converter

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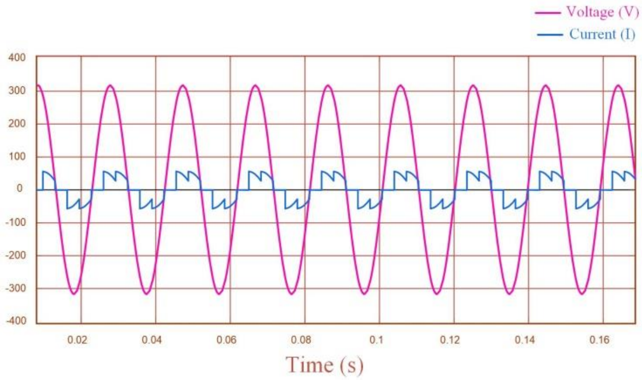

Fig.8. Output voltage of Inverter

Table 1 Comparative analysis of proposed system with conventional techniques

References	**MPPT Controller**	**Type of Converter**	**Input Voltage (V)**	**Components**				**Output Voltage (V)**	**Efficiency (%)**
				Switch	**Diode**	**Inductor**	**Capacitor**		
[8]	Artificial Neural Network (ANN)	Modified boost converter	80	1	3	1	3	300	93.4
[9]	PSO-ANN-based MPPT controller	Non-isolated high-raise DC-DC converter	36V	1	10	2	7	429	95
[10]	Advanced Perturb and Observation algorithm	Highly efficient DC-DC boost converter	525.1	1	2	2	2	713.8	97.86
Our Proposed Study	Incremental Conductance (INC) algorithm	Transformerless High gain converter	145.07	2	5	4	3	298.03	98.58

4. Conclusion

The rapid urbanisation and industrialisation increase the need of power capacity. The demand will reach the peak in future. To overcome such crisis, the traditional method alone cannot manage the demand. In consideration with this, solar system is utilised and this natural resource is available in plenty. This study designed a PV fed high gain converter to generate maximum power. But, sunlight will be inadequate in climate change. The converter incorporated within this system fails to produce the desired voltage. To tackle the fluctuations in power generation of solar system, this study employed INC MPPT method. Thus, it solidly regulated the output voltage magnitude by tracking peak power from the panel. Furthermore, it is converted into AC voltage and fed to the grid. The results showing that the proposed system produced output power of 614W with the efficiency of 98.5%. The low switching frequency decreased the converter losses and enhanced the efficiency. Further the integration of battery bank with this circuit can makes the system to feed power to the load in absence of solar system. As per the comparison, voltage gain capability and dynamic performance validating that the proposed converter is a promising method for low rating solar system to feed high power applications.

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