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Analysis of DC-DC Converter with High Step -up Gain for Alternative Energy Sources

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Abstract ***–*** *In recent years, the energy crisis is more predominant because of the expansion of the human population. So researchers have moved towards alternative energy resources for sustainable development. Power conversion requisites high gain in most renewable applications. This paper discusses a DC-DC converter with a high step-up ratio that renders efficacy, elevated voltage gain and curtail voltage stress. Here, we incorporate the merits of Active Switched Inductor (ASL)and step-up two capacitor cell (SU2C)strategies to attain lifted gain in the DC-DC converter for PV applications. The scope of this preferred converter is germane towards harnessing energy from the solar array to grid-tied applications. The introduced converter encompasses active switches, step-up capacitors inductors, and to escalate the voltage gain. One of the methods of Maximum Power Point Tracking (MPPT) is Perturb and Observe (P&O), which is accustomed to secure the best results of the proposed converter. The propounded converter is validated using MATLAB/SIMULINK.*

Keywords – *perturb and observe, maximum power point tracking, high step-up DC-DC converter, active switched inductor, step up two capacitor cell.*

I. INTRODUCTION

The exhaustion of non-renewable energy resources tempts the researchers to maneuver on to the renewable sources of energy. For transforming energy obtained from clean sources, DC-DC power converter with a heaved gain is more trending nowadays. These converters find their applications in various fields like grid-tied Photo Voltaic systems, Uninterruptable power supplies, and Electric Vehicles. A high voltage gain of quite 10 is achieved with this proposed work. The designed converter offers high efficacy of around 95%, less hassle on the switches to reinforce the system performance [1-3]. For up heaving, the gain, distinctly for PV applications, DC-DC converter unified with Active Switched Inductor is used. Novel soft switching techniques also encompass scaling back the switching losses. The various converter topologies are compared with the proposed converter, and hardware implementation is verified [2-3]. In this paper, for elevating the converter gain, the coupled inductor circuit is implemented. Moreover, to spice up the high efficacy along with voltage gain, three winding inductors are preferred [4]. The novel topology of the DC-DC converter replaces the prevailing one to intensify the voltage gain and clamp down the stress across the switches [5]. The basic non-isolated configurations of DC-DC converters were compared and analyzed for power quality improvement and also felicitous for renewable energy applications [6-10]. The voltage doubler circuit of the DC-DC converter imparts a high step-up gain is proposed. Here, the switching stress is greatly declined, which is tested for the 750-W prototype. This converter is fed by a power source delivered by a proton exchange membrane fuel cell with an output voltage of 400 V is verified successfully [11].

In order to prop up the voltage gain of the converter, the inductor and capacitor network are adopted. Multi-cell configuration is also utilized to attain the above-mentioned objectives [13,15]. Interleaved converters with switched inductor and capacitor network topology, hybrid boost converter topologies, along zero voltage switching techniques were also designed for renewable applications [12,13]. The ultra high gain non-isolated DC-DC converter is designed to attain high voltage conversion by employing the coupled inductor configuration, is tested for the prototype of 500W [14]. Interleaved boost converter find its application in various fields and are utilized to enhance gain and reduce stress across the switches. It renders low electrical losses and it is cost effective solution for energy harvestings applications [16]. Researchers moved towardsthe implementation of single switch DC-DC converter renders elevated gain and diminished losses. Boost topology of two input stages was combined for PV application was implemented and compared with other converters was verified [17,18,19]. High gain DC-DC converter with two input boost stages was combined with a feature of interleaved structure to attain the high efficiency [19,20]. The presence of coupled inductor in an isolated DC-DC converter with single output and dual input is implemented to achieve uplifted gain and ripple-free input current [21].

Due to the variation in insolation and temperature, the I-V characteristics of the panel gets changed. Hence in order to scavenge the utmost power from the PV panel, several algorithms were endorsed out of which PO algorithm of MPPT techniques is discussed and compared with other techniques [23-25].DC microgrid plays a vital role in rural areas, where solar is one of the major energy sources. The new switched capacitor-based boost converter is plied to endow the DC grid. The performance analysis of the preferred converter is validated via MATLAB Simulink [26]. A variable DC voltage acquired from solar is augmented to a voltage level suitable for various applications like the LED driver, DC drives, etc. THE intended DC-DC converter regulates the output voltage using the fuzzy logic controller is proposed in this scope [27]. Non-conventional energy sources are a major concern and become a feasible solution for DC drive applications. A novel switched inductor-based boost converter is presented in this scope [28].

II. ENERGY HARVESTING SYSTEM

Global energy demand increases continuously, so as to meet out this demand for electricity, researchers are still working on harnessing energy from alternative sources of energy. There are various renewable energy resources available to mitigate this problem, of which solar energy is found to be the most productive alternative source of energy. It offers more advantages like it's a clean source of energy; raw material is free of cost, inexhaustible, low maintenance, more commercial sources of energy when compared to other non-conventional energy sources. The generalized block diagram of the solar power capturing system is manifested in Fig.1.

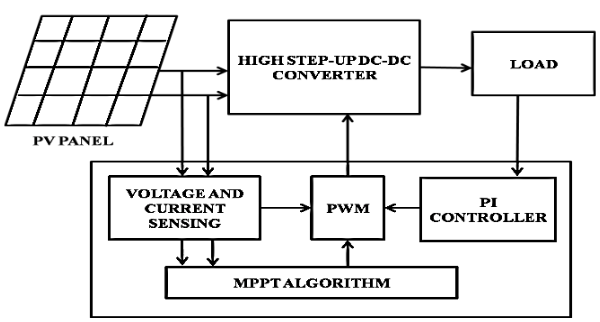

Fig.1: Generalized block diagram of solar PV system

The power electronic interface plays a crucial role in energy scavenging systems. There are various topologies of converters available. Here, a DC-DC converter with a high step-up gain is employed as a power electronic interface between the solar source and the load. The captured energy from the PV panel is engaged for various applications as we can use it for a standalone system, or we are able to integrate with the grid to make it a grid-tied system. The suggested system is best attracted to grid-tied applications due to its high voltage lifting capability.

A. Modeling of Solar PV system

A Solar cell works on the principle of the photovoltaic effect. It is a process that provokes voltage or current in a photovoltaic cell when it is subjected to sunlight. The packets of photons are emitted from the sunlight, and it is recombined to create electron-hole pairs that end up in the current in the solar cell. Solar cells are bridged in series and parallel combinations to acquire the required voltage and current.

Customarily, the solar cell is a p-n junction semiconductor. Electroluminescence could be a major effect that happens within the solar PV to generate electricity when exposed to sunlight. Fig.2. represent the PV cell's equivalent circuit. In this paper, the solar panel used to regulate the o/p voltage is Sun Earth Solar Power TDB 156-36-P 125W.

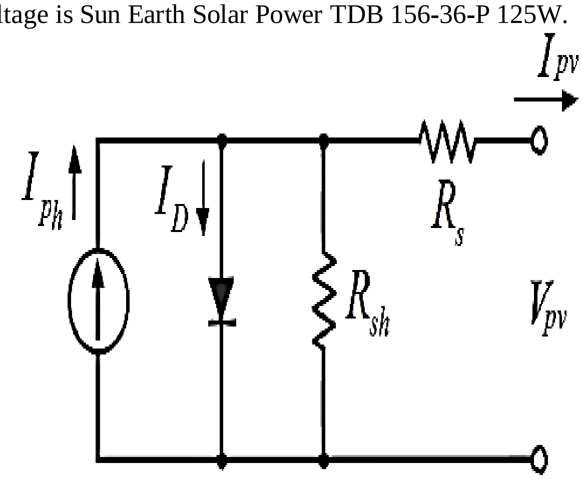

Fig.2: Equivalent Circuit of PV cell

To procure maximum power from the panel, it is evidently making use of the MPPT algorithms. There are several MPPT algorithms are available for the complete utilization of harvested energy from the sun. The Perturb and Observe are one of the most promising and easiest algorithms of maximum power point tracking methods to obtain the duty cycle of the proposed converter.

III. HIGH STEP-UP CONVERTER WITH HIGH GAIN

A. Converter Illustration

The circuit is organized with two power switches ($S_1$and S_2), two inductors (L_1 and L_2), two capacitors (C_1 and C_2), and two diodes (D_1 and D_2), as shown in Fig.3.During the on condition of the switches L_1 and L_2 are getting charged, while during off condition the inductors are being discharged.

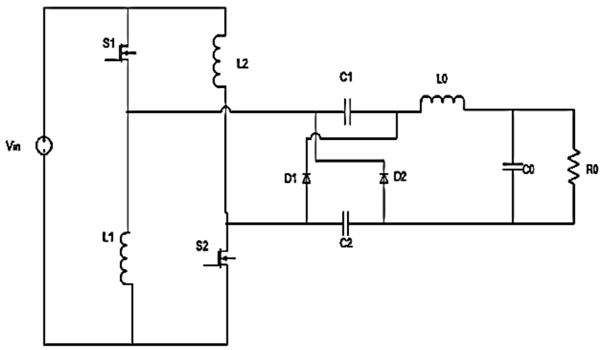

Fig.3: Circuit of High Step-up DC-DC converter

The step-up capacitor cell (SU2C) is operated to raise the voltage gain of the converter. This cell contains two diodes and capacitors that are charged in parallel when the diodes are in forwarding bias condition and discharged in series once they are in reverse bias condition. The diodes operate contrary to the switches. Table 1 represents the formulated specifications of the proposed converter.

TABLE 1.DESIGN SPECIFICATIONS OF THE CONVERTER

Parameters	Values
Input voltage (Vin)	22V
Inductors (L1, L2)	300 µH
Output Inductor (L0)	2.5 mH
Capacitors (C1,C2)	1 µF
Output Capacitor (C0)	100 µF
Output voltage (V0)	120V
Frequency (f)	50kHz

In this paper, a high gain DC-DC converter is incorporated to obtain elevated gain from the solar panel. Here the converter is used to obtain 120V for various load levels with specified irradiance level and temperature so as supervise the voltage level in the output end, and here the PI controller is utilized.

B. Operation of the proposed power converter

The preferred converter exhibits two operating modes. The continuous conduction mode and discontinuous conduction mode of the converter are depicted in Fig. 3(a-c) andFig.4 shows the chopping waveforms of CCM and DCM.

Mode: I

During the on-time of the switches S_1 and S_2, the inductors L_1 and L_2 are charged in parallel from the source V_{in}, and the capacitors C_1 and C_2 are getting discharged. Meanwhile, the diodes D_1 and D_2 are in the off state. The voltage of the capacitors that are charged on the prior cycle and also the source voltage have appeared across the load. The voltage across the inductors is uttered as,

$$V_{L1} = V_{L2} = V_{in}$$

$$V_{L0} = V_{in} + 2V_C - V_0$$

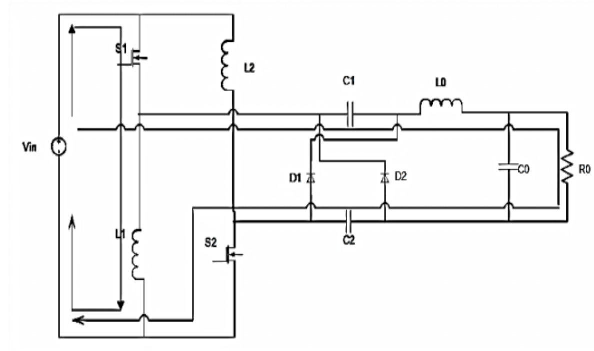

Fig. 3(a): Mode I: Switches ON

Mode: II

During the off-time of the two switches, the diodes (D_1 and D_2) are forward biased. The charged inductors L_1 and L_2now provide energy to charge the capacitors C_1 and C_2, which are connected in parallel, and delivers to the load. The voltage across the inductors and capacitor will be enumerated as,

$$V_{L1} = V_{L2} = \frac{V_{in} - V_C}{2}$$

$$V_C = \frac{V_0 - V_{in} D}{1 + D}$$

Finally, the voltage gain of the converter for CCM can be expressed as,

$$M_{CCM} = \frac{V_0}{V_{in}} = \frac{1 + 3D}{1 - D}$$

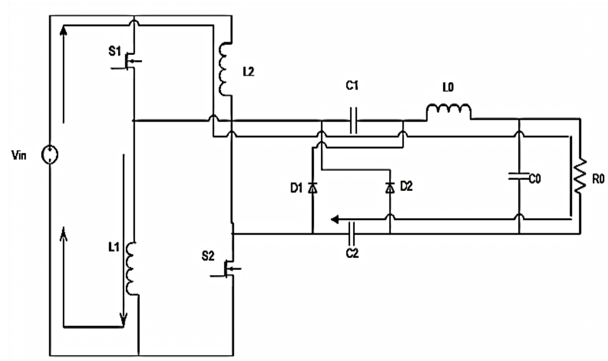

Fig. 3(b): Mode II: Switches are OFF

Mode: III

The discontinuous mode of operation is described in mode III. During this mode of operation, the gain can be obtained from the third operation state of the converter that is portrayed in Fig. 3(c). Mode I, Mode II follows the same as that of the CCM. If the inductance value is small, the circuit operates in discontinuous mode. Hence the duty cycle of the converter is expressed as,

$$M_{DCM} = \frac{V_0}{V_{in}} = \frac{1}{2} + \frac{1}{2}\sqrt{1 + \frac{8D^2}{K}}$$

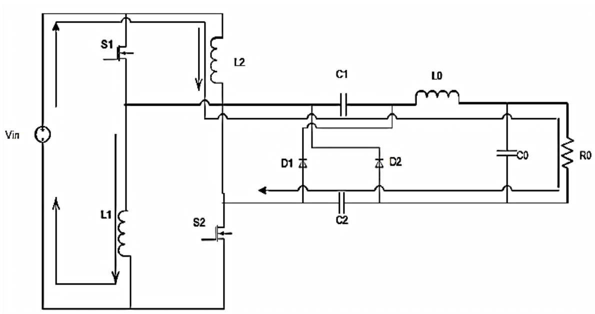

Fig. 3(c): Mode III: Switches and diodes are OFF in DCM operation

C. Design Analysis of the converter

Let us consider the converter operating in continuous conduction mode, and the analysis of the preferred converter is shown below.

$$L_0 = \frac{2V_{in}D}{\Delta L_0 f_s}$$

$$I_{L0} = \frac{P_0(1-D)}{V_{in}(1+3D)}$$

$$L = L_1 = L_2 = \frac{V_{in}D}{\Delta I_L f_s}$$

$$I_{L1} = I_{L2} = \frac{P_0(1-D)}{V_{in}(1+3D)}$$

$$C_1 = C_2 = \frac{P_0 D(1-D)}{V_{in} f_s (1+3D)\Delta L_C}$$

$$C_0 = \frac{V_{in}D}{4L_0 f_s^{\,2}\Delta V_{C0}}$$

D. Switching waveforms of the Converter

The customary switching waveforms for both Continuous Conduction Mode and Discontinuous Conduction Mode are shown in Fig. 4(a) and (b).

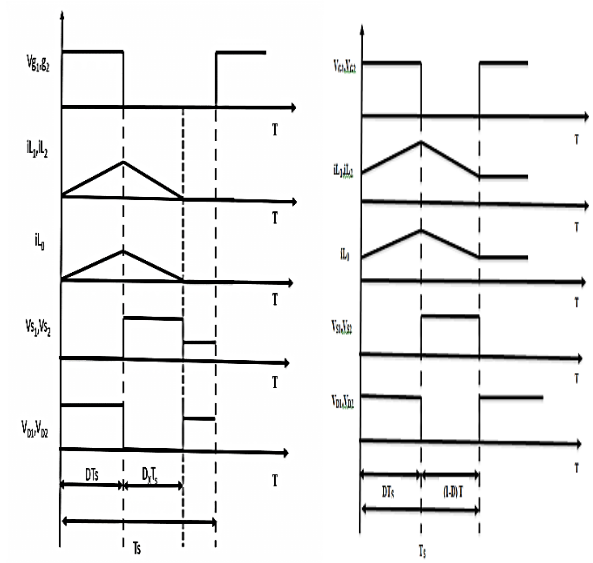

Fig.4: Switching waveforms of the proposed converter (a) CCM (b) DCM

IV. SIMULATION RESULTS

Simulation results of mentioned closed-loop high step-up DC-DC converter with MPPT are validated with the help of MATLAB/ SIMULINK and are shown in Fig.5.

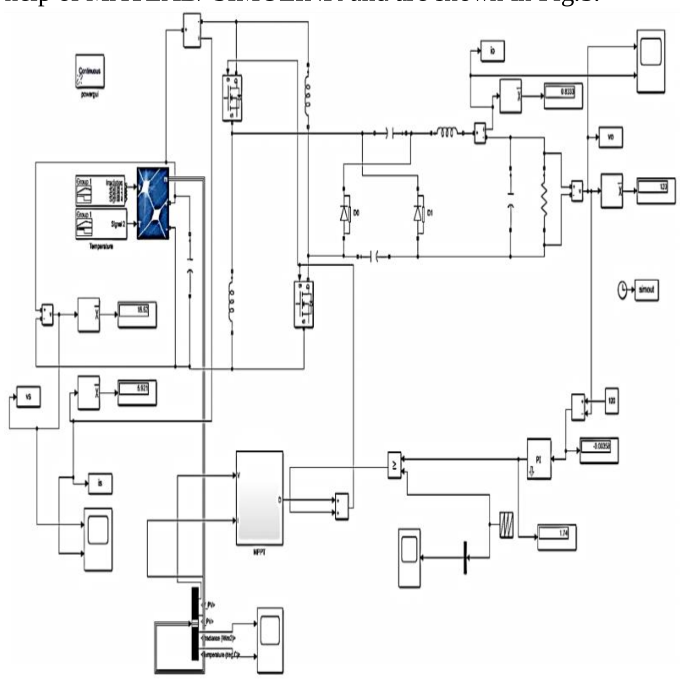

Fig.5: MATLAB Simulation of High step-up DC-DC converter with PV

Case 1: At irradiation level of 1000W/m²and temperature of 25˚C

Herewith 1000 W/m²and 25℃ as the irradiation level and temperature as constant, the results are observed by varying the load, and the efficiency is also shown in Table 2.

The output voltage and output current waveforms are depicted in Fig.5(a-b).

TABLE 2.AT IRRADIATION LEVEL OF 1000W/m^{2}AND TEMPERATURE OF 25 ˚C

Power (W)	Output Voltage (V_0)	Output Current (I_0)	Load (R)	Efficiency (η)
100	120	0.8334	144	90
75	120	0.625	192	88
50	120.1	0.4167	288	83

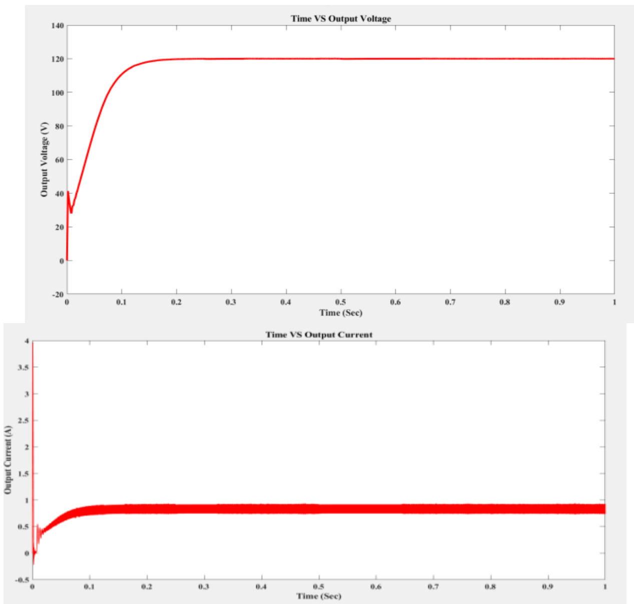

Fig. 5(a-b): Output Waveforms at 1000W/m^2 and 25˚C

TABLE 3 VARIATION OF REFERENCE VOLTAGE

S.No	Reference Voltage (V)	Input Current (A)	Output Voltage (V)	Output Current (A)
1	120	5.475	120	0.833
2	100	3.718	100	0.694
3	80	2.394	80	0.554
4	60	1.368	60	0.416
5	40	0.6102	40	0.277

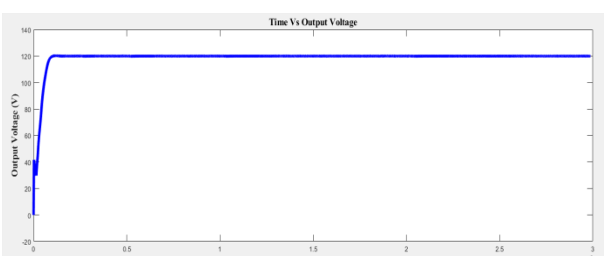

Fig. 5(c): Output Voltage Waveforms at 1000W/m^2 and 25˚C

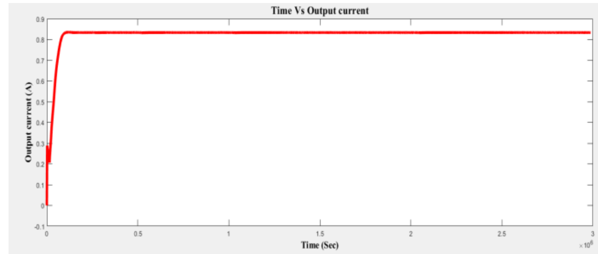

Fig. 5(d): Output Current Waveforms at 1000W/m^2 and 25˚C

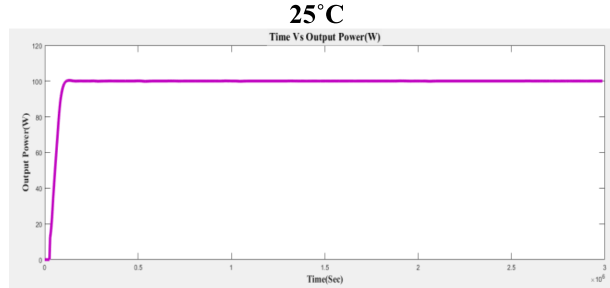

Fig. 5(e): Output Power Waveforms at 1000W/m^2 and 25˚C

Fig. 5(c-e) interrupts the output voltage, current, and power at the change in the reference voltage and maintaining the input irradiation level to be constant.

Case 2: At irradiation level of 850W/m^{2}and temperature of 20 ˚C

Keeping the irradiation level and temperature as constant at 850W/m^2 and 20 ˚C, by varying the loads, the results are observed as shown in Table. 3. The output voltage and output current waveforms are shown in Fig. 6(a), Fig.6(b). The output voltage is regulated for the varying load conditions, which are pictured in Fig.6(c).

TABLE 3.AT IRRADIATION LEVEL OF 850W/m2AND TEMPERATURE OF 20˚C

Power (W)	Output Voltage (V_0)	Output Current (I_0)	Load (R)	Efficiency (η)
100	120	0.8334	144	91
75	120	0.625	192	89
50	120.1	0.4168	288	83

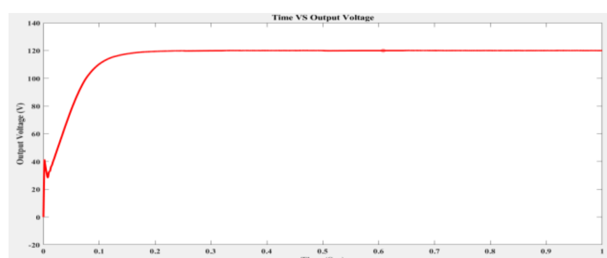

Fig. 6(a): Output Voltage Waveform at 850W/m^2 and 20˚C

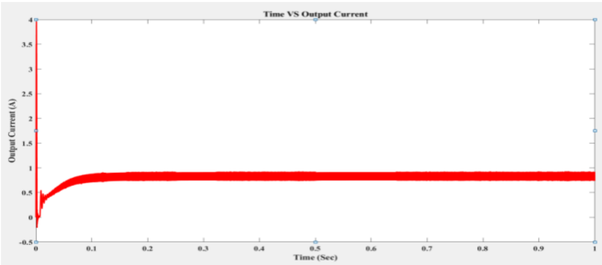

Fig. 6 (b): Output Current Waveform at 850W/m^2 and 20˚C

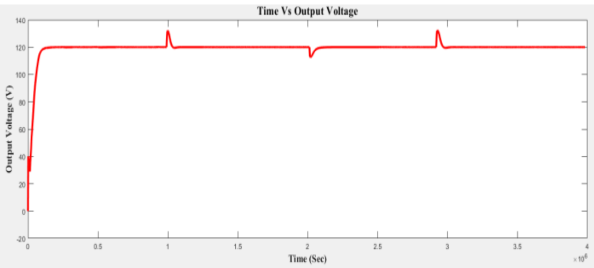

Fig. 6 (c): Output Voltage Waveform for change in load condition at 850W/m^2 and 20˚C

V. CONCLUSION

The proffered DC-DC converter with lifted gain for PV application is presented in this paper. The converter works on the duty cycle of 75% and produces an elevated voltage gain of thirteen. This converter includes a fewer number of elements that make the system more attractive and compact. The favored topology of the converter proffers many merits like high gain efficacy, less hassle on switched, and cost-effectiveness. The output voltage and current waveforms are scrutinized for constant irradiation and temperature of the PV panel. The Proportional and Integral controller is used to withstand the output voltage for varying load conditions. By making use of this Perturb and Observation method of MPPT algorithm, will procure maximum power from the panel. The efficiency is achieved around 80-90%. The results are validated using MATLAB. The suggested converter is best suited for both grid-tied and standalone solar applications.

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