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Multilevel Boost Converter with Modified MPPT and Model Predictive Control

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ABSTRACT: Maximum power point tracking (MPPT) algorithm is improved with Model predictive control (MPC). The perturb and observe(P&O) method serves as the foundation for the MPPT control's modification strategy. With the help of this updated control, the dc-dc multilayer boost converter (MLBC) can extract the maximum amount of power from a photovoltaic (PV) module, while boosting a modest dc voltage. The entire system, which consists of a PV model, an MLBC, and a modified MPPT, issimulated with change in solar radiation. The MATLAB/SIMULINK application is used to implement the control strategy.

KEYWORDS*:* Multilevel Boost Converter (MLBC), Model predictive control (MPC), Maximum power point. tracking (MPPT), Perturb and Observe algorithm (P&O).

I.INTRODUCTION

The globe has prioritised the energy issue, particularly in terms of the exploitation of Renewable Energies (REs), due to its limited oil reserves. A photovoltaic (PV) system is one of the main renewable energy sources. It has recently evolved into a higher target for the entire world. Renewable energy sources include things like biomass, wind, solar, mini-hydro, and others. Thephotovoltaic energy conversion systems is important since they have numerous advantages, including the fact that they don't need fuel, require little maintenance, and are environment friendly. But in order to make a PV system efficient, power extraction at the point of highest power is crucial. The primary disadvantage of a PV system is its high initial cost [1].There are many methods that have been used to increase dc voltage with high gain. The multilayer boost converter is employed inthis PV application. This work uses model predictive control with perturb and observe algorithm (P&O) (MPC).MPC has become a very important technique for managing electrical energy when power converters are involved. Even when nonlinearities are present, MPC is very simple to use. It can also do away with linear controllers and modulators [2]. Fast dynamic response obtains with this technique.

To address these issues, a topology known as the DC-DC Multilevel Boost Converter arepresented [2]. It is built on a Nx converter with one inductor, one switch, two (2N-1) diodes, and two (2N-1) capacitors. It is a boost converter with self-balanced N+1 output levels that are PWM driven. This system suggests a multilayer boost converter to increase the DC voltage coming from a renewable energy source [3,4]. A DC-DC converter based on a multiplier cell offer a high efficiency and big voltage conversion ratio. The converter with a PV and MPPT integration and isolated construction can achieve significant voltage gain.However, in order to get a higher voltage gain, extra interleaving cells are required, which raises the system's overall cost. Additionally, a different method is suggested to distribute the impact of partial shadowing on the PV array without changing the electrical connections of the PV modules and only by changing the actual location of where their performance enhancement has been addressed. Modified MPPT based boost converters for PV systems are addressed in this system for model productive control [5].

IIOPERATION OF MULTILEVEL BOOST CONVERTER

Only one switch is required and it offers many self-balanced voltage levels. By adding more levels and using extra capacitors and diodes, the output voltage can be raised to any value.

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Only two capacitors and two diodes are utilised to boost the additional level of these converters, without changing main circuit. In the other topologies like switched capacitor converters with a boost stage, this topology has only one switch, making it easier to regulate [6].

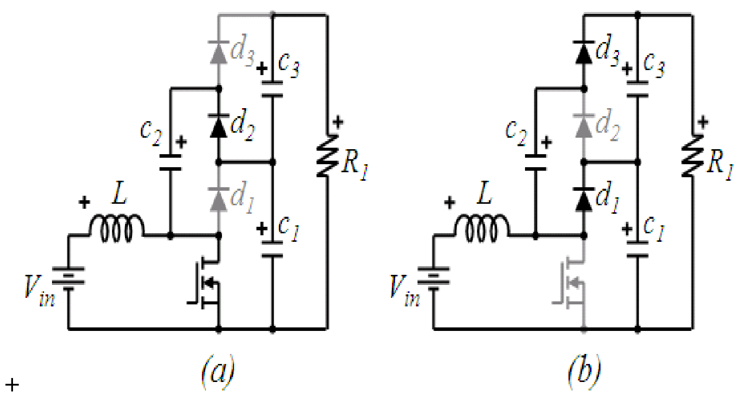

Fig 1Circuit Operation in a *2x MLBC* when the switch is (a) closed and (b)open

As shown in fig.1 (a) C_1 charges C_2 through the switch and diode D_2, if C_2's voltage is lower than C_1's voltage. The capacitor voltage across C_1+C_3 discharges in the load simultaneously, the diode D_1 turns on when a switch is turned off because the inductor charges the capacitor C1 until its voltage equals the total of the voltages from the voltage source and the inductor, The capacitor C_1+C_3 is charged through the voltage source, inductor, and capacitor C_2 as indicated once the diode D_2turns on. The voltage on the C_1+C_3 equals the total of the voltages on the voltage source, the inductor, and the capacitor C_3, which disables the diode D_3.

III. MODIFIED MAXIMUM POWER POINT TRACKING

As the photovoltaic module has a maximum power point, this point is continuously changing with the change of the module temperature and irradiation. The MPPT controller tracks this power point as long as it changes. In this section a maximum power point by using model predictive control (MPC) will be presented. In general P&O method has a simple feedback structure and fewer measured parameters like voltage and current sensor. It operates by periodically perturbing (i.e., incrementing or decreasing) the PV module terminal voltage and comparing the PV output power with that of the previous perturbation cycle. In comparison to PWM charge control devices, MPPT devices offer a 30% higher charge efficiency. With changes in the temperature and radiation of the module, this point is constantly shifting. If the perturbation leads to an increase or decrease in module power, the subsequent perturbation is made in the same or opposite direction. In this manner, the peak power tracker continuously seeks the peak power condition. When the steady state is reached, the algorithm oscillates around the peak point. In order to keep the power variation to be small, the perturbation size is kept very small. The algorithm is developed in such a manner that it sets a reference voltage of the module corresponding to the peak voltage of the module. the main goal to using the MPC in perturb and observe algorithm (P&O) is to increase the response of the control of MPPT on the PV system when there is abrupt change in a temperature or irradiation because MPC predict the future behaviour of the system.

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IV.ANALYSIS OF THE MULTILEVEL BOOST CONVERTER FORTHE IMPLEMENTATION OF THE MPC

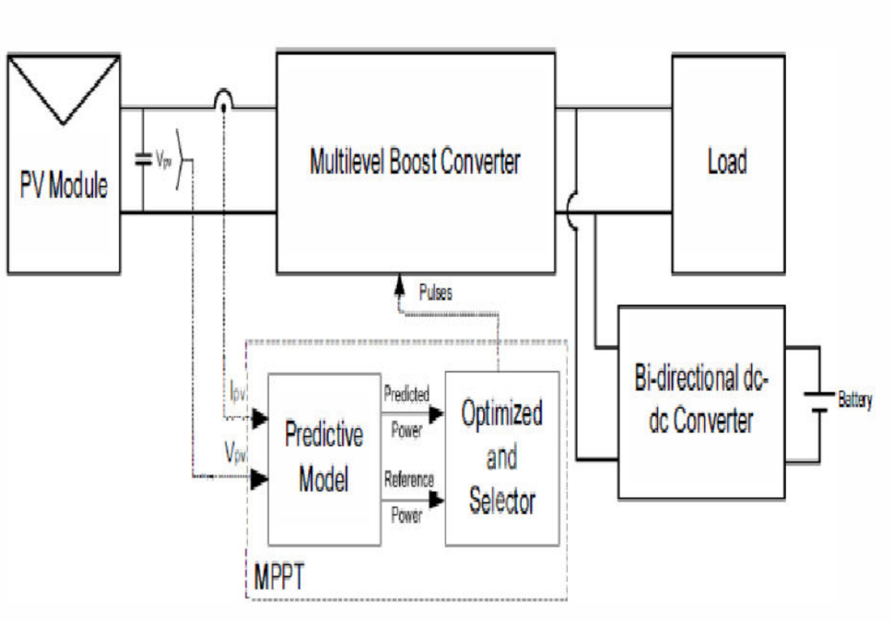

Figure 2: Implementation of the MPPT controller scheme through MPC on MLBC

The figure 2 shows the block diagram of our system and now will see the how the system works with using block diagram. PV module is connected to a MLBC then to a load like a dc motor. In addition to that, power electronics converter like a bi-directional dc-dc converter with a storage battery is connected in parallel with a dc load to take the power generated from a PV module to charging a storage battery. Moreover, when the power demand from the load is larger than the generatedpower from a PV, the battery feeds a load with a rest of power (sharing the PV module) throw a bi-directional dc-dc converter. MLBC boosts a small voltage of the PV module to be valid for feeding the load, and in the same time to extract maximum power from a PV module. The controller senses a dc voltage and a dc current of the PV module. Then the predictive model generates the predicted power and the reference power signals. Moreover, the optimized and selector take this signal and then give the pulses to theMLBC. This width of this signal is dependent on MPPT control.

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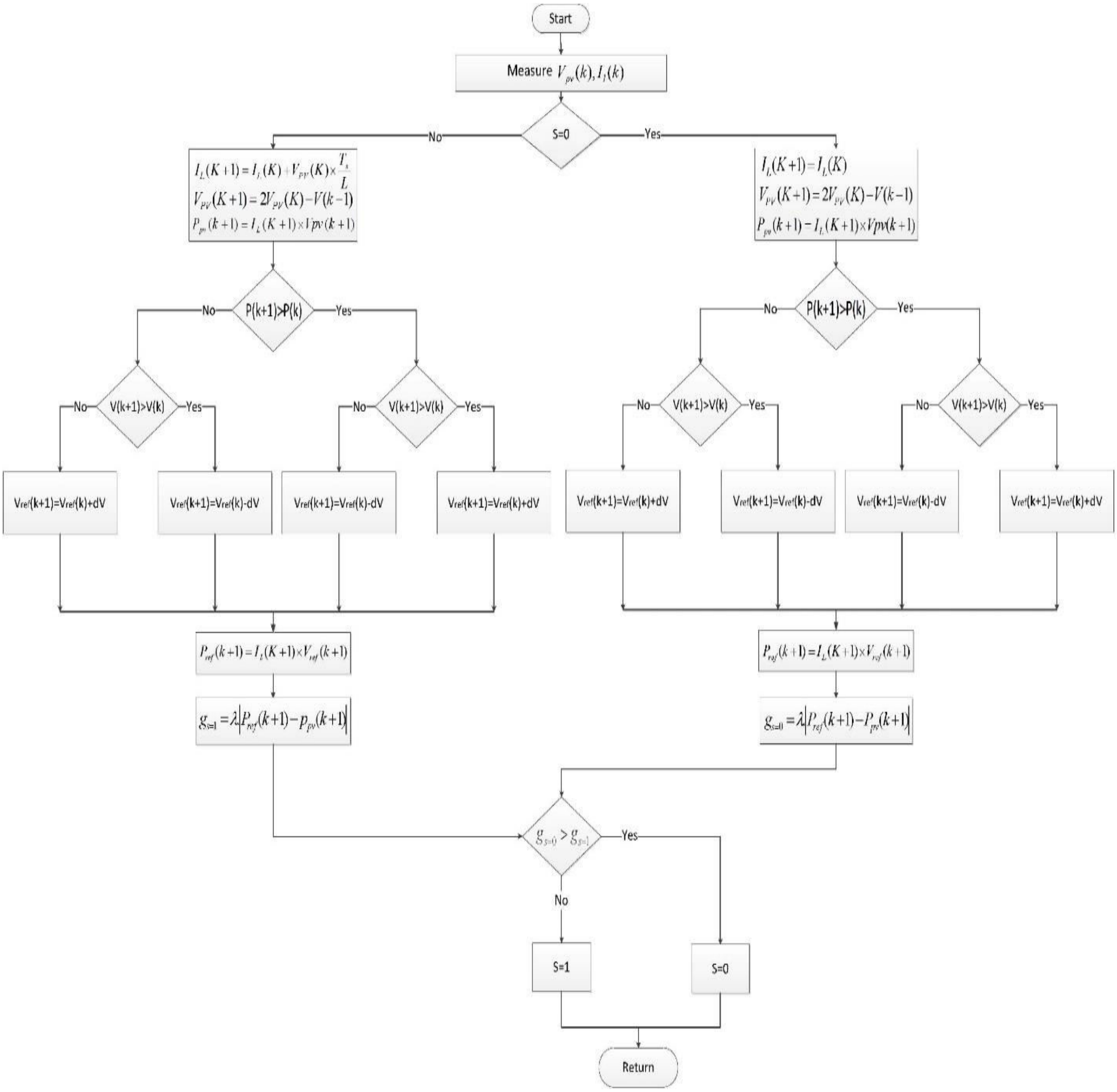

Fig 3: Flowchart of the modified MPPT control by using MPC.

The figure 3 shows the flow chart of modified maximum power point tracking control by using MPC. Now will see the working of the flow chart. The primary goal of the MPC is to forecast future PV module output voltage and current values (inductor current and capacitor voltage).

Therefore, the inductor volt-second balance and capacitor charge balance principles will be discussed in this part.

$$L\frac{dl}{dt} = V_{PV}(t) - I_L R_L \quad (1)$$

$$C\frac{dv_{pv}}{dt} = I_{pv}(t) - I_l(t) \quad (2)$$

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Where Vpv & Ipv isthePVmodule voltage and current respectively,$I_L$istheinductorcurrent,Cisthevalueofthecapacitor,ListhevalueoftheinductorandR$_L$is equivalent series resistance of theinductor(ESR).

For the second subinterval with the switch is turned off, the inductor is connected to the output throw a diodes and capacitors. The inductor voltage and capacitors current are then:

$$L\frac{dl}{dt} = V_{PV}(t) - I_L R_L V_{c1}(t) - V_d \quad (3)$$

$$C\frac{dv_{pv}}{dt} = I_{pv}(t) - I_l(t) \quad (4)$$

Where Vd is the forward voltage diode, VC_1 is the voltage of the capacitor.

The discrete time of the aforementioned equations (1)-(4) (the sampling frequency Ts) are: -

When a switch is turned ON:

$$I_L(K+1) = I_L(K)\left[1 - R_L \times \frac{T_s}{L}\right] + V_{PV}(K)\frac{T_s}{L} \quad (5)$$

$$V_{PV}(K+1) = V_{PV}(K) + [I_{PV}(K) - I_L(K) \times \frac{T_s}{C} \quad (6)$$

Also, when a switch is turned OFF:

$$I_L(K+1) = I_L(K)\left[1 - R_L \times \frac{T_s}{L}\right] + V_{PV}(K)\frac{T_s}{L} - V_{c1}(K) \quad (7)$$

$$V_{PV}(K+1) = V_{PV}(K) + [I_{PV}(K) - I_L(K) \times \frac{T_s}{C} \quad (8)$$

To minimise a cost function of the control error and the manipulated variable increments during the relevant prediction horizons is one potential predictive control criterion. Equation (9) depicts the cost function of this system when a switch is turned OFF, and equation (10), when a switch is turned ON (10).

$$g_{s=0} = \lambda.\,|P_{ref}(K+1) - P_{pv,s=0}(K+1)| \quad (9)$$

$$g_{s=1} = \lambda.\,|P_{ref}(K+1) - P_{pv,s=1}(K+1)| \quad (10)$$

Where,λ is the weighting factor of the power, So now after using equation (5) for the predictive inductor current in the ON state, for the predictive PV capacitor voltage for both two states the voltage of the PV module and the inductor current are measured then the controller observes the state of the switch if it is ON (S=l) or OFF (S=O). After that, a predicted power can be calculated from the predicted voltage and current according to equations (5), (6) and (8). Moreover, a reference voltage for the maximum power point of the PY module can be generated from comparing two points of the power. One of it is the predicted and another is the current point. If the predicted power is larger than the current power, the controller will check if the predicted voltage is larger than the actual voltage or not.predicted voltage is larger than the existing voltage, the predicted reference voltage will be generated by increasing the current reference voltage by dV. But if the predicted voltage is smaller than the actual voltage, the predicted reference voltage will decrease by dV. On contrary, if the predicted power is not larger than the current power, the controller will check if the predicted voltage is larger than the current voltage or not.

If the predicted voltage is larger than the current voltage, the predicted reference voltage willbe generated by decreasing the reference voltage by dV. But if the predicted voltage is smaller than the current voltage, the predicted reference voltage will increase by dV. Besides that, a predicted reference power can be calculated from a reference voltage and predicted current. Furthermore, the cost function will be calculated according equation (9) when the switch is turned OFF and equation (10) when the switch is turned ON. If the cost function when the switch is turned ON is larger than the cost function when the switch is turned OFF, the switch is turned OFF to reduce the cost function. But if the cost function when the switch is turned ON is smaller than the cost function when the switch is turned OFF, the controller latches the state of the switch toanother sampling time. After that the program is returned again to the first point.

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V. BI-DIRECTIONAL DC-DC CONVERTER

The figure 4 shows the circuit diagram of bidirectional buck boost DC-DC converter. Bidirectional buck boost DC-DC converter topology for battery charging and discharging application. this topology requires only one energy storage element that is inductor. The advantages of this topology are a smaller number of components, low cost, light weight and high efficiency. Now will see the working of this circuit with both buck mode and boost mode. Buck-boost converter topology is a fusion of two different converter topologies. The buck converter steps down the output voltage level and the boost converter steps up the output voltage level.

In the buck mode the output voltage is less than input voltage to charge the battery from DC. Switch S1 is triggered and S2 is kept off. When S1 is on the input current rises and flows through S1 and L(inductor). When S1 is off, inductor current falls until next cycle. At that time the bi directional converter working as buck converter. The buck converter requires only one switch and has high efficiency

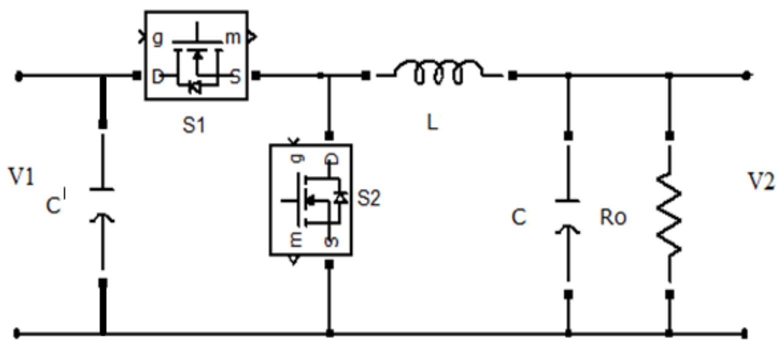

Fig 4: circuit diagram of bi directional converter with buck boost structure

The input current is continuous. However, the output voltage is very sensitive to changes in duty cycle. The average output current is less than the average inductor current, and a much higher rms current would flow through the filter capacitance, resulting in the use of a larger filter capacitor than those of buck regulator.Step-upswitch-mode voltage regulator is one in which the output voltage is higher than its input voltage. In the boost mode the output voltage is more than input voltage the battery discharges power to load with switch S2 triggered and S1 is off. When switch S2 is on the input current rises through inductor L and S2, when S2 is off the inductor current falls until next cycle. At that time bi directional converter working as boost converter.

VI. IMPLEMENTATION RESULTS

Table1: Performance of MPPT with change in irradiance of MLBC with Bi directional converter

Irradiance (W/m^2)	PV Voltage (V)	PV Current (A)	Input Power (W)	Output Voltage (V)	Output current (A)	Battery current (A)	Output Power (W)
1000	18.02	75.97	1367.4	230	3.447	-0.9733	792.81
900	17.74	73.21	1225.5	228.46	3.412	1.118	779.50
800	17.21	60.45	1110.7	226.5	3.32	6.229	751.98

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700	16.60	60.57	944.8	224.43	3.217	7.733	721.99
600	16.47	54.79	792.81	212.89	2.809	6.81	602.88
500	16.11	28.28	625.2	198.35	2.804	6.618	556.17
400	15.66	26.04	537.9	192.81	2.616	6.409	504.390
300	15.47	22.63	417.97	182.37	2.252	3.475	492.56
200	15.6	15.86	279.136	175.38	2.112	7.605	428.81

The figure 5 shows the output of model predictive control, if see this waveform, it is observed that the change in duty ratio as per the current power and previous power as per the requirement it changes. Figure 6 shows the final output duty cycle in that also andit is observed that duty ratio changes as per the detect change. These two figures are proving that our modified MPPT with using model predictive control works as per our expectation.

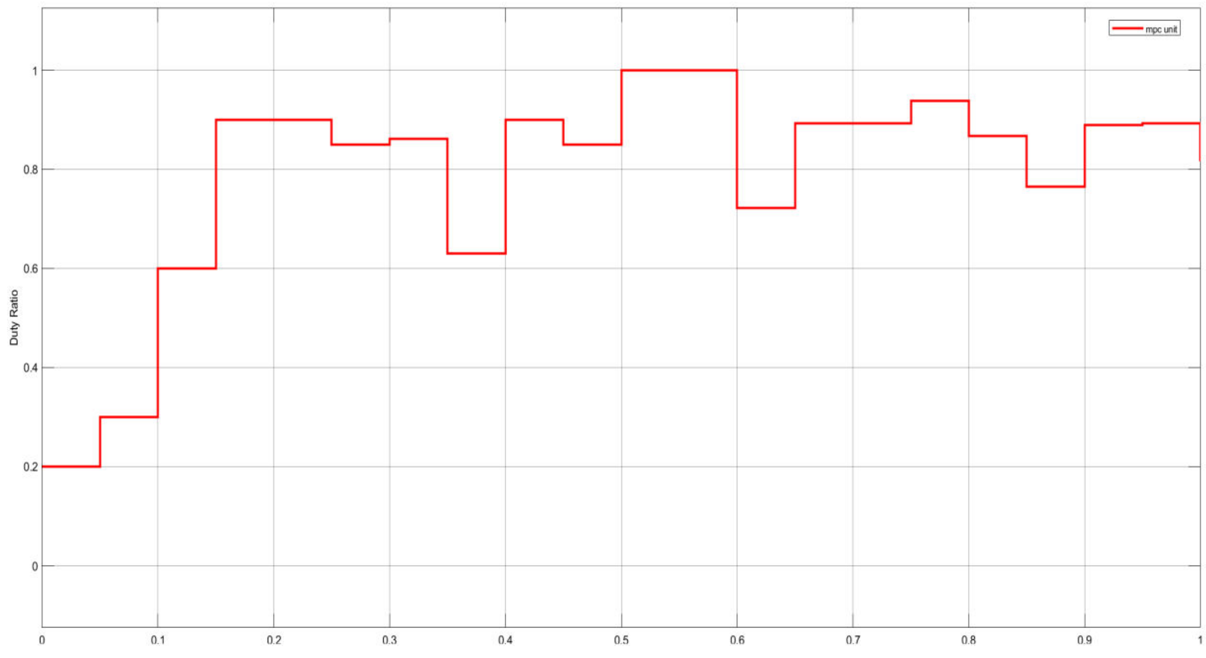

Fig5: Result of MPC with change in MPC duty ratio.

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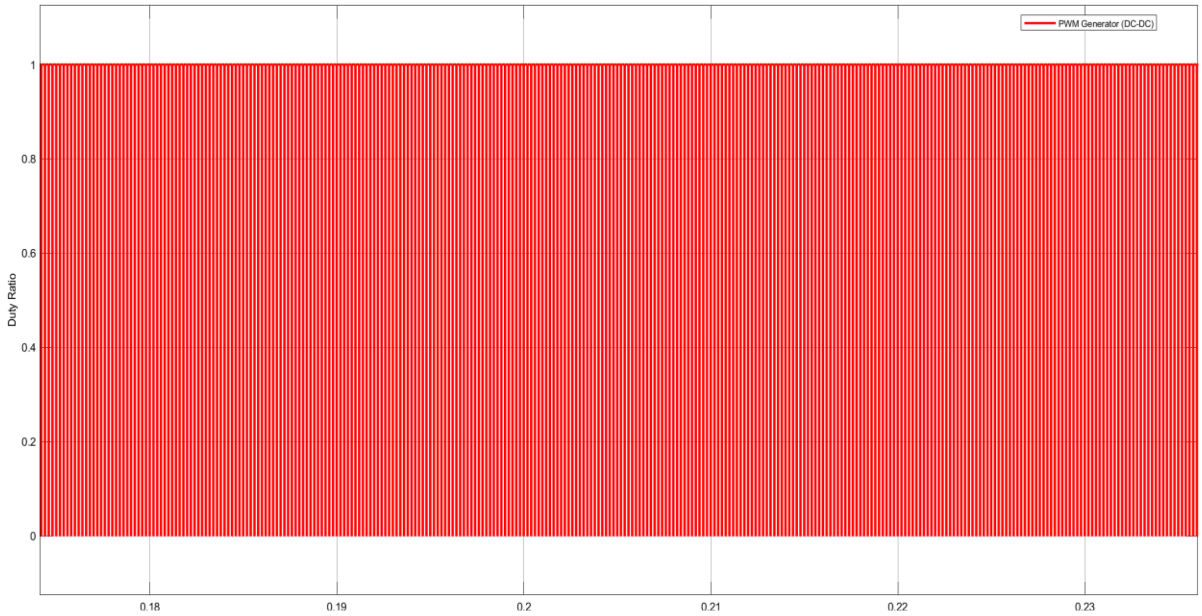

Fig 6: Result of final output duty cycle

The figure 7 shows the results of final output waveform of our system in that first we see the duty cycle after that the middle graph is showing the voltage measurement and the last one showing the mean of that graph. As per the requirement, for the1000 irradiance &30-degree temperature, desired output voltage 230 V is obtained.

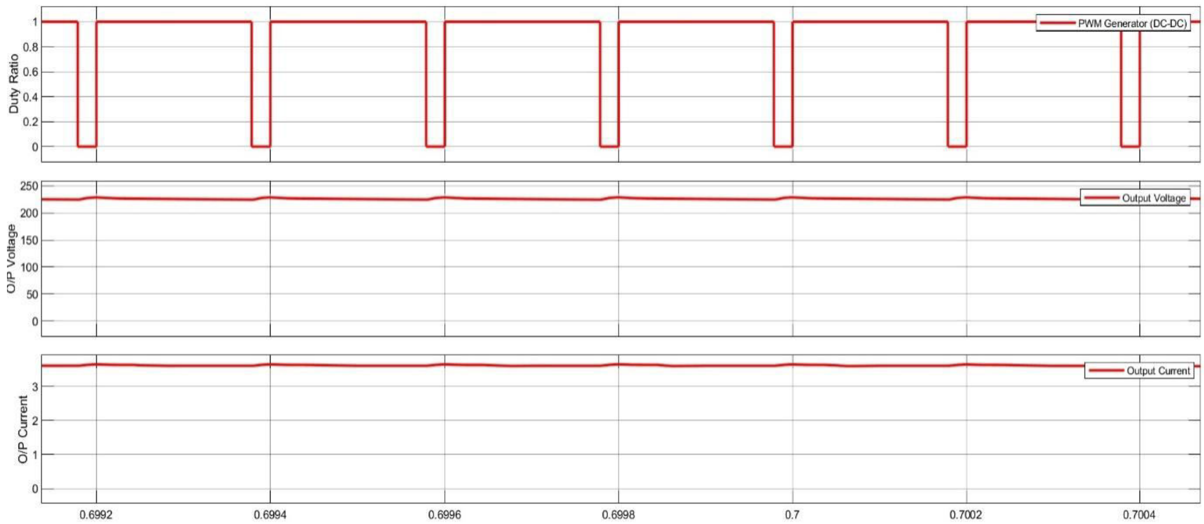

Fig 7: Result of final output waveform of system.

VII. CONCLUSION

This paper presents the modified maximum power point tracking control (MPPT) by using model predictive control (MPC). The algorithm used in this modification is perturb and observe algorithm (P&O). This modification is applied on the dc-dc multilevel boost converter that is connected to PV modules. This modification improves the response of the system. MLBC extracts the maximum power from PV modules at any level of the irradiation and temperature. The simulation results provided in this paper validate the correctness of the modified MPPT control. The

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comparative analysis of conventional and multi-level boost converter and why multi-level boost converter is much efficient as compare to the conventional boost converter is explained. For the maximum power point tracking, hill climbing (perturb& observe) method of control is used. P&O method has a simple feedback structure. This method is easy to understand and much reliable as compare to other MPPT technique. the study of design and simulation of bi directional converter with buck boost structure. Bi-directional converter fulfills the requirement of the load as per the requirement charging and discharging works. This circuit helps to reduce ripple current and reduce switching losses and number of switches.

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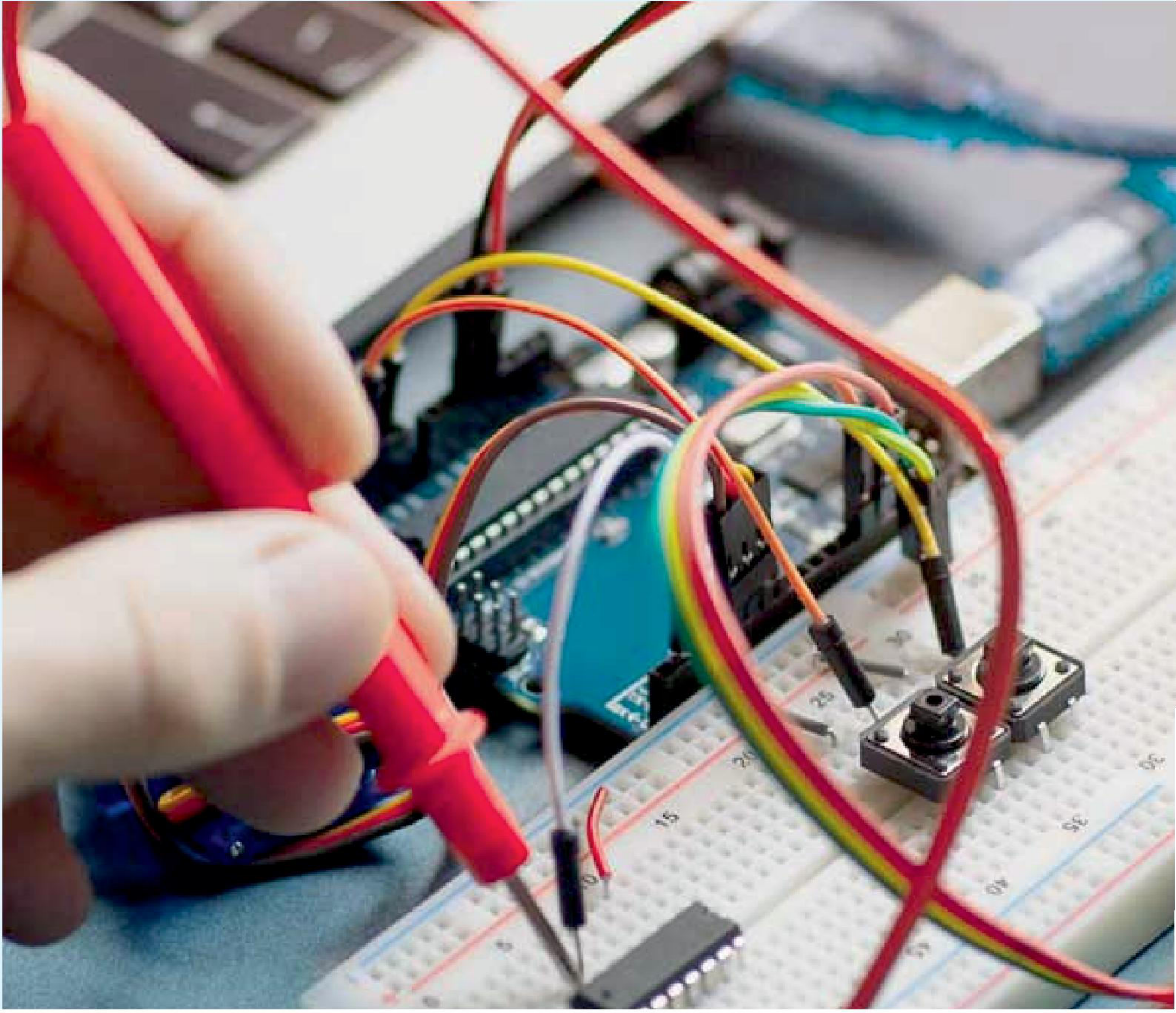

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