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Concurrent PV Conditioner with Interleaved Buck Converter Using Model Predictive Control

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ABSTRACT: The main objective of this paper is to design a low cost, high efficient, photovoltaic inverter system with reduced number of components and overall losses. A real time module of PV system with interleaved buck DC-DC converter is designed where Maximum power point tracking is incorporated with Model Predictive based Incremental Conductance which reduces the complexity and increases the efficiency. The occurrence of inter-harmonic and sub-harmonic distortions is addressed by adopting a power point tracking method along with interleaved buck converter. Furthermore, the efficiency can be increased to greater value using model predictive control method with incremental conductance as base. This project work further focuses on a novel approach to design single-phase inverter topology. The inverter is supported with an energy buffer circuit, a dc-dc conversion circuit and an H-bridge circuit. The energy buffer coupled with the inverter circuit will be capable of producing a multilevel voltage according to improve the Total Harmonic Distortion (THD) of the output of the inverter. The present design is capable of operating with 12V/24V panels and 12V/24V batteries with up to 5A output current.

KEYWORDS: Maximum Power Point Tracking, Model Predictive control, Incremental Conductance, Total Harmonic Distortion.

I.INTRODUCTION

The vitality deficiency and the climate contamination have been the real constraints for the human improvement. Photovoltaic (PV) sources are one of the critical players on the planet's vitality portfolio and will turn into the greatest commitments to the power age among all sustainable power source applicants by year 2040 on the grounds that it is really a perfect, emanation free inexhaustible electrical age innovation with high unwavering quality. The assignment of a greatest power point tracker (MPPT) in a photovoltaic (PV) vitality transformation framework is to constantly tune the framework with the goal that it draws most extreme power from the sun oriented cluster paying little heed to climate or load conditions.

Since the solar array has a non-ideal voltage – current characteristic and the conditions such as insulation, temperature, and wind that affect the output of the solar array are unpredictable, the tracker must contend with a nonlinear and time-varying system thus using Model Predictive Control Method. This method has a relatively fast response time for tracking the MPP. Additionally, both the open circuit voltage and the short circuit current of PV module techniques fail to track the MPP effectively if solar array cells are partially shaded or if some cells in the array are damaged. Then the state-of-the-art topologies are covered and classified based on the circuit performance. In a grid connected solar array power system an inverter is necessary to convert the DC power which is produced from the solar array to the AC power which is required for our electrical and electronics equipment. Hence, in this work the multilevel inverter is used for the

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conversion of DC-AC, because the total harmonics thus produced by the multilevel inverter is low while compared with other types of inverter [2].

The input of the multilevel inverter is fed through the interleaved buck converter. The buck converter is used to step down the input supply from the solar panel [5]. The output thus produced from the solar panel may vary based upon the sun's irradiation. In order to make the output of the solar panel as constant Maximum power point tracking (MPPT) is used [9][10]. The current and the voltage of the multilevel inverter can be controlled by using the artificial controller. P, PI, PID are some of the artificial controllers.

II.SYSTEM MODEL AND ASSUMPTIONS

The PMP7605 is developed around the MSP430F5132 controller IC. The design is targeted for small and medium power solar charger solutions. The present design is capable of operating with 12V panel and 12V battery with up to 20A output current. However, it can be easily adapted to 48V systems by just changing the MOSFETs to 100V rated parts. Also, it is possible to increase the current to 40A by using TO-220 package version of the same MOSFETs used in the design. The design has an operating efficiency of above 97% at full load in a 24V system. For 12V systems the efficiency is above 96%. This efficiency Fig. includes the losses in battery reverse protection MOSFET and panel reverse flow protection MOSFET, which are part of the design.

The high efficiency is the result of the low gate charge MOSFETs from TI used in the design, and the interleaved buck topology used. The interleaved buck topology reduces the component stresses by a great extent. Another feature is the relatively small sized components used, possible due to the high operating frequency (~200 KHz per stage). The design has built-in battery charge profiles for 12V Lead acid battery. The circuit takes only under 10mA of standby current while operating from battery. There is also a provision to connect a load to the battery with overload and short circuit cut-off built in. The design presently uses 'perturb and observe' algorithm for MPP tracking. This gives fast acquisition of MPP operation. Software programmable alarms and indications are provided in hardware, but are left non-confide. Surge protection and EMI filtering components are not present on this design, and has to be added depending upon required specification levels.

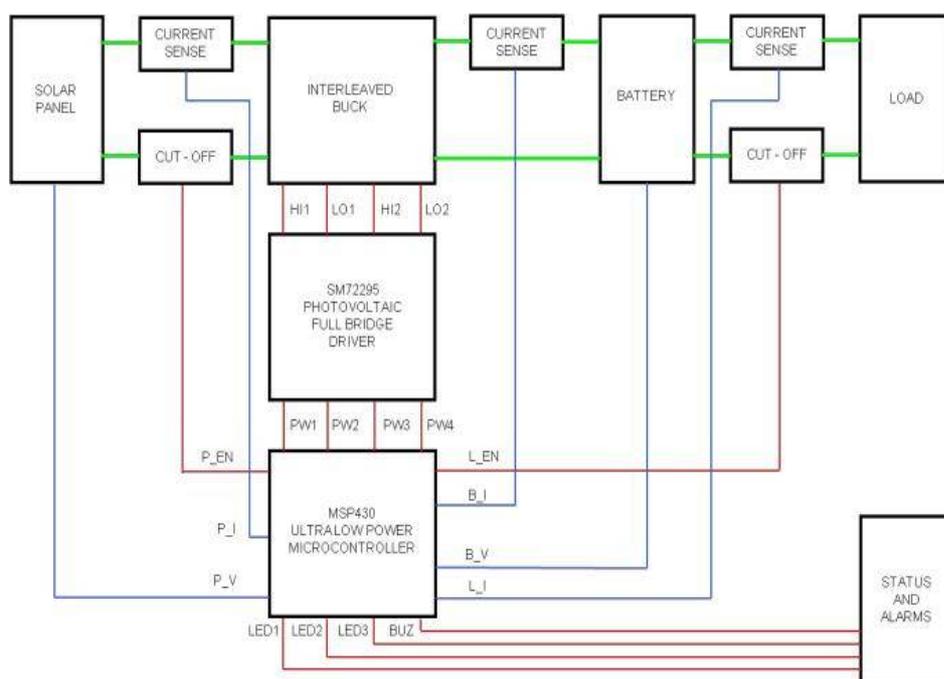


Fig. 1 Block Diagram of the proposed system



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III. MODEL PREDICTIVE CONTROL

The main characteristic of MPC is predicting the future behaviour of the desired control variables until a predefined step ahead in horizon of time. The predicted variables will be used to obtain the optimal switching state by minimizing a cost function. The model used for prediction is a discrete-time model which can be presented as a state space model [10]. The MPC for power electronics converters can be designed using the following steps: [9]

- Modelling of the power converter identifying all possible switching states and its relation to the input or output voltages or currents.
- Defining a cost function that represents the desired behaviour of the system.
- Obtaining discrete-time models that allow one to predict the future behaviour of the variables to be controlled.

The designed controller should consider the following tasks:

- Predict the behaviour of the controlled variables for all possible switching states.
- Evaluate the cost function for each prediction.
- Select the switching state that minimizes the cost function.

We can mathematically express the current produced by the solar cell as

$$I = I_L - I_D - I_{SH}, \quad (1)$$

Where, I= output current (A), I_L =source current (A), I_D = diode current (A), I_{SH} = shunt current (A).

In this scheme measured variables, $X(K)$ are used in the model to calculate predictions, $X(K+1)$ of the controlled variables for each one of the n possible actuators, that is, switching states, voltages, or currents. Then these predictions are evaluated using a cost function which considers the reference values, $X(K+1)$ design constraints, and the optimal actuation, S , is selected and applied in the converter.

The general form of the cost function, g , subject to minimization can be formulated as

$$g = [\bar{X}_1(K+1) - X_1^*(K+1)] + \lambda_1[\bar{X}_2(K+1) - X_2^*(K+1)] + \dots + \lambda_n[\bar{X}_n(K+1) - X_n^*(K+1)]$$

Where, λ is the weighting factor. To select the switching state which minimizes the cost function g , all possible states are evaluated and the optimal value is stored to be applied next. The power converter can be from any topology and number of phases, while the generic load. It can represent an electrical machine, the grid, or any other active or passive load.

IV. MAXIMUM POWER POINT TRACKING USING MODEL PREDICTIVE CONTROL

The low conversion efficiency of PV systems is a significant obstacle to their growth; therefore Maximum Power Point Tracking (MPPT) is required to ensure the maximum available solar energy is harnessed from the solar panel. Many MPPT methods have been suggested over the past few decades; the relative merits of these various approaches are discussed. The critical operating regime is low insolation. Capturing all of the available solar power during low insolation periods can substantially improve system performance. An effective MPPT controller and converter can use available energy to significantly reduce the amount of installed PV. The main contribution of this section is to improve the P&O method performance by predicting the error one step ahead in the horizon through model predictive control technique. The proposed method has faster response than conventional P&O under rapidly changing atmospheric conditions. A super lift Luo converter is chosen as a DC/DC converter. P&O determines the reference current for the MPC which determines the next switching state. This technique predicts the error of the next sampling time and based on optimization of the cost function g , the switching state will be determined.

The inputs to the predictive controller are the PV system current and voltage, and the reference current. Now after determination of the reference current using the procedure shown in Fig. 3, the cost function can be obtained as follows

$$g_{s=0,1} = \left| i_{pv\ s=0,1}(k+1) - i_{ref} \right| \quad (3)$$

The objective is to minimize the cost functioning. However in this proposed system the MPC-MPPT is done for one step ahead in horizon, but the discrete time equation can be extended to n -step in horizon as following

$$i_{pv}(k+n+1) = i_{pv}(k+n) - S \frac{T_s}{L_n} v_c(k) + (1-S) \frac{T_s}{L_n} v_c(k+n) \quad (4)$$

$$v_c(k+n+1) = S \left[1 - \frac{T_s}{RC} \right] v_c(k) + (1-S) \frac{T_s}{C_n} i_{pv}(k+n) \quad (5)$$

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Where, S is the switching state, Ts is the sampling time. By increasing the number of steps to two or three, the computation time will be increased, but better control performance expected to be achieved.

The Limitations of P&O method can be summarized as follows: The power tracked by the P&O method will oscillate and perturb up and down near the maximum power point. The magnitude of the oscillations is determined by the magnitude of variations of the output voltage. There is a misjudgment phenomenon for the P&O method when weather conditions change rapidly. The operating point is then farther away from the maximum power point. If the sun irradiance continuously increases, the distance between operating point and maximum power point will be farther. Consequently, the power loss of the power tracked by the P&O method will oscillate and perturb up and down near the maximum power point. The magnitude of the oscillations is determined by the magnitude of variations of the output voltage. There is a misjudgment phenomenon for the P&O method when weather conditions change rapidly. The operating point is then farther away from the maximum power point. If the sun irradiance continuously increases, the distance between operating point and maximum power point will be farther. Consequently, the power loss of PV modules will increase, and the efficiency of the PV system will reduce. The value of generally varies between 0.64 and 0.85 can be calculated by analysing the PV system at a wide range of solar radiations and temperatures. Advantage of model predictive control, Improve the efficiency, Predetermination of future error prevents oscillations lesser than other methods, Tracks the maximum power faster.

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V. SIMULATION AND RESULTS

A) Multilevel Inverter

Cascaded Multilevel inverter design through the MATLAB simulation is given below. The output for the cascaded multilevel inverter is given in the figure 2 and 3.

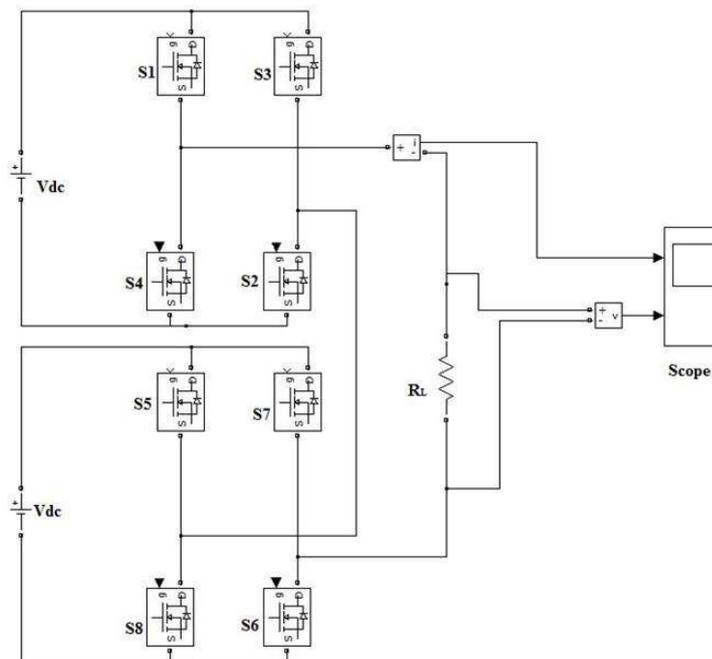


Fig. 2 Mat lab simulation for multilevel inverter

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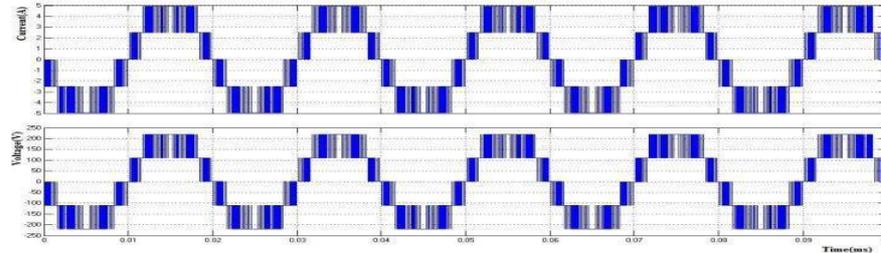


Fig. 3 Output for the MLI

B) Maximum Power Point Tracking

Solar M-file coding for MPPT and PV simulation is given in the Fig. 4. The overall open loop model is given in the Fig. 5. The closed loop of boost converter is given in the Fig. 5.

The modeling and simulation of the whole system has been done in MATLAB-SIMULINK.

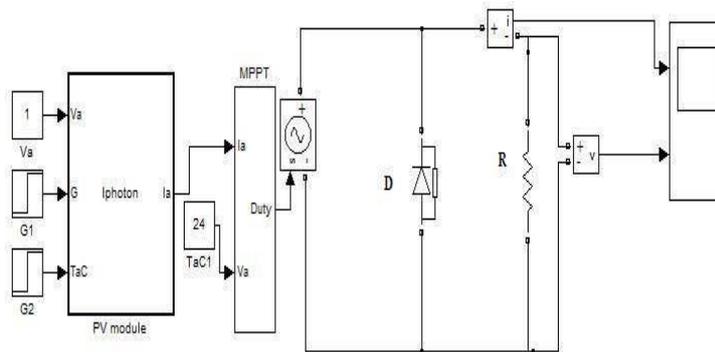


Fig. 4 M-file coding for MPPT and PV simulation

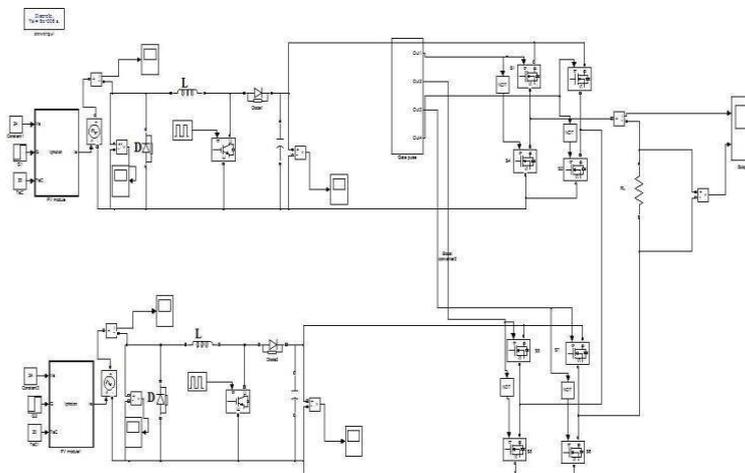


Fig. 5 Open loop model

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C) Closed Loop Model

The block diagram of the complete circuit is shown in the Fig. 6. This includes the PV module, buck converter, multilevel inverter and control circuit.

The modeling and simulation of the whole system has been done in MATLAB-SIMULINK

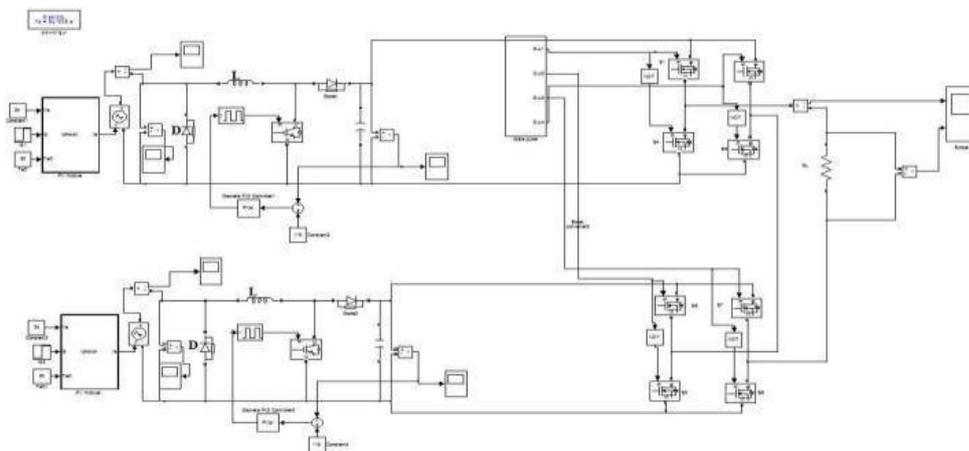


Fig. 6 Closed loop model

VI. PERFORMANCE AND WAVEFORMS

TABLE 1 TEST DATA FOR 12V SYSTEM

V_i (v)	I_i (A)	V_o (V)	I_o (A)	P_i (W)	P_o (W)	Efficiency (%)
17.19	15.06	12.44	20.00	258.88	248.70	96.1
17.16	2.19	12.05	3.00	37.58	36.17	96.2
17.33	11.00	12.32	15.00	190.63	184.79	96.9
17.70	0.01	0.00	0.00	0.14	0.00	0.0
17.27	3.61	12.09	5.00	62.34	60.46	97.0
17.52	5.40	12.15	7.57	94.61	91.98	97.2
17.42	7.20	12.20	10.00	125.42	122.03	97.3

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A) GATE WAVEFORM



Fig. 7 12V system, 20A load. Top and bottom gate waveforms show dead-time implementation.

B) SWITCHING NODE WAVEFORMS



Fig. 8 12V system, 20A load Individual channel switch nodes show interleaved operation

C) MPP ACQUISITION



Fig. 9 12V System, 20A Load. Red: Input voltage, Yellow: Output current



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VII.CONCLUSION

In this paper a maximum power point tracking using model predictive control method for standalone Photo Voltaic (PV) application is designed and implemented successfully in real time. The project on successful completion is developed into a product meeting the IEC standards and having an edge over the other commercially available standalone solar power condition unit in the market as it has a less THD due to implementation of an energy buffer and uniform sampling and high out generated with higher efficiency to suit a low cost affordable module. The simulated result has been generated using Webench and MATLAB and it has been found to match with our expected results. When this is applied in a real-time application, it automatically adjusts any deficiency in current, power to the load. The future scope of this work can be to implement the proposed inverter topology to interact with the grid for exchange of power. This can be done by active frequency and voltage matching of the output parameters of the inverters to synchronize with that of the grid in real time. The use of electrolytic capacitors in the energy buffer can be replaced with ceramic disc capacitors for improved reliability.

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