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PV Integration to DC Micro grid using Modified Converter Topology

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Abstract—The usage of photovoltaic for solar energy conversion is a rapidly growing source of green power supply. Enhancing the efficiency of this system is widely seen as important in supporting this trend. This concerns not only the improvement of the PV cell but also of the power electronics circuits and controls associated to them. The various difficulties identified for the development of such a system is that discontinuous mode of conduction must be avoided and ripple content must be reduced. Therefore, in order to achieve this, an interleaved boost converter with maximum power point tracking based irradiance adaptive control is developed.

Index Terms—Interleaved boost converter (IBC), photovoltaic (PV), discontinuous mode of conduction (DCM), Switching frequency modulation (SFM), module integrated converter (MIC).

I. INTRODUCTION

The global energy scenario is continuously changing. Finite fossil fuel resources, rising energy demands, power shortage, global warming, cyber-attack risks and new load types such as plugging electric vehicles are just some of the reasons for the energy sector to begin a journey towards the utilization of sustainable energies. Therefore, incessant research and developments are being undertaken to meet the challenges pertaining to solar power generation viz. high initial cost, variability, efficient energy conversion, requirement of space for PV panel installation etc. Thus, the main design objective of photovoltaic (PV) systems for a long time has been, to extract the maximum power from the PV array and inject it into the grid. However, special attention has to be paid to the reliability of the system, the power quality, and the implementation of protection and grid synchronization functions when the PV plant is connected to the grid. Also, the maximum power point tracking (MPPT) of a uniformly irradiated PV array and the maximization of the conversion efficiency are some of the design issues associated with such systems. Hence, maximization of energy production and application of suitable control strategies to solve the problems related to the partial shading phenomena and different orientation of the PV modules toward the sun is necessary in modern power plants.Again, improving the efficiency of PV systems concerns not only the improvement of the PV cells, but also of the power electronic circuits and controls connected to them. The overall PV system efficiency is greatly affected by the following three factors. Firstly, the granularity level of distributed maximum power point tracking (DMPPT) affects the efficiency of the system. Hence, a module integrated converters (MIC) or power optimizers representing module-level DMPPT can highly improve the efficiency of the PV power harvesting system. Secondly, it is influenced by the accuracy and speed of the utilized MPPT algorithm. Thus, recent research has considered employing various converter topologies and novel MPPT algorithms within MICs for PV system efficiency maximization. Thirdly, the power conversion efficiency of the employed converter topology plays a key role.Further, the successful application of switching frequency modulation (SFM) improves the PV system efficiency beyond the above three factors. However, only fixed switching frequencies are selected to maintain continuous conduction of the MIC at various irradiance levels. Attainment of uniform power quality is another desirable feature. For this, an interleaved boost converter is utilized which can modify the output by reducing the ripple content in both current and voltage thus improving the power quality.

II. PROPOSED SYSTEM

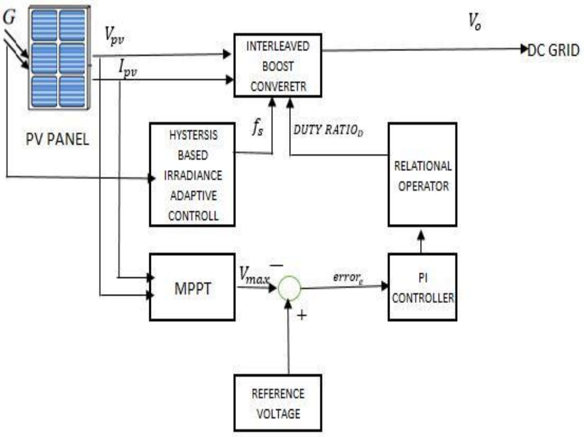

Fig 1: Block diagram of the proposed system

Here, in the proposed system, the PV panel is connected to the DC grid via an interleaved boost converter whose duty ratio is obtained by the application of PI with MPPT controller whereas the switching frequency is controlled by a hysteresis-based irradiance adaptive control using SFM technique. Utilization of optimal SFM in the PV system is carried out as three main parts: implementation of irradiance adaptive SFM scheme and its optimization, selection of a suitable MIC topology and MPPT algorithm.

A. Irradiance Adaptive SFM and its Optimization

The strength of PV current is directly proportional to the solar irradiance. At high irradiance, converter can operate in continuous conduction mode. Hence, low switching frequency can contribute to a high efficiency. Whereas at low irradiance the converter may move to DCM due to the low supply current. At that instant the power drawn from the input source is zero as the inductor current is zero in DCM. Hence, the switching frequency must be increased to maintain the operation of the converter in CCM. Therefore, the switching frequency f_s *is* proposed to be adaptively controlled with the solar irradiance.The optimization of the SFM scheme requires proper selection of the following parameters: the minimum switching frequency f_{smin}, the maximum switching frequency f_{smax}, the frequency steps f_{smax}, f_s and the irradiance thresholds G_i. These parameters are selected by following the trajectory of the switching frequency boundary for the operation of boost converter in CCM at different irradiance levels.

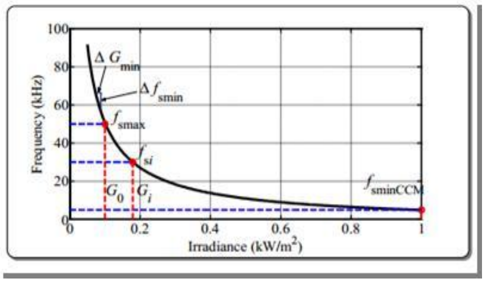

Fig 2: Trajectory of the switching frequency boundary for operating boost converter in CCM at different irradiance levels.

Finally, in order to avoid an unwanted frequent variation or bouncing of the switching frequency due to inaccuracies, such as due flying objects or sensor faults, hysteresis of the irradiance thresholds is proposed. Here, the dead bands are designed such that they do not exceed the CCM boundary.

B. *MIC Topology*

A three phase interleaved boost converter topology is proposed. Basically, an interleaved boost converter is an improvement over the conventional boost converter in which a number of boost converters are connected in parallel. In an IBC, the phase number is determined by the number of boost converters connected in parallel. These converters have the same switching frequency and their phase shift is provided by $360^{\circ}/n$ where n is the phase number. The advantages of using IBC are minimization of ripple content in input current, lower switching and conduction losses and higher power capabilities. Thus, at high irradiance, the interleaved cell is activated adaptively due to which the overall losses are reduced because the conduction loss reduction exceeds the switching loss increase. Hence, the objectives of power conversion efficiency are fully supported by the adaptive MIC topology.

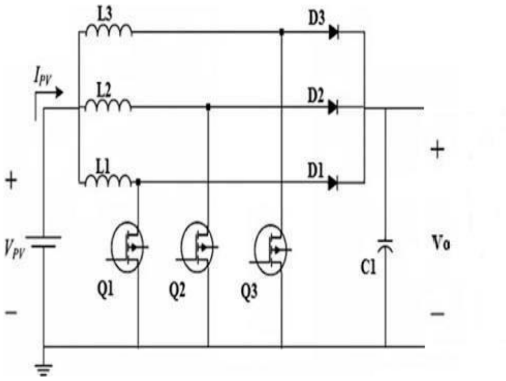

Fig 3: Three phase interleaved boost converter

C. Design of the proposed Interleaved Boost Converter

The duty ratio *D* for the interleaved boost converter of efficiency η is given by:

$$Duty\ ratio, D = 1 - \frac{\eta V_{in}}{V_o} \qquad (1)$$

For CCM, the selection of the inductors and capacitor for IBC is as follows:

$$L_{1,2,3} \geq \frac{V_{in}.D.T_S}{2.I_{in}}, \qquad (2)$$

$$C \geq \frac{D.V_O.T_S}{R.\Delta V_O} \qquad (3)$$

The equation relating the switching frequency f_s, PWM duty ratio *D*, PV module steady state average voltage V_{in} and current I_{in} is as follows:

$$f_s \geq \frac{D.V_{in}}{2.I_{in}.L} \qquad (4)$$

D. Maximum Power Point Tracking

Here, Incremental Conductance MPPT technique is employed. This controller measures the incremental change in PV array current and voltage to predict the effect of a voltage change. Here, the incremental conductance of the PV array is utilized to compute the sign of the change in power with respect to voltage. The proposed method offers various advantages such as good yield under rapidly changing atmospheric conditions, good tracking efficiency, response is high and well control for the extracted power.

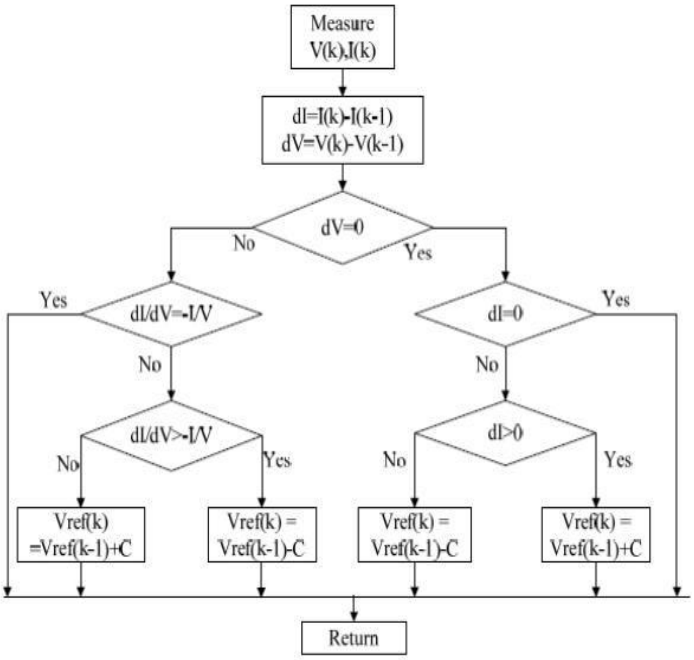

Fig 4: Flowchart of Incremental Conductance MPPT method

In this paper, a PI controller is also designed for the interleaved boost converter to extract the maximum power from the PV source keeping constant output voltage for a particular load. Hence, the Incremental conductance algorithm along with PI controller improves the overall performance of the converter system.

III. DC MICRO GRID INTEGRATION

An adaptively controlled module integrated converter is employed for integration of PV into DC micro grid. Here, the input voltage of the MIC is adjusted for MPPT and the output voltage is defined by the DC bus voltage control units. Here, 120 V is assumed for DC micro grid.

IV. SIMULATION RESULTS

The adaptive topology and the optimal Switching Frequency Modulation scheme are analyzed by simulation. The parameters of the SFM scheme are initially determined. MATLAB/SIMULINK was used to simulate the PV-MIC system and the proposed control scheme.

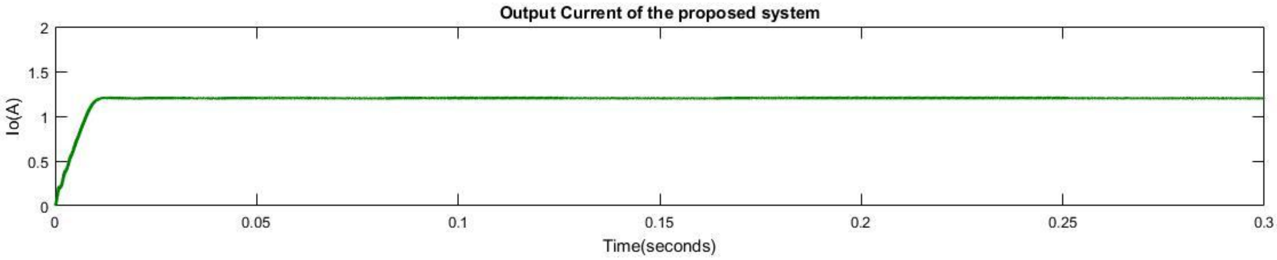

Fig 5(a): Output current waveform of the proposed irradiance adaptive PV module integrated converter

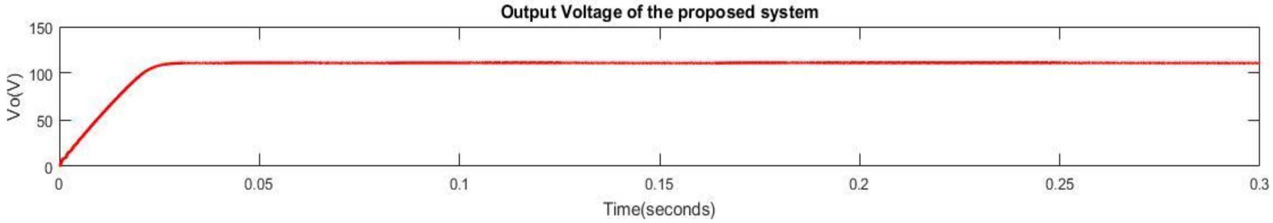

Fig 5(b): Output voltage waveform of the proposed irradiance adaptive PV module integrated converter

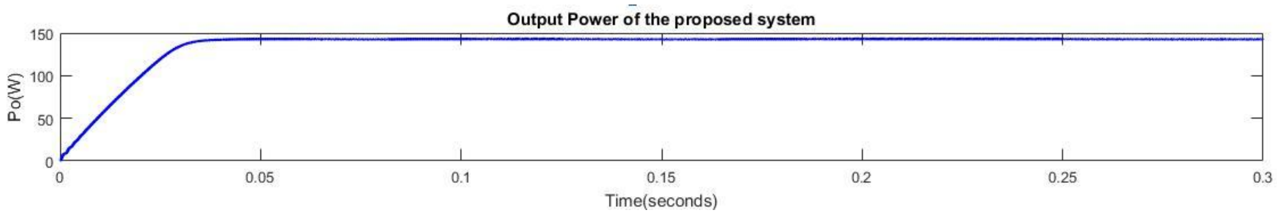

Fig 5(c): Output power waveform of the proposed irradiance adaptive PV module integrated converter

The performance result of the simulated model is given below in the following table:

TABLE I: MIC COMPONENTS AND CONTROL PARAMETER

Parameters	Values
PV module Voc	54.5 V
PV module Vmp	45 V
PV module Isc	8.67 A
PV module Imp	7.45 A
Output current, Io	1.2 A
Output voltage, Vo	120 V
Output Power, Po	144 W
Efficiency	98%

The overall power losses of the MIC includes the loss in tracking the MPP, the measurement loss, the MIC conduction and switching power losses, and the power needed for the control circuit. The efficiency in tracking the MPP was always above 98.5 %, keeping the MPPT losses below 1.5 %. Therefore, the power conversion efficiency was shown to be about 98 %, giving a total power conversion loss of around 2 %. The control circuit power consumption is about 1 W.

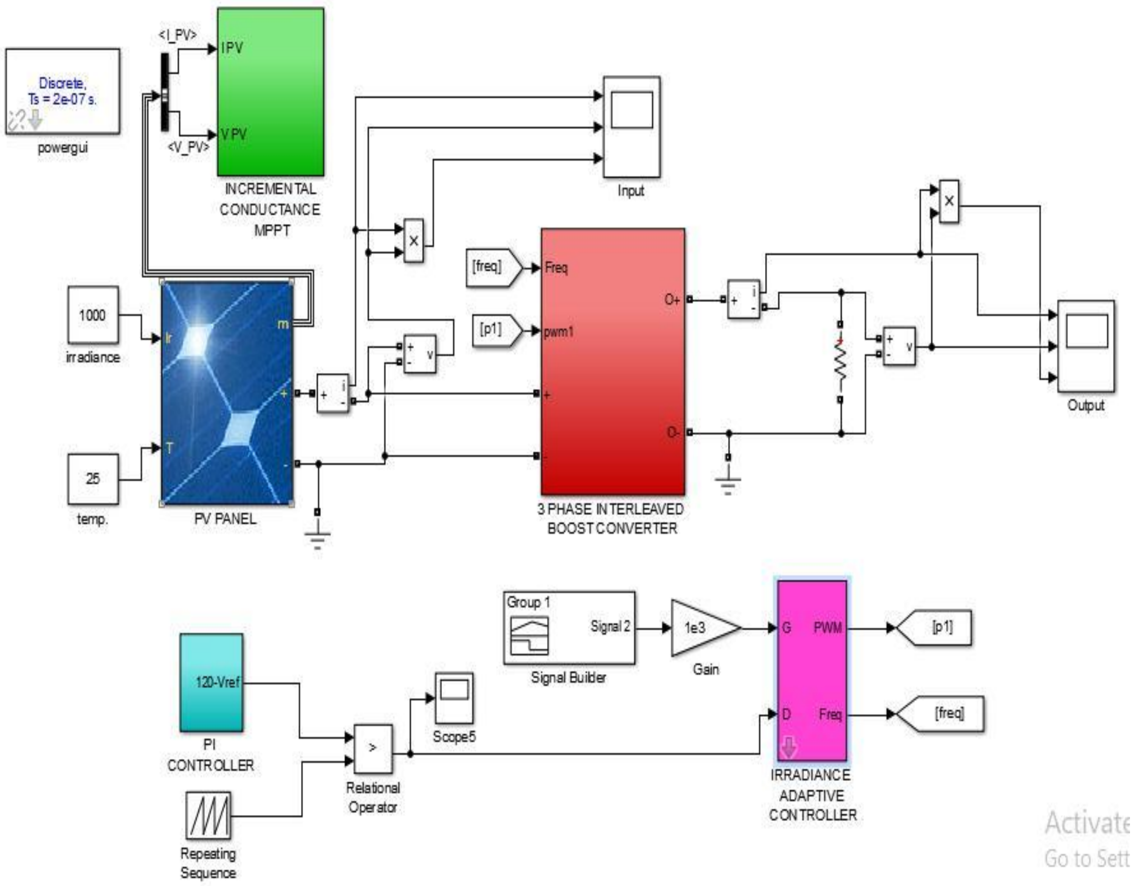

Fig 6: MATLAB Simulink model of the proposed irradiance adaptive PV module integrated converter.

V. CONCLUSION

This paper describes about the design and implementation of a PV module integrated converter (MIC) suitable for boosting voltages for DC micro grid applications. Here, an irradiance adapted switching frequency is selected by proposed switching frequency modulation (SFM) that is always high enough to avoid operation in discontinuous conduction mode. At a high irradiance, the SFM sets a lower value for the frequency in order to obtain high efficiency through low switching losses. This automated procedure is effective in searching for the optimal number and values of switching frequencies. A three phase interleaved boost cell is also activated at high irradiance to retain a high level of power quality. Hysteresis functions support the transitions between different discrete switching frequencies as the irradiance changes. The adaptive MIC control scheme is complemented by an MPPT designed for fast tracking. Thus, by combining the SFM with the adaptive usage of the boost converter interleaved cells and a fast MPPT, targets of efficiency and power quality are reached.

The efficiency for the entire MIC including all power conversion and control functions was measured at around 95% whereas the efficiency of the power conversion alone in MIC was found to be around 98%. Hence, high efficiency and power quality can be attained by employing the irradiance adaptive PV module integrated converter.

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