

# PERFORMANCE ENHANCEMENT OF SINGLE PHASE GRID CONNECTED PV SYSTEM UNDER PARTIAL SHADING USING CASCADED MULTILEVEL CONVERTER

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## ABSTRACT:

Conventional photovoltaic (PV) centralized single stage and two stage string grid tie inverter suffers from the problem of lower efficiency, high filter size, and limited depth of operation for remaining in connection with the grid particularly under lower insolation/partial shading condition. This paper proposes a staggered PV connection through cascaded multilevel converter (CMC) for PV-grid tie application utilizing independent MPPT controller, providing the larger depth of operation under partial shading condition, with smaller filter size and EMI. For dynamic and steady state performance evaluation a d-q frame based control algorithm is investigated for the single phase PV-CMC system. Further to establish the stability of the proposed controller, a detailed plant model is also investigated along with detailed comparative analysis is also done for operation of PV under partial shading condition for a conventional PV inverter, two stage string inverter vis-à-vis proposed CMC-based approach. The improved performance analysis is demonstrated both through simulation and experimentation.

**Keywords:** CMC, PV, MPPT, EMI, PV connection, cascaded multilevel converter .

## 1. INTRODUCTION:

The serious environmental concern due to overuse of fossil fuel led the world community to search for greener sources of power for energy requirement. Photovoltaic (PV) has emerged as the best alternative for fulfilling the energy demand with the advent of distributed generation and being closest to load centers. PV panels being costly and having lower conversion efficiency, therefore, extraction of maximum possible power is mandatory, otherwise, it may cause unnecessary heating of the PV panels and further degrades the life of the PV panels [1]. Various MPPT algorithm such as perturb and observe (P & O), Incremental conductance (INC) etc. are advocated only for operation with unshaded conditions of panels, which is uncommon in urban areas [2]. Under partial shading conditions such algorithms fail to track the maximum power point (MPP) normally. As a result complex algorithms for reaching global maximum power point (MPP) employing scanning are reported [3]. Further single stage and double stage circuit

configuration are reported in literature for grid connected PV system [4]. In double stage topology isolated or non-isolated DC-DC converters are used in conjunction with voltage source converter (VSC) [5]. Isolated topology though enhances the overall cost of the system, but provides an additional advantage in terms of isolation, which avoids leakage current, preventing occurrence of hazardous situations. But for the low wattage PV system low cost non-isolated converters are preferred. To further reduce the cost operation of roof top PV system, the single stage grid connected PV-system is advocated for small systems [6]. Conventional VSC with 2 level output suffers from partial shading condition due to bypassing of few panels in the string, making it difficult to make up the DC bus. Subsequently, it fails to deliver power into the grid, and driving the voltage across the panels towards the open circuit voltage, leading to total loss of PV power generation. This will unnecessary burden the grid, even if PV generation is otherwise available. German grid code for LV grid dictates that PV system should remain connected with the

grid to the extent possible, supporting the grid and to derive the accelerated payback on hardware installation under partial shading conditions up to the limits of power generation [7]. The cascaded multilevel converter (CMC) for PV system shows a promising future for single stage grid connected roof top PV system. The cascaded structure enjoys the advantage of operation with the low switching frequencies of the H bridges, thereby improving the efficiency of the system in conjunction with low EMI to produce high quality stepped voltage waveform at the terminals. Moreover, due to low PV voltage at individual DC links, the ratings of switching devices will be of lower value, which offsets the cost of multiplicity of H-bridge cells [8]. The structure provides the benefit of integrating each PV panels through separate DC links [9]-[11]. Even with small size of string on separate DC link, the flexibility for maximum power extraction from PV panels through each H-bridge and enhanced throughput will be guaranteed. In comparison to a large size string of PV panel operating with conventional 2 level VSC system, the MPP for either individual panel or small string of PV panel remains in operation to contribute towards a wider range of power transfer using CMC. To guarantee individual MPP of each panel set, there may be balance/unbalance voltage requirement.

## 2. PREVIOUS STUDY:

The reported cascaded PV system utilizes static reference frame based control, using proportional controllers. But such control does not guarantee the error reducing to zero. On the other hand controllers based on the instantaneous power theory do not guarantee stable operation for the whole range of irradiance levels [20]. Further an advanced voltage oriented control based on d-q frame for PV-CMC is advocated [21]. In [22], zero sequence control is also embedded in d-q based control for solving interphase power imbalances. While in [3], d-q based model predictive control is advocated for efficiently solving the problem of imbalances in PV output at individual H-bridges. The panel mismatch issues are also reported considering d-q frame for single and three phase system [4]. The reported control scheme could not justify the ripple contents in the output of PV voltages and power which exhibit, higher fluctuation and

ripple content due to dormancy of decoupling component and feed forward control for faster dynamic performance. The reported literature highlighted the discussion on varied insolation, leading to power imbalances, leaving while the thorough analysis and experimental dynamics performance of the system with partial shading condition. A comparative assessment of grid connected PV generators using cascaded PV system vis-à-vis conventional single stage and two stage 2 level PV string inverter under partial shading condition is also needed to be investigated.

## 3. PROPOSED SYSTEM:

A d-q based control algorithm for single stage grid connected PV system using CMC is proposed. For lucid and easy understanding, a detailed working operation of the PV-CMC system using phasor analysis is presented with change in insolation level. Through proper analysis and control, the unperturbed grid connectivity upon reduction in reference MPP voltage due to partial shading or due to low insolation is also presented in the paper. Under non-uniform insolation on the PV panels, or under shading conditions, individual DC links voltages would be different for extraction of power at MPP from the set of 4 panels on each links. The proposed controller is also capable of taking care of the regulation of individual DC link voltages according to voltage dictated by MPP algorithm. The controller enjoys maximum utilization of Photovoltaic- CMC (PV-CMC) unit for real power transaction of maximum available power, by maintaining grid current at UPF with enhanced range of operation under insolation change and partial shading conditions. Further to support the performance of PV-CMC unit a detailed comparative analysis with respect to conventional single stage and two stage 2 level PV string inverter under normal and partial shading condition are also.

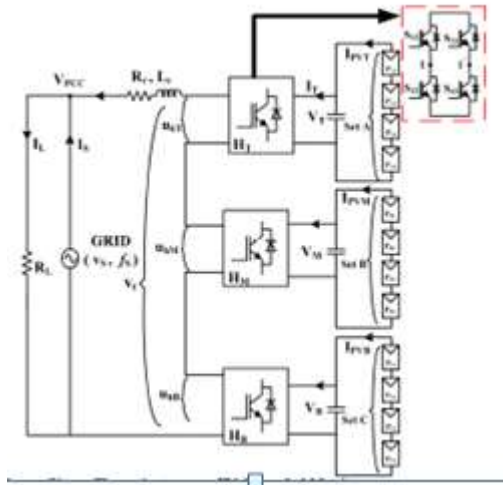


Fig.3.1. Proposed system

4. SIMULATION RESULTS:

The schematic of single phase grid connected CMC unit housing a set 4 PV panels on each DC links namely set A, B, C. Having the advantage of modularity ‘n’ number of H-bridges may be connected in cascade for having individual MPPT control for PV panel string on individual DC links shows the scalability of the proposed system. With the n number of bridges, output voltage of converter will be of 2n+1 level thus further reducing the voltage THD. In the present work 3 H-bridges are cascaded to form output of 7 levels. The CMC unit is connected to PCC point via interface inductor (Lr). At the PCC point resistive loads are also connected to consume the locally produced power from PV panels. Each DC link capacitor is designed at appropriate value considering the ripple voltage and power transaction. DC link is maintained at MPP voltage by the grid, references of which are derived from MPPT controllers at individual DC links.

To make it feasible for PV generated power to be transacted to the LV grid (230 V), the summation of DC link voltage must be sufficiently greater than peak value i.e 325 V. Further to provide sufficient margin during transients, the modulation index is kept at 0.9. Accordingly the sum of DC link voltages is kept at 360 V, which is selected by choosing adequate number of PV panels in a string. For a VMPP voltage of 30.46 V each DC link shall carry 4 panels to accommodate a voltage of around 120 V, thus aggregating to 360 V for 3 DC links provided by proposed PV-CMC. PV-

VSC system shall accordingly cascade 12 panels in series keeping power at par with PV-CMC.

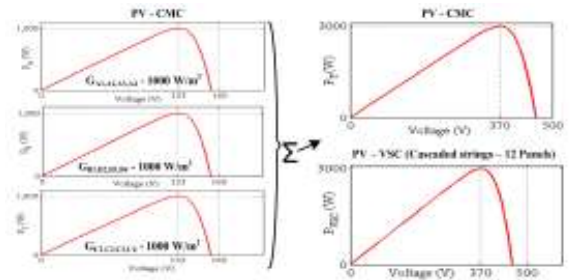


Fig.4.1. Simulation output.

To reduce the power loss under such condition, the panels use inbuilt bypass diode. The situation become more detrimental and lossy with the use of conventional 2 level VSC connecting a big string of PV panels at DC bus to arrive at higher voltage for single stage grid connected operation, due to steep fall in voltage at global MPP. For studying the effect partial shading condition on performance of PV-VSC and PV-CMC system, a set of four test conditions marked for string Set A, Set B, and Set C are investigated, the details of which are shown in Fig.4. For clear cut understanding of their performance, P-V curves for PV-CMC system and PV-VSC system under different aforementioned test condition are presented.

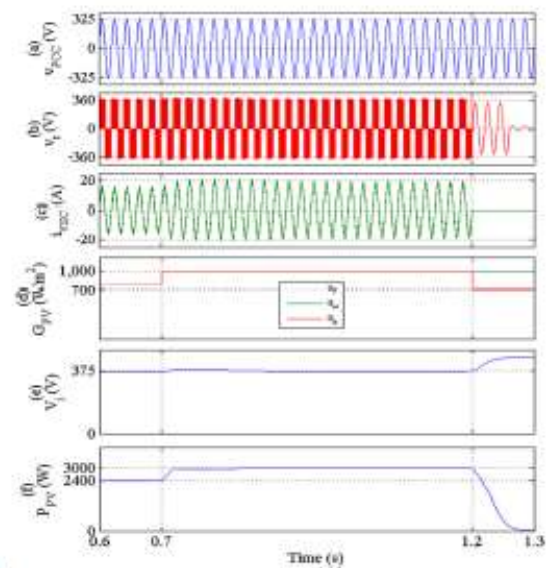


Fig.4.2. Results of voltage and currents.

But since each independent strings is connected in series at DC link, there will be a common DC current, provided flexibility in DC bus voltage is available, the un shaded

panel may be displaced from MPP point to accommodate inception of shaded panel. Such complex and tedious control is difficult to implement and it also decimates the efficiency of VSC. Even though with loss of power generation from one string, other two strings are transferring the generated power to the grid by appropriately boosting the voltage to reach the level of reference DC link voltage (assumed sum of individual DC voltage of each DC-DC converter,  $V_T + V_M + V_B$ ).

## 5. CONCLUSION:

The enhanced performance of PV-CMC over single and double stage PV-VSC system during partial shading condition is established both by simulation and experimentation results. The effectiveness of the control algorithm under influences of dynamic and uneven insolation across the bridges is clearly demonstrated through results. For investigation of the feasibility of the controller a detailed stability analysis is also presented. The comparative performance presented clearly shows the advantages of using proposed topology over conventional one. Despite of varying insolation condition, the DC link voltage of individual H-bridge are maintained at voltage dictated by MPP and current transacted through CMC is maintained at UPF ensuring improved power quality operation. The proposed structure and algorithm has the advantage of modularity, greater depth of operation so as to provide better grid connectivity and meets the requirement of partial shading condition/varying insolation.

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