Harmonic Analysis of PSO Tuned PI Controller Gains for Multilevel Inverter Base P and O MPPT Photovoltaic System

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Abstract

Objectives: The problem of instability in utilization of energy from PV system and harmonics injection due that is concerned here. The Analyzing of PV system and implementing with suitable techniques to attain permissible THD value is main objective of the work. Methods/Statistical Analysis: In this work for tracking maximum power perturb & observer method is employed. This PV system is integrated using Diode Clamped Multilevel Inverter (DCMLI), for this DCMLI APOD modulation technique is developed. PSA and PSO optimization methods are adopted for PI controller tuning which acts as voltage controller for DCMLI. As PSA is basic and local best optimization technique and PSO for its global best characteristics these methods are opted. Findings: The proposed closed loop system gives better control over open loop system. Tuning of the PI controller plays a crucial role in this closed loop system. In the applied heuristics tuning methods Particle Swarm Optimization (PSO) gives best THD control than Pattern Search Algorithm (PSA). The proposed techniques using PSO optimization is well suitable for PV system as the THD obtained by this is within standard acceptable limits. Actual existing systems like PV system with optimizations employed for MPPT's or PV system with different multilevel topologies involves more complexity and less output quality than the proposed system. An integrated system is developed i.e. PV with suitable MPPT and multilevel inverter with advanced multilevel modulation tuned with heuristic optimization methods are proposed together for a standalone and also for grid application. Here the proposed system in the area of PV using optimization technique employed for multilevel inverter along with the multilevel modulation technique employed for the DCMLI plays an important role. Application/Improvements: The proposed system is developed based on voltage controller of multilevel inverter it can also be developed along with current controller system. The main objective of this work is to harmonic analysis a PV system with a multilevel inverter in standalone and grid connected mode using PSO and PSA optimization techniques.

Keywords: Diode Clamped Multilevel Inverter, Harmonic Analysis, MPPT Technique, Optimization Techniques, PV Array, Tuning of PI Controller,

1. Introduction

Solar energy gained more importance in renewable as it's abundant in nature. Solar energy suffers with a main defect of low efficiency of the conversion system. It includes maximum power tracking and the converter system. When the solar array is subjected to various operating conditions that may resulted from atmospheric conditions or from manufacturing tolerances leads to number of maximum points on P-V curve due to the mismatching of bypass diodes. So, irrespective of these unavoidable factors global maximum power point has to be find, which can be done by using MPPT technique. P&O MPPT technique is used in this paper as it can track the peak point in global area also.

The output obtained from solar array is fed to DC-DC boost converter and then to inverter system. Researchers are going on this conversion system to increase the system efficiency. Development of multilevel inverter shows a path for that. A five level DCMLI system is developed
and integrated in this paper. Multilevel modulation technique for a multilevel inverter becomes a research track in now a day. APOD is a voltage based modulation techniques in multilevel modulation are proposed in this paper and the simulation results are presented. The block diagram of the system is given in Figure 1. Various optimization techniques were proposed by the researchers for tuning of different types of controllers to improve the efficiency of the output. By approaching conventional techniques for settling gains of controllers the system experiences heavy computational burden. So application PSA and PSO of the respective techniques basing on the computational speed and area of computation i.e., local or global area exploitation yields optimized results.

2. PV System Model with Multilevel Inverter

2.1 PV Array

Single diode model is the most general model used for the mathematical representation of PV cell due to its operational feasibility and modeling simplicity and its circuitry is given in Figure 2.

A standard data sheet of a PV panel has STC which is known as solar irradiation of 1000 watts per sq meter at 250 °C is equivalent to one sun. The modeling equations of the PV cell for \( t \) are given as follows.

The I-V characteristic equation of a PV cell is given as:

\[
I = I_{ph} - I_S \left( \exp \left( \frac{q(V + IR_s)}{kT} \right) - 1 \right) - \left( \frac{V + IR_s}{R_{SH}} \right)
\]  

(1)

The photocurrent mainly based on the solar isolation and cell working temperature, is given as

\[
I_{ph} = \lambda I_{sc} + K_1(T - T_r)
\]

(2)

Short circuit current is given as

\[
I_s = I_{rs} \left( \frac{T}{T_r} \right)^3 \exp \left[ \frac{qE_a}{kA} \left( \frac{1}{T_r} - \frac{1}{T} \right) \right]
\]

(3)

Using the proposed MPPT method power loss can be minimized. As P&O has incredible advantages it is implemented in this paper.

The P&O methodology is developed by calculating the slope (dp/dv) on the PV module P-V characteristics.

2.2 Inverter System

Wide usage of power electronic inverters with multilevel operation extends the generation range. The foremost model developed in MLI is DC MLI which is suitable effectively for PV system utilization.

This paper introduces a 5 level DC MLI with APOD modulation technique for grid connected or standalone PV system. This paper introduces a 5 level DC MLI with APOD modulation technique for grid connected or standalone PV system.

Multiple carrier voltage method is classified into two types. 1) Level Shift 2) Phase shift.

APOD topology is a level shifted PWM in multi carrier PWM technique in which level shifting of pulses are done by alternative opposition and disposition of phases. The APOD requires (n-1) carrier waveform where n is the level of phase waveform. The carriers are displaced by 1800 phase alternatively. The pattern of the APOD scheme is shown in Figure 3.
3. Proposed System Model

3.1 PI Controller with Optimization Technique

Implementation of closed loop attains the system stability. The output from the grid is given to the PI controller in this proposed paper by using 2-phase to 3-phase transformation\(^{12,13,15}\).

In order to achieve optimized computation of switching angles, PSA and PSO techniques are implemented to reduce THD at multilevel inverter output voltage\(^{22}\).

3.1.1 PSA Optimization Topology

PSA is approached as follows, basing on the constant model and the step length feasible descent direction is searched. The computation is started by formulating a set of points termed as mesh. A set of points are vectors \(\{M_j\}\) are considered to form a pattern. This set is given as \(N\) independent variables of objective function in an \(N\)-dimensional search space\(^{12}\).

Search and poll plays a key part of the iteration. Until and unless a smaller value is set from the iterations of the algorithm polling of the mesh point is done. When the above criteria are met the poll is said to be successful. Then the expansion of mesh is done by multiplying the current mesh size by expansion factor for the next iteration. If the poll is unsuccessful then the mesh size is get reduced by using a contraction factor, such that the next iteration starts with smaller mesh size and the process continues until the convergence criteria is met\(^{14}\).

3.1.2 PSO Optimization Topology

PSO algorithm is inspired from some social models like fish schooling, bird flocking and swarm theory which is implemented effectively for nonlinear function optimization. This optimized algorithm is approached as follows. The objective function variables are randomized first the local minima function is formulated at first which is termed as \(P_{\text{best}}\) by performing the \(j\)th iteration between the individuals. A comparison is made in between the neighborhood function to optimize its velocity and from this global optimum value is evaluated. After computing the iterations local best termed as \(P_{\text{best}}\) and global best as \(g_{\text{best}}\) terms are determined. Such that the optimal individual global fitness function is attained as \(g_{\text{best}}\)\(^{14}\).

The velocity vector \(V_j\) is evaluated using the formula referred below.

\[
V_{j_{k+1}} = W V_{j_k} + A_1 \text{Rand}_{pop}(P_{j}^a - Y_j) + A_2 \text{Rand}_{pop2}(P_{g}^a - Y_j)
\]

\[
Y_{j_{k+1}} = Y_j + V_{j_{k+1}}
\]

Where, \(Y_j\) is the particle speed of \(j\)th particle and \(K\)th parameter, \(W\) is the inertia weight, \(j\)th particle index is formulated as \(Y1=Yj1, Yj2, \ldots, Yjn\). Where, \(Y\) is the position and \(n\) is the discrete time index. Randpop1 and Randpop2 are random variables. \(A1\) and \(A2\) are the coefficient of acceleration. \(P\) is the best position at \(j\)th particle and \(k\)th parameter and \(g\) is the optimum position found by the swarm\(^{19,23}\).

From the block diagram in Figure 1 it is clearly shown that PI controller circuit is employed between DCMLI and grid (load). PI controller gains are to be set in order to improve the efficiency of grid output. These optimization techniques are employed for PI controller gains tuning that can be explained as follows, the error for the PI controller is a voltage function. This error voltage is the difference between actual reference voltage and the voltage from the grid. Minimization of this error voltage is the objective function for these optimization methods. Based on the output voltage obtained after PI controller gate pulses of the DCMLI are activated, as the voltage wave after the PI controller is considered as the reference voltage wave for the pulse generation. Such that reduction error in the voltage waveform lowers the THD content and improves the system efficiency. Here the proposed optimization methods PSA and PSO are simulated individually and a comparison is made in between them.

<table>
<thead>
<tr>
<th>Table 1. PSA and PSO comparison</th>
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<td>Closed Loop System</td>
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<table>
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<tr>
<th>Pattern Search Optimization</th>
<th>Particle Swarm Optimization</th>
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<tr>
<td>Without Filter THD</td>
<td>Without Filter THD</td>
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<tr>
<td>22.19%</td>
<td>5.09%</td>
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<tr>
<td>With Filter THD</td>
<td>With Filter THD</td>
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<tr>
<td>12.08%</td>
<td>3.08%</td>
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4. Results and Discussion

The proposed model is developed for a 440V and 1000W application. The output the power plot with current and the voltage obtained at the end of the solar panel after using MPPT algorithm is shown in Figure 4.

Figure 4. Output power from the solar panel.

A 5-level stepped output after connecting the DCMLI in between solar panel and grid in closed loop operation of PSA is shown in Figure 5 and the THD of the respective waveform is shown in Figure 6. The controller gains using PS algorithm are \( K_p = 0.315 \) and \( K_i = 0.574 \).

Figure 5. Three phase output at grid before using filter in closed loop PSA tuning.

Figure 6. THD for output at grid before using filter in closed loop PSA tuning.

To mitigate the output voltage harmonics of such grid connected inverters filters plays a prominent role. The output voltage in three phase closed loop using filter in PSA application are given below in Figure 7 and its THD content in Figure 8.

Figure 7. Three phase output at grid after using filter in closed loop PSA tuning.

Figure 8. THD for output at grid after using filter in closed loop PSA tuning.
The output voltage in three phase closed loop without using filter in PSO application are given below in Figure 9 and its THD content in Figure 10, and with filter application is shown in Figure 11 and its THD value is given in Figure 12. The controller gains using PSO algorithm tuning are $K_p=0.273$ and $K_i=0.923$.

Figure 9. Three phase output at grid before using filter in closed loop PSO tuning.

Figure 10. THD for output at grid before using filter in closed loop PSO tuning.

Figure 11. Three phase output at grid after using filter in closed loop PSO tuning.

Figure 12. THD for output at grid after using filter in closed loop PSO tuning.

5. Conclusions

The work presented in this paper gives its contribution in the area of application of power electronics in renewable. A 5 level Diode Clamped Multilevel inverter with APOD multilevel switching are designed for the PV system. The proposed P&O MPPT methodology because of its advent features shows its superiority than other MPPT's. Also proposed multilevel inverter system along with APOD multilevel switching topology yields best results for the proposed PV system. The THD content in the voltage waveform are reduced greatly and are in permissible IEEE standards by tuning the controller gains using PS and PSO optimized algorithms in which PSO yields best results. Such that the proposed PV system gives lower harmonic values by using DCMLI with PSO tuning. The results provided support the work of this paper.

6. References

4. Shadmand MB, Member S, Mosa M, Balog RS. Maximum power point tracking of grid connected photovoltaic sys-


**Nomenclature**

IPH Light-generated Current or Photocurrent
ISCell Saturation of Dark Current
q Electron Charge
kBoltzmann Constant
TCell Working Temperature
AIdeal Factor
RSHHshunt Resistance
RSSeries Resistance
IsCell Short-Circuit Current
KICell Short-Circuit Current
TrCell Reference Temperature
λ Solar Isolation in kW/m²
IRSCell Reverse Saturation Current
EGBand-Gap Energy