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Model predictive control for distributed MPPT algorithm of cascaded H-bridge multilevel grid-connected PV inverters

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This paper concentrates on an algorithm with model predictive control for current and distributed MPPT for cascaded H-bridge multilevel photovoltaic (PV) inverter applications. In conventional method, in each sampling period, a discrete-time model is employed to predict the current future values for all vectors of voltage. The voltage vector will be approved if it minimizes the cost function. Because multilevel inverter has so many available voltage vectors, there is a large quantity of calculations, hence it makes difficult in implementing the normal control method. A varied control strategy that extensively decreases the calculations volume and eliminating common-mode voltage is proposed. To raise the PV modules performance and enlarge the systems power, a distributed maximum power point tracking (MPPT) control scheme for each phase of multilevel inverter is offered, that allows its DC-link voltage to be regulated separately. The recommended approach is double-checked by using a model simulated in MATLAB-Simulink software.

K e y w o r d s: model predictive current control, multilevel inverter, photovoltaic, cascaded h-bridge, MPPT, common-mode voltage

1 Introduction

Grid-connected PV systems have high improvements in generating clean energy. This achievement can track the highest power points of PV modules to obtain the maximum possible power out of the system, injecting a current having low total harmonic distortion into the grid and raising the system performance. Multilevel inverter topologies [1][2] were introduced to PV applications many years ago. These topologies offer several advantages such as: injecting a low total harmonic distortion grid-current, reaching high efficiencies with low switching frequency, featuring many DC-link sources. These properties make multilevel inverters possible to lower the consequence of mismatching between PV modules [3]. Among some various structures of multilevel inverters [4], the cascaded H-bridge (CHB) described in [5] is the outstanding one. It has high modularity, ability of reducing common-mode voltages [6], easy to design physical model, small number of semiconductor components, and high reliability [7]. Moreover, each isolated DC sources of this topology that can be generated from PV arrays, makes maximum power point tracking (MPPT) algorithm individually be achieved as well as maximize the power harvested from PV system [8][9].

A PV inverter structure with modular cascaded H-bridge multilevel in applications connecting to the grid is performed in the research. Due to several disadvantages of common-mode voltage [10], it will be eliminated by using voltage vectors producing common-mode voltage by zero. The mismatch issues between PV modules [11] are mentioned to indicate the significant role of MPPT algorithm that is also recommended in the next section.

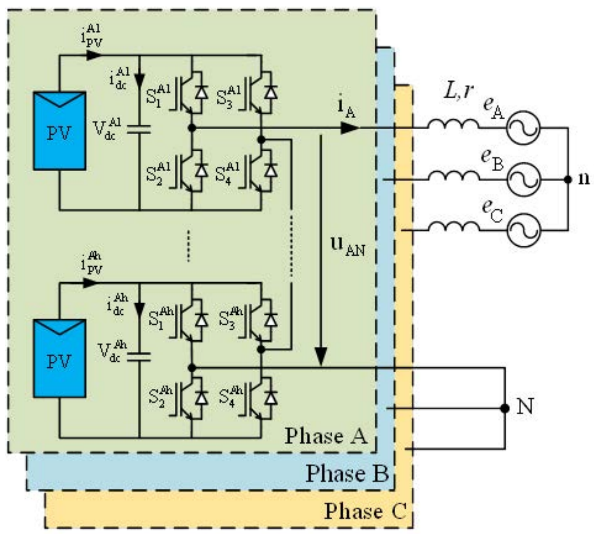

Fig. 1. Structure of grid-connected CHB multilevel PV inverter

Recently, model predictive control (MPC) has been employed more often in studies because this method has fast dynamic response, comprises more desired demands in the cost function of the controller flexibly [12][13]. This algorithm applies a discrete-time model to forecast the future system performance. In each period sampled, the cost function is calculated for all control cases of converter

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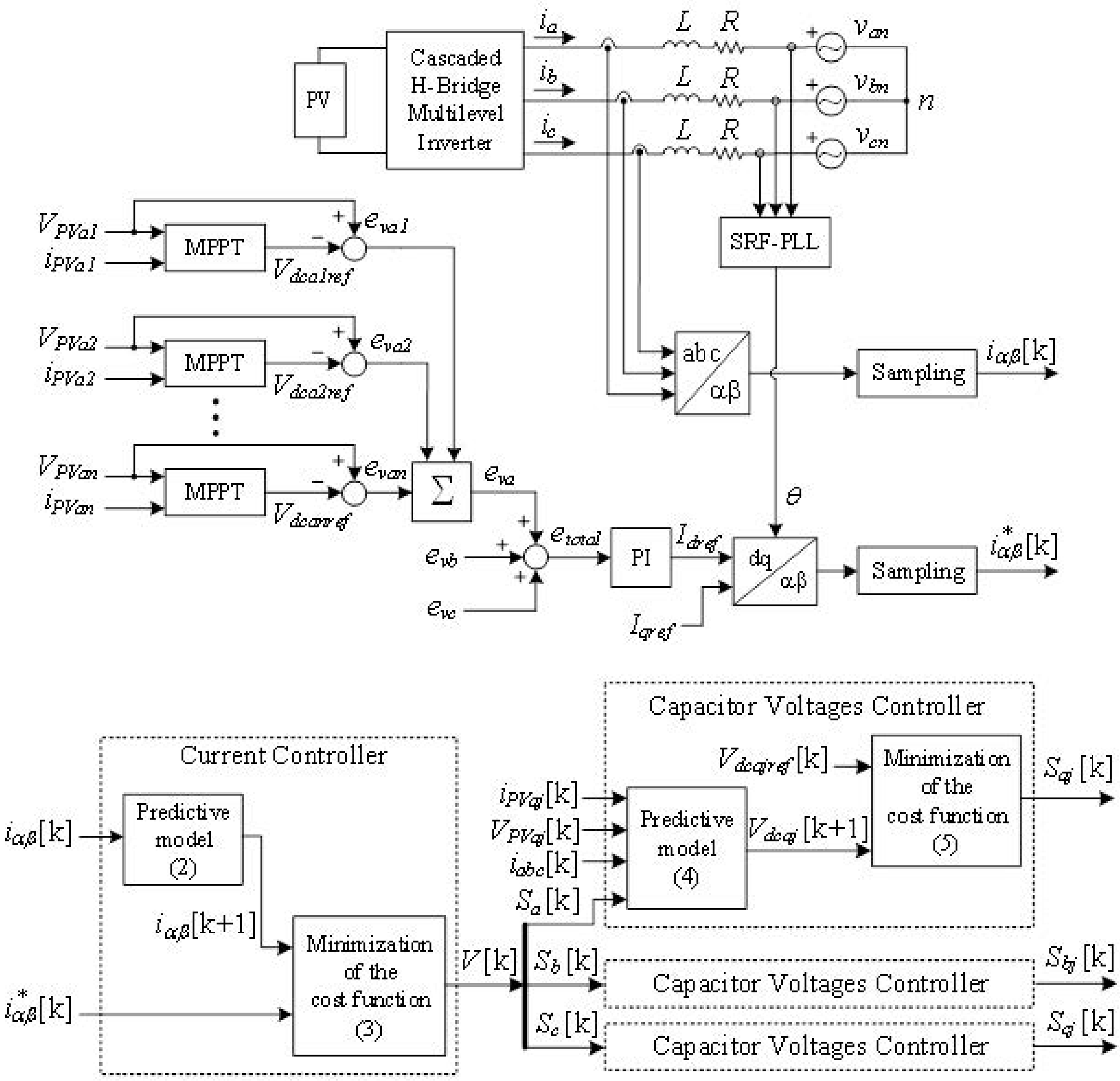

Fig. 2. Block chart of the introduced predictive control method

and the one minimizing the cost function is selected to apply to the system. Multilevel cascaded H-bridge inverter has so many switching states. Thus, the implementation of the control algorithm employing standard processors is difficult, particularly when the system requires high frequency of switching. The paper shows an optimized model predictive current control which can reduce the computational volume in each sampling period by selecting a set of the suitable voltage vectors. A three-phase 11-level cascaded H-bridge inverter model in MATLAB-Simulink software is adopted to prove the recommended algorithm through achieved simulation results.

2 System description

Figure. 1 shows the structure of the three-phase cascaded H-bridge multilevel inverter powered by PV modules for grid-connected application. Each phase comprises many H-bridge modules which are series connected, moreover, the H-bridge DC-sides are powered by a PV module or a PV module short string. The effect of an inductor filters connected between the inverter and the grid is to lower the distortion of the current harmonic in total.

3 Control system

3.1 Predictive current control algorithm

As presented in Fig. 1, the equation of phase A for a three-phase inverter connecting grid is

$$L\frac{\mathrm{d}i_{\mathrm{A}}}{\mathrm{d}t}+Ri_{\mathrm{A}}+e_{\mathrm{A}}=v_{\mathrm{AN}}+v_{\mathrm{Nn}}, \tag{1}$$

where e_A is the voltage of the grid phase v_{An}, and v_{Nn} is the common-mode voltage Using the transformation from three-phase *abc* signal to $\alpha\beta$ frame and approximating

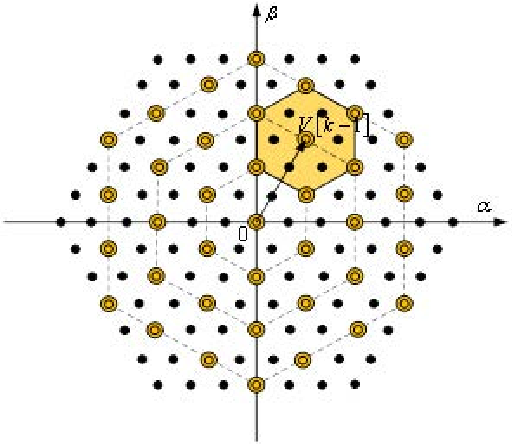

Fig. 3. Voltage vectors for a three-cell CHB inverter

the derivative components [12] in (1), the following formula is achieved to predict the future vector of the current

$$i_{\alpha\beta}[k+1] = \\ = \frac{T_S}{L}\left(v_{\alpha\beta}[k] - i_{\alpha\beta}[k]\left(R - \frac{L}{T_S}\right) - v_{\alpha\beta\mathrm{grid}}\right), \quad (2)$$

Forecasting the current value afterwards by (2) for each voltage vector. To accept the suitable voltage vector for applying to the system, the controller uses the cost function (3).

$$g[k+1] = \left(i^*_{\alpha\beta}[k+1] - i_{\alpha\beta}[k+1]\right)^2. \quad (3)$$

In which, $i^*_{DC}[k+1]$ is the predictive set value of the current. Assuming that the sampling period is sufficiently small $i_{\alpha\beta}[k+1]$, equals approximately $i^*_{\mathrm{DC}}[k]$. In case of a for broader sampling period, there is a need of an extrapolation of the predictive reference.

The cost function (3) is calculated for all inverter voltage vectors. The regulator will find the minimum value in obtained values and the corresponding voltage vector will be adopted. According to [14], consequently, (2) and (3) are performed 1331 times for cascaded H-bridge inverter with 11 levels to achieve their suitable result.

The block chart of the model prediction current controller is shown in Fig. 2. The measured currents here are used to predict x future current values, corresponding to x available voltage vectors, in which, x equals to 1331 for an 11-level inverter. The cost function reviews these predictive values, and the voltage vector minimizing it is accepted. Numbers of voltage vectors evaluated to achieve the suitable solution is so high, hence this algorithm performs difficultly in a normal platform. The paper proposes the only small set of voltage vectors utilization in each sampling period to reduce the computational volume. First, only voltage vectors setting up the zero common-mode voltage are considered [6]. In Fig. 3, those vectors are performed by a spot in a circle. In spite of reducing the calculations number, it is not low enough. So that, a set of only seven voltage vectors is considered in each sampling period. This set consists of the voltage vector selected previously and its six adjacent voltage vectors. Hence, the predictive algorithm with seven adjacent voltage vectors has an advantage in cutting down the computational volume.

3.2 Predictive control for distributed MPPT

Some MPPT methods have been researched and conducted recently [15]. In this paper, the incremental conductance method [16] has been put forward. In each module of the H-bridge, the reference value of DC-link voltage is determined by a MPPT algorithm. Like the predictive current control algorithm in the preceding part, each phases DC-link voltages in the future are calculated (4) for a given state case corresponding to each state level. For example, the state level 4 in one phase of 11-level cascaded H-bridge inverter has 5 state cases: (1,1,1,1,0); (1,1,1,0,1); (1,1,0,1,1,); (1,0,1,1,1); (0,1,1,1,1).

$$V_{\mathrm{DC}\ lj}[k+1] = V_{\mathrm{PV}\ lj}[k] + \frac{T_{\mathrm{S}}}{C}\left(_{\mathrm{PV}\ lj}[k] - i_l[k]S_{lj}[k]\right), \quad (4)$$

where $l \in \{\mathrm{A,B,C}\}$, j is from 1 to h, where h is the total number of H-bridges in each phase, $S_{lj}[k]$ is the level of cell j in phase l . To select the suitable state case for controlling DC-link voltages, the voltage prediction is performed in cost function

$$g_{\mathrm{PV}l}[k+1] = \sum_{j=1}^{h}\left|V_{\mathrm{DC}lj\mathrm{ref}}[k] - V_{\mathrm{DC}lj}[k+1]\right|, \quad (5)$$

where $V_{\mathrm{DC}lj\mathrm{ref}}[k]$ is the reference DC-link voltages. (5) is performed for one-by-one state case, and the case minimizing it is chosen and then put into the system.

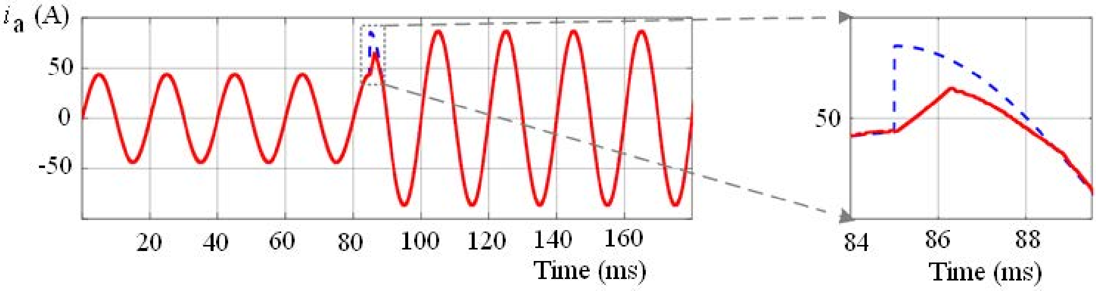

Fig. 4. Measured current (red line) and reference current (blue line) in phase a for a stepping change in the set value's amplitude

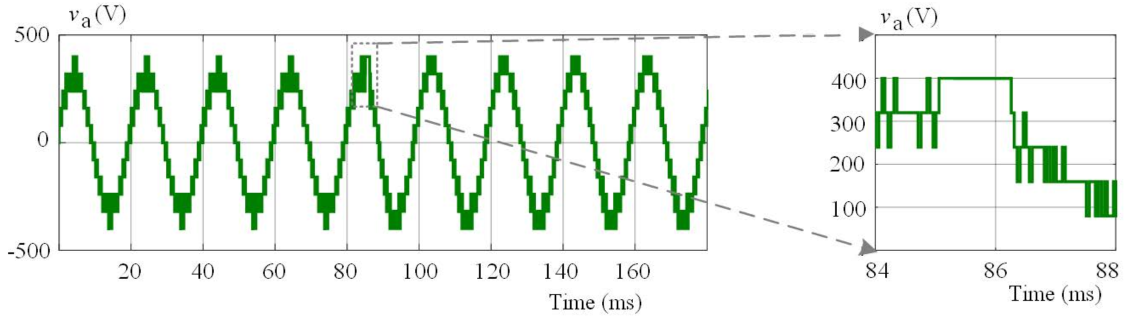

Fig. 5. An inverter voltage stepping change of reference's amplitude

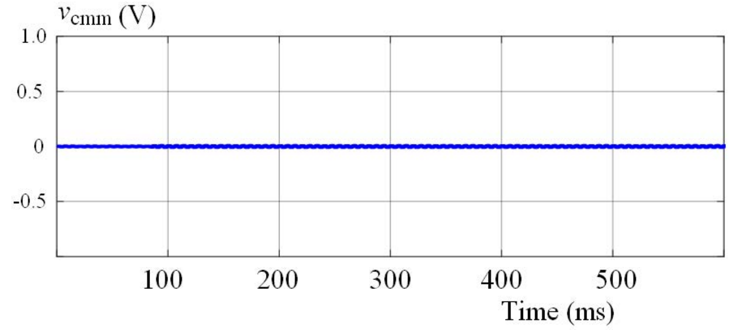

Fig. 6. Multilevel inverter common-mode voltage

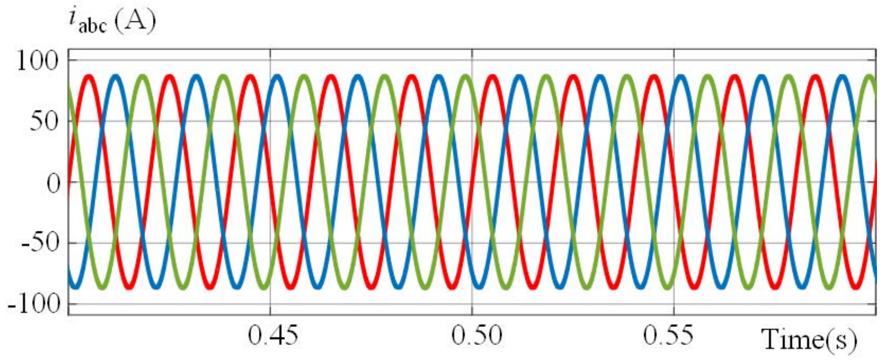

Fig. 7. Measured currents in three phases

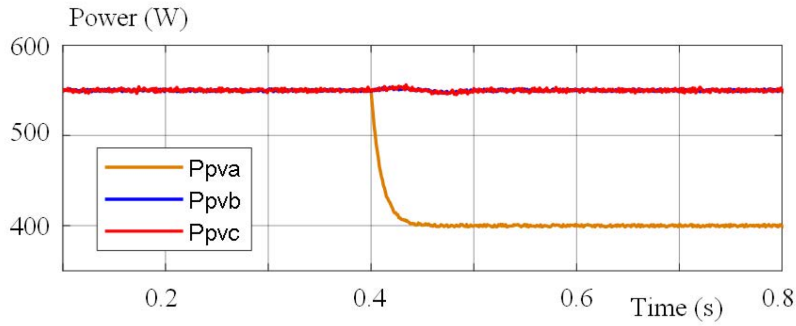

Fig. 8. Power obtained from PV panels with distributed MPPT in per phase

4 Performance evaluation

The recommended schemes as well as a three-phase 11-level CHB PV inverter are implemented and evaluated with MATLAB-Simulink. A PV module in each H-bridge is considered as its independent source. Three inductors are connected between this inverter and the grid. The parameters of the system are 380 V rated grid voltage, 5 mH inductor filter, 0.1 grid resister, 2200 F DC-link capacitor.

Figure 4 demonstrates the predictive current control performance for a stepping amplitude of the reference current. The proposed method can be seen to have particularly good reference tracking. Fig. 5 indicates that the maximum of inverter voltages change is one level. When only voltage vectors generating zero common-mode voltages are considered and the set of seven vectors are employed, the voltage waveforms are symmetrical. Furthermore, the common-mode voltage is extensively lessened, as presented in Fig. 6.

Figure 7 illustrates the measured currents are so balanced in three phases. To check the performance of distributed MPPT controller, all panels are operated under the same irradiance ($S = 1000$ W/m2). Moreover, all phases of inverter are generating the highest power (550 W). After the moment $t = 0.5$ s, the irradiance in panels in phase a is reduced. In Fig. 8, the power taken in phase a drop to 400 W, the same for those from the others. The distributed MPPT controller works well.

5 Conclusions

This paper demonstrates a cascaded H-bridge multilevel PV inverter in applications with grid connection. The proposed MPC algorithm has exceptionally good reference tracking with fast responding time (about 4 ms). The common-mode voltage is eliminated completely. PV system performance in overall is improved by controlling DC-link voltages independently and the power extracted from PV modules is maximized.

References

[1] S. Daher, J. Schmid, and F. L. M. Antunes, "Multilevel Inverter Topologies for Stand-Alone PV Systems", *IEEE Transactions on Industrial Electronics*, vol. 55, no. 7, pp. 2703-2712, July, 2008.

[2] H. Truong, C. Mai, C. Nguyen, *et al*, "Modified space vector modulation for cascaded H-bridge multilevel inverter with open-circuit power cells", *Journal of Electrical and Computer Engineering*, vol, 2021.

[3] A. M. Noman, K. E. Addoweesh, A. A. Alabduljabbar, *et al*, "Cascaded H-bridge MLI and three-phase cascaded VSI topologies for grid-connected PV systems with distributed MPPT", *International Journal of Photoenergy*, vol. , no. Mli, 2019.

[4] S. Akanksha, J. Kartick, and D. Madan, "An inclusive review on different multi-level inverter topologies, their modulation and control strategies for a grid connected photo-voltaic system", *Solar Energy*, 170. 633-657. 10.1016/j.solener.06.001, 2018.

[5] S. Kouro *et al*, "Recent Advances and Industrial Applications of Multilevel Converters", *IEEE Transactions on Industrial Electronics*, vol. 57, no. 8. pp. 25532580, 2010.

[6] H. Zhang, A. V. Jouanne, S. Dai, A. K. Wallace, and F. Wang, "Multilevel inverter modulation schemes to eliminate common mode voltages", *IEEE Transactions on Industry Applications*, vol. 36, no. 6, pp. 1645-1653, no. v.-Dec, 2000.

[7] C. M. Van, S. Duong-Minh, D. Tran-Huu, *et al*, "An improved method of model predictive current control for multilevel cascaded H-bridge inverters", *Electrical Engineering*, vol 72 , no. 1, 111, 2021.

[8] S. Duong-Minh, D. Tran-Huu, and V.-H. Phuong, "Model Predictive Control of Cascaded H-Bridge Multilevel PV Inverter with Distributed MPPT for Grid-Connected Applications", *International Symposium on Power, Energy and Cybernetics*, (ISPEC), NA(ISPEC), 2020.

[9] S. S. Katkamwar and V. R. Doifode, "Cascaded H-bridge multilevel PV inverter with MPPT for grid connected application", *2016 International Conference on Energy Efficient Technologies for Sustainability*, ICEETS , pp. 641646, 2016.

[10] J. Rodriguez, J. Pontt, P. Correa, P. Cortes, and C. Silva, "A new modulation method to reduce common-mode voltages in multilevel inverters", *in IEEE Transactions on Industrial Electronics*, vol. 51, no. 4, pp. 834-839, Aug, 2004.

[11] P. Bakas, A. Marinopoulos, and B. Stridh, "Impact of PV module mismatch on the PV array energy yield and comparison of module, string and central MPPT", *2012 38th IEEE Photovoltaic Specialists Conference*, Austin, TX, , pp. 001393-001398, 2012.

[12] P. Cortés, A. Wilson, S. Kouro, J. Rodriguez and H. Abu-Rub, "Model Predictive Control of Multilevel Cascaded H-Bridge Inverters,"*IEEE Transactions on Industrial Electronics*, vol. 57, no. 8, pp. 2691-2699, 2010.

[13] S. Vazquez, J. Rodriguez, M. Rivera, *et al*, "Model Predictive Control for Power Converters and Drives: Advances and Trends", *IEEE Transactions on Industrial Electronics*, vol. 64, no. 2, pp. 935947, 2017.

[14] M. V. Chung, D. T. Anh, P. Vu, and M. N. Linh, "Hardware in the loop co-simulation of finite set-model predictive control using FPGA for a three level CHB inverter", *International Journal of Power Electronics and Drive Systems*, (IJPEDS), 2020.

[15] T. Esram and P. L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques", *IEEE Transactions on Energy Conversion*, vol. 22, no. 2, pp. 439-449, June, 2007.

[16] M. L. Devi and M. Chilambarasan, "Design and simulation of incremental conductance MPPT using self lift cuk converter", *International Conference on Renewable Energy and Sustainable Energy*, (ICRESE), Coimbatore, pp. 105-111, 2013.

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