A Novel Control of TCDIC in Solar Photovoltaic Based Stand-Alone Scheme with Energy Storage Element

B.ARUNA
PG scholar EEE, JNTUACollege, Pulivendula, Andhra Pradesh, India.
Email:arunahoney2508@gmail.com

***ABSTRACT**: For Electrifying areas where the availability of grid is nowhere, Solar Photovoltaic (PV) based stand-alone has been developed. Implication of appropriate storage scheme is done for assurance of uninterruptable supply. The focus of this investigation is to build up a reliable and proficient power-electronic interface. The significant complications in designing that system are, extraction of most possible maximum power from PV, control battery charge and voltage boosting. To tackle this issue, a Transformer Coupled Dual-Input Converter (TCDIC) is proposed. In expansion to it, Ripple Correlation Control (RCC) for minimizing the ripples is actualized in this paper.*

***Index Terms:** Two-input dc converter, Battery, PV based stand-alone scheme, Charge control.*

I INTRODUCTION

For survival of human being electricity is being renowned as an essential need. Awkwardly, billions of Indians have no access to electricity, and the majority of this population belongs to rural. In order to improve shortage of electrical energy, several initiations had taken, and the bulk of them attentive towards the generation by developing Renewable Energy Sources (RES).

Among the available RES, solar ensures to be a prominent source of energy to meet the demand by interfacing the electronic converters between battery, PV and load [1], [2]. As the nature of PV power is irregular, there is a need of storage element which can be apprehended by the implication of battery. However, to enhance the proficiency of an standalone system there is a need for unfailing power electronic interface. The investigation manages this issue.

In general, to meet the demands of household a single phase supply of 230 V of frequency 50HZ is required. In order, to meet the load series connection of several batteries and PV modules are done which leads to considerable reduction in power yielding. To defend this issue there is a requirement of algorithm for maximum power point tracking with added converters to convert DC from PV, battery to AC of 230 voltage. Generally for this operation single phase full bridge inverters are used.

The necessity of high gain to promise 230V AC supply can be done by the implication of step-up transformer which is of low frequency at the output of inverter. This increases the volume, size and weight of a system. To deal this scenario Transformer based converters are employed for high gain.

TCDIC based standalone scheme is proposed which can be realized by the association of PV with the battery. The yield of voltage can be enriched by the assistance of high frequency step-up transformer. By the development of appropriate control algorithm, TCDIC can perform boosting of voltage, control of battery charge and MPPT operation. Generally this can be accomplished by the inclusion of more number of DC-DC converting stages [3], [4] but by this proposed TCDIC it is reduced to single stage. By the implication of full-bridge inverter at TCDIC output, DC-AC conversion is achieved.

II OPERATING PRINCIPLE OF TCDIC

It can be said from the fig .1 that there is no need of any devoted converter for PV MPP action. Here only 1converter is present between PV array and battery with this charging proficiency of battery gets increases. Switches S_1, S_2 are operated in balancing mode.

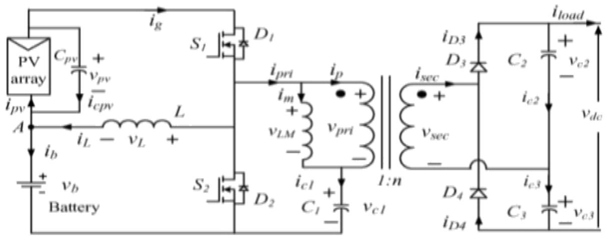

Fig. 1. TCDIC Circuit

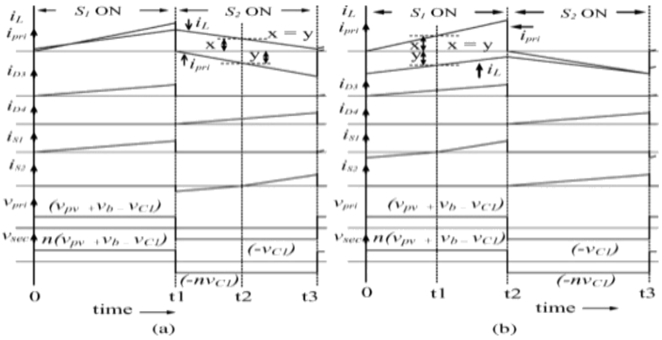

Fig. 2. Waveforms of current and voltages for the elements of TCDIC

A. Operation of converter while current through inductor is positive

Waveforms shown in Fig 2(a) for positive I_L, different diverse modes are explored for this case

a) Mode I

When S_1 conducts voltage across inductor L is given by PV array voltage v_{pv} there by increases I_L, voltage of primary of transformer is

$v_{pri} = (\mathrm{v_{pv}} + \mathrm{v_b} - \mathrm{vc_1})$ $\mathrm{v_b}$: voltage of battery ;

vc_1: Voltage of capacitor C_1; hence C_1 charges due to increment in I_{pri} there by increasing in I_{sec}, the diode D_3 gets biased forward. Finally capacitor C_2 charges, is specified as

$vc_2 = n(v_{pv} + v_b - vc_1)$ here n = turns ratio.

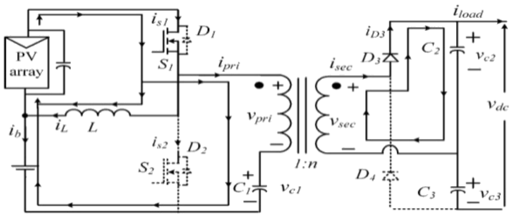

Fig. 3. Equivalent diagram of TCDIC in mode I and I_L is positive.

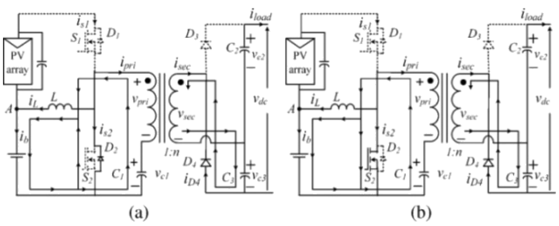

Fig. 4. Equivalent diagram of TCDIC when I_L is positive. (a) Mode II (b) Mode III

b) Mode II

In this mode S_2 gets turn on. At starting I_1 stands positive and S_1 turns off so I_{pri} becomes 0. Since $I_L > I_{pri}$, diode D_2 gets forward biased. Now voltage across inductor is $v_l = -v_b$ and I_L decrements. The voltage of transformer primary is given by $v_{pri} = -vc_1$. Thus I_{pri} is negative and decrements by discharging C_1 . When comes to secondary I_{sec} gets reversed so D_4 becomes turn on, capacitor C_3 charges and this is given by $vc_3 = n(vc_1)$. $I_L > I_{pri}$, diode D_2 biased in forward. This works until $I_L = -I_{pri}$.

c) Mode III

When I_L is less than - I_{pri}, diode D_2 reversed biased, and S_2 start conducting. Remaining working is similar to mode II.

B. Operation of converter while current through inductor is negative

Waveforms shown in Fig2(b) for negative I_L, different diverse modes are examined for this case

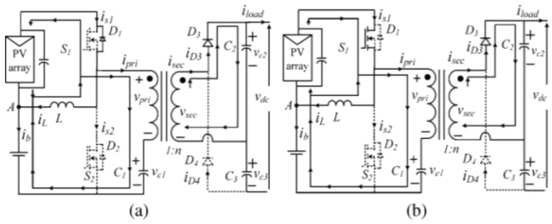

Fig. 5. Equivalent diagram of TCDIC when I_L is negative (a) Mode I (b) Mode II.

a) Mode I

This mode starts when S_1 on and S_2 sets off condition. At beginning of this I_L is negative, I_{pri} is 0. Hence the diode D_1 starts conducting. Remaining operation is similar to above section mode I as discussed earlier. This mode exists up to I_{pri} is equal to -I_L.

b) Mode II

When $I_{pri} > -I_L$ diode D_1 gets biased in reverse and S_1 begins conducting leftover operation is identical to mode I which is discussed in above case.

c) Mode III

This mode comes while S_1 gets on, S_2 turns off. In this case both currents I_L, I_{pri} gets negative and S_2 conduct. With this both LV and HV currents of transformer become negative, diode D_4 starts conducting. Capacitor C_3 gets charged in this mode

$v_l = -v_b, v_{pri} = -vc_1,\ vc_3 = n(vc_1)$. The circuit for this mode as similar as exposed in Fig. 4(b) excluding the direction of I_L which is opposite.
From Fig.1, potential across inductor L is given by

$$v_l = -v_{pv} \quad \text{While } S_1 \text{ sets ON}$$
$$v_l = -v_b \quad \text{While } S_2 \text{ sets ON} \quad (1)$$

Average potential drop across L is
$V_L = D\,V_{pv} - (1-D)v_b$ where D is the duty ratio of switch S_1. By equating average voltage of inductor to 0.

$$V_{pv} = \left[\frac{(1-D)}{D}\right] \quad (2)$$

From (2), it is being justified that PV voltage can be inhibited by controlling D. Average output voltage of TCDIC, is specified as

$$V_{dc} = (vc_2 + vc_3)$$
$$= \left[n\left(v_b + v_{pv} - vc_1\right) + nvc_1\right]$$
$$= n(v_b + v_{pv}). \quad (3)$$

$$I_L + I_{cpv} = I_b + I_{pv}. \quad (4)$$

Taking only average values of all currents over switching cycle and $I_{cpv} = 0$.

$$I_b = I_L - I_{pv}. \quad (5)$$

From (5) it is illustrious that, for $I_L > I_{pv}$ battery is charged and for $I_L < I_{pv}$ it gets discharged. Hence with I_L and I_{pv} it is possible to control charging and discharging of battery. Section IV presents the control strategy of TCDIC.

III. CONTROL STRUCTURE

The controller is to be implemented in order to accomplish maximum power extraction, limiting the battery from over charging and discharging, converting DC to AC by maintaining the voltage of load at a desired level. The first two objectives can be accomplished by a controller in TCDIC and for the later one Ripple Correlation Controller along with conventional proportional integral controller is employed in order to mitigate the ripples and to regulate the voltage of inverter via sinusoidal pulse width modulation.
Desired functionalities can be achieved by operating TCDIC in any of succeeding modes.

1) MPPT mode:
In this mode maximum power being abstracted from PV to operate so any of the conditions below has to be satisfied.
i) Availability of maximum power should be greater than load demand P_l and surplus of it will gets consumed by the battery without overcharging.
ii) $P_{mpp} < P_l$, without over discharging the battery should be capable to supply P_l- P_{mpp}. The power of PV in MPPT can be defined as

$$P_{pv} = P_{mpp} = (P_b + P_l) \quad (6)$$

Where P_b: Power of battery, positive during charging and negative during discharging.

2) Non-MPPT mode:
Over charging of battery can be overcome by limiting the maximum charging current to I_{bmax}.This I_{bmax} restricts the power absorbed by the battery to $P_{bmax} = I_{bmax} * v_b$. When $P_{mpp} > P_l$ and surplus of it i.e. $P_{mpp} - P_l$ is higher than P_{bmax} it leads to overcharging of battery, to restrict it from happening the system has to be reduce the extraction of power from PV. This operation represents the Non-MPPT mode.

3) BO (Battery Only) mode:
Without over discharging, if the battery is capable of meeting the load demand when power from PV is zero.

4) Shutdown mode:

This mode operates when the battery is incapable to supply P_l-P_{mpp} and maximum power much less than demand i.e., $P_{mpp} < P_l$, in order to prevent the battery over discharging of a battery the system has to be shutdown.
The control algorithm is implemented, so as to choose suitable mode of operation which can be done by Decision Making Blocks (DMBs). The control block DMB-1 sets reference voltage of PV (V_{pvref}) and decides the operation mode whether it is MPPT or BO. If I_{pv} >0, MPPT operation is chosen and when power of PV is not available mode of BO mode is chossen. Now V_{pvref} taken as V_{pvr} to regulate the output voltage V_{dc} within desired 350-460V. To set reference for the inductor current I_{Lstar} error between V_{pv} and V_{pvref} is passed to PI controller. To prevent battery from over discharging and charging I_{Lmin}, I_{Lmax} respectively are derived

$$I_{Lmax} = I_{bmax} + I_{pv} \quad (7)$$
$$I_{Lmin} = I_{bmin} + I_{pv} \quad (8)$$

Where I_{bmin} and I_{bmax} are permissible discharging and charging current limits of the battery respectively based on the SOC level. Block DMB-4 engaged to carry aforesaid tasks. Block DMB-2 adjusts reference level for inductor current I_{Lref} after sorting the constraints levied by I_{Lmin} and I_{Lmax}[5] . When I_{Lref} rests within its recommended limit, the system sets to operate either in MPPT mode (for$I_{pv} > 0$) or in BO mode for $I_{pv} \leq 0$. When I_{Lref} knock its lower limit, thereby indicating limit of over discharge reached, from the switches gating pulses is being withdrawn by DMB-3 and shuts the system. I_{Lref} attains its upper limit when battery over discharges, this state arises only when $P_{mpp} > P_l$ and surplus is more than P_{bmax}. In this condition, I_{lref} is limited to I_{Lmax} to limit the battery charging current to I_{bmax} and the MPPT is bypassed. As the battery charging current is limited to I_{bmax}, power consumed by the battery is restricted to P_{bmax}.

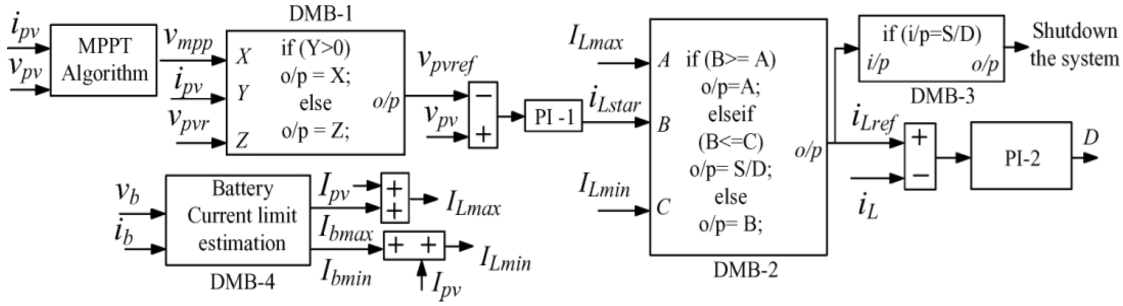

Fig. 6. TCDIC control structure

This makes the available PV power more than $(P_l + P_{bmax})$. This additional power of PV starts charging capacitor which was placed across PV array and increases its voltage beyond V_{mpp} thereby shifts the operating region of PV to the right of MPP point. This process prolongs until the drawn power of PV array becomes more than $(P_l + P_{bmax})$. In non-MPPT mode, the PV being operated on right side of MPP and $P_{pv} < P_{mpp}$. If there is any fall in demand during non-MPPT operation the drawn power from array of PV will be more than $(P_l + P_{bmax})$ and the excess of it charges the capacitor across PV which shifts the PV point of operation to the right side of previous point. Similarly if there is any increment in load, the discharge of PV capacitor starts as it shifts operating point to left of MPP. This paths increment in drawn power from PV and continuation of exercise prolongs until the restoration of power balance. In case the extent of load demand increases in such a way that MPP ceases to supply load, battery starts discharging and I_{Lref} becomes lesser than I_{Lmax} which makes system to function in MPPT.

Ripple Correlation Control (RCC)

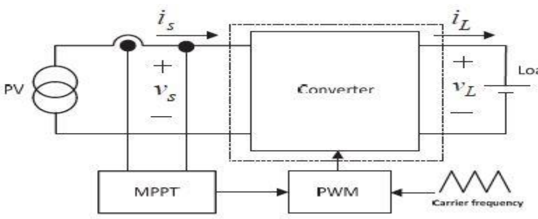

Fig. 7. Implication of RCC in MPPT system

Generally in the case of load fluctuations this stand-alone scheme undergoes different mode transitions which leads to the ripples. So in order to mitigate a control algorithm is implemented in incremental conductance MPPT technique. The proposed technique reads the PV current, voltage and load power and modifies the waveform of reference from conventional MPPT via output power feedback. This yields lower ripple both at load terminal and PV terminal.

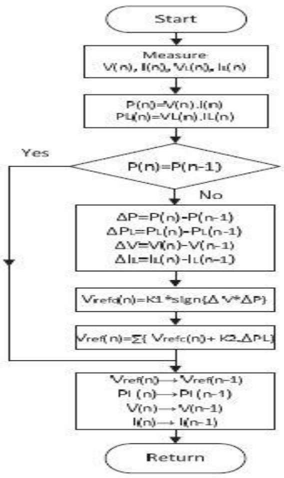

Fig. 8. RCC flow-chart

IV. SIMULATION RESULTS

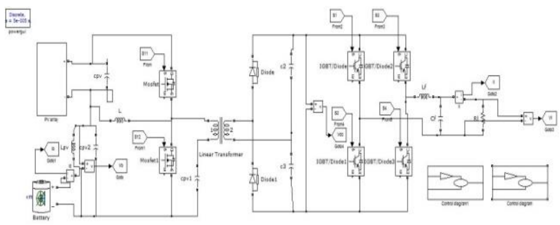

Fig. 9. Simulation Diagram.

Simulated Responses

1. In MPPT mode

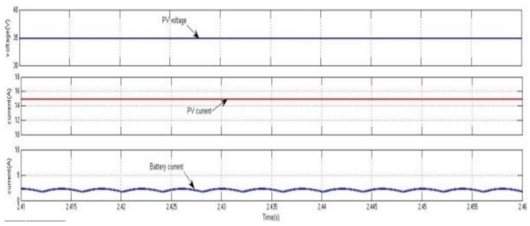

Fig. 10. i) Voltage of PV and Currents of PV and battery

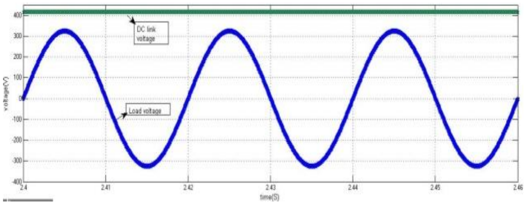

Fig. 10. ii) Voltages of DC link and load

2. **Non-MPPT mode**

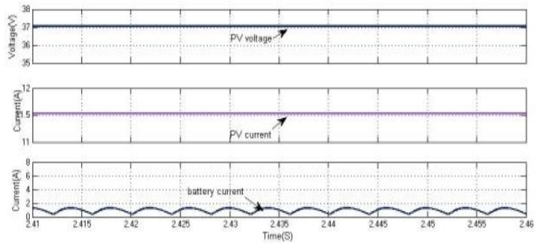

Fig. 11. i) Voltage of PV and Currents of PV and battery

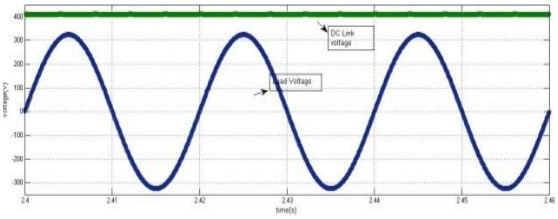

Fig. 11. ii) Voltages of DC link and load

3. **Transition mode between MPPT and non-MPPT.**

a. **By conventional method**

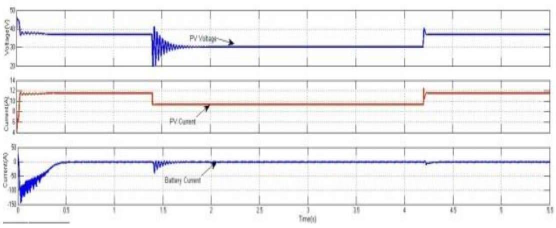

Fig. 12 i) Voltage of PV and Currents of PV and battery

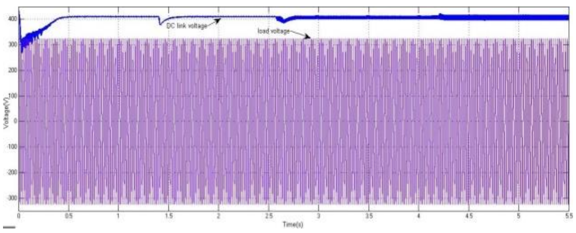

Fig. 12 ii) Voltages of DC link and load

b. **By RCC technique**

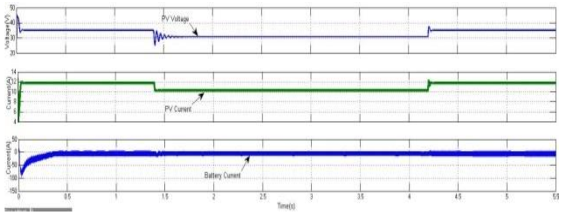

Fig. 13 i) Voltage of PV and Currents of PV and battery

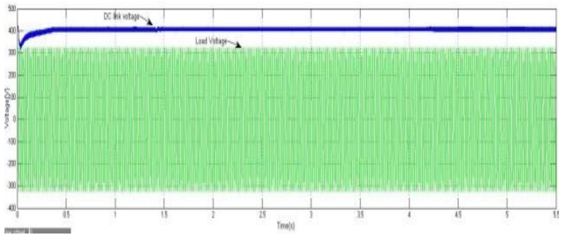

Fig. 13 ii) Voltages of DC link and load

From above figures once can notice the reduction in ripple content compared to the conventional. Therefore it is proved that RCC ensure smooth transition.

4. **Transition between MPPT and BO modes**

a. **By conventional method**

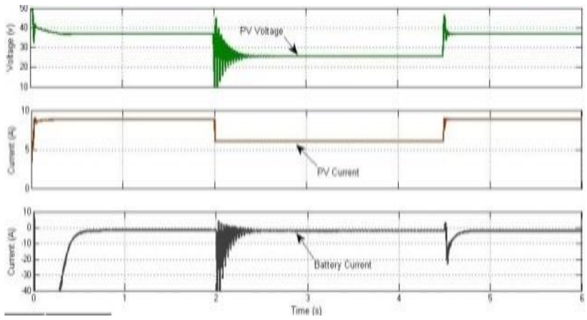

Fig. 14 i) Voltage of PV and Currents of PV and battery

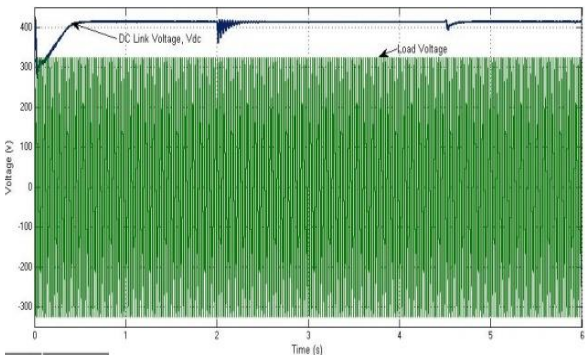

Fig. 14 ii) Voltages of DC link and load

b. By RCC technique

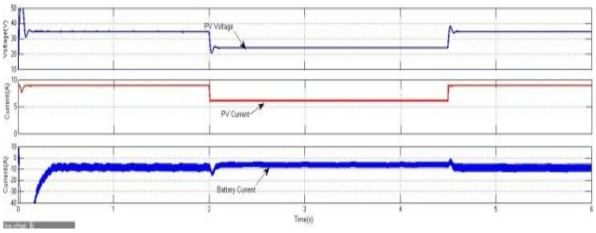

Fig. 15 i) Voltage of PV and Currents of PV and battery

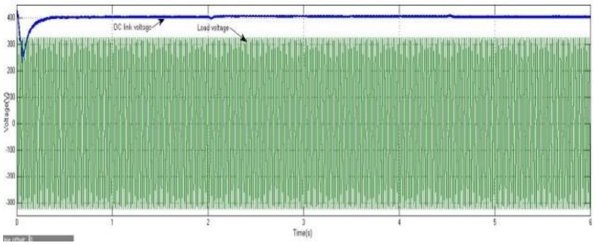

Fig. 15 ii) Voltages of DC link and load

For the MPPT operation as shown in Fig.10 level of insolation is kept at 1KW/m^2 which gives P_{mpp}, I_{mpp}, V_{mpp}, as 525W, 15A, 35V respectively. Whereas load is chosen to be 450W i.e., less thanP_{mpp}. For transition of mode between MPPT and non-MPPT as figured in 11. The insolation is fixed at 0.75KW/m^2 I_{bmax} is set to 1A which in turn sets P_{bmax} to 36W. Firstly, load demand is kept at 450W and at 1.2s the load is changed to 250W and so starts charging. Once it reaches to 1A it gets restricted and system tries to enter into non-MPPT mode. At 4.2s demand is risen to 450W which is more than P_{mpp} and restoration of MPPT mode takes place.

The demand is fixed at 350W at a insolation of 0.5KW/m^2 for the mode transition between MPPT and BO. At 2s the insolation is reduced to a minimum and load is decremented to 200W then battery only starts supplying to meet the load. At 4.5s the insolation increased to 0.5KW/m^2. Therefore restoration of MPPT takes place.

CONCLUSION

PV based standalone scheme is realized by the implication of TCDIC which fulfil the desired requirements. For the smooth transition, RCC stands supportive even under various possible modes.

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