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PV-Battery System for Smart Green Building using Transformer Coupled DC-DC Converter

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***Abstract*—Power from Solar is absolutely perfect for use with irrigation systems for gardens; allotments; greenhouses and also for supporting the main grid. Since the power generation of PV system is highly depends upon the environmental conditions such as availability of sunlight; atmospheric temperature; wind speed etc. Combining a storage device with PV is one of the viable solutions to deal with the intermittency of renewable energy sources. Conventional methods of combining these components involve multistage converters and single-stage converters. The no of stages and switches increases the overall efficiency of the system decreases. In the conventional system an individual converter is used for maximum power point tracking and also a battery charge controller. These two individual converters are not used in every time. Transformer coupled dual input DC-DC converter is discussed in the system which integrates both the MPPT and battery charging discharging control. A coordinated control is used for making the system to work in four different modes of operation and there by satisfying the efficient MPPT and battery current tracking. The system is simulated and studied under various conditions in MATLAB/Simulink platform.**

Keywords—PV-Battery System; MPPT Tracking; Battery Charge Control; Integrated Converter; TCDIC

I. INTRODUCTION

Remote rural areas that live off the grid can benefit from a home photovoltaic cell system. A photovoltaic home system can be defined as a standalone system suitable for a wide range of residential applications such as home appliances; lightning computer and water pumping.

The system is used to supply both DC and AC for home electrical devices with help of proper DC-DC converters and DC-AC inverters. They can be used for power up to a load 300VA. These basic loads include fan; mobile phone chargers; lamps; TV; Radio; etc. Conventional standalone photo voltaic system consist of three power electronics converters.They are maximum power point (MPPT) tracker; battery charge controller and an inverter for feeding the AC loads. MPPT controller extracts maximum power from PV panel. Whereas charge controller enhances the efficiency of battery and its life time by controlling proper charging and discharging of battery under varies SOC levels. PV panel of 12 V or 24 V and a battery of usually 12V or 24 V is common in such stand-alone systems. Due to lower voltage input; these systems require additional boosting of voltage through a transformer. As the no of converters and transformer increases it will increase size and cost of the system.

Use of a system with integrated maximum power point tracking and battery charging control is advantageous for system which require low cost and higher reliability[2][3][4]. A standalone PV system is usually designed with low voltage levels for the PV and the battery in the range 12V or 24V; such systems will be requiring additional boosting up if the input voltage is low. These systems will be using low frequency step up transformer at the inverter output end. However these will increases the no of switches and more no of converter stages which will reduce the overall efficiency of the system.

To address above mentioned issue; the high-gain requirement can be provided through intermediate dc–dc converters which interface the PV and battery. This can be realized by employing three stages of dc–dc conversion. But; the use of more number of converters leads to poor efficiency. And makes the system less reliable. High-gain multilinking transformer-based converters can be used to address this issue. They also have more no of switches which lead to the poor efficiency of overall systems. Furthermore; existing stand-alone schemes employ an additional dedicated dc–dc converter to realize MPP operation. As PV power remains unavailable for more than a day; the utilization of MPPT tracker converter becomes very poor [6][7][8].

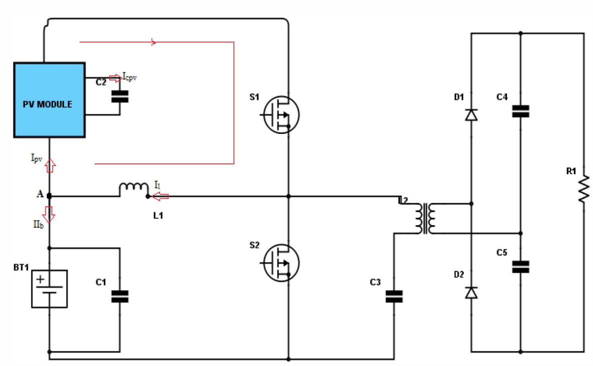

Fig. 1: Transformer Coupled Dual Input Converter

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For eliminating above mentioned limitation and poor efficiency factors PV battery system can use a power converter which works both as MPPT trackers and battery charge controllers. System which make use of such converters presented have the following limitations 1) The presence of resonant elements makes the system sensitive to parameter variation,2) permissible variation in the duty ratio of the switches is limited within a certain range and 3) voltage gain is quite limited. A similar approach has also been reported in [10] and [11] for application in a grid-connected scheme.

II. Transformer Coupled Dual Input Converter

A. *Operating Principle of TCDIC*

Transformer coupled dual input DC-DC converter helps the PV-Battery system to perform both the Maximum Power Point Tracking (MPPT) as well as the battery charging-discharging control. In the conventional system the MPPT tracking as well as the battery charging discharging process are controlled using two independent power converters which increase the size as well as the cost of the system. This makes the system not suitable for most of the application such as rural electrification mobile power generation units used for disaster management etc. TCDIC helps to overcome those mentioned drawbacks of PV-Battery system by reducing the converters number to one and also reduces the number of switches there by reducing the switching losses also the overall system cost and size is reduced. As Shown in Fig.1; the proposed system consist of PV connected in series with battery coupled with an inductor and input is connected to the primary side of isolation transformer through two power MOSFET switches which acts complimentary to each other to feed the DC loads of a smart green building. By proper controlling of current through the inductor MPPT tracking as well as the efficient battery current controlling is done. The high frequency isolation transformer helps to step up the low voltage from the PV-Battery system and also does the high voltage isolation.

As mentioned above by controlling the inductor current converter does its integrating action. So we can describe the converter at two modes ie; when inductor current becomes negative as well as operation at which inductor current becomes positive.

B. *Inductor Current Becomes Positive*

In the TCDIC operation when the current through the inductor becomes positive there can be various switching modes. Those various switching modes of operations can be described using the wave forms shown in Fig. 2(a),(b). The floe current during those switching modes are discussed with help of Fig. 3 and Fig. 4.

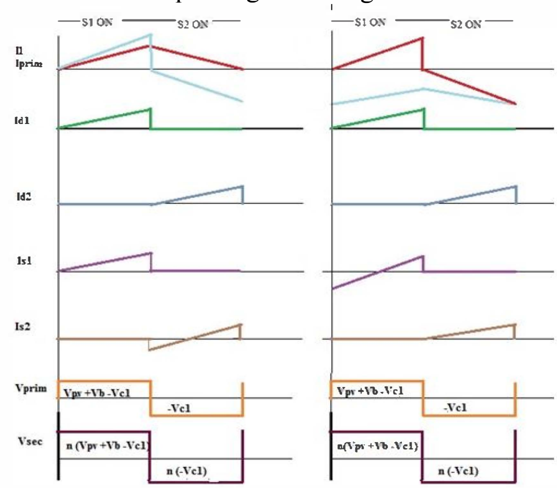


Fig. 2: Current and Wave Forms Across Switches; Diodes; Voltage Across Primary and Secondary of Transformers
(a) When Inductor Current Positive; (b) Inductor Current Negative

Mode 1: As shown in Fig.3 during mode 1operation the switch S1 will be at 'ON' state where as the switch S2 will be at 'OFF' state. The PV array voltage will be impressed across the inductor 'L_1' and the inductor current will start increasing. The input side of the transformer will now be having the voltage of V_{prim}=(V_{pv}+V_b-V_{C3}); V_b is the battery voltage and the V_{C3} is the voltage across the capacitor connected to the primary side of transformer. Since the primary side voltage of transformer increases the current at the primary side also increases as shown in Fig 2(a). These will helps to increase the secondary side current of transformer. At the ssecondary side of transformer the diode D1 gets forward biased and the capacitor C4 gets charged; which can be expressed as V_{C4}=n(V_{pv}+V_b-V_{C3}); n is the turns ratio of the isolation transformer.

Mode 2: During the mode 2 operation the switch S1 will be at 'OFF' condition and switch S2 will be at 'ON' condition. For the first short period of this mode; the inductor current value will be higher than the primary current value; which makes the diode in the Mosfet switch S2 forward biased for short duration and the voltage across the inductor becomes equal to (-V_b); hence the inductor current began to reduce. During this time the primary side voltage of transformer will be (-V_{C3}) which leads to the decrease in value of primary current and capacitor C3 will start discharging. The current on the secondary side will get reversed and diode D2 becomes forward biases and capacitor C5 will be gets charged with a value of V_{C5}=n(-V_{C3}). This mode continues till I_l becomes equal to (-I_{prim}).

Mode 3: As in Fig. 2(a) when I_l becomes smaller than ($-I_{prim}$); switch S2 becomes conducting. Rest of operations remains same as that of mode 2.

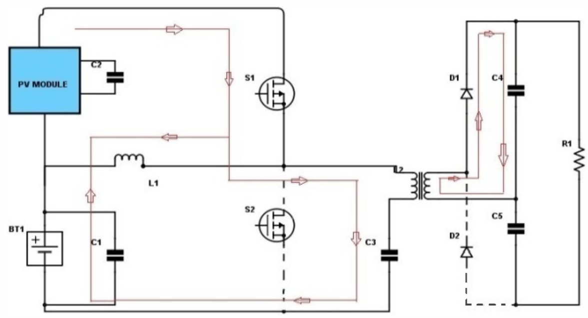


Fig. 3: TCDIC When Switch S1becomes on for Positive Inductor Current

C. *Inductor Current Becomes Negative*

When inductor current becomes negative converter will have three switching modes of operation. Fig.2(b) shows the different wave forms during this state.

Mode 1: During this mode the switch S1 will be turned 'ON' and switch S2 will be at turned 'OFF'. At the beginning the inductor current will be negative and the primary current will be zero which forward biases the diode of Mosfet switch S1 and the a primary voltage becomes; $V_{prim}=(V_{pv}+V_b-V_{C3})$. And the secondary side voltage becomes equal to $n(V_{pv}+V_b-V_{C3})$; the capacitor C4 gets charged. This mode will continue till primary current becomes equal to ($-I_l$).

Mode 2: This mode starts when I_{prim} becomes more than that of ($-I_l$); during this time switch S1 starts conducting and the primary and secondary side voltage values remains same as in the previous mode of operation.

Mode 3: During this mode of operation switch S1 will be 'OFF' and switch S2 will be 'ON'. Both of the currents will have negative values. Since the primary side current value becomes negative secondary current will also falls into negative value. Diode D1 at the secondary side becomes forward biased; therefore capacitor C5 becomes charged up to $n(-V_{C1})$ as shown in Fig.2(b).

D. *MPPT and Battery Charge Control*

When the switch S1 becomes ON voltage impressed across for inductor can be written as

$$V_l=V_{pv} \quad (1)$$

and inductor voltage when S2 becomes ON can be written as

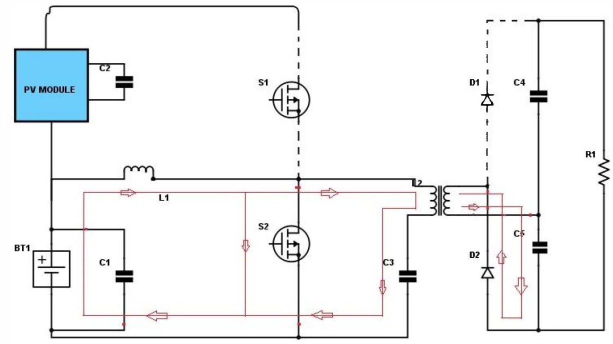


Fig. 4: TCDIC When Switch S2 Becomes on for Positive Inductor Current

$$V_l=-V_b \quad (2)$$

Considering the average voltage drop across inductor

$$V_l=DV_{pv}-(1-D)V_b \quad (3)$$

D is the duty ratio of switch S1. By equating the average voltage across inductor as zero we get

$$V_{pv}=[(1-D)/D]V_b \quad (4)$$

Since the battery voltage V_b remains constant; the PV voltage can be converges to its MPP value by proper controlling of D.

E. *Battery Charge-discharge Control*

As discussed the battery current control is achieved by the inductor current control.

Applying KCL at point A on Fig.1; gets,

$$I_l+I_{cpv}=I_b+I_{pv} \quad (5)$$

Considering average values of the I_l; i_{cpv},i_b,and i_{pv} over a switching cycle and noting that $i_{cpv}=0$; (5) becomes

$$I_l=I_b+I_{pv} \quad (6)$$

From (6) it can be noted that I_b becomes negative when $I_{pv}>I_l$,ie the battery is discharged. I_b become positive when $I_l>I_{pv}$ and the battery gets charged.

III. Control System

The controller of the proposed system is designed in such a way that it controls the MPPT tracking as well as the battery charging discharging control. In order to perform the mentioned goals the control algorithm forces to operate the converter in four modes of operations.

MPPT mode of operation:During this mode of operation PV will be operated at its MPP value.The load at this condition will be either greater than P_{pv} or lesser than P_{pv}. When PV has surplus power the battery is charged. When PV had power deficit battery can supply the power.

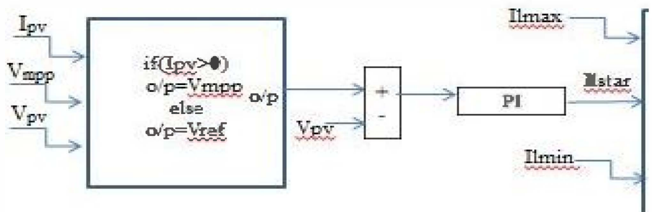


Fig. 5: Control System for the TCDIC

Non MPPT *mode of operation*: This mode of operation helps the efficient charging control of the battery storage. When the total load demand becomes less than the P_{mpp} and battery SOC level reaches 100 %; there is no need of surplus power. During this condition the operating point of PV can be shifted to its Non MPPT mode ie operating point will shift to the right hand side of V_{mpp}. The battery charging current will hit at its maximum charging current limit and will restrict the further charging of battery.

Battery Only (BO) *mode of operation*: When there is no availability of power from PV,ie if I_{pv} <<0 then the system will be totally depend upon the power from battery. System will continue in this mode till the battery SOC reaches the safe discharge limit.

Shutdown (SD)*mode of operation*: If both the Inputs fail to provide the load demand of system; then the whole system needs to be shutdown. During this time the controller will with draws pulses from both the switches S1 and S2. This mode protects the battery system from over discharge.

The control algorithm that is designed to select the proper mode of operation for the system; depending on the level of SOC of the battery and the availability of power from the solar array; is shown in Fig.5. It consists of four decision making blocks and two PI controllers. These decision making blocks set the reference values for the control algorithm to generate required duty cycle for the converter. Block one determines whether the system should operate in MPPT mode or Battery only mode. It first checks the availability PV by checking the I_{pv} value. If PV is available then it sets the voltage reference value as V_{mpp} and makes the system to operate in MPPT mode. If PV is not available then block 1 sets the V_{ref} as V_b ie battery voltage and makes the system to operate in battery only mode. Then the error value is taken between V_{ref} and V_{pv},which is fed into a PI controller and required I_{lstar} reference current is obtained. With reference to the current SOC level of battery the charging discharging currents I_{bmax} and I_{bmin} respectively are tracked and added with the current from PV. The maximum and minimum inductor current limits are obtained as follows.

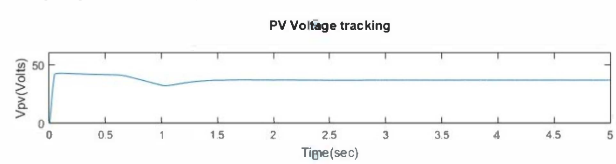
$$I_{lmax}=I_{pv}+I_{bmax} \quad (7)$$

$$Ilmin=Ipv+Ibmin \quad (8)$$

Block 2 compares the three inductor current values I_{lstar}; I_{lmax}; I_{lmin} and determines whether the system should work on Non MPPT mode or Shutdown mode. If the I_{lstar} is greater than the maximum inductor current I_{lmax} then block 2 gives the output as I_{lmax} to set the battery charging current as I_{bmax} this situation arises only when the system operates in the MPPT mode. The other case ie if I_{lstar} is less than that of I_{lmin} then system won't be able to feed the load demand so that system will fall into shut down mode of operation. When inductor current I_{ref} remains in the prescribed limit,the system operates either in MPPT mode or BO mode. The error between reference current from block 2 and actual inductor current feed into the second PI controller which generated the final pulses for the converter operation.

IV. SIMULATION RESULTS

A Transformer coupled PV battery system for smart green building to serve DC load is designed and simulated on MATLAB/Simulink platform; simulated performance under variable operating conditions are discussed in this section. Since the system is designed for serving the dc loads of smart green building the power rating is taken as 500W.The PV modules are selected to generate maximum of 525W at its STC and a the battery voltage level is chosen and 36V and the State Of Charge(SOC) variations are considered within 30-80%. With these considerations the variation of input voltage of converter is assumed to be 80V and since the designed value for output voltage is taken as 450 required transformer ratio is taken as 6. The other systems parameters are given in the TABLE.I. The system is simulated under different conditions by varying the irradiance of PV and load conditions. Corresponding I_{mpp}; V_{mpp} and P_{mpp} are 15A,36V and 525W respectively. The load demand is kept below $P_{mpp.}$ and the battery SOC level kept below 80%.Fig.6(a) shows the voltage across the PV panel; as mentioned in the control algorithm the PV is working at its V_{mpp} value to feed the load as well for charging the battery.



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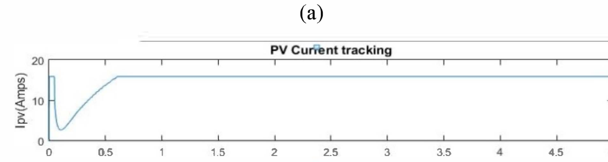

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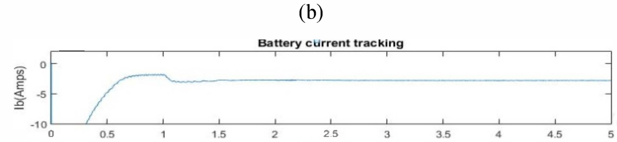

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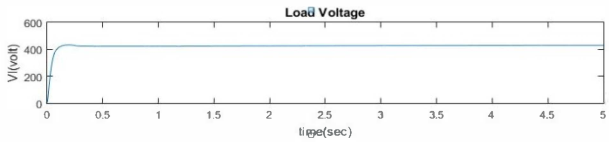
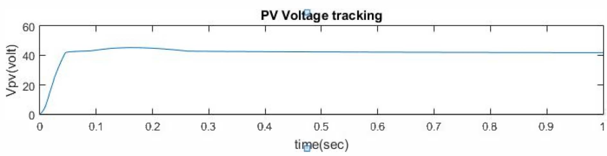


(d)

Fig. 6: (a)PV V_{mpp} tracking at MPP mode,(b)PV I_{mpp} tracking at MPP mode,(c)Battery charging current control at MPP mode,(d)Load voltage at MPP mode.



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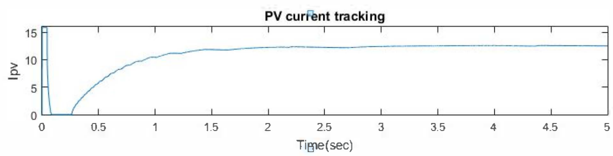

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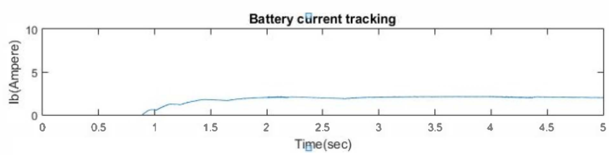

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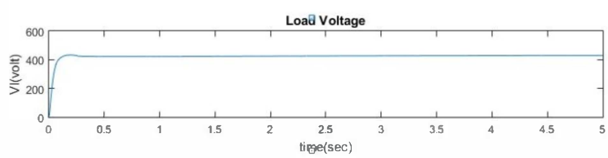
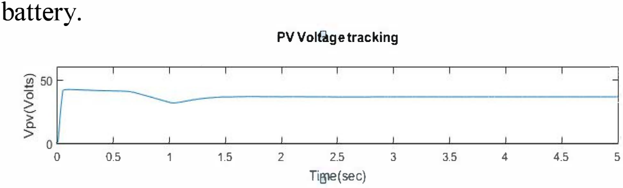


(d)

Fig. 7: (a)PV V_{mpp} tracking at Non-MPP mode,(b)PV I_{mpp} tracking at Non-MPP mode,(c)Battery charging current control at Non-MPP mode; (d) Load voltage at Non- MPP mode

Fig. 6(b) shows the I_{pv} which settles at it I_{mpp} value and battery is charging with a current value of 2.5A as in Fig. 6(c). Fig. 6(d) shows the load side voltage maintained around 400V. For next mode of operation insolation level is kept as 1000KW/m^2. (I_{mpp}=12A,V_{mpp}=43V). The load demand is kept less than 450W and the battery SOC level is considered as less than 80%. After serving the battery when battery power limit exceeds the maximum battery power P_{bmax}; then the control algorithm makes the PV to work at Non MPPT point by shifting its voltage on the right hand side of V_{mpp} and the PV current is tracked to the expected value which are shown in Fig. 7(a),(b) respectively. The battery current is tracked to its maximum current limit as shown in Fig. 7(c). The load side voltage maintained at a range of 400V as shown in Fig. 7(d).

The simulated response of the system to describe BO modes are shown ih Fig.8(a),(b),(c),(d).The insolation level is kept at 0KW/m^2 (I_{mpp}=0A,V_{mpp}==35V) during this period when insolation reaches to zero PV current also becomes zero and system enters into the battery only mode. The PV voltage reference for the BO mode is kept at 35V. In the battery only mode the power from PV becomes almost zero and the entire load is feed by the battery.



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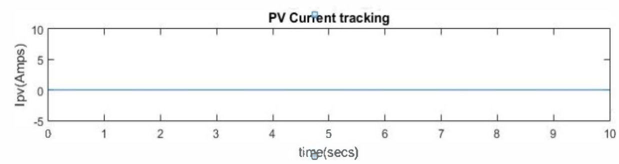

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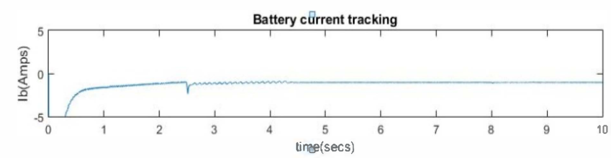

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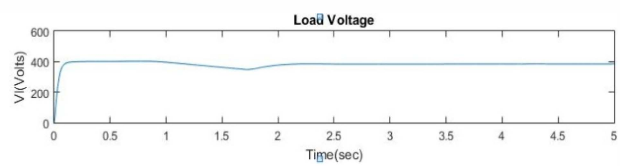


(d)

Fig. 8: (a)PV V_{mpp} Tracking at BO Mode,(b)PV I_{mpp} Tracking at BO Mode,(c) Battery Charging Current Control at BO Mode, (d) Load Voltage at BO Mode

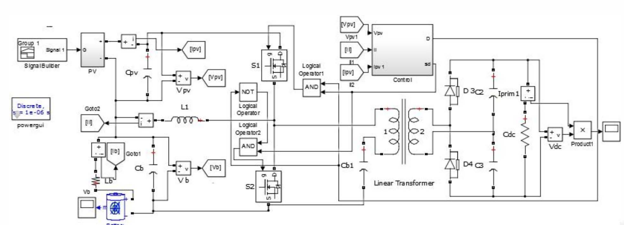
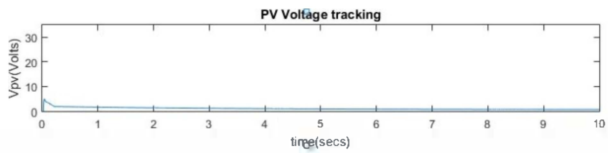


Fig. 9: MATLAB/Simulink Model of the Proposed System

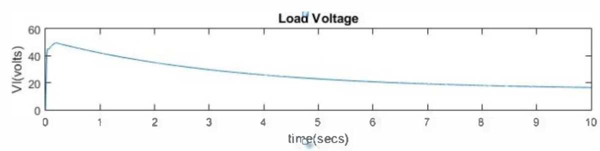
When there is deficit of power in both PV and battery; system fails to feed load and moves to the shutdown mode of operation. In this mode of operation PV insolation is kept zero and load demand is kept higher after some times when battery hits its maximum discharges limit and system fails to feed the load controller will withdraw the pulses from switch. In shut down mode of operation PV modules fails to operate in its MPP value as shown in Fig. 10(a) and also system is not able to maintain its load voltages at 350V instead it falls to a very low value as in Fig. 10(b).

TABLE 1

Parameters	Value
DC power ratting	500W
Capacitors	C_{pv}=1500µF,C_b=1500µF C4=C5=2000 µF; C3=470µF.
Inductor	L1=2.8mh
Switching frequency	15kHz
PI Controller gains	PI-1:Kp=0.1,Ki=0.5 PI-2:Kp=0.3,Ki=0.2



(a)



(b)

Fig. 10: (a) PV V_{mpp} Tracking SD Mode; (b) Load Voltage at SD Mode

V. CONCLUSION

Among the RES (renewable energy sources) available in the world PV based energy harvesting are more reliable for rural; off grid and also for green energy applications. Since the electrical energy available from PV is DC we can use it for serving the DC loads which reduces the conversion losses. Since RES depends largely on the environmental condition a battery storage system is very essential in PV based standalone system to obtain uninterrupted power supply.

Such a PV-battery based system is proposed in this work which is used serve the DC loads of smart green building. Apart from conventional system the MPPT tracking as well as the efficient battery charging discharging is controlled by a single converter which increases the reliability and efficiency of the system. Need of dedicated converter for ensuring MPP operation of the PV array is taken out here which leads to enhanced utilization of power converters also lesser no of components as the system has only one conversion stage. Isolation as well as the boosting up of input voltage is done using transformer without increasing the number of PV panels and battery. System provides easy and potent control structure ensuring proper operating mode selection and smooth shift between different possible operating modes. The system operations are validated at different operating conditions in the MATLAB/Simulink platform.

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