Failure detection-less approach for wide sustained operation of MPPT based stand-alone solar photovoltaic system during failure/disconnection of battery

Pritam K. Gayen | Satyajit Saha

Electrical Engineering Department, Kalyani Government Engineering, Kalyani, India

Correspondence
Pritam K. Gayen, Electrical Engineering Department, Kalyani Government Engineering, Kalyani, West Bengal 741235, India.
Email: pkgtar@gmail.com

Abstract
Batteries play an important role in stand-alone two-stage converter (boost converter and inverter) based solar photovoltaic (SPV) systems. Here, the maximum power point tracking (MPPT) operation of a stand-alone solar system is carried out with the usage of a battery by absorbing excess solar power. Nevertheless, instability (abnormal rise of DC link voltage) can appear during the real-time operation of the battery-based solar energy conversion system due to the action of the MPPT controller, if a sudden battery breakdown happens. In this respect, a failure detection-less solution is proposed. The suggested strategy restricts operation of the MPPT and helps to settle the output power of the SPV at non-maximum level on its P-V curve as per necessity. Thus, voltage instability at DC bus (link between boost converter and three-phase voltage source inverter [VSI]) is prevented. Here, the bus voltage can be kept within a predefined upper and lower limit. The limits are decided accordingly to the SPV characteristics. Simultaneously, the required load powers (both active and reactive portions) are supported by the VSI. In the proposed strategy, the output of the MPPT algorithm is restricted by adopting a saturation limit for a certain duty ratio. The critical task is to find the value of the saturation limit, as the limit supports all-time operations (it allows desired performances under all maximum power situations and avoids instability under all non-maximum operating conditions). The procedure of determining the limit is thoroughly described. The conventional approach uses a failure detection-based separate control algorithm. At the same time, the proposed concept does not require a separate algorithm. The suggested concept is validated via a MATLAB-SIMULINK-based simulation study and down-scaled experimental set up.

KEYWORDS
battery, failure detection-less approach, maximum power point tracking, solar photo-voltaic, stand-alone condition
1 | INTRODUCTION

In recent decades, solar photovoltaic (SPV) energy conversion systems have been considered as one of the most promising renewable sources of electrical energy throughout the world. Research works on stand-alone SPV system having battery storage are published in various articles. The stand-alone system is used in diversified applications such as water pumping, process, spacecraft, electric vehicle, and electrification in remote areas. Figure 1 shows the schematic diagram of stand-alone SPV system, which is connected to isolated load via DC-DC boost converter and three-phase voltage source inverter (VSI). DC-DC bidirectional converter based battery storage is integrated at common DC link. The study of this article concentrates on SPV system of Figure 1. In this scheme, battery unit improves reliability and efficiency of the system. Extraction of maximum power from stand-alone SPV array is possible under battery connected mode by action of maximum power point tracking (MPPT) logic. Here, battery will store power during surplus of solar power (solar power is greater than load power) and will deliver stored power during crisis period. If battery is incapable to absorb surplus power during fully charged condition or failure/partial active condition or removal, then unstable situation will arise in the system of Figure 1, that is, uncontrolled rise of DC link voltage appears. For avoiding the instability, it is essential to produce fractional (nonmaximum) solar power for load by SPV array under battery failure mode. In this respect, various strategies are already proposed in published literature studies. The published article proposes usage of dumping load in this situation to dissipate extra solar power, but it is difficult to handle this type of load in controlled manner and also, it is inefficient solution due to wastage of solar energy. Another solution can be thought as required power tracking (RPT) logic. Measurement of load power is mandatory for implementation of RPT. There is complexity in implementation of the algorithm, as various intermediates conditions are required to be checked. Fractional solar power generation involves separate control logic for stabilizing operation of battery-less stand-alone SPV system. The above cited RPT or control logic of fractional solar power generation needs detection of battery failure.

In this article, simple logic is proposed to prevent unstable operation of battery-less SPV system, that is, suggested logic helps to support nonmaximum load power without usage of separate algorithm and also, dumping load is not required. During absence of battery, duty ratio of boost converter is restricted by adopting saturation limit for duty cycle at output of MPPT. In effect, DC link voltage is kept within predetermined limits. Subsequently, voltage control loop of VSI maintains required load powers from safe DC link voltage at input terminals of VSI. In this way, the proposed logic restricts output of MPPT algorithm to run it as non-MPPT algorithm for supplying required load powers. Thus, stable nonmaximum operation through restriction on output of MPPT algorithm is guaranteed during disconnection/failure period of battery. Here, selection of all-time saturation limit is crucial task so that it must not hamper MPPT operation during active condition of battery.

To summarize, contributions of this article are outlined as follows:

1. Instability of stand-alone SPV system is avoided by restricting output of MPPT algorithm, if load power is less than peak solar power.
2. In the situation, abnormal increase/very high value of DC bus voltage is prevented.
3. Changing over from MPPT algorithm to non-MPPT algorithm is not required as the determined solution supports both modes of operation. Thus, no detection process is involved for deciding switching instant from one to another algorithm.
4. Load power measurement is also not involved in the suggested logic (load power monitoring process is not involved), that is, sensorless feature of proposed scheme.
5. Arrangement of dumping load is not required, that is, cost-effective solution.

**FIGURE 1** Schematic diagram of SPV system with battery storage
Fundamental issues of SPV system under isolated loading condition and conventional control loops are discussed in Section 2. Section 3 describes proposed solution and associated analysis. Validating results of both simulation and experimental studies are presented in Section 4. Conclusions are given in Section 5.

2 | BASICS OF STAND-ALONE SPV

The traditional control loops for various converters are shown in Figure 1. These loops are briefly discussed in this section. Here, MPPT logic regulates duty ratio of boost converter to capture maximum solar power and thus, it adjusts required boosting level. Voltage regulating loop of VSI supports load powers by adjusting modulation index (MI). The bidirectional DC-DC converter is controlled to maintain constant DC link voltage by regulating of charging or discharging current of battery. In MPPT mode, active power balance is required for stable operation of overall system as given below,

\[ P_m = P_b + P_l. \]  

In Equation (1), \( P_m, P_b, P_l \) are symbolized as maximum solar power, battery power, and active load power, respectively. In Equation (1), charging power of battery (storage) is considered as positive sign. Here, instability appears in the system if \( P_m > P_l \) under failure or disconnection or inactivation of battery (\( P_b = 0 \)). This situation happens under fully charged condition of battery or breakdown or maintenance of battery storage. Thus, in these situations, activation of MPPT algorithm causes adverse effect on the system such as abnormal increase in DC bus voltage. The uncontrolled rise of DC bus voltage causes failure of power converters. Required amount of dump load can be arranged to absorb excess solar power for mitigating the adverse effect. But, management of dump load is very difficult. Also, it incurs wastage of power and needs extra infrastructure to accommodate. Thus, this can be treated as inefficient technique to solve the problem. A separate load power tracking (LPT) algorithm can be thought on the basis of load power measurement and accordingly, system can be controlled. But varying and unpredictable nature of loads can hamper accuracy of monitor process in real world scenario and also, it needs detection technique for transferring from MPPT to LPT algorithm.

To overcome the above said limitations of conventional approaches, simple logic is proposed in the next section (Section 3), that is, suggested logic avoids the necessity of any detection process, transition from one algorithm (MPPT) to another algorithm (LPT), load powers monitoring process, and usage of dump load. The typical P-V characteristics of SPV module are shown in Figure 2, which is used in subsequent discussions of this article.

3 | PROPOSED SOLUTION

In this section, proposed solution is described as follows:

3.1 | Determination of upper limit of DC bus voltage

The stand-alone SPV system having battery back-up is already shown in Figure 1. But, Figure 3 indicates that battery-less SPV system (during outage of battery) is supplying electrical power to isolated load. In this situation, instability (uncontrolled rise of DC bus voltage “\( V_{dc} \)” in Figure 3) appears due to action of MPPT, as this logic forces to dump excess solar power to DC link capacitor.

At this point, it is thought that MPPT algorithm is required to be restricted so that it behaves like non-MPPT algorithm under battery-disconnected mode. Thus, MPPT virtually works as LPT algorithm during failure of battery. But, logic for the restriction must be carefully decided so that it does not hamper system’s performance under MPPT mode. In this respect, a simple approach is proposed, which is explained in reference to solar conditions (variation of temperature and irradiation level as shown in Figure 2). Here, the variations of SPV’s output voltage range from around 200 V to around 350 V (input voltage range of boost converter) for change of solar conditions (variations of temperature and irradiation of 25°C-100°C and 250-1000 W/m² respectively). Within the range of voltage variation, any power up to maximum capacity (series of P-V characteristic as shown in Figure 2) can be supported by the SPV array. In Figure 2, maximum capacity of the SPV array is shown around 108 kW. The target of this article is to propose solution for supporting all power levels
within its capacity in the range of above said solar conditions and the solution should not involve transition from one algorithm to another one. Also, detection of battery's condition is not needed. In proposed concept, entire maximum and nonmaximum power points can be accomplished by adopting all-time saturation limit for duty ratio at the output of MPPT logic as explained below:

The constant DC link voltage is taken as 800 V under MPPT mode. Therefore, upper threshold value of controlled duty ratio can be calculated on the basis of lowest value of SPV's output voltage (200 V) as, \(1 - \frac{(200/800)}{2} = 75\%\) for supporting all maximum power points of SPV characteristics. This upper threshold value of duty ratio (75%) causes maximum value of DC link voltage of around \(\frac{350}{1-0.75}\) = 1400 V under nonmaximum power situation. Here, the highest value of SPV's output voltage is 350 V as per Figure 2A and B (right-side points of peak point). Therefore, output voltage of boost converter can maximally reach up to the above stated limiting value, that is, 1400 V under nonmaximum operating condition. In this way, all-time saturation limit (75%) at output of MPPT logic is determined for the SPV system from its characteristics. Here, the upper limit of duty ratio (75%) at output of MPPT supports all-time operation so that safe limit of DC bus voltage (1400 V) is not violated under non-maximum power condition as well as chosen DC link voltage (800 V) is not disturbed in maximum power condition. Thus, DC link voltage can be always kept within predefined upper and lower limits (800 to 1400 V) for entire range of output voltage variation of concerned SPV depending on solar conditions. In the process, the actual output of MPPT algorithm (duty ratio) has been indirectly suppressed by the saturation limit that is, MPPT is tactically operated to behave like non-MPPT algorithm under battery disconnection mode, but MPPT is allowed to work under maximum power condition (with battery connection). Thus, the process of changing over from one algorithm to another algorithm along with detection of switching instant is not required in suggested concept.
To summarize, MPPT with saturated output causes no overcharging of DC link capacitor to raise DC bus voltage beyond pre-determined tolerable limit and damage of components can be avoided. Within feasible output voltage range (200 V to 350 V for described case) of concerned SPV module, both maximum and non-maximum power points can be met up without overvoltage situation at DC bus by adopting saturation limit (75% in the case). As the saturation limit depends on the output voltage range of SPV module, it varies from one system to another system as per described procedure. Figure 4 shows incorporation of system specific saturation limit ($D_{\text{sat}}$) at output of MPPT for controlling DC-DC boost converter. This modification is needed in traditional control scheme.

### 3.2 VSI operation

Next, voltage control loop of VSI adjusts modulation index for maintaining standard load voltage, thereby it supports load powers. By ignoring losses of VSI, active power balance between input and output of VSI can be mathematically written as,

$$P_i = V_{dc}I_{dc}. \quad (2)$$

In Equation (2), $V_{dc}$, $I_{dc}$ = Input DC bus voltage (within limit) and current for inverter.

### 3.3 Avoidance of instability with non-maximum power supply

Finally, avoidance of instability in the system (shown in Figure 3) is discussed henceforth. In the context of nonmaximum power loading (solar power is greater than load power), MPPT logic in Figure 3 tries to dump surplus solar power to DC link capacitor. It causes voltage rise at DC bus. In turn, controlled duty ratio of boost converter tends to increase and ultimately, reaches to predefined saturation limit ($D_{\text{sat}}$) at output of MPPT (shown in Figure 4). Due to the saturation of duty ratio, the rise of DC voltage beyond upper limit (1400 V) is restricted. In consequence, safe DC bus voltage at output of boost converter is guaranteed in the proposed case. Here, duty ratio always saturates at limit due to tendency of dumping excess power into DC link capacitor and accordingly, obtained value of output voltage of boost converter across the capacitor can be calculated by multiplying SPV’s output voltage (input voltage of boost converter) with the value of saturated boosting factor. Thus, DC bus voltage varies within its limiting value (800-1400 V) depending on solar conditions (output voltage of SPV).

At safe value of DC bus voltage, required load powers are supported by VSI via regulating loop as discussed before. At this time, the input-output power balance for boost converter can be mathematically expressed as,

$$P_{pv} = V_{pv}I_{pv} = V_{dc}I_{dc}. \quad (3)$$

In Equation (3), $P_{pv}$, $V_{pv}$, $I_{pv}$ = Power, voltage, and current output of SPV array and losses of the converter are neglected.

From Equations (2) and (3), required load power extraction from SPV array is ensured by the mathematical relationship given below,

$$P_{pv} = P_i. \quad (4)$$

Here, MPPT is running all-time, but its effect (release of excess power to capacitor) is prevented by upper saturation limit of duty ratio under nonmaximum power condition. Thus, nonmaximum power operation is established as per Equation (4) via intermediate safe DC bus voltage in case of battery disconnection. In this way, instability in the system is
removed and simultaneously, nonmaximum load powers are supported. From the above discussions, it can be commented here that avoidance of instability can be done under non-maximum loading condition by adopting all-time saturation limit. This limit does not hamper MPPT under normal (battery connected) mode as its value is decided for supporting all-time operation. Here, determination of value of saturation limit is crucial as per procedure discussed in this section.

4 RESULTS

The proposed concept is validated in both simulation and hardware platforms. The description of these studies and obtained results are presented as follows.

4.1 Simulation study

The SIMULINK software-based model of the overall system is prepared. Here, standard peak load voltage is taken as 325 V (230 V rms) and its frequency is 50 Hz. The characteristics of SPV module used in this study are already presented in Figure 2 and this simulation study is described henceforth on the basis of discussions in Section 3.

4.1.1 Performance without saturation (conventional case)

The performances of system in simulation platform are shown in Figure 5 with and without battery connection under running of “perturb and observe (P&O)” MPPT logic. Here, no saturation limit is used. Up to simulation time \( t = 1.25 \) seconds, the system is running under battery activation mode. The temperature and irradiation for SPV module are initially set at 25°C and 1 kW/m², respectively. In this condition, maximum power is 100 kW. The load of 70 kW, 10 kVAR is switched. Surplus solar power, that is, 30 kW is absorbed by battery.

At \( t = 0.5 \) second, solar conditions are changed to 75°C and 1 kW/m² and corresponding maximum power is 82 kW. At the changed solar condition, load powers are still supplied by SPV array and excess active power \((82-70 = 12 kW)\) is stored into battery.

Next, new loads having powers of 60 kW, 7 kVAR are switched at \( t = 1.0 \) second and solar conditions (75°C and 1 kW/m²) are unchanged. Here, MPPT operation is performed in desired manner as shown in Figure 5 and surplus power \((82-60 = 22 kW)\) is absorbed by battery. Various responses in Figure 5 (up to \( t = 1.25 \) seconds) show desired performances of system during MPPT mode of operation (battery connected mode).

At \( t = 1.25 \) seconds, the battery is suddenly disconnected. It is noted that DC link voltage is rising abnormally due to action of saturation-less MPPT logic. It indicates instability of the system, as excess solar power causes abnormal rise in voltage across DC bus capacitor.

4.1.2 Performance using saturation (proposed case)

Next, Figure 6 shows performances of proposed concept under various dynamic conditions at different intervals similar to conventional case study (just discussed before in respect of Figure 5) with running of saturated MPPT throughout simulation time. The upper saturation limit of 0.75 per unit (p.u.) for duty ratio is incorporated at the output of perturbs and observe (P&O) MPPT algorithm in SIMULINK model. In the proposed method, all responses up to \( t = 1.25 \) seconds under MPPT controlled mode are similar to just previous case study (conventional case). It demonstrates that operation of the system using saturation limit does not hamper MPPT operation during battery connected mode. Now, battery is suddenly disconnected at \( t = 1.25 \) seconds. Thereafter, Figure 6 shows that performance of system under non-maximum power condition (battery disconnection mode) is working satisfactorily with the help of proposed logic. DC bus voltage is kept within safe limit of 1400 V with saturated duty ratio of 0.75 p.u. and load powers are simultaneously maintained. No instability is appeared, unlike conventional case.

Further investigations are done in simulation platform to test the ability of proposed solution for supporting various nonmaximum load powers in discrete step within loading limit of 100 kW. Here, solar conditions are set at 25°C and 1 kW/m² and corresponding maximum power is 100.8 kW. During running condition of simulation model, loads
FIGURE 5  Various obtained responses in simulation platform having no saturation limit with battery (0-1.25 seconds) and without battery (1.25-1.5 seconds) for conventional case
**Figure 6** Various obtained responses in simulation platform having proposed saturation limit with battery (0-1.25 seconds) and without battery (1.25-1.5 seconds)
FIGURE 7  Various obtained responses in simulation platform with proposed solution under different non-maximum power loads condition at particular solar condition (25°C & 1 kW/m²)
are switched at every interval of 0.25 second with increasing step of 12 kW along with varying amount of reactive power. Figure 7 shows obtained responses of various variables by usage of suggested logic and their behavior are found in desired manner. Here, duty ratio is always saturated at value of 0.75 p.u. under all nonmaximum loading conditions. Different DC link voltages under the various nonmaximum conditions are kept below 1400V. Here, DC link voltage increases with decrease in load active power, as SPV’s output voltage increases with decrease in power requirement. Figure 7 demonstrates wide sustained operation of the system under battery disconnected mode with help of proposed logic.

Figure 8 shows comparative results between detection based conventional method and proposed detection-less concept. It shows that sharp rise of DC link voltage occurs at $t = 1$ second due to small amount of delay during detection of failure condition of battery. The undesirable fact happens as detection based approach usually takes initial lapse of time to operate. On the other hand, any abnormal voltage rise does not happen due to adoption of proposed detection-less technique at same time.

Entire simulation work validates feasibility and superiority of proposed logic for supporting both maximum and non-maximum load power during running of MPPT. Here, all-time saturation limit supports desired operation under both maximum and non-maximum power conditions.

4.2 Experimental study

Downscaled experimental set up used in the study of this article is shown in Figure 9. Here, SPV simulator (ITECH: IT 6514C) acts as DC power source. It is connected to AC load via DC-DC boost converter and three-phase VSI. This represents stand-alone SPV system under battery disconnected mode. Power MOSFETs (TOSHIBA: 2sk3878) are used to fabricate power converters. The SPV simulator is connected to PC/laptop for real-time setting of solar conditions, characteristic and also, real-time monitoring of various input and output variables of SPV simulator using its compatible software (SAS 1000). Specifications of various parameters used in experimental set up are provided in Table 1. The dsPIC 30F4011 controller is used to realize MPPT control action with saturation limit and voltage control loop for VSI. Variable resistor load box is used to vary load powers. Digital storage oscilloscopes (KEYSIGHT: DSOX2024A and SCIENTECH
TABLE 1 Specification of various components

| Components/Parameters | Specifications/Values |
|-----------------------|-----------------------|
| $V_1$ (peak), $\omega$ | 40 V, 314 rad/s       |
| L, C (Boost Converter) | 500 $\mu$H, 470 $\mu$F |
| Filter inductance ($L_f$) | 1 mH       |
| Filter capacitance ($C_f$) | 10 $\mu$F |
| Switching frequency ($f_s$) | 5 kHz for VSI, 40 kHz for boost converter |
| $K_p$, $K_i$ | 0.01, 20 |

FIGURE 10 (A) SPV characteristic, (B) three-phase load voltage (50 V/div) and per phase current (2 A/div), and (C) PWM waveform ($D = 50\%$) and DC link voltage (100 V/div) under maximum power (90 W) condition

Hall-effect sensors are used to sense AC voltages (LEM: LV-25P) and currents (LEM: LTS-25NP).

At first, solar characteristic of SPV simulator is set through its software. The PV simulator characteristic has been set with specifications of short circuit current of 1.94 A, open circuit voltage of 60.7 V and maximum (peak) power of 90 W (current and voltage value of 1.79 A and 50.26 V, respectively, at maximum power). Here, temperature and irradiation for PV simulator are set at values of 25°C and 1 kW/m², respectively. The characteristic is chosen so that the output voltage variation of the SPV simulator ranges between 50-60 V for supporting maximum and various nonmaximum power points.
The constant DC bus voltage under maximum power condition is taken as 100 V. The saturation limit is decided on the basis of procedure in Section 3.1 as, \((1 - 50/100) = 0.5\) per unit (p.u.). With the saturation limit (0.5 p.u.), maximum limit of DC link voltage is calculated as 120 V \((60 / (1-0.5))\). Here, 60 V is upper limiting value of SPV’s output voltage. Thus, DC bus voltage varies between 100 and 120 V for entire range of operations according to setting of SPV characteristic. Let establish maximum and nonmaximum power loading condition on stand-alone SPV simulator with all-time saturation limit of 0.5 p.u. as follows.

To establish the maximum power point operation, load resistor must be chosen such that the peak solar power is absorbed by the load at standard voltage. Therefore, load resistance is set at a value of 27Ω and standard per phase load voltage amplitude is taken as 40 V. In this condition, plot of obtained SPV simulator characteristic, load voltage and current, PWM waveform of boost converter, and DC bus voltage is shown in Figure 10. The power output of PV simulator is 90 W. Thus, expected value of peak power is achieved due to setting of maximum loading conditions as mentioned above. The amplitude of load voltage and current are found as around 40 V and 1.47 A \((40 V/27\Omega)\), respectively. The obtained value of DC bus voltage is 100 V (selected value of DC bus voltage in experimental set up). The controlled duty

![Figure 10](image_url)

**Figure 10** (A) SPV characteristic, (B) three-phase load voltage (50 V/div) and per phase current (2 A/div), and (C) PWM waveform (D = 50%) and DC link voltage (100 V/div) under nonmaximum power (60 W) condition
ratio is around 0.4974 p.u. (1 − [50.26/100]), that is, within set value of saturation limit (0.5 p.u.). Responses of Figure 10 establish that the calculated saturation limit of duty ratio in experimental study does not hamper maximum power point operation, that is, proposed concept does not restrict MPPT operation under maximum loading condition.

Next, the operation under nonmaximum power situation is performed in hardware platform. Therefore, load resistor is increased to 40 Ω at standard load voltage of 40 V (reduction of load current) to set nonmaximum operating point. Here, the same characteristic of SPV simulator is retained as stated in previous paragraphs. Figure 11 shows responses of various variables under the non-maximum power condition. The amplitude of load current in Figure 11 is 1 A, that is, desired value. Here, three-phase power output of SPV simulator is close to 60 W at 40 Ω load and it indicates non-maximum power operation of SPV simulator. At solar power of 60 W, the corresponding output terminal voltage of SPV simulator is 57 V as per its characteristic. In Figure 11, the DC link voltage is obtained as around 114 V due to restriction by saturated duty ratio (0.5 p.u.), that is, $57 / (1 − 0.5) = 114$ V. This value is less than maximum limit of DC bus voltage (120 V). Therefore, Figure 11 demonstrates stable nonmaximum power operation with suggested logic.

It is appeared from the above simulation and experimental results that suggested logic justifies battery failure detection-less approach for maintaining stable and wide range of loading operation (both maximum and non-maximum loading conditions).

5 CONCLUSION

In this article, proposed logic avoids instability of MPPT-based stand-alone SPV system during disconnection/failure of battery and simultaneously, supply of nonmaximum load powers by the SPV is assured. Involvement of dump load or load power estimation or separate algorithm is not required in proposed concept. Here, stable and safe DC link voltage is ensured through restricted MPPT logic. Conceptually, MPPT algorithm is operated as non-maximum power tracking algorithm by adopting all-time saturation limit. The procedure for determining the saturation limit for sustained operation is described in respect of feasible range of operation of SPV. The proposed solution also supports wide range of operations of stand-alone SPV system under variations of both solar and load power conditions. Both simulation study and hardware implementation demonstrate usefulness of proposed technique in stand-alone SPV system. Here, the proposed approach is independent of detection process of battery failure, alike conventional approach. Thus, it is faster to operate and does not depend on accuracy of detection method.

CONFLICT OF INTEREST

Authors have no conflict of interest relevant to this article.

ORCID

Pritam K. Gayen https://orcid.org/0000-0003-2599-4905

REFERENCES

1. Perveen G, Rizwan M, Goel N. An ANFIS-based model for solar energy forecasting and its smart grid application. Eng Rep. 2019;1(5):1-29.
2. Diouri O, Es-Shai N, Errahimi F, Gaba A, Alauoi C. Modeling and design of single-phase PV inverter with MPPT algorithm applied to the boost converter using back-stepping control in standalone mode. Int J Photoenergy. 2019;2019:1-16. https://doi.org/10.1155/2019/7021578.
3. Pehlivanturk C, Ozkan O, Baker DK. Modeling and simulations of a micro solar power system. Int J Energy Res. 2014;38(9):1129-1144.
4. Baral S. A study of effects on economic indicators for different heat source temperature on thermal storage-based solar organic Rankine cycle system. Eng Rep. 2020;2. https://doi.org/10.1002/eng2.12102.
5. Reichelstein S, Yorston M. The prospects for cost competitive solar PV power. Energy Policy. 2013;55:117-127.
6. Philip J, Jain C, Kant K, et al. Control and implementation of a standalone solar photo-voltaic hybrid system. IEEE Trans Ind Appl. 2016;54(4):3472-3479.
7. Maddalena ET, Moraes CGS, Bragança G, et al. A battery-less photovoltaic water-pumping system with low decoupling capacitance. IEEE Trans Ind Appl. 2019;55(3):2263-2271.
8. Singh B, Sharma U, Kumar S. Standalone photovoltaic water pumping system using induction motor drive with reduced sensors. IEEE Trans Ind Appl. 2018;54(4):3645-3655.
9. Chernaya MM, Shinyakov YA, Osipov AV. Spacecraft power system. Proc 17th Int Conf on Young Specialists on Micro/Nanotechnologies and Electron Devices (EDM). Erlagol (Altai Republic), Russia: Institute of Electrical and Electronics Engineers (IEEE); 2016.
10. Onose B-A, Hanek MA, Vataselu G, et al. Advanced modular photovoltaic system for plug-in small electric vehicles (PsEV). Proc IEEE EV, Bucharest, Romania; 2017.
11. Padmagirisan P, Sankaranarayanan V. Powertrain control of a solar photovoltaic-battery powered hybrid electric vehicle. Front Energy. 2019;13:296-306.
12. Debnath D, Chatterjee K. Transformer coupled multi-input two stage stand alone solar photovoltaic scheme for rural areas. *Proc IEEE IECON*, Vienna, Austria; 2013;7028-7033.

13. Debnath D, Chatterjee K. Two-stage solar photovoltaic-based stand-alone scheme having battery as energy storage element for rural deployment. *IEEE Trans Ind Electron*. 2015;62(7):742-750.

14. Park S-J, Shin J-H, Park J-H, et al. Dynamic analysis and controller design for standalone operation of photovoltaic power conditioners with energy storage. *J Electr Eng Technol*. 2014;9(6):1532-1541.

15. Siraj K, Awais M, Khan HA, et al. Optimal power dispatch in solar-assisted uninterruptible power supply systems. *Int Trans Electr Energy Syst*. 2019. https://doi.org/10.1002/2050-7038.12157:1-15.

16. Xiao J, Bai L, Lu Z, Wang K. Method, implementation and application of energy storage system designing. *Int Trans Electr Energy Syst*. 2014;24(3):378-394.

17. de Brito MAG, Galotto L, Sampaio LP, e Melo GA, Canesin CA. Evaluation of the main MPPT techniques for photovoltaic applications. *IEEE Trans Ind Electron*. 2013;60(3):1156-1167.

18. Abo-Elyous FK, Abdelshafy AM, Abdelaziz AY. MPPT-based particle swarm and cuckoo search algorithms for PV systems. *Modern Maximum Power Point Tracking Techniques for Photovoltaic Energy Systems*. Cham, Switzerland: Springer; 2020. https://doi.org/10.1007/978-3-030-05578-3_14.

19. Ponkarthik N, Kalidasa MK. Performance enhancement of solar photovoltaic system using novel maximum power point tracking. *Int J Electr Power Energy Syst*. 2014;61:194-201.

20. Atawi IE, Besheer AH. The effect of modeling types characterization for PV power source on maximum power point tracking. *IEEE J Trans Electr Electron Eng*. 2016;11(S1):S49-S56.

21. Nguyen AT, Chaitusaney S, Yokoyama A. Optimal strategies of siting, sizing, and scheduling of BESS: voltage management solution for future LV network. *IEEE J Trans Electr Electron Eng*. 2019;5(14):694-704. https://doi.org/10.1002/tee.22856.

22. Abu-Rub H, Iqbal A, Moin Ahmed S, Peng FZ, Li Y, Baoming G. Quasi-Z-source inverter-based photovoltaic generation system with maximum power tracking control using ANFIS. *IEEE Trans Sustain Energy*. 2013;4(1):11-20.

23. Gunlu G. Dynamically reconfigurable independent cellular switching circuits for managing battery modules. *IEEE Trans Energy Convers*. 2017;32(1):194-201.

24. Thang TV, Ahmed A, Kim C-I, Park JH. Flexible system architecture of stand-alone PV power generation with energy storage device. *IEEE Trans Energy Convers*. 2015;30(4):1386-1396.

25. Kellogg WD, Nehrir MH, Venkataramanan G, Gerez V. Generation unit sizing and cost analysis for stand-alone wind, photovoltaic, and hybrid wind/PV systems. *IEEE Trans Energy Convers*. 1998;13(1):70-75.

26. Das M, Agarwal V. Novel high-performance stand-alone solar PV system with high-gain high-efficiency dc–dc converter power stages. *IEEE Trans Ind Appl*. 2015;51(6):4718-4728.

27. Sangwongwanich A, Yang Y, Blaabjerg F. High-performance constant power generation in grid-connected PV systems. *IEEE Trans Power Electron*. 2016;31(3):1822-1825.

28. Yang Y, Blaabjerg F, Wang H. Constant power generation of photovoltaic systems considering the distributed grid capacity. *IEEE Applied Power Electron Conf and Expos - APEC 2014*. Fort Worth, TX: IEEE; 2014:379-385.

29. Ramaiah AB, Maurya R, Arya SR. Bidirectional converter for electric vehicle battery charging with power quality features. *Int Trans Electr Energy Syst*. 2018;28(9):1-19.

30. Rasin Z, Rahman M. Control of bidirectional DC-DC converter for battery storage system in grid-connected quasi-Z-source pv inverter. *IEEE Conf on Energy Conver (CENCOn)*. Johor Bahru, Malaysia: IEEE; 2015.

31. Online website: https://in.mathworks.com.

**How to cite this article:** Gayen PK, Saha S. Failure detection-less approach for wide sustained operation of MPPT based stand-alone solar photovoltaic system during failure/disconnection of battery. *Engineering Reports*. 2020;2:e12139. https://doi.org/10.1002/eng2.12139