ISLANDING OPERATION AMONG SOLAR HYBRID SYSTEM AND GRID-TIED PV SYSTEM IN BUILDINGS

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Abstract—
In the solar hybrid system including PV and battery storage they supply electricity to building at the on grid and off grid condition. The integrate grid tied PV system they improve the un -integated operation .To charge the battery in off grid mode many hybrid on/ off grid grid inveters are not allow. To prevent excessive power to the grid tied to the inverters. The combination of smart meter and solar irradiance sensor which used in this work. DIgSILENT Power Factory software which is used for performance of islanding operation among solar hybrid and grid tied PV system.

Keywords—Islanding , Photovltaic, Generation

Introduction
Distributed Generation (DG) continues to gain emphasis profit from electric utilities and customers. DG is small-scale electric power source, that connects point of consumption or to the customer side of the meter, in a Distribution Network (DN) [1, 2]. A number of electrical power sources are available on a larger scale that causes suitable for on-site generation in buildings. Renewable energy sources, such as solar photovoltaic (PV) panels, which are particularly suited to building integration, and small scale wind turbines. In addition, combined heat and power (CHP) systems may be installed in larger buildings.
Large no. of power sources are suitable so that causes they makes suitable to the generation in buildings. There are various renewable energy sources are available like PV panel which are suitable for building integration . The integration of PV system give benefits like saving the electricity cost as well as power quality improvements. Solar hybrid system including the PV panel and battery storage system .The solar hybrid system provide continuous electricity to the building when electricity outage. The PV array system in large scale solar hybrid system they have there power converter and connect to the electricity system separately . But another side PV array and battery storage small amount of solar hybrid system which are integrated to the main grid through solar hybrid grid inverter .At on/off grid this inverter which is used . In islanding operation there is challenge like keep the constant power supply.

2. GRID-TIED PV INVERTER AND SOLAR HYBRID ON-OFF GRID INVERTER
The configurations of grid-tied PV inverter and solar *hybrid on/off grid inverter are shown in Figure 1. A PV panel -side DC/DC converter captures the maximum power from the solar irradiance according to the maximum power point tracking (MPPT) algorithm. In case of solar hybrid on/off grid inverter, it includes a battery – side DC/DC converter to control the charging/discharging of energy storage.*
During the grid-connected operation, the grid-side DC/AC inverter is able to convert DC power from PV. arrays/battery to AC power and then synchronizing with the distribution system via the grid interface control. Apart from injecting power to the network, the grid-side inverter of solar hybrid system can absorb the power from the main grid for charging the battery.
In the event of loss of grid voltage, the typical grid-tied PV inverter is forced to disconnect via the anti islanding protection. While the solar hybrid on/off grid inverter remains connected and then switched the operation from grid-following mode to grid-forming mode to provide the references for system voltage and frequency during islanding operation. Based on decentralized control [17], [18], the droop control methods are applied to control active and reactive power of solar hybrid on/off grid inverter. The frequency-droop and voltage-droop characteristics can be written as; methods are applied to control active and reactive power of solar hybrid on/off grid inverter. The frequency-droop and voltage-droop characteristics can be written as; where P and Q are the active and reactive powers produced by the inverter, KP and KQ are the droop gains, $f0$ and $V0$ are the reference frequency and voltage.
When the solar hybrid on/off grid inverter is working in the off-grid mode, the PV array will provide power to the load first and then charge the battery. In addition, if there is exceeding PV power after supporting the load, it will charge the battery first, as shown in Figure 2 (a). However, the battery cannot be charged by other energy sources such as diesel generator, until the PV power is unavailable. On the other hand, the battery will discharge power to the load if the PV power is insufficient (see Figure 2 (b)).
In a case that the battery power is running out and the PV power is not enough to supply load, the load will be disconnected. The electricity supply is then interrupted, and the outage event may happen. Only PV power can provide

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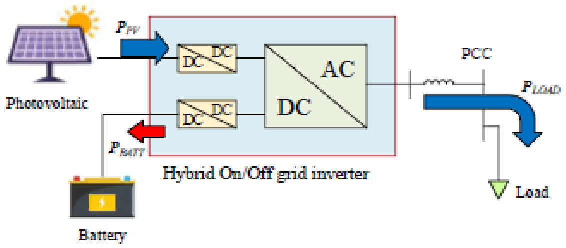
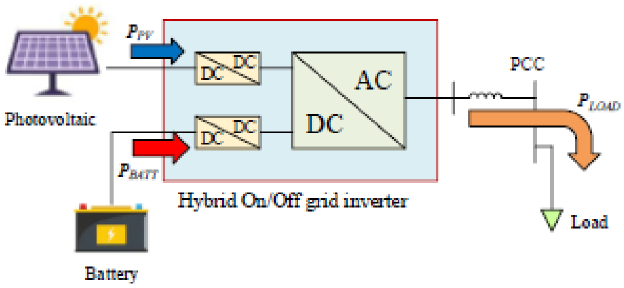
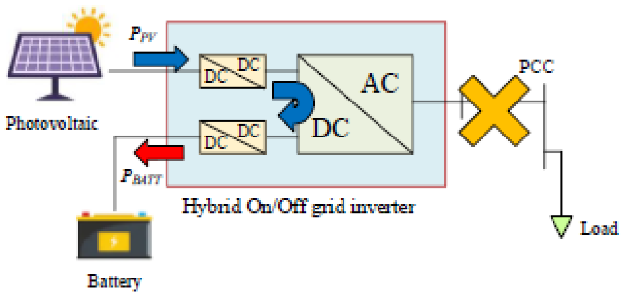
the battery charging, as presented in Figure 2 (c). When it reaches the acceptable level of battery, the load is therefore reconnected, and the solar hybrid system will resume supplying power to the load.
The grid-tied inverter is possible to resynchronize with the isolated system, after the solar hybrid on/off grid inverter can supply load properly. However, it needs to ensure that the supporting power from the other inverter will not lead the excess injection to the system which cause the abrupt changes in system voltage and frequency. Therefore, the active power curtailment control is necessary for allowing the grid-tied inverter to be included in the islanding operation.



(a) PV supplies power to load and then charging the battery.



(b) Both PV and battery supply power to load



(c) PV provides the battery charging after the battery ran out

Fig. 2. The operation of solar hybrid on/off grid inverter in off-grid mode.

3. POWER CURTIALMENT CONTROLLER

A particular power curtailment controller is introduced to prevent the exceeded power of grid-tied PV inverter during islanding operation. It is the real-time control which requires the combining information of load consumption and PV output of solar hybrid on/off grid inverter. In addition, the load consumption is measured by high resolution power meter and the PV output of solar hybrid on/off grid inverter is estimated via the solar irradiance measured by the pyranometer. The real time data is accordingly sent to the power curtailment controller via communication system, for determining the suitable PV output of grid-tied inverter, as demonstrated in Figure 3. From Figure 3, the PV power of solar hybrid on/off grid inverter (*PPV,hybrid*) is calculated by using the measured solar irradiance. It is adapted from the PVWatts manual [19] which the impact on cell temperature is neglected. The predicted PV output, predict *P PV*, at time, *t*, can be written as; where Itr is solar irradiance (W/m2). Pdc0 is the nameplate DC rating of PV array is the DC-to-AC derate factor. If the size of PV array of solar hybrid system and grid-tied PV system is known, the PV outputs of those systems can be predicted by using (2)
and then written in terms of predict PV,hybrid P and predict PV,grid tied P respectively.
After the grid-tied inverter can re-synchronize with the islanded electricity system, The PV power will supply to the system only when the load consumption, PLOAD, is higher than predict PV,hybrid P . Therefore, the grid-tied inverter's PV power set-point, PPV,grid-tied is considered as; real operation, a small amount of power from the battery may be

required to secure the power balancing mechanism due to the error from the prediction and some power losses, such as line loss, which are not included in (2) to (5).

The performance of proposed power curtailment algorithm is examined based on computer simulation in DIgSILENT *PowerFactory* environment. The test system is a building made up of solar hybrid on/off grid inverter and grid-tied PV inverter. The measured data in Thailand is used to generate the daily load profile and solar irradiance profile. To demonstrate PV power curtailment potential, an islanding condition is established by disconnecting the building from the main grid during periods when aggregated PV generation exceeds load usage. The PV power outputs of the solar hybrid on/off grid inverter and the grid-tied PV inverter, as well as the battery condition, are investigated in two scenarios: 1) the grid-tied PV inverter is not included in the islanding operation, and 2) the grid-tied PV inverter with power curtailment is included in the islanding operation.

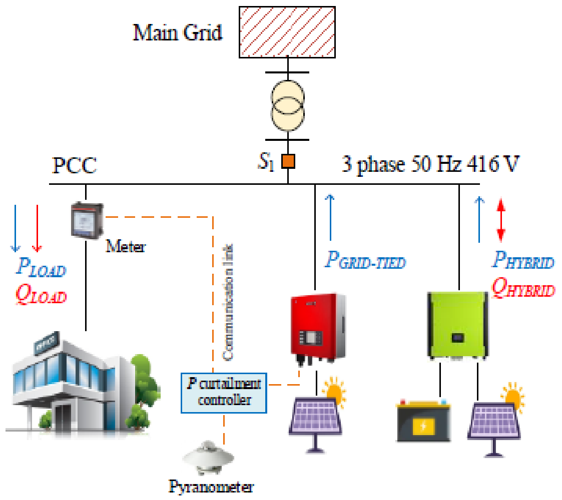


Fig. 3. The proposed active power curtailment controller.

4. TEST SYSTEM

Based on Figure 3, the experimental building which connects to a three-phase 416 V, 50 Hz distribution network, has been tested in this study. In addition, the 5 kW/5 kWh solar hybrid system and 5 kW grid-tied PV system are installed in this system. The size of inverter in both systems is 5 kVA and the battery is a gel type.

The characteristic of daily load demand is shown in Figure 4. While the 24 hour - solar irradiance and power generation of 5 kW PV system, calculated by using (2), are demonstrated in Figure 5

During the grid-connecting operation, solar hybrid on/off grid inverter and grid-tied PV inverter have been operating at the maximum power point to supply PV powers into the system as much as possible which are at a constant power factor of 1.0. In this test, the reverse power flow occurred by the PV generation exceeds the load demand is permitted. In on-grid mode, the battery is fully charge at 80% of state of charge (*SoC*) all the time.

Additionally, the battery can be charged either by PV power of the solar hybrid on/off inverter or absorbing power from the grid.

The main grid is separated by disconnecting the switch *S*1. Assuming the loss of grid supply occurs between 9.00 a.m. and 17.00 p.m., on the same day (11 hours of islanding condition). During the islanding operation, the solar hybrid on/off grid inverter is operated in grid-forming mode to provide the system frequency and voltage regulations

To maintain power balancing mechanism, the solar hybrid system needs to deal with the changes of active and reactive powers consumed by the load. The main power generation is from the PV array, while the battery will supply power only when the PV generation of hybrid system is inadequate

In off-grid mode, the battery cannot be charged from the other energy sources if the solar hybrid on/off grid inverter is supplying electricity into the islanded system. The solar hybrid system can support electricity supply until the battery *SoC* is lower than 20 %. Hence, the solar hybrid on/off grid inverter is pulled out from the system. During this time, no electricity is supplied to the load. The solar hybrid on/off grid inverter resumes supplying the electricity, after the battery is charging by PV power of solar hybrid system until the *SoC* is 80%.

After the main grid is reconnected by closing the switch *S*1, solar hybrid on/off grid inverter and grid-tied PV inverter return to grid-following mode and therefore feeding PV power at the maximum power point. If the battery level is lower than 80%, the battery will be charged suddenly. In order to charge the gel-type battery with a reasonable time, it is recommended that the charging power should be 15 to 25 % of the battery capacity [20].

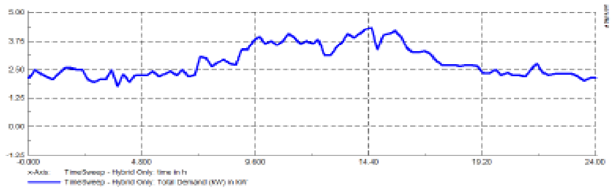
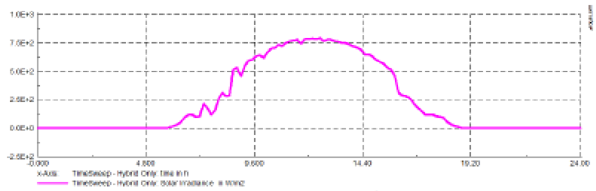
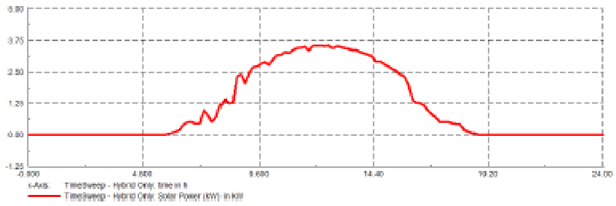


Fig. 4. Daily load profile.



(a) Solar irradiance (W/m2)



(b) Predicted PV power (5 kW capacity).

Fig. 5. Daily solar irradiance and predicted power generated by 5 kW PV system.

5. SIMULATION RESULTS AND DISCUSSION

The performance of islanding operation is investigated in two scenarios, with and without the supporting from the grid-tied PV system, by using the 24-hour time sweep load flow calculation on DIgSILENT PowerFactory software. The simulations are on 1minute time step. The results from computer simulation are discussed as followings

5.1 Case 1: The Grid-Tied PV System is Not Included in Islanding Operation

In this case, only solar hybrid on/off grid inverter supports electricity supply during in the event of loss of grid voltage. The simulation results are in Figure 6 to Figure 9. Voltage at the PCC and supplied load are shown in Figure 6. PV powers of solar hybrid on/off grid inverter and grid-tied PV inverter are presented in Figure 7. The battery charging/discharging and the level of *SoC* are illustrated in Figure 8. The flow of active and reactive powers through the solar hybrid on/off grid inverter is demonstrated in Figure 9.

After the islanding is detected, at 9.00 a.m., the grid-tied PV system is disconnected while both PV and battery in the solar hybrid system can smoothly supply electricity power to the load. It can be seen that the solar hybrid system can support active and reactive powers, without any interruptions, only for 5 hours 24 minutes.

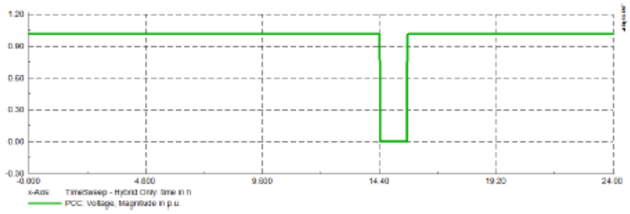
In addition, at 14.30 p.m., the battery level is lower than 20 % and then the solar hybrid system is disconnected causing the load is unsupplied.

The loss of electricity supply occurs around 1 hour for charging battery by PV power until the *SoC* reaches 80 %. Since 15.30 p.m., the solar hybrid system can resume supplying electricity to the load. After the main grid is reconnected at 17.00 p.m., the grid-tied PV system is able to re-supply power to the grid. Due to the *SoC* is lower than 80 %, the battery is then charging with the rate of 1 kW charging power (20% of battery capacity). It can be seen that the active power is flowing back through the solar hybrid on/off grid inverter, during the on-grid charging process.

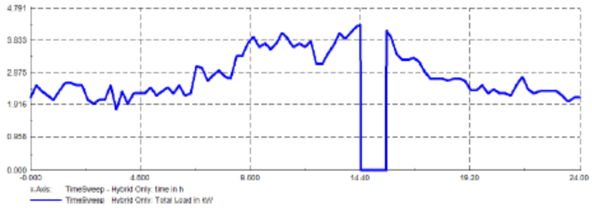
5.2 Case 2: The Grid-Tied PV System with Power Curtailment Control is Included in Islanding Operation

The supporting from the grid-tied PV system with additional power limit control during islanding operation is demonstrated in Figure 10 to Figure 13. The power curtailment controller, as explained in Section 3, can adjust the output of grid-tied PV system to maintain the balance between power generation and load consumption, effectively. With the support from grid tied PV system, the battery will provide a lower power supply when comparing to the case 1. It also showed that the battery increased the discharging power significantly after 16.00 p.m., since the PV generation is dramatically dropped in the late afternoon due to low solar irradiance

Furthermore, it is found that the integration of grid-tied PV inverter with solar hybrid on/off grid inverter for islanding operation can enhance the uninterrupted operation in the building. In this test, with the small amount of power supplied by battery, the islanding operation can provide continuing electricity supply without interruption. Additionally, the battery *SoC* was slightly reduced since the energy stored in the battery was used only about 25% of its capacity, during the loss of grid voltage.

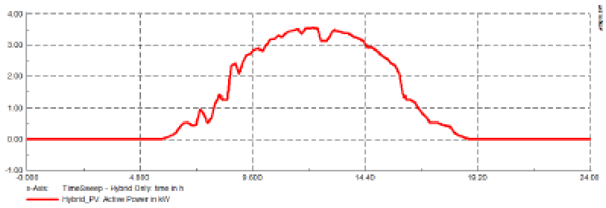


(a) Voltage at PCC.

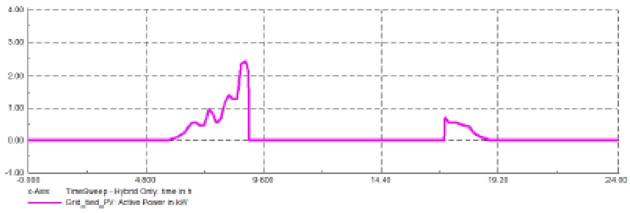


(b) Supplied load.

Fig. 6. Voltage at PCC and supplied load in Case 1.

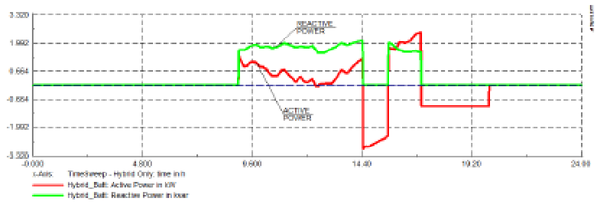


(a) PV power of solar hybrid on/off grid inverter

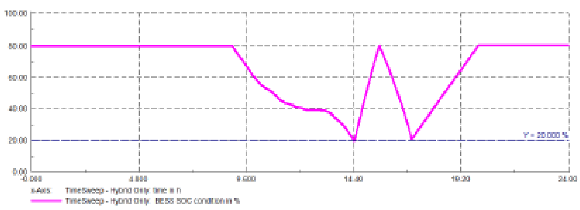


(b) PV power of grid-tied PV inverter.

Fig. 7. PV powers supplied by solar hybrid on/off grid inverter and grid-tied PV inverter in Case 1.



(a) Active and reactive powers of battery



(b) Battery %*SoC*.

Fig. 8. Battery power and the level on *SoC* in Case 1

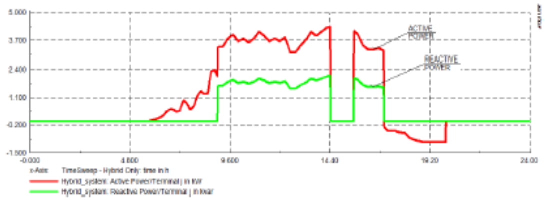


Fig. 9. Active and reactive powers of solar hybrid on/off grid inverter and grid-tied PV inverter in Case 1.

The proposed power curtailment controller attempts to automatically adjust the power set-point in power limiting function found in many commercial grid tied PV inverters, in order to balance PV generation and load demand during off-grid condition. It is found that the use of load consumption and solar irradiance information for power limiting control, comparable to the usage of *P/f* droop controller [6], [17], [18], can also prevent the surplus PV feeding in isolated system effectively.

As a result, the system frequency and voltage may be kept within the statutory limits. The controller, measuring instruments, and communication system, on the other hand, must be fast enough to deal with rapid variations in load demand and solar irradiation. Furthermore, the safety margin would be considered, with the power output of the grid-connected PV inverter being lower than the predicted value in (4) to guarantee that no excess PV injection occurs.

Conclusion

The study found that the combination of smart meter and solar irradiance sensor which is power curtailment controller they allow the grid-tied PV inverter which colllaboration to solar hybrid to avoid exceeding PV generation during islanding operation based on the simulation results, active power controller can successfully adjust. Identify applicable funding agency here. If none, delete this text box.

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