A Smart System for Managing Solar Panels Installed on Grid

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Abstract. This paper presents a smart system prototype, which is on an Arduino platform, to managing solar panels and batteries installed on grid in a household. The batteries here are as storage of surplus power produced by solar panels in supplying loads. The aim of employing a smart system is to reduce use of power consumption from grid maximally and to increase the lifetime of batteries. In the lab project experiment, we used some lamps with a 40 watt of the total of power to representing electric loads in a household and three power sources that are a power grid using PLN, a solar panel with a 50-watt power output, and a 100Ah Battery. All of the power sources and the load connect in parallel, and operate in DC circuits with 12 Volt of operational voltage. One of some testing, which was done about ten testing cases, showed that when the battery was in full charging, and the panel produced a maximum power, there was no power coming out from the grid to supply the loads instead the panel was solely supplying the loads. Employing a smart system to manage solar panels on grid gives a highly significant advantage because the system programmed can do complex controls.

1. Introduction

There are two general methods in installing solar panels in a household. The first one, which usually take place in a rural area where there is no a connecting grid, is called off grid. In this method \cite{1}, the solar panels installed work without getting support or backup from a grid, when they supply power into electrical loads. A grid in this context can be seen as a huge electrical network provided by a big company which is usually a state company like PLN in Indonesia and it never stops to operate. The second method named on grid \cite{2} the solar panels work with the grid together in supplying electrical power for electrical loads. The main reason to install the solar panels when a grid already installed in a household is to reduce the use of electrical power from the grid so a consumer will pay less for his electric consumption.

In the on grid, the solar panels installed parallel with the grid in a household have the first priority to serve the load, as a case that if they produce electricity in which is able to fulfil the entire of a load need, then the grid do not give its power to the load. In one condition, when the solar panels cannot totally provide electrical power for the load by themselves, the grid will join to give a portion of power together with the solar panels. Shortly, giving an assumption that the load needs 40-watt power, the solar panels produce 30-watt power, then the grid has to give 10-watt of its power.

To make this method having most power benefit in reducing electric bill, some additional storage devices like batteries should be used. When the solar panels produce a lot of power energy, but in one condition there is no much needed power of the load, then some of power energy produced by panels will be wasted. This wasted energy should be storied in batteries to make this method giving more beneficial effects \cite{3}. An easily calculated case to make this having sense of understanding is by assuming the panels produce 40-watt of power, the loads just consume power as much as 10 watt, so meanwhile the batteries store the 30 watt power surplus, no power is produced by the grid.
Unfortunately, a battery has a lifetime which depends on how many times of charging process are on
the battery. To get a long lifetime of a battery and to use maximally the produced power, solar panels
need a smart system. This smart system, based on Arduino Microcontroller platform, manage the solar
panels installed on grid method to having the best performance. A state machine to design real time
complex algorithms was applied to make the system working reliably. Without a smart system to manage
solar panels on grid, installing solar panels in a household just give a cost than a profit [4].

In different method with other projects like in [3] that allows power flowing in the grid in two
directions, this smart system does not allow power flowing to the grid in a bidirectional way, and instead
power flows from the grid without having a chance to flow back. This method will be suitable for a
household installing solar panels in a small scale because a household does not need to install an
additional device that a company of an electric grid provider usually requires. To run this smart system,
we used the \textit{on grid} works in DC circuits with an operational voltage, 12 Volt. Working in DC is easier
to testing our smart system, and for the future project this smart should be tried in AC.

The smart system, which was done, in this research project contains smart algorithms in which all
the algorithms are written in C language and uses an Arduino microcontroller as a hardware chip. To
recognize the maximum power produced by solar panels, and decide actions the smart system should
take in controlling panels, batteries, and the grid, the Perturbation and Observation (P&O) algorithm
had been implemented on the system [5]. The best time to charging and discharging, so the lifetime of
a battery is durable, was handled by utilizing the algorithm of Energy Time Shift (ETS) [6].

2. A Model of Solar Panels on Grid
The smart system prototype to control solar panels installed on grid in our research project was not built
from basic electronic components. Some parts of the system electronic module boards which available
a lot on the market were used. The circuit schematic for system on grid is discussed in [7]. In some
blocks of the schematic, the MPPT circuit block, which is using switch IGBT controlled by Incremental
Conductance, is presented on [8]. Another MPPT with Perturb and Observe algorithm is on [5]. This
block is a Chunk converter, which is a DC-DC converter to transmit power by using ideal switches.

![Diagram of Solar Panels on Grid](image-url)

**Figure 1.** The model of solar panels installed on grid with a smart system included to manage the electric power flow in advantages to get a reducing power consumption from a grid.

The model of a smart system, proposed in this paper, is shown in Figure 4. The electric power is
provided absolutely from grid, which is represented by a state electric company, PLN. As the power
flow only from the grid and are not allowed to flow back to entering the grid, this system is different
with the others, which is generally allowing the power of energy surplus into the grid [2] [9] [10]. The
converter converts AC power from the grid to DC power output, and the output will be connected
parallel with the output of the solar panel, the loads and the battery.
The power flow, as presented in Figure 2, demonstrates how solar panels, a grid, and a battery work together to supply the required power to household loads. The converters in the solar panels convert the variable DC voltage output from the panels, typically around 10-14 Volts, to a 12 Volt operating voltage for the grid system tested in this lab project. The power flows out from solar panels and never returns. An AC-DC converter is needed to convert the 220-Volt AC voltage of the Indonesian grid into 12-Volt DC voltage in the grid side. The output voltage is used as a reference for the system and as an absolute power resource to ensure the loads never suffer power deficits. On the battery side, the converter plays a significant role in charging the battery. A digital interface is embedded in each converter to facilitate communication with the main controller embedded with smart managing algorithms.

The detailed flow of power is illustrated in Figure 2, showing the integration of solar panels, batteries, loads, and a grid in parallel. This figure highlights how solar panels, a grid, and a battery collaborate to meet the power needs of household loads. Every source has a converter with distinct functions. The solar panel converter transforms the variable DC voltage output from the panels, typically around 10-14 Volts, to a 12 Volt operating voltage for the grid system tested in this lab project. The power flows out from solar panels and never returns. An AC-DC converter is employed in the grid side to convert the 220-Volt AC voltage of the Indonesian grid into a 12-Volt DC voltage. This converter's output voltage serves as a reference for the system and a guaranteed power resource that prevents load power deficits. On the battery side, the converter is crucial for charging the battery. A digital interface is embedded in each converter to enable communication with the main controller embedded with smart managing algorithms.

Figure 3 illustrates the schematic circuit of solar panels on grid proposed for research by [7].
In this experimental lab research, we used the buck-boost converter, which is widely available on market, nowadays. This converter is having a controlling digital input in which it is connected into the Arduino as the main controller. By using Arduino to control the converter, we can set the maximum current flowing out from the converter. The voltage of this converter automatically adapt to the reference voltage which is the voltage from the converter of the grid side. The converter of solar panels and the converter of the battery act as a current source in a parallel circuit with the converter of the grid acting as a voltage source. As a current source, these converters have a priority to supply current as much as determined by the main controller. In this research project we used converter that having 5-Amp maximum current output so maximum power that can be delivered is 60 watt, which the operation voltage of system is 12 Volt.

![Figure 4. The circuit of the dual-stage boost converter](image)

![Figure 5. A buck-boost converter to convert variable DC voltage to 12 Volt](image)

3. The Smart System on State Machine

Making the design of system easily to read and to develop, this paper presents using a state machine diagram. This system is having three state machines, and each for controlling the battery, controlling the solar panel, and as a main controller which communicate to each other through triggers appeared in the state machine. The state machine of battery controlling monitor of the battery condition and the blocking and opening of power flowing.

![Figure 6. The main state machine which is a design of managing the system overall](image)

In different function, the state machine for controlling the solar panel is a design to describe how the flow of process of controlling. The maximum of power produced by solar panels are monitored, which the information will be used as a trigger in the main state machine. The main state machine is a design to draw process in managing the system overall. We code these entire state machines using Arduino Due, which is based on a 32 bit ARM microprocessor.
4. Results
In the testing process, we used lamps to represent the loads of a household, which the total power of the lamps, in the unit of watt was 40. In the first case within the 100% fully charged battery and the solar panel with a specification of 50 watt maximum output power in getting the full of sunlight, we got the data by seeing on the display of the system, that power flowed into the lamps was 40 watt, and then power came out from the panel as much as 40 watt also, but no power entered or exited from the battery and the grid. From the first case, a rough analysis can be made to know if the system already works appropriately. As the grid supplied a zero electric power to the lamps when the panel has a capability to supplying all the power that the lamps needed, this is a proving result of what we hope on the system.

| Case | P_{Solar} | P_{Battery In} | P_{Battery Out} | P_{Loads} | P_{Grid} | Percentage of The Charged Battery |
|------|-----------|---------------|-----------------|-----------|---------|----------------------------------|
| 1    | 40        | 0             | 0               | 40        | 0       | 100%                             |
| 2    | 20        | 0             | 0               | 40        | 20      | 0%                               |
| 3    | 50        | 0             | 0               | 40        | 0       | 90%                              |
| 4    | 50        | 30            | 0               | 20        | 0       | 20%                              |
| 5    | 30        | 0             | 0               | 40        | 10      | 40%                              |
| 6    | 10        | 0             | 20              | 30        | 0       | 90%                              |
| 7    | 0         | 0             | 40              | 40        | 0       | 90%                              |
| 8    | 0         | 0             | 40              | 40        | 0       | 70%                              |
| 9    | 0         | 0             | 40              | 40        | 0       | 40%                              |
| 10   | 30        | 0             | 0               | 40        | 10      | 10%                              |
Making the solar panel to produce 20 watt of power, emptying the charged battery to zero, and using the same loads as on the previous case, we did it intentionally for the second case of the testing process. By observing the results revealed on the system, there was no power flowing in or out of the battery, but as expected the grid generated 20 watt as amount of a power deficit produced by the solar panel to meet the total power that the loads needed. An analysis for this case explained that the system smartly did not let the power to flow into the battery, and because the power from the solar was not enough to supply the loads, then the grid had to support the deficit of power.

On the third case, we made the battery in that charged of 90% by measuring the voltage level of the battery, and the panel got a full of sunlight so it generate the maximum power output. Observation on the system showed that no power flowed into the battery despite the surplus power from the panel because the system manages to not charge a battery too often, and surely this work has a purpose to extend the battery life. Reducing the number of charging and discharging processes will increase the life time of a battery [11]. The system just wasted the surplus of the produced power instead of use it because of the battery life reasons.

![Image](image_url)

**Figure 9.** The product of a smart system to managing solar panels installed on grid

On setting the solar panel to produce 50 watt as the maximum it can produce and observing the charge of the battery about 20%, we, for doing testing of the fourth case, ensured there were power going to the battery while the load just needed 20 watt of power. The fifth case is for testing, if the system prevented the power coming out from the battery considering that the battery needed to be charged until it was full of charge. This showed the system made a decision in process to extend the life time of the battery [12]. When the battery was fully charged, it supplies totally the power requirement of the loads until the battery down to 10%, which this process was written on the seventh case.

5. **Conclusion**
The aims of this project to reduce power use from grid and to extend the battery life time were already employed on a smart system prototype. This smart system was built using a microcontroller, which is based on Arduino platform. It is easily programmed because supported by a lot of libraries, contains
some complex controls to make it having a powerful decision in managing. The system was already tested in a lab experiment, and the given results were appropriate of instructed. This system do not let the power flow into the grid to avoid a cooperation work with a grid company instead focusing to how reducing power use from a grid. In further research project, adding a prediction algorithm on the system will make the system more powerful in managing solar panels installed on grid.

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References
[1] S. Misak and L. Prokop, “Off-grid power systems,” 2010 9th Conf. Environ. Electr. Eng. EEEIC 2010, pp. 14–17, 2010.
[2] S. Narendiran, “Grid tie inverter and MPPT - A review,” Proc. IEEE Int. Conf. Circuit, Power Comput. Technol. ICCPCT 2013, pp. 564–567, 2013.
[3] N. K. Kim, H. J. Cha, J. J. Seo, and D. J. Won, “SOC management algorithm of battery energy storage system for PV ramp rate control,” 2017 6th Int. Youth Conf. Environ. Energy, IYCE 2017, 2017.
[4] G. Bhanu Prakash, A. R. R. Chandra, and P. P. Gupta, “Study of operational modes of a grid connected solar power generation with storage battery,” 2016 Int. Conf. Comput. Power, Energy, Inf. Commun. ICCPEIC 2016, pp. 477–481, 2016.
[5] N. Barua, A. Dutta, S. Chakma, A. Das, and S. S. Chowdhury, “Implementation of Cost-effective MPPT Solar Photovoltaic System Based on the Comparison between Incremental Conductance and P&O Algorithm,” Int. WIE Conf. Electr. Comput. Eng., pp. 143–146, 2016.
[6] S. A. Abdelrazek and S. Kamalasadan, “Integrated PV Capacity Firming and Energy Time Shift Battery Energy Storage Management Using Energy-Oriented Optimization,” IEEE Trans. Ind. Appl., vol. 52, no. 3, pp. 2607–2617, 2016.
[7] M. R. R. Mojumdar, A. M. W. Bhuiyan, H. Kadir, M. N. H. Shakil, and A. Ur-Rahman, “Design & Analysis of an Optimized Grid-tied PV System: Perspective Bangladesh,” Int. J. Eng. Technol., vol. 3, no. 4, pp. 435–439, 2011.
[8] A. Safari and S. Mekhilef, “Incremental conductance MPPT method for PV systems,” Can. Conf. Electr. Comput. Eng., pp. 000345–000347, 2011.
[9] S. Chakraborty and M. A. Razzak, “Design of a transformer-less grid-tie inverter using dual-stage buck and boost converters,” Int. J. Renew. Energy Res., vol. 4, no. 1, pp. 91–98, 2014.
[10] I. Ranaweera, S. Sanchez, and O. M. Midtgård, “Residential photovoltaic and battery energy system with grid support functionalities,” 2015 IEEE 6th Int. Symp. Power Electron. Distrib. Gener. Syst. PEDG 2015, no. 1, 2015.
[11] K. Thirugnanam, S. G. Kerk, C. Yuen, and S. Member, “Battery Integrated Solar Photovoltaic Energy Management System for Micro-Grid,” Innov. Smart Grid Technol. Asia, pp. 1–7, 2015.
[12] T. Kaur, J. Gambhir, and S. Kumar, “Arduino Based Solar Powered Battery Charging System For Rural SHS,” 2016.