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# Bidirectional Monitoring and Control Technology of Solar Photovoltaic Module Using Power Frame

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In this study, we proposed a power internet of things (PIOT) architecture using a power frame for power and communication, which was constructed by merely using voltage and current sensors and omitting communication modules. With this technology, the costs of constructing hardware can be decreased and the control process can be simplified. Solar energy is renewable, has low environmental impact, and is widely applied in various fields. However, it has low conversion efficiency and often requires a large amount of land and many solar panels, which increase the costs of constructing hardware and maintaining one. We proposed a concept relative to an object-oriented device (OOD) and Pu's count technology for constructing PIOT using a power frame, wherein solar photovoltaic modules (solar power panels) in PIOT were objectified to redesign an individual module monolith, and only voltage and current sensors were used, thereby sending a power frame for charging in the traditional DC bus and building a bidirectional monitoring technology between a management module and a solar power panel monolith without adding additional communication carriers and power sources. This can decrease the cost of communication carriers. In addition, because the solar power panel was considered as a monolith whereby the number of power generation devices can be randomly reduced, PIOT was built under a flexible solar power generation system to provide a low-cost platform with automated management. The power frame transmitted data of the solar photovoltaic module, and the power frame itself also had energy, thereby allowing a management module to recognize the classification of the transmitted energy and the quantity of electricity when the management module end received the power frame, which may serve as a basis for future power trading whereby a solar power trading platform can be developed in the future. Then, a testing platform that consisted of a personal computer, Arduino Mega2560, the packaged software Matlab®, and a power supply was established to simulate the solar power generation system and verify the feasibility of the theory via simulations and experiments.

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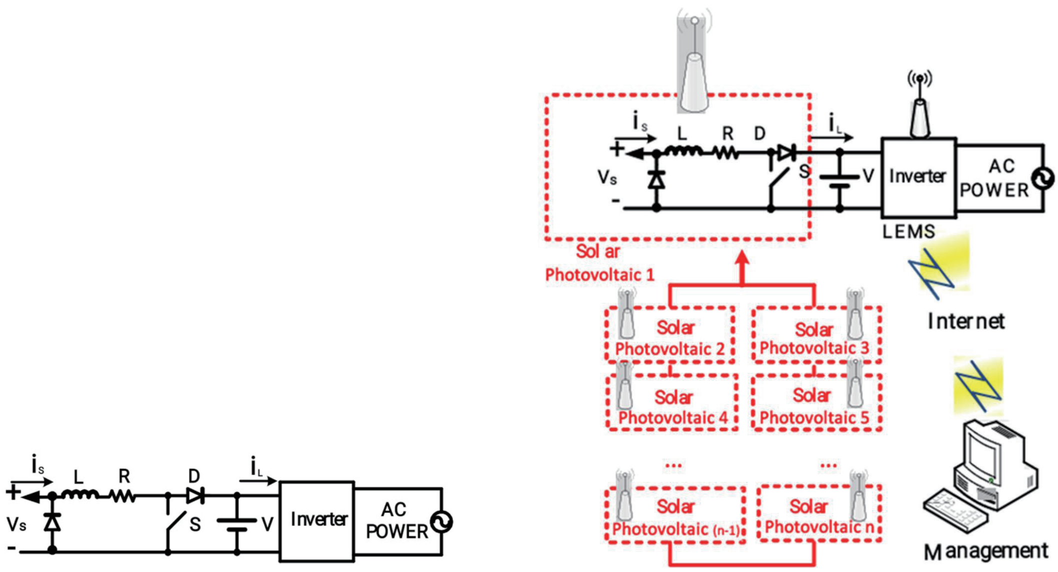
## 1. Introduction

Green energy such as solar energy is a type of energy generated from natural resources and does not pollute the environment during conversion into electricity. Thus, green energy has been extensively applied to replace fossil-fuel power and nuclear power in recent years.[1–3] Figures 1(a) and 1(b) show an architecture of a traditional solar panel. Because of its low power density, a large number of solar photovoltaic power panels are applied during electricity generation by the synthesis of series and parallel topologies to meet the required power demand and then using an inverter in connection with a large regional grid to provide AC power.[1–3] Figure 1(a) shows an architecture of a single solar power panel, wherein "V" and "Vs" represent the voltage of the storage battery and the output voltage of the solar photovoltaic power panel, respectively. "S", "L", "R", and "D" represent the power switch, inductance, resistance, and diode, and "$i_S$" and "$i_L$" represent the output current of the solar photovoltaic power panel and the input current of the inverter, respectively.

Furthermore, a large number of solar power panels are often needed, as shown, for example, in Fig. 1(b), in which the series topology is combined with the parallel topology for connection to meet the demand for electrical power. In terms of management, traditionally, a fixed number of solar power panels are divided into multiple regions. Each region includes a local energy management system (LEMS) center in conventional solar generation power systems, equipped with an inverter, which is responsible for the central management of power generation properties and safety maintenance and control relative to the corresponding region, and supplies loading poles to the region and the control from the energy management system (EMS). This combines a




(a) (b)

Fig. 1. (Color online) Traditional solar photovoltaic power generation system: (a) circuit architecture of LEMS and (b) architecture of EMS.

management system and other local control centers to become an EMS for attaining collaboration and outputting.(1,3) The inverter shown in the figure is often deemed to be a control center of the power-generating region, which integrates the power generation efficiencies of all solar power panels and records the final power generation quantity, and then transmits data to the management module system for the system dispatching or valuation.(4–11) However, when this hierarchical hardware management is adopted, the specifications of solar power panels need to be fixed and the installation thereof needs to be unchanged. Requisite communication devices are also installed to transmit the control command, where it increases both the cost of communication hardware equipment and the complexity of control and maintenance. Although studies on solar power generation have many facets to be discussed, the safety of power generation, fault diagnosis, troubleshooting, and human maintenance are still required.(4,5) Recent studies have focused on fault diagnosis and automation technology. Without considering the functional structure of the power supply, partial solar power panels were frequently subject to factors such as the covering of sundries or physical environments or attenuation elements of each power panel because the solar power panels occupied a large area.(7) These factors caused the amount of power generated by partial solar power panels to differ in the local region, with the result that the inner loop current or the power matching problem was easily incurred. These phenomena decreased the power generation efficiency and caused a hotspot effect in less severe cases, and the worst-case scenario was that a fire was caused by a short circuit.(4–7) In other studies, the researchers mainly monitored the output current of the solar power panels in series-parallel connection to diagnose fault points and then used a WiFi communication device to warn a remote controller.(1–6) Li et al. mainly used an infrared unmanned aerial device whereby the output current of the solar power panels was determined when thermal images were sent back via the communication to diagnose fault points.(7) In other studies, the power generation efficiency of the solar power panels covered with snow was investigated and the reasons why the solar power panels broke were analyzed.(4,5,8–11) Therefore, the mass power generation efficiency of the solar power panels and the safety monitoring demand have caused severe burdens on the solar power generation system, and automation was the main solution. Regarding automation, current studies were aimed at the automated maintenance of the solar power panel and the automated fault monitoring. The former was developed to reduce the cost of human maintenance. The latter was aimed at the safety maintenance of the system, and then, a communication module, such as Zigbee, Bluetooth, or Lonework, was used. In recent studies, WiFi communication technology has been used to send back the voltage and current values of the solar power panels to a controller whereby the positions and angles of the solar power panels were actuated and controlled to determine the maximum power point for solar power generation.(8–11) In some studies, Zigbee is used in remote monitoring application.(4,11) Generally, the communication module is classified into a cable mode and a wireless mode, both of which have advantages and disadvantages. The main disadvantage of the former involves the wiring and the main disadvantage of the latter involves the high cost of the architecture due to the more expensive wireless communication module.(12–14) In any event, both modes are easily subject to the interference of electrical signals. In some studies, the researchers installed a WiFi communication modules on the both solar power generator and inverter to transmit the information and execute a monitoring operation.[8–11] However, when the amount of power generation increased, the number of WiFi communication modules also increased, and this increased the number of IP addresses. The hardware cost of the communication platform always increases depending on the number of communication modules installed in this communication system.[8–11,12–14]

## 2. Principles

In reference to Fig. 1(a), in terms of solar photovoltaic power panels, the traditional solar power panels occupy a large area and are often connected in parallel and in series, which has been fixed for generating electricity for several decades, with the result that the places where solar photovoltaic power panels are disposed lay idle, and like nuclear power generation, power plants cannot have other applications. Accordingly, the disadvantage of the installation of solar power panels on the roof is that the house may not be rebuilt for several decades. In this study, we used a method of installing solar photovoltaic power panels in a random area to solve this problem. According to this method, an object-oriented device (OOD) was first adopted for reference. As shown in Fig. 2(a), the traditional architecture was divided into two independent modules, namely, a solar photovoltaic module and a management module. Each independent module was independently monitored by a micro control unit (MCU). Each independent solar photovoltaic power panel could also have special functions, so the solar photovoltaic power panels became movable objects capable of being randomly combined in a stacking mode whereby a power internet of things (PIOT) was constructed, and an area for power generation could be freely changed. Consequently, the problem that solar photovoltaic power panels have occupied roofs for several decades could be solved and even a solar power trading mode could be changed.

In reference to Fig. 2(b), the traditional solar photovoltaic power system does not recognize and record the amount of power generation of every solar photovoltaic power panel. Thus, it only uses a LEMS equipped with an inverter to collect the power converted by all solar photovoltaic power panels within a local region whereby AC power is acquired for supplying electricity to a small region and even to provide an interactive communication with a management center, thereby constructing an EMS used to control the load flow of a large region. However, this

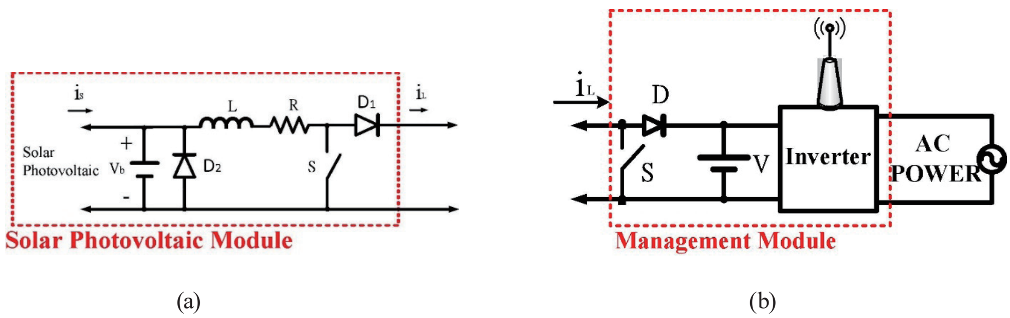



Fig. 2. (Color online) Architecture of object-based solar photovoltaic power panel: (a) solar photovoltaic and (b) management modules.

system does not know whether the specific solar photovoltaic power panels in the regions broke and fails to know the parameters relative to the power generation. To recognize the amount of power generation of every solar photovoltaic power panel, the solar photovoltaic power panel per unit, as shown in Fig. 1(b), needs to add one communication device, which, nevertheless, requires extra high cost for the communication system and greatly increases the complexity of the management.[4,6]

## 2.1 Communication method in PIOT

### 2.1.1 Method of transmitting electricity via solar photovoltaic module

In this study, the solar power panel per unit and the management unit were configured to bear a monolithic object independently, which, in practice, led to the architecture shown in Fig. 3(a). With regard to the solar photovoltaic module, when it sent power, the switch S1 of the module was directly controlled to implement steps (I) and (II). In step (I), switch S1 was in action, which was called a charging period, as shown in Fig. 3(a), where the electricity generated by the solar photovoltaic module was stored in the inductance, called step (I), and Eq. (1), based on time t as a variable, could be deduced according to Kirchhoff's law, and the current shown in Fig. 3(b) within this period, called step (II), could be deduced from Eq. (2).

$$L\frac{di_s}{dt}+Ri_s=V_s \tag{1}$$

$$i_S(t)=\frac{V_s}{R}-\left(\frac{V_s}{R}-i_1\right)e^{-Lt/R} \tag{2}$$

In step (II), switch S1 was not in action, which was called a conversion period, as shown in Fig. 3(b), where the energy stored in the inductance was transferred to the battery, and Eq. (2) could be deduced according to Kirchhoff's law.

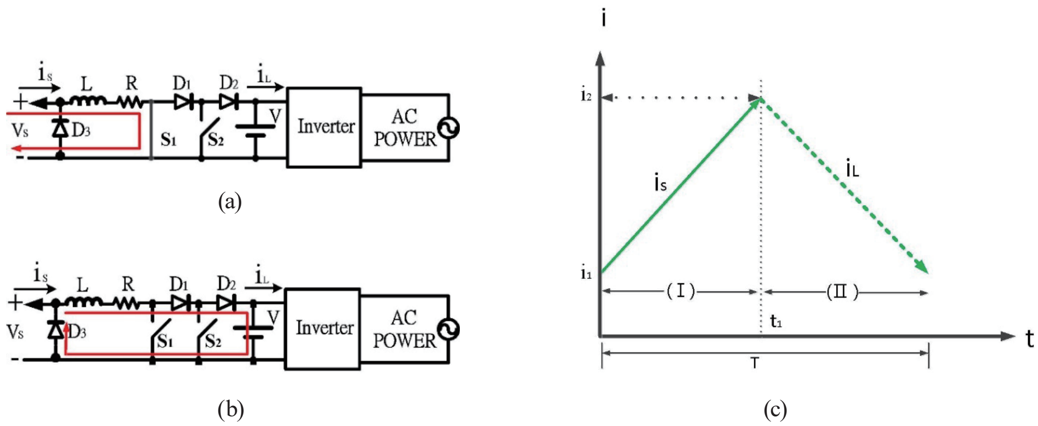



Fig. 3. (Color online) Charging architecture of object-based solar photovoltaic power system: (a) current flow route of charging period, (b) current flow route of conversion period, and (c) current waveform over entire cycle.

$$L\frac{di_L}{dt}+Ri_L+V=V_s \tag{3}$$

$$\begin{aligned} i_L\left(t'\right)&=\frac{V_s-V}{R}-\left(\frac{V_s-V}{R}-i_D\right)e^{-Lt'/R}, \quad t'=t-t \\ i_L\left(t'\right)&=i_L\left(t\right)=i\left(t\right). \qquad\qquad t=t_1 \end{aligned} \tag{4}$$

Here,

$$i_1 = i(t' = T - t_1), \tag{5}$$

$$i_2 = i(t = t_1). \tag{6}$$

The current was not communicated through the solar panel at step (II), and the current could be deduced from Eq. (3) under the condition of $V_s = 0$, wherein

$$i\left(t'\right) = \frac{-V}{R}-\left(\frac{-V}{R}-i_U\right)e^{-Lt'/R}. \tag{7}$$

The control of the energy storage of the solar power generation system relied on the action of switch S1. Diode D3, shown in Fig. 3(b), was used for protecting the solar photovoltaic module while merely considering that the electricity power generated by the solar energy was stored in the battery in a continuous current mode. The objective was to protect the power panel, which prevents the path from having a break while putting electricity to the storage battery for charging or the solar power panel from being damaged because of undue power immediately added to the solar power panel. Figure 3(a) shows the current waveform calculated by integrating Eq. (2) with Eq. (4), where $i_U$ and $i_D$ represent the maximum value $i_2$ and the minimum value $i_1$, respectively. Figure 3(c) shows the current waveforms of the charging and conversion periods, wherein $i_S$ represents the current of the solar power panel and $i_L$ represents the current stored in the storage battery. The average power $P$ of solar power panels stored in the battery can be deduced from Eq. (8). Because of the continuous properties of the inductive current, the control over the conduction time $t_o$ controls $i_s$ directly, controls $i_L$ indirectly, and the stored power $P$.

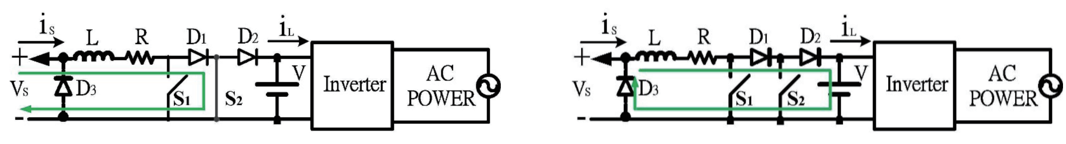
$$P=\frac{1}{T}\int p\left(t\right)dt=\frac{1}{T}\int_{t=t_o}^{t=T}Vi(t)dt=\frac{V^2}{R}\left\{\left(\frac{V_s}{V}-1\right)\left(T-t_o\right)+\frac{L}{TR}\left[\frac{e^{(T\text{-}t_o)R/L}+e^{t_oR/L}-e^{TR/L}-1}{1-e^{TR/L}}\right]\right\} \tag{8}$$

### 2.1.2 Method of transmitting electricity via management unit

Figure 3(b) shows a method of sending power to a management/storage battery; the path for sending data from a solar photovoltaic module to a management module end is also shown. In this study, we did not use additional communication devices. Instead, the above charging circuit path was deemed to be a communication medium and the management module end used sensors to detect the input current or terminal voltage of switch S2, thereby receiving signals sent by the solar photovoltaic module. Likewise, with regard to the method of sending data from the management module end to the solar photovoltaic module, it is shown in Fig. 4 that a power circuit charged by the solar photovoltaic module was directly adopted to serve as a communication medium, with the management module end used to control the switch S2 of the module, and with the solar photovoltaic module used to detect the output current or the terminal voltage of switch S1 via sensors, thereby receiving signals sent by the management module end. Accordingly, the bidirectional communication could be achieved by mere waveforms generated while transmitting electricity, and there could be no need to install additional communication platforms. Traditionally, the continuous pulse width modulation (PWM) follows the above principle to control the amount of power generation of solar power panels per unit. Because the waveform of PWM does not have the communication function, additional communication modules are needed to assist the solar photovoltaic power panels, which occupy a large area in generating electricity. This traditional condition increases the costs of the communication hardware and human maintenance for automation. To achieve the automation control and reduce the cost of communication modules, we submitted a concept relative to the power frame to replace PWM, and the power frame used the Pu's count (PK) encoding technology featuring an automated adjustment for the speed and data lengths of the communication, preventing the interference caused by noise.[12–14] Furthermore, only the data conversion was carried out on the software without adding additional hardware, so the cost of the communication system applied to the solar photovoltaic power generation system could be considerably reduced.

### 2.2 Modulation of power frame

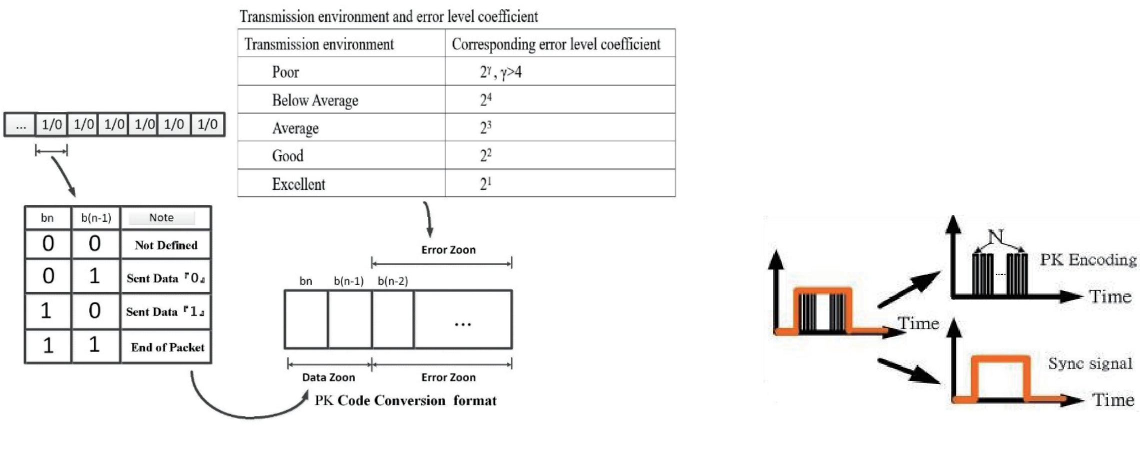
The theory of this study objectified the solar power panels and the management module, thereby constructing a solar power generation system in an Internet of Things mode for simplifying the construction of a solar power generation system. To reduce the cost of constructing the hardware of the communication system, a new charging technology called power frame charging technology was developed in this study, which used power cables directly to supply communication paths without adding any communication cables. In this study, we proposed a new concept called the power internet of things (PIOT) for simplifying the construction of an automated solar power generation system and a new power style called the power frame for power and communication devices in PIOT. The power frame consists of an




(a) (b)

Fig. 4. (Color online) Charging architecture of object-based solar photovoltaic power generation system: current flow routes of (a) charging and (b) conversion periods.

adjacent electrical power wave after Pu's count modulation (PKM). Although it was different from the power line carrier technology, the electrical wave with the communication function was provided, and electricity and communication signals were also supplied. Its basic principle was different from PWM. Specifically, it only used the variable level voltage reference to modulate direct current so that the output electrical wave would be generated to activate the electrical load. The power frame technology used the PK encoding technology to modulate direct current. Figures 5(a) and 5(b) show the PK encoding process and the output waveform subjected to this process, respectively, wherein the conversion process used the bit or bit data as the modulation unit. In reference to the packet format shown in Fig. 5(a), it would need to fill in conversion codes $\kappa = (b_n, b_{n-1})$ corresponding to the bit data on the data zone. Moreover, it would need to fill in the communication environment level coefficients corresponding to communication environments on the error zone and then convert them into corresponding decimal values (PL) according to Eq. (9), whereby the number of pulses corresponding to the transmitted bit data could be determined. After PK encoding, the first feature shown in Fig. 5(b) indicates that the bit data was changed into a serial PK code pulse of the same frequency, even when the transmitted data was 『1』 or 『0』 after being modulated. A sync signal existed in it, so a receiver of the communication would only need to calculate the number of pulses during the sync time in order to restore the bit data transmitted by a transmitter. In addition, there is no need to consider the pulse speed during communication, thereby allowing the communication speed to be automatically adapted. It is worth mentioning that after transmitting all the bit data, additional end bit data was added to remind the receiver that the transmission has ended. The existence of the end bit data $\kappa = (1, 1)$ can help the system adapt to data with various communication lengths automatically without being limited by the communication data length, wherein $\gamma$ represents a communication environment parameter determined by the communication environment to prevent the communicating noise from interfering with the reliability of the communication.(12–14)




(a) (b)

Fig. 5. (Color online) PK encoding principle: (a) architecture of PK code conversion and (b) waveform after PK encoding.

$$PL = (\kappa * 2^{\gamma}) + 2^{(\gamma-1)} \tag{9}$$

In reference to Figs. 3(a) and 4(a), the PL value generated after PK encoding was used to control the number of actions of switch S1 (or S2). The number of pulses of the output electrical power waveform, similar to the PWM electrical wave, could provide the electricity of the drive load, and the transmitted bit data was allowed to be smoothly restored after calculating the number of pulses. This arrangement might overcome the deficiency of the PWM electrical wave, namely, the lack of the communication function, and could also have the advantage of fighting against noise via PK encoding for being automatically adapted to the speed and data lengths of the communication. The serial waveform formed by transmitting several bits was called the power frame. In this study, the solar photovoltaic module was designed on the basis of the object-oriented concept submitted as shown in Fig. 2(a). Because each module was an independent monolith, the number of modules, similar to an IoT, could be randomly increased or decreased. Moreover, Fig. 6 shows a power control system (PCS) formed by combining multiple EMSs.

## 3. Experiments and Verification

To verify the correctness and practicability of the theory, Fig. 7 shows a testing platform that includes a personal computer, Arduino Mega2560, serving as a control center, a solar photovoltaic module used to simulate a power supplier of solar power panels, a management module system using Arduino Mega2560 as a control center, and at least one oscilloscope. Arduino Mega2560 served to capture the voltage and current signals of each module and control the action of the corresponding switch. The data was transmitted to the personal computer to

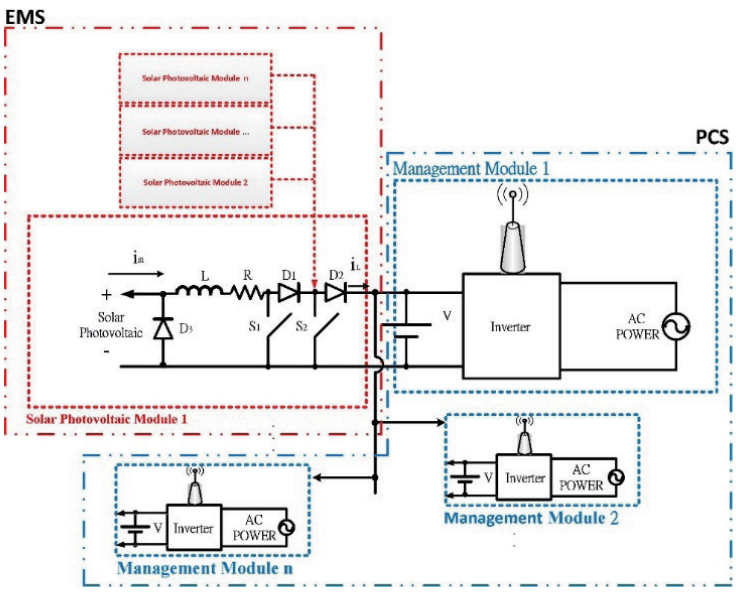



Fig. 6. (Color online) Architecture of power generation system of solar PIOT with bidirectional communication.

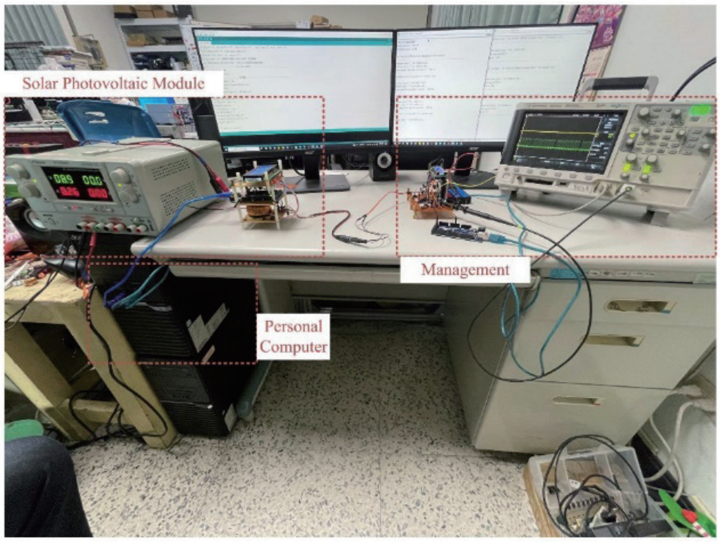


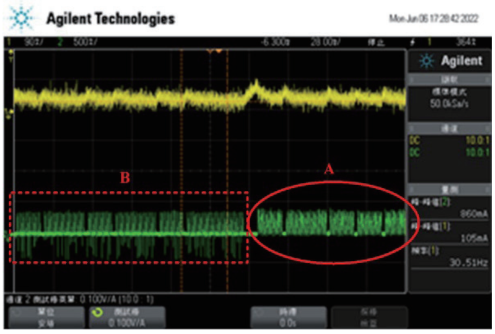

Fig. 7. (Color online) Testing platform.

record and analyze it using the Matlab® software installed in the personal computer, and concurrently, the oscilloscope was used to display the current and voltage waveforms.

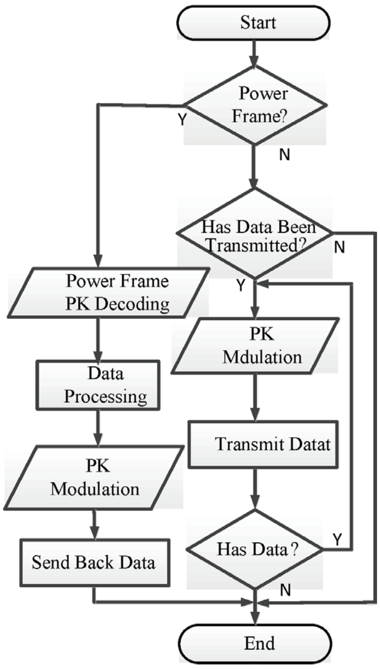
In reference to Fig. 8, while merely linking the management module to the passive load, not to a battery, the power generation system, simulating the power supply operated by the solar photovoltaic module, executed the bidirectional communication to display waveforms. The upper portion of Fig. 8(a) shows the yellow waveform to represent the current induced between loads, whereas the lower portion shows the green waveform to represent the captured terminal voltage waveform of switch S2 when the current is induced by switch S1, with the region "B" showing the waveform of the power frame sent from the solar photovoltaic module to the management module and with the region "A" showing the waveform of the power frame sent from the management module to the solar photovoltaic module. Figures 8(b) and 8(c) show the flowchart of communication between the management module and the solar photovoltaic module using PK encoding technology.

In reference to Fig. 9, after linking the management module to a battery, the power generation system, simulating the power supply operated by the solar photovoltaic module, executed the bidirectional communication to display waveforms. The figure shows the yellow waveform to represent the captured terminal voltage waveform of switch S2 during communication, with the right half region showing the waveform of the power frame sent from the solar photovoltaic module to the management module and with the left half region showing the waveform of the power frame sent from the management module to the solar photovoltaic module.

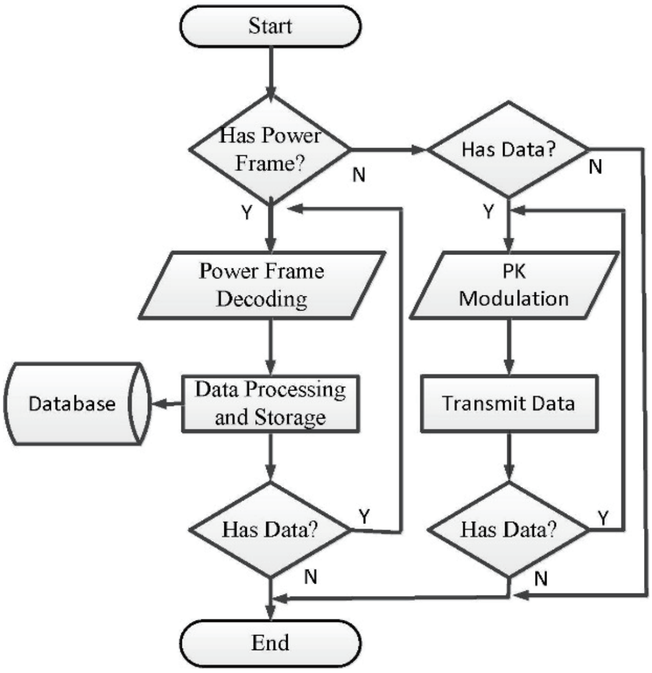
In reference to Figs. 10(a) and 10(b), after linking the management module to the battery, data 『Set&L13-0』 was sent to the power generation module where power was supplied by the solar photovoltaic module. The objective was to test the action of the warning light of the solar photovoltaic module remotely set by the management module, thereby simulating the remote load variable control. The luminance of the light was in the range of 0–255 while changing the




(a)




(b)




(c)

Fig. 8. (Color online) Bidirectional communication of power supply of solar photovoltaic module: (a) waveforms, (b) block diagram showing process of transmitting data from solar photovoltaic module to management module, and (c) block diagram showing process of receiving data from management module to solar photovoltaic module.

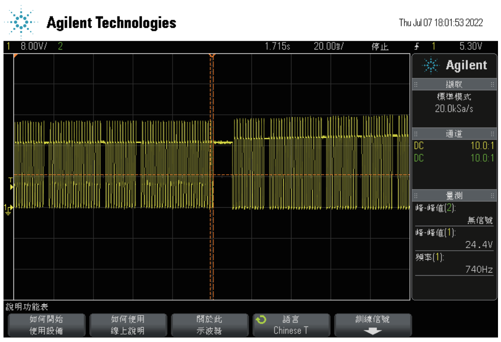
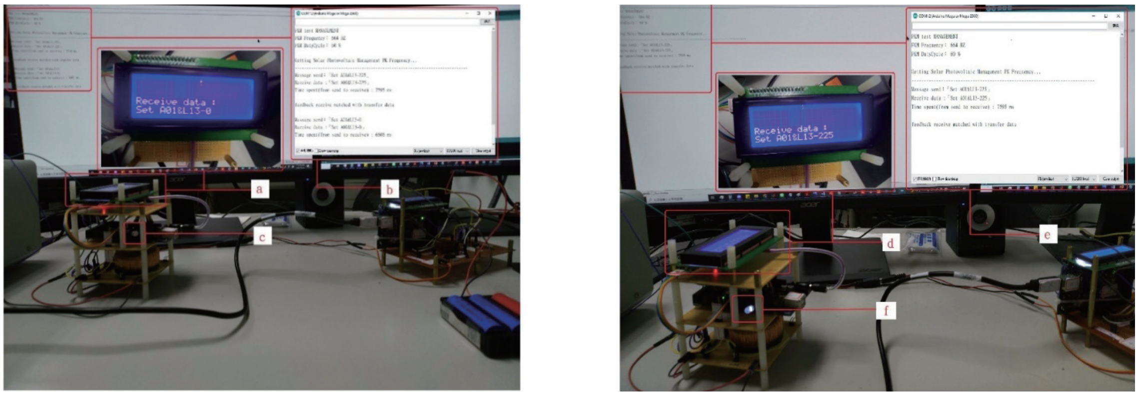



Fig. 9. (Color online) Waveform of bidirectional communication while linking management module to battery.




(a) (b)

Fig. 10. (Color online) Loading action of lights at solar photovoltaic management end under control of waveform of power frame sent to solar photovoltaic module while linking management module to battery: (a) before and (b) after.

state of light from “All Off” to “All On”. When the luminance was set to 0, the light in the region “b” of the figure was out, thereby indicating that the warning light of the solar photovoltaic module was correctly actuated while receiving the data from the management module. The regions “b” and “a” in Fig. 10(a) display the corresponding output communication data of the management module and the received communication data of the solar photovoltaic module, respectively, wherein the region “c” in Fig. 10(a) shows a correct receiving action of the solar photovoltaic module (the light in the solar photovoltaic module was turned off). Furthermore, the regions “e” and “d” in Fig. 10(b) display the corresponding management and solar photovoltaic modules to indicate the data 『Set&L13-255』 sent from the management module to the solar photovoltaic module, respectively, wherein the region “f” in Fig. 10(b) shows a correct receiving action of the solar photovoltaic module (the light in the solar photovoltaic module was turned on). Accordingly, the architecture developed in this study could meet the requirement.

This experiment was used to test the PIOT architecture and theory of the solar power generation system designed with the OOD concept proposed in this paper, and to verify whether the solar power generation system has the ability to communicate in both directions. In reference to Fig. 11, after linking the management module to the battery, the solar photovoltaic module sent back the waveform of data 『Set&L13-0』 to verify that when the power generation system where power was supplied by the solar photovoltaic module used the power frame to execute the bidirectional communication, the energy transmitted by the power frame could be synchronously put into the battery for charging and discharging. The figure shows the blue waveform to represent the power waveform $p(t)$ that was put into the battery in the management module for charging after the sampled current flowed into the battery during communication. Because a value was instantaneously obtained after the current and voltage were sampled, the waveform sent to the personal computer could only be displayed in a discrete mode. Accordingly, the sampled current at each point was directly multiplied by the voltage of the battery, and thus, the present transient power value inputted and stored in the battery could be calculated when the voltage sensor detected the voltage of the battery. The figure shows the region “c” to display the

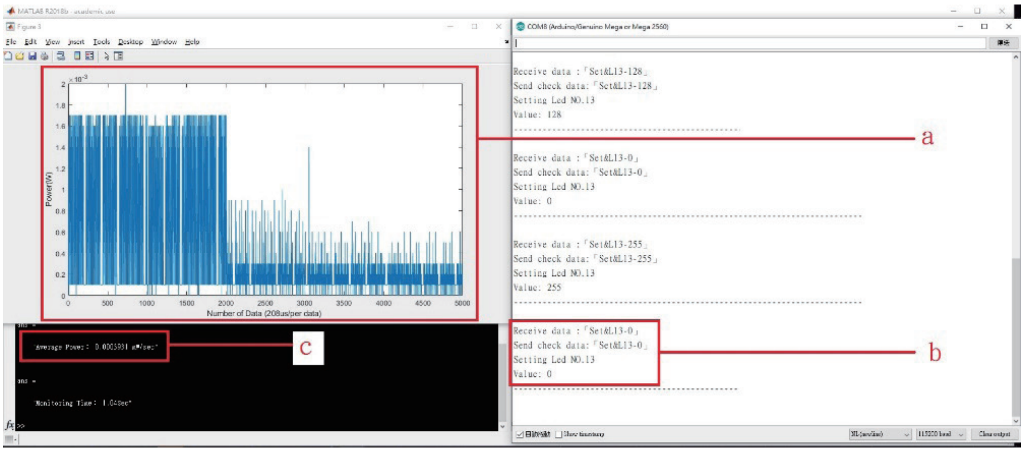



Fig. 11. (Color online) Transmitted data and charging power relative to reception of waveform of power frame of solar photovoltaic module while linking management module to battery.

average power deduced and calculated after the battery in the management module received p(t), thereby indicating that the solar photovoltaic module transmitted electricity via the power frame and that the management module inversely deduced the data 『Set&L13-255』 sent and correctly received by the solar photovoltaic module according to the power frame. This also represents that the power frame could also put the electrical energy carried by the power frame into the battery in the management module for charging and discharging during communication using the power frame to transmit electricity.

In this experiment, we used two pulse waves of different speeds and modulated the same data after PK encoding, then we sent it between the management module and the solar photovoltaic module to test the correctness of the data transmitted after PK encoding and verify if the PK encoding principle has the ability to automatically adjust the communication speed. Note that PK encoding was executed before converting the transmitted data into the power frame. Because the PK code for communication would only be used to calculate the number of pulses without considering the speed of the pulses, different communication speeds could be automatically adapted.[12–14] In reference to Fig. 12, the power frame used two output waveforms under the modulation of two pulse speeds, namely, 548 and 781 Hz, and the accuracy of their communication data was tested. The figure shows the data transmission from the management module equipped with the battery to the solar photovoltaic module, thereby testing the action of the warning light of the solar photovoltaic module remotely set by the power frame of different frequencies output by the management module. The left half portion of the figure shows the data received by the solar photovoltaic module and the right half portion thereof shows the data transmitted by the management module. The upper portion of the figure shows the power frame using 548 Hz pulse modulation and the lower portion thereof shows the power frame using 781 Hz pulse modulation. By comparing these two modules, the correctness of the communication was verified, so the architecture submitted in this study could meet the requirement. The communication waveform after PK encoding modulated with different duty

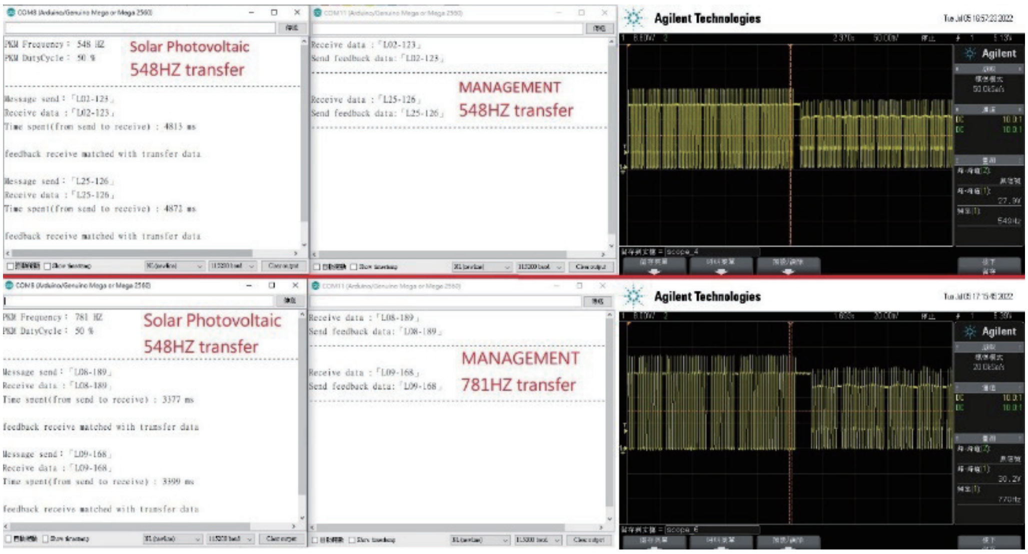



Fig. 12. (Color online) Waveforms of power frame of different frequencies sent to solar photovoltaic module and correctness of communication data thereof while linking management module to battery.

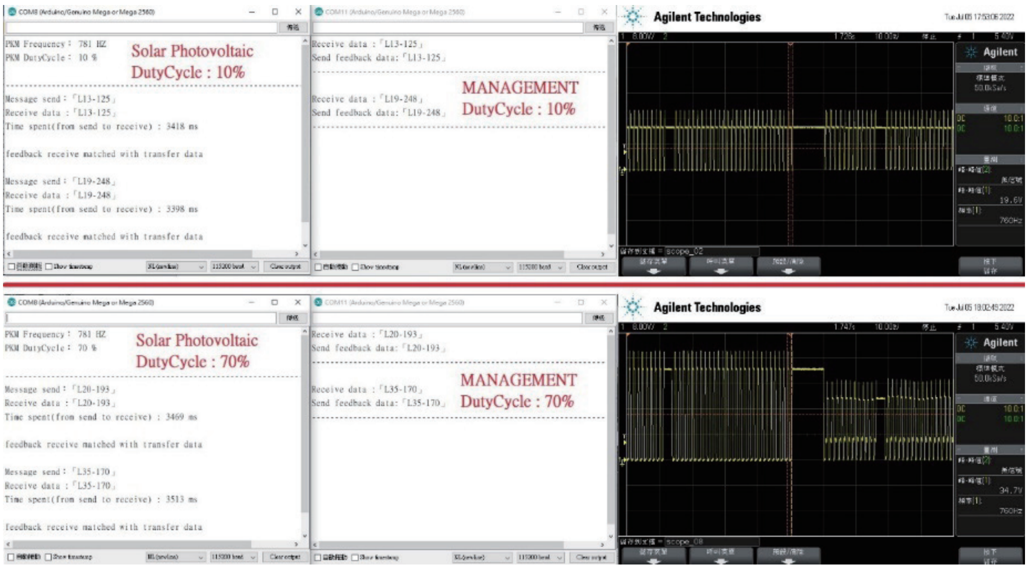



Fig. 13. (Color online) Waveform of power frame on different duty cycles sent to solar photovoltaic module and correctness of communication data thereof while linking management module to battery.

ratios is shown in Fig. 13, and the result after communication verifies that PK encoding is not limited by the pulse wave format. In reference to Fig. 14, this experiment was used to test the possibility of the remote control of the management module and simulate the possibility of the automatic control of EMS. Two sets of solar photovoltaic modules (A01 and A02) were prepared, and one set of batteries was installed in the management module, thereby simulating the system as shown in Fig. 6. In the figure, the letter “a” indicates that the data 『Set A01&L16-200』 was

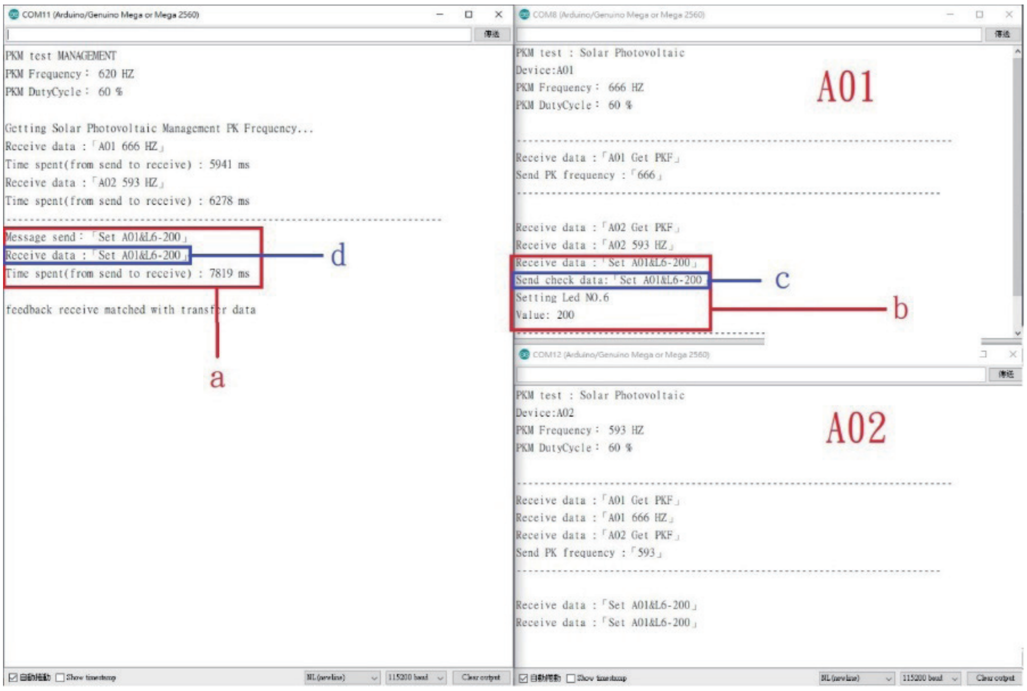



Fig. 14. (Color online) Received waveform recognition of power frame of each solar photovoltaic module and correctness of communication data thereof while linking management module to battery under multiple sets of solar panels.

sent from the management module (A01 and A02) in PIOT, and the command was used to control the light of the solar photovoltaic module A01 according to the luminance at 200 and record and receive the data sent back and received by the designated solar photovoltaic module for implementing the handshake control, whereby the correctness could be verified. In Fig. 14, the letter "b" shows that the solar photovoltaic module A01 sent back the data of the letter "c" after receiving the data, which was indicated by digitization. The solar photovoltaic module A02 was not the designated module, so no record was made after receiving the data, and the data was not sent back and executed. According to the above experiments and the correctness of data, multiple solar photovoltaic modules using the power frame for communication could be feasible.

## 4. Conclusions

In this study, we developed a novel method to design solar photovoltaic panels based on the the OOD concept and to build a solar power generation system as internet of things, called PIOT. This solves the complex problem in the traditional solar power generation system control process and hardware cost without any communication equipment. Then, a power frame was also presented for constructing an automated solar power generation system, and the power and communication ability of the power frame was provided for the devices in PIOT. The system merely used voltage and current sensors to objectify the solar power panel and the management module for constructing PIOT by connection in a stacking manner to meet demand, which could facilitate the movement of solar power panels according to the changes in shade and sunshine environment, to change the entire area pattern of the power plant, to prevent damage caused by the shade, and concurrently to solve the problem that traditional solar photovoltaic power panels have been used for many years. This is the first contribution. We also developed the power frame to simultaneously recognize and correspond to solar power panels with power generation during charging, and store the generated electrical energy into the battery, and the information hidden in the power frame can make a record, thereby decreasing the cost of installing a communication system, simplifying the complexity of the control, and building a recording platform relative to electricity to facilitate power trading. This is the other contribution.

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