Discussions on Photovoltaic Power Conditioners Installed in Veranda of Apartment Houses

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Abstract
Various types of utility-interactive photovoltaic power generations including domestic applications have been presented and widely accepted in a society. A lot of innovative researches about power converters that interface between photovoltaic arrays and ac utility system have been also discussed. The actual application style of such solar panels is almost ones on top of the roof of detached house. However, some residents living in the apartment house are having a fairly strong desire to install the PV panel and contribute for natural energy generation. In order to give a reply, a simple and concise photovoltaic power conditioner installed in verandas of apartment house is presented. Considering fairly reduced generated power and narrow space to install, the system constructions should be more simple and concise. In this paper, the system construction which gratifies their wishes is introduced. These PV system can be easily connected like usual home electric appliances by attached plug For reverse power flows and increasing harmonics, their protection circuits might be provided on the input power line. System construction and system performance are presented and discussed.

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1. Introduction

It is an important assignment for humanity to make efforts for conquering the problems against environmental conservation, resource and energy, with keeping the developments of economy, science and technology,. This background is outlined by Hu etc. (1994) [1]. The usage of the renewable energies is expected to be able to mitigate these problems. Among them, photovoltaic power generation system has various advantages like usage of inexhaustible and unpolluted sunlight. This is advantageous for easy maintenance and construction from small power to large one, and also can be installed in various location even in city center. Thus, this power generation system is a promising one with bright future.

As an utilization form, utility interactive power generation system has been accepted and widely applied. In such power generation system, it is necessary to install the chopper, in which the lower voltage of solar cell should be boosted to suitable voltage and inverter, by which the dc power of boosted voltage should be converted to ac power of the power system.

Various innovative PCSs, power conditioners including inverter and the like have been presented by many authors such as Takahashi etc. (1991) [2]. It is said that, however, it should be reduced the cost even more. It is also said that the systems are approaching to an ideal ones as efficiency and the like, but present cost prevents to spread in a wide application.

In such discussions, there are many subjects to be solved to utilize the PV power in utility interactive power generation form. Even more, various safeguard equipments required for regulations make the cost increase [3], [4]. Thus, it is required to obtain even more low cost PCS. In such extremely small capacity PCS as discussed in this paper, a way of handling would be different compared to usual power ones. In such case of reduced generating power, quantities of reversed power to the power system would be much reduced, where another mitigated regulation or deregulation would be required. Thus, in such photovoltaic power generation systems, there are so many subjects to be resolved.

Under such states accepted by electrical utility industry as recognitions and assessments for renewable energy, spread of application is strongly sustained by financial supports of public organizations. As a result, the number of consumers hoping to install such PV power generation system are increasing gradually. For financial supports, however, installation of solar panel is restricted to house having roof.

From these situations, there are alao many residents living in the apartment house who wish to install the PV panel. In the present state, however, there is no scheme to perform these requirements subject to such residents. System construction and system performance are presented and discussed in this paper.

2. Circuit Configuration

Fig.1 shows the proposed conversion scheme which converts the power from solar cells to ac utility system.

The particularity of the scheme lies in that a full-wave rectified waveform is supplied from the dc side and converted into sinusoidal current by an interactive inverter which is controlled in-phase with the utility voltage.

The dc power in the primary circuit is converted to the secondary circuit by a forward converter with a single switching device of high performance. Consequently, a dc power flow into the ac utility system due to abnormality can be prevented by the insulating transformer. It is essential that there should be no dc power-flow from the solar array to the ac utility system. Moreover, the output voltage can be easily boosted by varying the turn ratio of the transformer.

When the main switch Q_m turns on, the current flows through the primary winding 1. In the secondary winding, the current flows through winding 2, diode D_2, inductor L_O, and IGBTs-Q_1, Q_2 or Q_3, Q_4 in accordance with the polarity of the ac utility voltage.

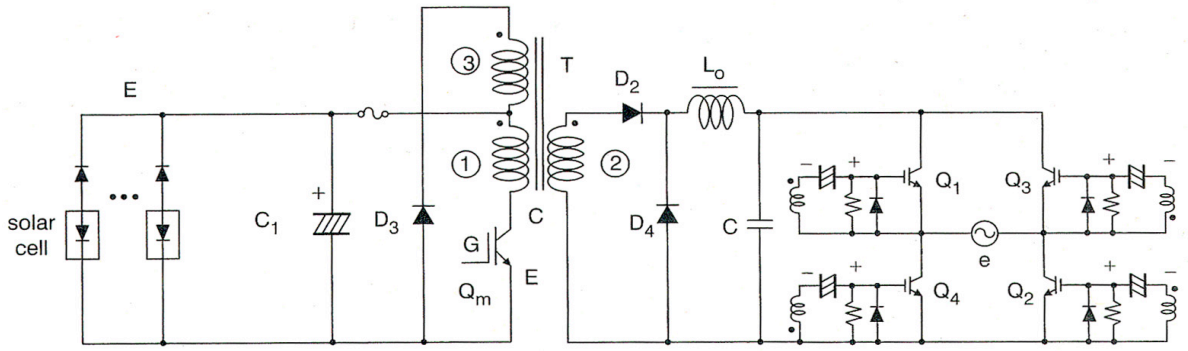

Fig..1. PCS constructed in forward converter.

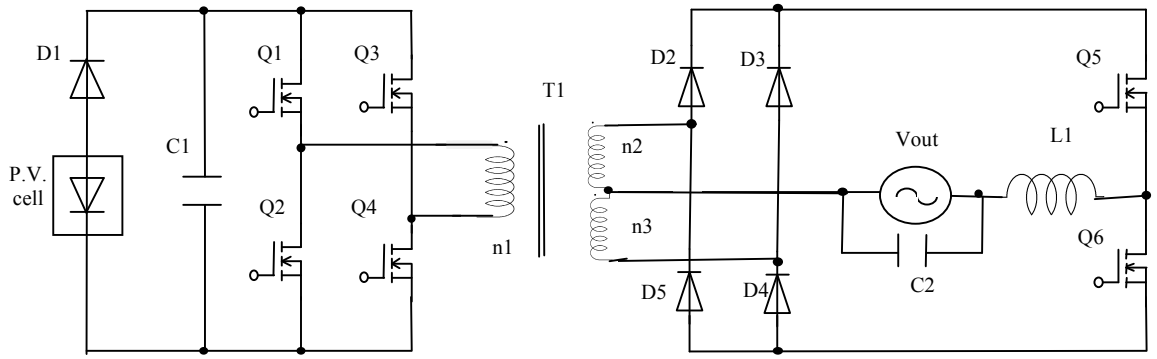

Fig.2. PCS constructed in center-tapped converter.

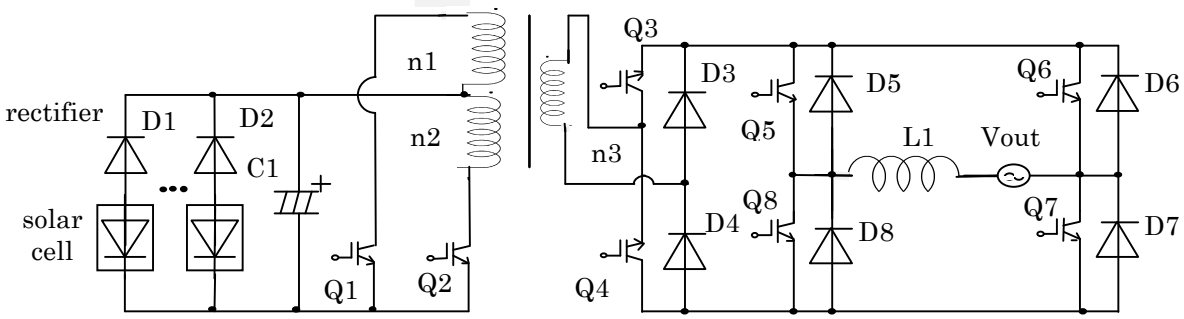

Fig.3. PCS constructed in center-tapped converter.

When Q_m turns off, the current by the magnetic energy stored in the filter inductor L_O flows into the ac utility through the free wheel diode D_4 and the corresponding inverter legs. The winding 3 performs a role to discharge the energy in the core during the switching-off period.

The wave shaping method for output sinusoidal one is performed by main switch Q_m. The output bridge circuit of Q1-Q4 is operated in lower commercial frequency. This system is reported as utility-interactive power conditioner of 3kW, whose efficiency is fairly large in 92 %.[1] In this PV panel in veranda, however, the capacity is fairly reduced like three or four hundred watts, so the significant effect for efficiency might not be expected. But, because of small power, it is important to improve the efficiency effectively. By means of using single high frequency switch with hifh performance, improvement for efficiency could be expected. Actually, application could be realized to 3kW utility interactive power conditioner. The remaining four switches are constituted in lower frequency and lower voltage drop switches, so the efficiency could be more improved in this portiont.

The almost all compact dc-dc power supplies are constituted by forward converters, so this construction knowhow could be available in easy way. The proposed veranda solar power is 200W per unit and the like, so this converter application to the veranda solar is promising. The only week point is that the high voltage in double is applied across the main switch at turning-off period. Thus, the protection circuit like snubber is necessary.

Fig.2 shows center-tapped converter proposed by Takahashi etc.(1995), which is developed from [1] but another original result can be obtained as compact 200W power conditioner.

Fig.3 shows PCS having center tapped converter proposed by one of the author and Naruse etc.(1999), which operates as 1kW PV power generation. This PCS has double main switches compared to above mentioned forward converter having single switch, where the size of transformer is reduced in half and magnetizing current is also reduced. By means of this, circuit efficiency can be increased.
Bridge circuit of the output operates lower commercial frequency. Transistors in the secondary winding can be replaced by diode bridge, but the output bridge connected to power system must be operate in an high frequency for sinusoidal wave shaping.

Fig.4 and Fig.5 show schematic diagrams for forward converter type power conditioner and center tapped type power conditioner, respectively. Each circuit shows characteristic of operations, in which the proposed upper circuit described splendid feature that is operated with no dc power flow due to inter-mediate transformer and no dc boost chopper. Instead of these, in a case of lower case of circuit, it is necessary to install boost chopper and dc power detector to prevent the dc power flow.

Fig.6 shows MPPT and charge controller. The proposed circuit construction is more simple because of single feedback signal instead of double one. These three schematic diagram represent that each construction becomes very concise and simple.

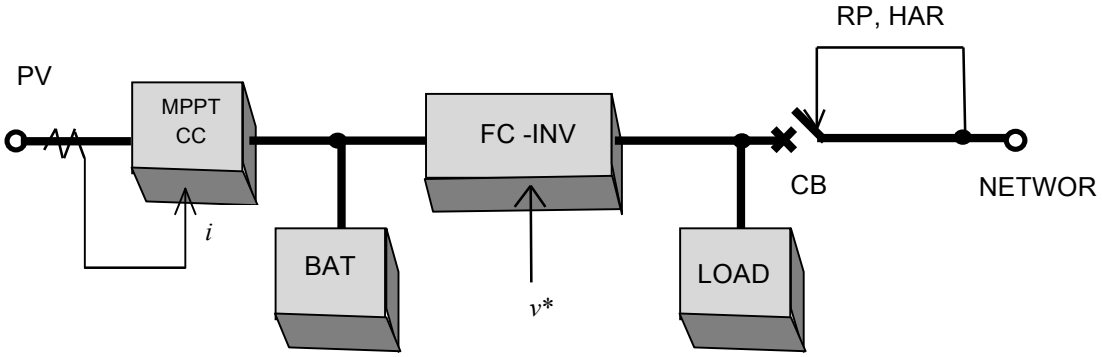

Fig.4. PCS constructed in forward converter.

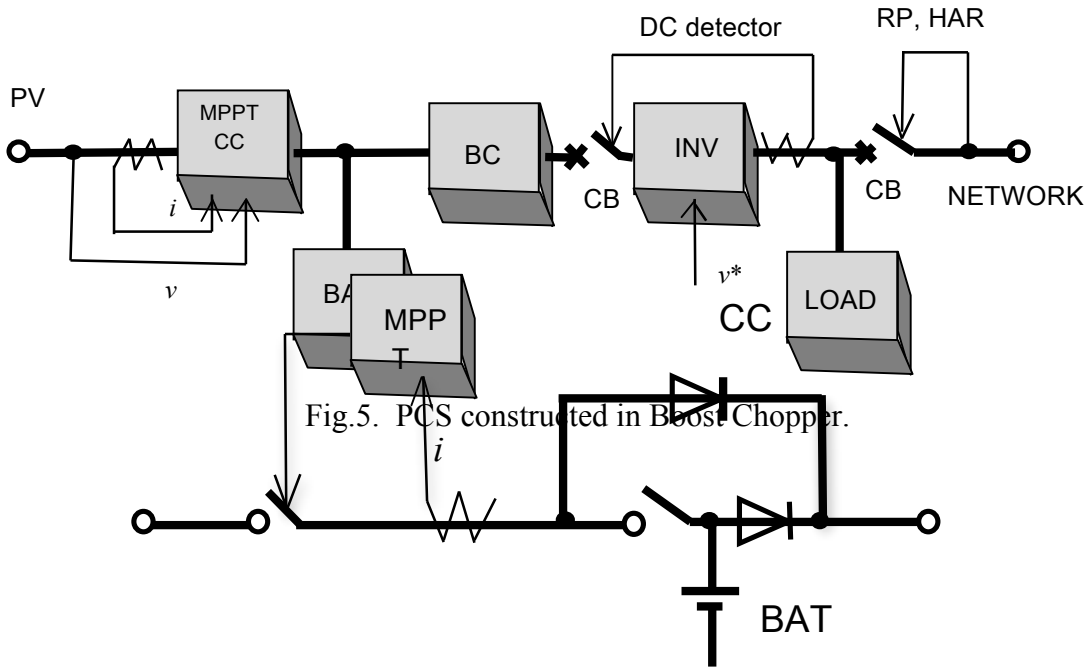

Fig.5. PCS constructed in Boost Chopper.

Fig.6. MPPT and Charge Controller.

INV: Inverter, RP: Reverse Power Flow Detector
HAR: Harmonic Detector, CB: Circuit Breaker, CC: Charge Controller
MPPT: Maximum Power Point Tracker, BC: Boost Chopper
FC: Forward Converter

3. Maximum Power Point Tracker

There are so many strategies to take the electric power more efficiently out of the solar battery. One of these is a mountain climbing method which is often used as control theories for the conventional PV power generation. It makes the operating

point of the solar battery oscillate artificially by the microcomputer in order to pursuit the maximum power point.

In this conventional control theory, however, the operating point always fluctuates around the maximum point. Therefore, it is insufficient to make operate effectively. In order to solve these problems, the control theory should be modified efficiently.

The proposed control theory in this paper can be realized by application of simple electronic circuits, which distinguishes a sign of each differentiation of the output power P and output voltage V of the solar battery. It always makes an operating point keep at the maximum power point as following.

The proposed control theory will be explained by the P-V characteristic curve in Fig.7. A sign of each differentiation such as dP/dt and dV/dt is examined when a certain operating point is varied on the characteristic curve. If the operating point moves towards I, differentiation of P and V becomes $dV/dt<0$ and $dP/dt<0$, respectively. On the other hand, if the operating point moves towards II, differentiation of P and V becomes $dV/dt>0$ and $dP/dt>0$, respectively.

In other words, even if the operating point moves toward either direction in the section i, the differentiation of P and V always becomes the same sign each other. Then, the product of dV/dt and dP/dt always becomes positive sign, that is $(dV/dt)*(dP/dt)>0$. Secondly, let us explain a case where the operating point is in the section ii. In this section, the product becomes always negative, that is $(dV/dt)*(dP/dt)<0$, even if the operating point moves towards either III or IV.

Accordingly, the output voltage V is made increased if the resultant value is positive in region i. The output voltage V is made reduced if value is negative in region ii. Consequently, the operating point can be kept staying at the maximum power point.

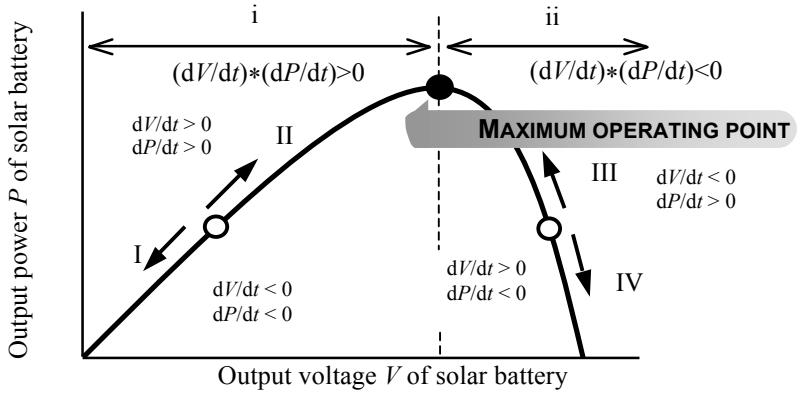

Fig.7. P-V characteristic curve.

4. Actual Electronic Control Circuit

The output current I and the output voltage V of the solar battery are detected. Then, the output power P is calculated by the multiplier. This value and the output voltage V are transmitted to each differentiator. Then, dP/dt and dV/dt can be obtained after processing in differentiator. The product of dV/dt and dP/dt can be obtained by

another multiplier, whose output signal goes through the PI controller. In such a way, this control signal is given to the chopper circuit for the solar battery.

Fig.8. shows the control circuits to realize an inter-connection of such solar battery to the power system. This control circuit is operated according to the operation in Fig.7.

Solar voltage is replaced by the duty factor d of the chopper circuit, where the first stage is operated by chopper. The input voltage E_1 is inversely proportional to the duty factor. Namely when the duly factor increases, E decreases, and vice versa. Consequently, the detection of the output voltage and the calculation of the output power P become unnecessary. As previously mentioned, the maximum current can be obtained by controlling the output current.
The method by means of Exclusive-OR is the same way as usual. It can be seen that the control circuit shown is very simple. The distinctive point is that there is no need of the multiplier for detection of the power. This characteristic is a remarkable feature.

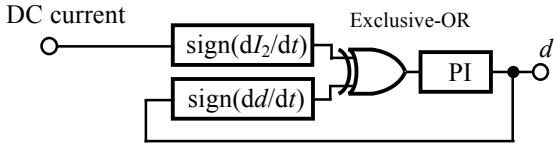

Fig.8. MPPT control circuit.

5. Circuit Configuration of Indoors Wiring

5.1. Method of Utilizing Existing Wiring

Fig.9 shows indoor wiring from PV panel to utility network. For PV panel installed in veranda, there are various types such as from board type panels (BTP) to flexible PV panels (FSP) which can be rolled up like a curtain. In BTP, PCS like a thin box is attached to reverse side of board. These are selected in accordance to installed location. For usual roof installation type, in the connection box, a group of diodes protecting the reverse current, handling switches to each line and circuit breaker of lines with double polar and dual element are installed. In this case, handling switch is operated manually, while circuit breaker is made turned off by over current automatically. In thin type PCS, manual switches and line circuit breakers are installed in PCS. In FSP, PCS could be attached to outer side of cylindrical box.

When the load is connected to the line from PV panel, it is necessary to avoid the large power load to this line. This line is used for important load with reduced power like at interruption. When emergency power supply for interruption is expected at night, it is necessary to install the battery as optional equipment. Because of minimum capacity of exclusive line for interruption, battery capacity could be reduced as a matter of course. Recently, domestic battery storage systems with small PV panel are put on the market and can be available. These equipments might be connected to this exclusive line. In this situation, it might be necessary to supply the battery for charge from the ordinary power system, but it would be the prospective one in a practical use. In such a way, the line from PV panel uses the existing one. In order to utilize as the emergency power supply, it is important to select appropriate apparatus carefully for interruption.

For example, the important apparatuses such as light equipment, PC for collecting information, charger for cellular phone and refrigerator to protect foods are connected to this line at interruption. For the conventional refrigerator, however, the large rush current flows at turned-on, so this PV power could not respond to such power. Thus, the inverter type refrigerator can be used which suppresses the rush current and mitigates the power flow. Consequently, the inverter type would be recommended.

For other lines except such PV one, the ordinal electric apparatuse is connected. Usually, the PV line and ordinary line are supplied in the same way. The large capacity air conditioner, cocking heater, washing machine and large capacity light should not connect such PV line.

The excess power from the exclusive line with PV panel can supply to the ordinary lines. Even though the generated power is small, the regulations are necessary where circuit breakers for reverse power flow and increased harmonic generation should be installed. However, in the power system, these detectors could be equipped simply. In such a way, for the circuit break against reverse power flow and increased harmonic generation, such quantities are merely detected in the power system, and the breaker is operated in the exclusive line. Consequently, the line is disconnected from the ordinary line that does not break from the power system. Thus, the PV line is supplied in succession.

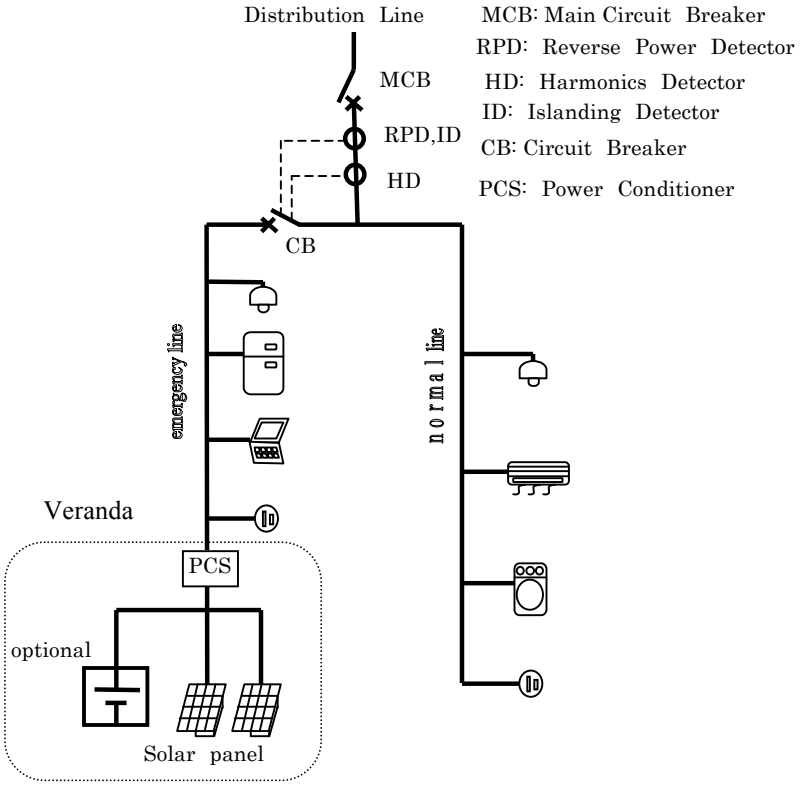

Fig.9. Indoor wiring from PV panel to utility network

5.2. Method of New Construction for PV Line

In Fig.10, another line is placed for exclusive use from PV panel to the switch board. This line is turned-off from the power system when interruption at disaster and the like. However, the power from the PV is supplied to this exclusive line, from which

important loads are supplied even at interruption. When the circuit breaker is closed, that is turned-on, the ordinary load is supplied as usual, or excess power flows inversely to utility line if generates.

As compared to above mentioned method using existing line, the wiring route can be selected flexibly and placed to the necessitated room, so it is advantageous in effectiveness. In a case of wiring in the already built house, destroying the scenery would be worried. In newly-built, however, there is no problem of such concern, so it is advantageous in such situation.

5.3. Method by Placing Exclusive and Important Load Lines

Exclusive line and important load line are newly placing as shown in Fig.11. When the harmonics and the like generated from PV panel are detected, the exclusive line from the system is disconnected. Other ordinary line and important line for the interruption are supplied in succession.

In a case of interruption, the under voltage relay detects it and the improved loads at interruption are supplied from PV panel. The ordinary loads are disconnected. In an inconvenient of PV power, this line only is disconnected. The normal loads and important loads are not influenced. It is advantageous that the important loads can be supplied at interruption. However, it is necessary to place double lines as new built, so it is disadvantageous for additional installation for existing line.

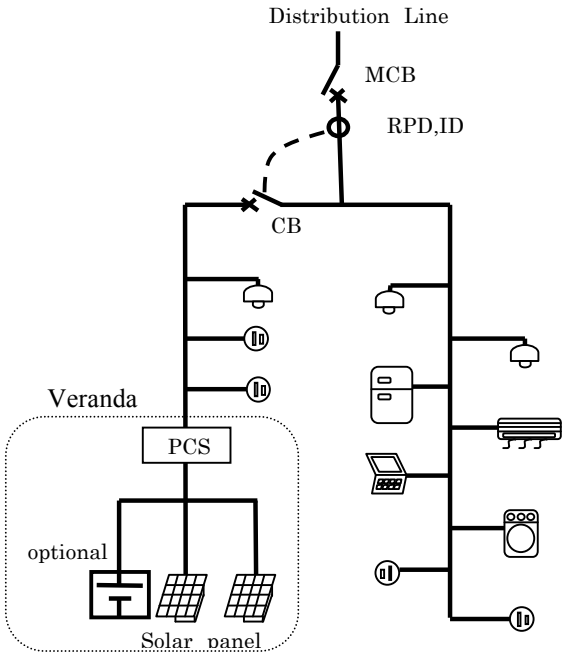

Fig.10. Circuit configuration of veranda solar (Method by new construction for exclusive line)

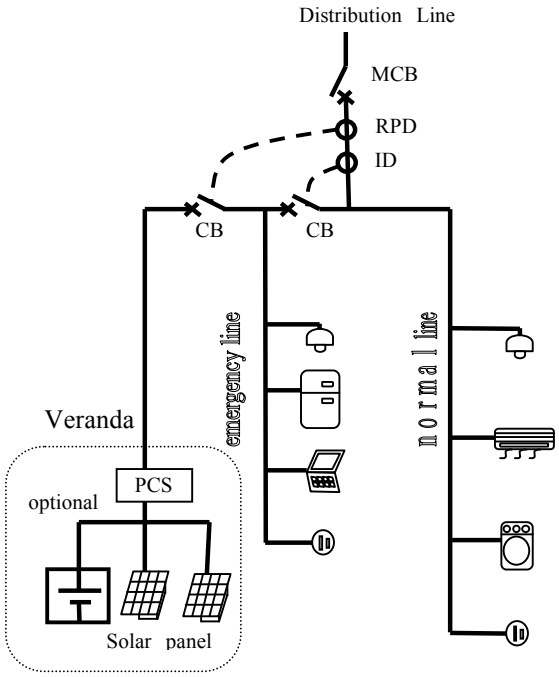

Fig.11. Circuit configuration of veranda solar (Method by placing exclusive line and important load line)

Fig.12. shows one example of actual appearance in the veranda, where the solar panel in 200W can be winded up in the cylindrical storage box. The solar panel is constructed in flexible sheet form. At strong wind, long absence or another usage of veranda, the solar panel can be winded up in the storage box. According to the space

of veranda, another solar panel can be installed more. The panel is pushed out forward a little and curved outside as shown. By means of this situation, effective area for light receiving can be enlarged.

Fig.12. Actual appearance of the installed veranda solar.

7. Conclusions

In a perception of that improvement of environment is obligation for humanity, a lot of people are wishing to settle the PV panel. It is a truth that many residents living in apartment house not only have interesting, but also desire to install the PV panel. An adequate scheme to be realized for residents living in the apartment house is discussed and proposed as an actual method of veranda solar.

In settlement at a narrow space like verandas, amounts of generating power is restricted, so even lower cost is required. If the PV panel is handled as like home apparatuses having attachment plug, the settlement cost can be much reduced. In addition, if the unified specification is introduced and the mass production is promoted, more reduced cost apparatus is supplied to the market such as compact power conditioner.

In a system interconnection, there are many problems coming from regulation, so it is an obligation to break the circuit when detecting reverse power flow or increased generation of harmonics. However, only by means of breaking the solar panel circuit from the power system, reverse power flow is prevented, so such regulation is not applied to such system. As a result, settlement of solar panel can be easily accepted. In a case of power selling, it is necessary to provide an additional power meter, and a new troublesome would arise regarding to the cost

In dealing with an interruption, the system cannot be used for uninterruptible power supply to all loads, but can be supplied to the selected important load. In a method of providing the exclusive line for interruption, this line is supplied even in normal time. In long term feeding for interruption, for instance, during night, it is necessary to provide a battery system, which is installed at primary side of transformer of power conditioner.

On the other hand, in roof top solar system, to make PV panel cost low is significant, but in veranda solar, to make power conditioner cost low is much significant. In this

paper, the forward converter type power conditioner is presented, which has only single switch that is high cost in high frequency. The other switches for inverter are in low operating frequency, low voltage drop and low cost ones. This proposed photovoltaic power conditioner system is suitable for comparably small capacity one.

Acknowledgement

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References

[1] Yan Hu, Keiju Matsui, Takashi Sugiyama, Kenji Ando and Isamu Yamamoto,"3kW Utility-interactive Power Conditioning System using Forward Converter", Proceedings of Static Power Converter Meeting in IEEJ, SPC-94-89, pp.49-56, (1994)

[2] Sakae Shibasaki, Isao Takahashi, Shinzo Sakuma, Noriyasu Mimura, Yoshihiko Asano, "Small Quantity and Thin Type 200W Inverter for Photovoltaic Systems", Proceedings of National Convention in IEEJ, 739, pp.4-50-51,1995-3

[3] Satoshi Naruse, Keiju Matsui, Shiro Hirose, Tadashi Kobayashi and Kenji Ando:'Utility-interactive power conditioner using forward converter with double switches', Proceedings of national convention in IEEJ, 839, 1999-3

[4] Edit:Ohmsha,"Guide Book of Technical Standard Concerning Electrical Equipment", 1st edit., pp.52-63, pp.376-382, 2013

[5] Technical Committee for Customer Equipment, edit., "Indoor Wiring Regulation - electrical code for customer equipment", Japan Electric Association, pp.858-860, 2012-2

[6] R.L.Steigerwalt, A.Ferraro, and R.G.Turnbull: 'Application of power transistors to residential and intermediate rating photovoltaic array power conditioners', IEEE Trans. Ind Appl,, 1983, IA-19, (2) pp. 254-260

[7]A.Khoder, K.Al-Haddad and V.Rajagopalan: ' Innovative utility-interactive dc to ac power conditioning system'. Conference Record of 1985 IEEE IAS Annual Meeting, Toronto, Canada, 1985, pp. 1151-1155

[8] Chihiro Okado. : 'Development of inverter for photovoltaic generation'. Proceedings of 10th Photovoltaic Generation System symposium, Tokyo, Japan, 1993, pp. 411 (in Japanese)

[9] R.L.Steigerwalt, B.KBose, B.K. and P.M.Szczesny: Design and construction of an advanced power conditioning subsystem for small photovoltaic applications'. Sandia Report, SAND 83-7037, 1985

[10] Satoshi Naruse, Keiju Matsui, Shiro Hirose, Tadashi Kobayashi and Kenji Ando:'Utility-interactive power conditioner using forward converter with double switches', Proceedings of national convention in IEEJ, 839, 1999-3