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A Investigation on the Actual Condition of PV Maintenance on Residental Buildings

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ABSTRACT

Residental photovoltaic power system achieved remarkable results in distribution and activation through 'One Million Green Homes Program' led by the government. However, system maintenance and management after installation are relative unsatisfactory. Thus, problems, such as malfunctioning, decrease in efficiency, breakage, etc, are occurring in succession which means that expensive facilities are not used effectively.

This study attempted to propose a more preferred alternative to the photovoltaic power system currently applied and installed to the housing by investigating and analyzing the said system, identifying management practices, and deriving problems. For this study, 48 houses equipped with photovoltaic systems in J City were chosen and they were analyzed after preliminary research and field investigation.

The results revealed that most of the surveyed systems in J City are still in fairly good conditions. But the instruction and information regarding the appropriate operational management of those surveyed systems have not been delivered to the owner. Therefore, promotion education and related manual deployment should be done by the contractor. In terms of installation, inadequate system location and some warranty services are required to be improved, which are usually caused by a lack of careful planning and construction. In addition, the follow-up management needs to be provided about five years later after installation considering system deterioration.

KEYWORD

Photovoltaic(PV)
Maintenance
Promotion·education
After service(A/S)

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1. Introduction

1.1. Background and Objective

Aiming for the discussion on the global issue that the average rise of the earth should be curbed within 2℃ until 2100, UN Climate Summit Conference was held last September and the policy for increase of energy efficiency and renewable energy drew a keen attention. This emphasis can be confirmed by the fact that 37% of power plants built from 2009 to 2013 are those for renewable energy plants[1)].

In the meantime, the Korean government set up a goal of renewable energy distribution up to 11% of the total primary until 2035 in the Second National Energy Basic Plan. As the action plan, the government announced it would place more importance on the generation of solar and wind power, reducing the energy wastes. In this context, it is considered proper that attention is more given to the introduction of new renewable energy to construction sector, reduction of energy consumption and increase of energy efficiency.

In particular, photovoltaic (PV) power generation has grown more than any other energy sources due to its economic cost and high quality. It seems that this growth has resulted from the satisfactory performance of Housing Support Business Project, which is part of Renewable Energy Distribution Policy by the government. The representative example of the project is 'One Million Green Homes Program'[2)]. The Housing Support Business Project has been run for last 10 years and, as a result, 160,000 houses were supplied as of 2013, recording the annual average increase rate of 46%[3)].

However, the project has focused only on installation and distribution all the while and thus the maintenance of power system have been left relatively less cared. Therefore, problems regarding PV power system have taken place here and there such as malfunction or insufficient energy efficiency. Naturally countermeasures are voiced to come up. It is essential to replace consumables and maintain and repair PV power system in a timely manner to secure the optimally efficient operation of the highly priced facilities and equipment whose life cycle are normally 15 years. However, few studies have been attempted on this area.

In this respect, the present study aims to examine and analyze PV power system installed in houses; understand the current status of its maintenance and operation; find out problems; derive solutions to them; and propose a desirable direction to the efficient

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1) www.energy.korea.com/ko/
2) This project is the goverment-sponsored busiess project that distributes a million domestic households with PV power system until 2020.

maintenance of PV power system, so the expensive facility can operate for a long time and reduce CO_2 emission of construction sector.

1.2. Method and Scope

The present study selected PV power system installed in J city as research object to examine the current status of the maintenance of PV power facilities that were distributed through PV Power Housing Support Business Project. An actual condition survey was carried out in 2 stages - preliminary and filed survey to encourage the interest and response of building owners for the sake of research efficiency. Naturally the scope of this study is limited to the opinions of facility users. To attain the objective of the study, theoretical review was conducted on the methods and contents of the maintenance of PV power facilities. And then a survey with questionnaire and field survey were followed to understand the actual conditions of the maintenance of PV power facilities. Based on them, problems were found and solutions to them were suggested. <Fig. 1> shows the flow chart of this research.

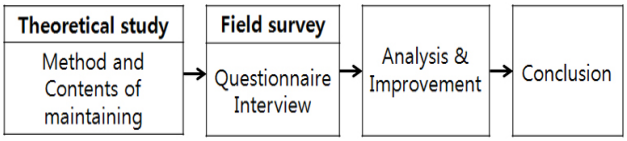

Fig. 1. Flow Chart of this Study

2. Theoretical Review

2.1. Definition and Necessity of Maintenance

Maintenance of facility means a series of actions to maintain facility at normal state of operation such as general inspection, repair, and restoration to enhance continence and safety of users as well as preserve the functions of finished system or facility[4]. That is, it is to eliminate risk factors from constructed facility in advance through inspection and maintenance and repair and replace damaged parts so that it can operate normally and keep initial conditions of construction.

In general, the life cycle of facility heavily depends on the conditions of use and the extent of maintenance. Therefore, it is only when facility is well maintained and managed against deterioration dye to the passage of time that it can guarantee the benefit of users and increase the efficiency of construction cost, so eventually improvement of economic.

3) Source: New Renewable Energy Center, Korea Energy Management Corporation

Year	'07이전	2007	2008	2009	2010	2011	2012
Number	7,181	7,317	9,142	14,895	26,364	28,990	45,530
Growth		23%	25%	63%	77%	18%	47%

2.2. Method of Maintenance of PV Power System

Since the scale of PV power system for household is largely 3kW, which is small, it is not mandatory to maintain and manage it unlike a large-scaled PV power system for industry of which maintenance is stipulated in Article 73 of Electric Utility Act[5]. However, a voice is being raised for the need of at least basic maintenance of the small-scaled PV power system because sudden functional deterioration, malfunction due to the degradation of its components, which have negative impact on the endurance. Naturally there can be difference in the extent of maintenance between large- and small-scaled PV power system, but the actual maintenance of small-scaled PV power system can be divided into 3 types[6] based on the guideline of large-scaled PV power system: construction maintenance, routine maintenance and regular maintenance.

Of them, it is desirable from the viewpoint of general facility users and owner that routine maintenance is regularly performed to detect malfunction. And when there is malfunction, they are advised to seek for consultation from constructor or expert. Since maintenance is usually based on bare-eye inspection, it can be effective as long as inspector is equipped with at least basic knowledge on the facility. The contents of general maintenance are shown in <Table 1>[7] and it is common that general maintenance is carried out once a month.

Table 1. Recommended items for the general maintenance

Compo-nents	Checklist		Checkpoint
PV module Array	Visual inspec-tion	damage or taint of module surface	· should be no contamination or damage
		erosion or rust of trestle	· should be no erosion or rust
		damage of connection cable	· no damage to the connecting cable
Junction box	Visual inspec-tion	erosion or damage of the outer box	· should be no erosion and damage
		damage of connection cable	· no damage to the connecting cable
Inverter	Visual inspec-tion	erosion or damage of the outer box	· should be no corrosion of the outer box · charger should not be exposed
		damage of connection cable	· no damage to the connection wiring of the inverter
		ventilator opening/filter	· vent open · ventilator filter open
		murmur, stench, smoke and over heat	· no abnormalities in the operation
		display malfunction	· no error message, no flashing lights
		electrical status	· no trouble of display window

4) Wikipedia Korea

5) According to the current law related to electric facility, senior electric safety supervisor should be designated for facility with capacity of 1 MW or more. For facility with capacity of 1,000 kW or less, electric safety management can be subcontracted. It is not obligatory to designate electric safety supervisor for facility that uses 20 kW or lower

6) Kim Yong-R, Operating and Maintenance of PV System, D.B. Info, 8. 2013

General maintenance[8] is not mandatory for small-scaled facility of less than 3kW like residential facility. It is classified as general electrical facility. Therefore, if routine maintenance is regularly performed in accordance with <Table 1>, it will meet the goal of prevention.

2.3. After-Sale Service of PV Power System

It is currently stipulated in Korea that PV power facility should be maintained through free-of-charge after-sale service[9] after the installation of PV power facility. Although the period of mandatory maintenance varies a bit according to the terms of Guarantee of Maintenance Implementation Contract against Defaults, it is 3 year to 5 year in general. Even in case that the constrictor or installer of the facility closes business during terms of guarantee, free-of-charge maintenance on default can be provided by a designated agency. After the charge-free period, the owner of the facility needs to pay for the service. According to a study[10] related to this, a total of 246 after-sale service was filed and served for 5 years (from 2007 to 2011). As seen in <Table 2>[11] that shows the frequency of default of PV power system, default took place in an inverter more than any other parts of PV power system. It suggests that the quality (especially endurance) of inverter should improve.

Table 2. The number of implemented PV A/S

Item	inverter trouble	fuse change	breaker faulty	wiring connection trouble of module
numbers	150	20	9	13
Item	**terminal damage**	**diode trouble**	**wiring faulty**	**confirmation after restart of inverter**
numbers	10	7	7	30

3. Survey and Analysis of Actual Conditions of Maintenance

3.1. Method for Actual Condition Survey

For research object, PV powers system installed residential facilities in J city for last 4 to 5 years were selected. They include 28 urban households and 20 rural households. Actual condition survey was carried out in 2 stages: preliminary and field survey. In the preliminary survey, questionnaire interviews were employed on 50 urban and 30 rural household owners after understanding the status of PV power system installation in J city. The intent and contents of the questionnaire were explained to them. And their responses concerning maintenance were used for field survey.

Table 3. Major items for observation inspection & interview

Components	Major Item	Research Methods
PV Module	- Damage/Cleanliness Levels of PV Modules - Outward Wiring Status of PV Modules - Fixing Condition of PV Modules	- Observation Inspection - Owner Interview
Inverter	- Installation Location - Damage, Cleanliness and Corrosion Levels - Abnormality Sound, Oscillation, Over Heating, Odor, etc - State of the Internal Ventilation	- Observation Inspection - Owner Interview
Junction box	- Corrosion, Damage to the External - Outward Wiring Status	- Observation Research - Owner Interview
Support Structure	- Corrosion of the Support Structure - Fixing Condition	- Observation Research - Owner Interview

In the field survey, bare eye inspection was conducted on the components of PV power facility by item as in <Table3> which is simplified from the observation items and research methods of PV power facilities installed in accordance with <Table 1> after collecting the questionnaires prepared and distributed as in <Table 4>. In addition, interviews with the owners were carried out to establish the objectivity of the collected data. 5-point Likert scale was applied to the evaluation of the questions.

3.2. Actual Condition Survey and Analysis

Of 80 households to which the questionnaires were distributed in the preliminary survey, data analysis was performed on 40 households that sincerely participated in bare-eye observation, interviewing and questionnaire survey.

1) Analysis of Questionnaire Survey

Data analysis showed that PV power facilities had been used for 5 years on average so they were considered to be relatively new facilities. Almost half (23) of the households had used the system for about 3 years and 17 households (35%) had used it for 4 years. Therefore, 83% of PV power facilities used by the total households were in the 3rd or 4th year of use. It also indicated that 92% of the facilities were still eligible for free-of-charge maintenance service after sales (mostly up to 3 years) up to the point[12] of the survey. Therefore, most of them are still within the warranty period or just passed it, so it seemed that they wouldn't have much change of frequent failure.

The owners revealed their awareness of the relationship between CO_2 emission from PV power generation and consumption of building energy and global warming as follows. Only 14% of the owners

7) The same book (Ibid)

8) General maintenance items are the same as routine inspection items. But general maintenance is executed on the measurement and test of part of resistance and

9) Excluding the damage to module and equipment failure due to natural disaster and consumer's carelessness.

10) Lee Dae-Bum, Jung Hyung-Yong, Woo Sang-Bok, Ro Sun-Hwan, Choi Kwang-Ju, Baek Dong-Hyun, After Service Consideration of Grid-connected photovoltaic Power Generation for Household, Conference Journal of TKIEE, 2011.Pp 253

11) The same book (Ibid)

12) 2. ~ 4., 2014

Table 4. Questionnaire items for the survey and the results [%/numbers]

Division	Questions	Never	No	Common	Yes	Very Positive
Pre-knowledge level	Do you know about Photovoltaic?	2.1/1	12.5/6	50.0/24	31.3/15	4.2/2
	Is energy consumption of the building related with global warmth?	4.2/2	25.0/12	35.4/17	22.9/11	12.5/6
Maintenance level	Was there failure after installing the Photovoltaic facility?	14.6/7	31.3/15	39.6/19	14.6/7	-
	Do you know A/S procedures in failure of the Photovoltaic facility?	8.3/4	10.4/5	43.8/21	31.5/15	6.3/3
	Was rapid measures for A/S application? (26 facilities)	-	15.4/4	53.9/14	30.8/8	-
	Did the owner provide a separate maintenance for the facility?	6.3/3	48.0/23	31.3/15	14.6/7	-
Satisfactory degree	How is satisfactory degree in use of the facility?	-	10.4/5	29.2/14	37.5/18	23.0/11
Others	How long is the use of Photovoltaic facility?	1 year	2 years	3 years	4 years	5 years
		4.2/2	12.5/6	48.0/23	35.4/17	-
	How long is the free A/S period of your facility?	2 years	3 years	4 years	5 years	No idea
		-	91.7/44	-	-	8.3/4
	What's failed portion of Photovoltaic facility? (7 facilities)	Inverter	Solar module	Connection box	Wiring	Others
		28.6/2	14.3/1	-	-	57.1/4

answered 'I Don't Know' and less than 30% responded 'No relationship'. Like this, most of them thought of PV power facilities positively and it turned out that they were well aware of PV power system.

Upon the item of error and maintenance of PV power facility, only 7 (14.6%) out of 48 households said that they had problem with PV power facility. It was very low level of error and maintenance because the facilities hadn't been much degraded. Therefore, questionnaire survey was conducted on a total of 26 households for the quickness of after-sale service: 7 households that had error/problem in PV power system and 19 households that responded on average', which means no error but incontinent. The results showed that 14 households (53.9%) checked 'average' on A/S quickness and 8 households (30%) said 'quick'. However, 4 households (15.4%) responded that after-sale service was not quick enough. In general, the respondents thought of the quickness of after-sale service positively. It indicates that the system of 'A/S Exclusive Company for New Renewable Energy Facility' was effective to some extent.

Meanwhile, the participants answered to the question about their awareness of A/S application procedure when PV power facility is in error as follows. 43.8% said 'average' and thus it turned out that 39 households (81.4%) were aware of the procedure while 9 households (19%) didn't know it. However attention needs to be given to the fact that most of 'I Don't Know' owners were very old.

Putting together, about 22 households (46%) are aware of the importance of maintenance of PV power system and pay attention to the management of the system. However, more than half (26 households or 54%) of the respondents turned out that they do not maintain the facility. Therefore, it seems that a proper countermeasure needs.

2) Bare-Eye Inspection and Interview Analysis

While collecting the questioners, bare-eye inspection and interviewing were carried out on 41 out of 48 households in accordance with <Table 3> to know failure and status of maintenance of PV power system.

The solar panels were in good condition as a whole in terms of cleanness and they were fixed fast on the supports. However, some panels were polluted with dirt and found to have some problems on the back of the panels in terms of the attachment of Styrofoam and installation location.

The appearance of inverters was also clean and no abnormalities were found such as peculiar noise or smell. Besides, they were correctly installed below the array of the solar panels except two facilities that were installed on the rail of the top, so they were exposed to external environment such as snow and rain.

Junction boxes were also kept in good maintenance. No damage or abnormal wiring was observed. The support structures on which PV power system is installed were not corroded and well fastened. For the shape of the support structure, 34 houses had it on horizontal roof structure and only 7 had it on slant roof structure. Therefore, junction boxes were installed on horizontal roof structure 5 times more than on inclined roof structure.

In the interviews with 7 households that experienced the failure of PV power system, 3 households suggested specific part of failure: one for module replacement and two for inverter. The rest 4 households didn't know or clearly remember which part they had problem in PV power system though informed.

4. Problems and Improvements

The problems found in the analysis of maintenance are summarized in <Table 5> by the perspective of owner (user), installer and institution.

4.1. Problems from Owner (User)'s Perspective

According to the analysis of the questioners, only 15% of the owners and users answered 'Don't Know' or Don't Know' to the question about their technical understanding of PV power, so it

Table 5. Analyzed problems and improvements plan

Division	Problems	Improvement Plan
Owner Aspects	· Poor knowledge about the photovoltaic facility · No provision of information about facility and adequate operation & management and education for the facility · Lack of knowledge for management methods, or wrong management · Handle facility simply as means of saving electrical charge · Excessive interests in national subsidy	· Performance of advertisement and education by the constructor before or after construction · Manual distribution and explanation especially about maintenance of facility · Performance of continued social mass media P/R in the revel of promoting citizen sense for new generation energy · Establishment of regular checking system through dedicated suppliers by area
Contractor Aspects	· Insufficient site examination for planning and construction · Unreasonable installation outside of actual condition such as deterioration of building · Standardized arrangement in a single panel · Uncertainty of A/S system following frequent closure	· Required for introducing guidance, supervision system for plans and construction capacity for the constructor · Establishment of visual checking system for reporting the installation completion · Continued guidance from a single panel to a series type of array · Maintain the quality level via a strict review when selecting dedicated suppliers by area
Institutional Aspects	· Insufficient advertisement of free A/S system · Poor management system after performing a free A/S system · The limited number of dedicated suppliers (18 for photovoltaic as of 2014)	· Establishing an effective operation of the system through a positive P/R and a thorough management and supervision by the government · Increase of the numbers of dedicated suppliers and performance of education for a smooth post-management after the free A/S period.

turned out that they were very positive on the power system. However, face-to-face interviews with them found that their knowledge of the system was not deep. Therefore, it is necessary for them to have at least basic knowledge of the applied technology in order to keep a good maintenance of the facility by users and it seems also necessary to provide the users with information related to the operation of PV power system after installation. Otherwise, it seems there would be much chance for users to reflect the maintenance of PV power facility or, at best, cause unintended problems such as scratching the surface of solar panels with rugs because it is true that they don't have proper knowledge and are not in a situation where they can't be trained or educated or adequately informed of the power system.

In addition, most of the owners or users are old and elderly headed households. Therefore, because it is not easy for them to acquire enough technical understanding on the maintenance of the system, there exists an apparent limitation in the maintenance of PV power facilities.

4.2. Problems from builder (Installer)'s Perspective

Some of the households have the support structures of PV power system installed in unsuitable space due to lack of space and thus where the shade of a building covers the system. Furthermore, the shapes of the array of PV power facility are monotonous and single layered<Fig. 2>.

This insufficiency evidences that no proper and enough preparation is made when a builder make a plan and starts construction. It is very essential to place the size, shape and direction of a house in consideration for installing PV power system. Particularly, it is required that installation of PV power system in an old house should be considered and analyzed in the context of the life cycle of the system and a house building. As a result, efficient operation of the system can be realized and it will be led to a good maintenance of the system.

Fig. 2. Condition of the surveyed facilities

4.3. Problems from Institutional Perspective

As examined in 3.2, 65% of the research objects of this study stayed within the period of free warranty (A/S) as of the point of the research. Therefore, there were relatively new and did not have many cases of systemic and physical failures. As a result, only 14.6% was filed for after-sale service.

In the meantime, since 2007, Korea Energy Management Corporation has been operating the system of 'A/S Exclusive Company for New Renewable Energy Facility' in order to satisfying the civic complaints and enhancing the operation rate of new renewable energy facilities through proper maintenance and management. It stipulates mandatory maintenance period. As a result, it seems to contribute the improvement of the maintenance of the related facility to considerable extent. However, when we

consider that actual failure starts to appear from the 5th year of use, maintenance will be a key issue after free-of-charge after-sale service, 2 or 3 years later from now on, some countermeasure against it should be prepared. In particular, it is recently often seen that customer service system stops due to sudden opening and closing of companies in PV power system industry, which is sluggish these days. It is not a promising sign at all for the overall development of PV power industry and also its maintenance.

Therefore, the government initiates and manages the system of exclusive maintenance company for PV power facilities so a series of regular inspection, A/S application and restoration can be systematically realized under the maintenance and supervision PV power facility owners (maybe at their own expense) as well as the builders and A/S providers. This can improve the endurance of high quality and optimal operation of PV power facility, which will bring in value added to the system.

5. Conclusion and Suggestion

PV power generation facility for residential purpose has notably grown and been active through housing projects. However, the facilities are left negligent or lacking of maintenance after installation. As a result, it has brought out several problems including system malfunction and insufficient operation or damages. It is nothing more than wasting high cost facility. In this respect, the present study aimed to examine and analyze PV power system installed in residential buildings; understand the current status of its maintenance and operation; find out problems; derive solutions to them; and propose a desirable direction to the efficient maintenance of PV power system, so the expensive and environment-friendly facility can operate for a long time. To attain the objective, this study carried out questionnaire survey with 10 questions on 48 households, made bare-eye observation on 4 components of PV power system and conducted interviews with the owners.

The results revealed that most of the research objects (PV power facility) in J city were in quite good conditions because it had not been long since installation and the awareness of the owners were proven pretty positive on the system. They had not adequate information of the maintenance of PV power system and not been informed of it. Therefore, they had difficulty with direct maintenance. It indicates that proper education should be provided in a form of written manual by the builder after construction. In addition, it turned out that PV power facility constrictor lacked of thorough planning and preparation in installing the facility. It was observed that daylight was insufficiently secured due to the improper location of the facility. Moreover, PV power facility was installed particularly in rural area without considering aging houses which raises the endurance of the facility and actually some after-sale service was requested to the builder in the area. It was found though the interview with the owners that such inappropriateness is attributed to performance oriented work culture. Therefore, the government needs to establish a system in which the drawing of the facility by the builder is confirmed and the actual status of installation is inspected with bare eyes under its supervision.

Although it appears that companies are exclusively designated for the maintenance of PV power facility and provide free-of-charge after-sale service, the number is 18 companies as of 2014, which is not enough. Therefore, more companies should be designated as exclusive maintenance provider though incentive system. Furthermore countermeasure starts to be prepared against old facilities that will come to existence (facilities that have been 5 years after installation) to enhance the convenience of users and efficiency of PV power facility.

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