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Optimal Design of a Residential Photovoltaic Renewable System in South Korea

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Abstract: An optimal design model for residential photovoltaic (PV) systems in South Korea was proposed. In the optimization formulation, the objective function is composed of three costs, including the monthly electricity bill, the PV system construction cost (including the government's subsidy), and the PV system maintenance cost. Here, because the monthly electricity bill is not differentiable (it is a stepped piecewise linear function), it cannot be solved by using traditional gradient-based approaches. For details considering the residential electric consumption in a typical Korean household, consumption was broken down into four types (year-round electric appliances, seasonal electric appliances, lighting appliances, and stand-by power). For details considering the degree of PV generation, a monthly generation dataset with different PV tilt angles was analyzed. The optimal design model was able to obtain a global design solution (PV tilt angle and PV size) without being trapped in local optima. We hope that this kind of practical approach will be more frequently applied to real-world designs in residential PV systems in South Korea and other countries.

Keywords: optimal design; photovoltaic system; renewables; residential building; South Korea

1. Introduction

South Korea is in the world's top 10 energy-consuming countries, and it heavily depends on imports of fossil fuels (natural gas, coal, and oil) [1–3]. Due to recent public awareness regarding the issue of polluted air, pressure to reduce its dependency on fossil fuels has increased. In addition, the Fukushima disaster that occurred in Japan has caused the present government to support the nuclear phase-out policy.

Therefore, various renewable energies (photovoltaics (PV), wind, geothermal, hydro, biomass, fuel cells, etc.) have been currently developed, which also helps in the country's pledge at the 2015 Paris Climate Conference to cut its carbon emissions by 37% below the business-as-usual (BAU) level by 2030.

In addition, the Korean government has recently declared a national project aiming for power generation by renewable energies to account for 20% of the total generation output by 2030 (85,905 GWh (13.6%) by 2025 and 134,136 GWh (20%) by 2030) [4]. This project especially focuses on PV and wind energies (more than 75% with respect to the generation capacity, and more than 50% with respect to the generation amount). The Korean government plans to provide urban-type self-sufficient PV systems to 760,000 residential houses by 2022, and 1,560,000 houses by 2030 [5].

To this end, as one of practical efforts, Korean government already ruled that 5% of total construction cost should be invested in renewable energy system for large public buildings (total floor area is greater than or equal to 3000 m^2), and it also subsidizes 60% of the construction cost if private residential buildings install PV renewable systems [6].

Korean government also plans to promote rural-area PV systems using low-interest loans and higher-weighted RECs (Renewable Energy Certificate). The REC is a market-tradable and non-tangible instrument that certifies that the owner possesses one megawatt-hour (MWh) of electricity generated from any renewable energy resource [7]. RPS (Renewable Portfolio Standard) required for large power producers (≥500 MW) also works well after FIT (Feed-In Tariff) system ends. In order to enhance the social receptivity to PV systems, the Korean government has approved private enterprisers, to gather individual private investors, to join in PV development projects.

The objective of this study is to propose an optimal model for residential PV system design. In this model, the construction and management costs will be minimized, while considering various practical design factors such as PV generation amounts with different tilt angles, the Korean progressive electric rate, the unit cost of a PV panel, the interest rate, the project period, the electrical usage of general electric appliances, and seasonal appliances, lighting appliances, and stand-by power.

The rest of this paper is organized as follows. The optimal design model for the residential PV system is proposed in Section 2. Residential electricity demand is broken down in detail, and the monthly electrical generation amounts with varying tilt angles are proposed in the form of polynomial functions in Section 3. The optimal design solution is obtained by using an evolutionary algorithm, and compared with that from previous gradient-based methods in Section 4. Finally, in Section 5, we conclude our paper with some future directions.

2. Optimization Formulation

The objective function to be minimized in this residential PV design optimization is the total cost (C_T), which consists of the electric bill from grid ($C_{Electric}$), the PV-related construction cost (C_{Cst}), and the PV-related maintenance cost (C_{Mtn}), as shown in Equation (1) [6]:

$$\text{Minimize} C_T = C_{Electric} + C_{Cst} + C_{Mtn} \tag{1}$$

where the annual electric bill ($C_{Electric}$) is the sum of the monthly bills, and each monthly bill ($C^m_{Eelctric}$) is calculated based on the monthly grid-supplied amount ($D^m_{Electric} - PV^m_{Electric}$) when monthly residential demand ($D^m_{Electric}$) is greater than the monthly PV generation amount ($PV^m_{Electric}$), as in Equation (2):

$$C_{Electric} = \sum_{m=1}^{12} C^m_{Electric}(D^m_{Electric} - PV^m_{Electric}) \tag{2}$$

For the monthly bill ($C^m_{Electric}$), Korea adopts a six-stage progressive electric rate system, which charges a higher rate for higher electricity usage, as shown in Table 1.

Table 1. Korean progressive electric rate (US$1 ≈ 1100 KRW).

Range	Base Rate (KRW)	Progressive Rate (KRW/kWh)
Up to 100 kWh	370	55.1
101~200 kWh	820	113.8
201~300 kWh	1430	168.3
301~400 kWh	3420	248.6
401~500 kWh	6410	366.4
More than 500 kWh	11,750	643.9

For example, if one household consumes 50 kWh for a certain month, the monthly electric bill will be 3125 KRW (=370 + 50 × 55.1); if it consumes 150 kWh, the monthly electric bill will be 12,020 KRW (=820 + 100 × 55.1 + 50 × 113.8). Thus, if we draw a monthly electric bill from 0 to 600 kWh, we obtain a stepped piecewise linear function, as shown in Figure 1.

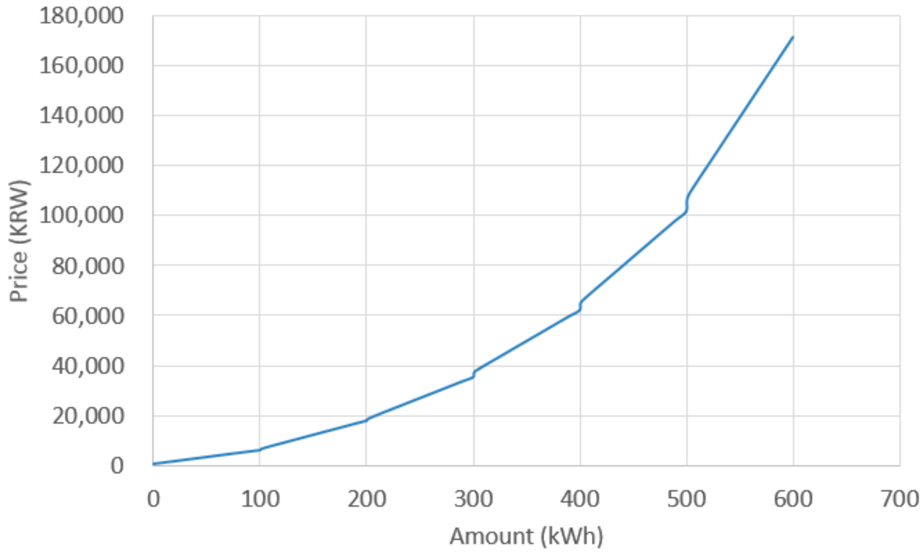

Figure 1. The six-stage progressive electric rate in Korea.

For the PV-related construction cost (C_{Cst}), in order to fairly consider this one-time cost alongside other annual costs ($C^m_{Electric}$ and C_{Mtn}), a capital recovery factor [8], which is the ratio of a constant annual return amount to the initial construction cost (C_{Icc}) for a given length of time, is introduced as in Equation (3):

$$C_{Cst} = \frac{r(1+r)^n}{(1+r)^n - 1} C_{Icc} \quad (3)$$

where r is the interest rate (6.5% in this study) and n is number of system operation years (or the number of annual returns received; 25 years in this study).

The decision variables in this residential PV design optimization are the size of the PV panel (or module; S^{PV}) and the tilt angle of the PV panel (A^{PV}; horizontal line is 0°). These two decision variables have value ranges as constraints:

$$0 \leq S^{PV} \leq 3(\text{kW}) \quad (4)$$

$$15° \leq A^{PV} \leq 60° \quad (5)$$

3. Application of the Residential PV System

The above formulated PV design model is assumed to be applied to a typical Korean residential building. For a typical Korean residential building, the monthly demand ($D^m_{Electric}$) can be assessed in four groups of consumption (general electric appliances, seasonal electric appliances, lighting appliances, and stand-by power) [6].

The first group of consumption occurs in general (year-round) electric appliances such as the television, refrigerator, and washing machine, as shown in Table 2. For example, a typical Korean residential building has two TV sets, which consume 270 W (=135 W × 2) over 6.9 hr per day, and 28 days per month, based on a statistical survey. Interestingly, a Korean house also possesses a special refrigerator which preserves only Kimchi, because it is an essential dish for every meal in Korean daily life.

Table 2. Power consumption of general electrical appliances.

Appliance	Power Consumption (W)	Daily Usage Hours (hr)	Monthly Usage Days (days)
Two TV sets	270	6.9	28.0
Refrigerator	67	24.0	30.0
Refrigerator for Kimchi	30	24.0	30.0
Washing Machine	515	1.5	17.5
Vacuum Cleaner	899.1	0.6	21.6
Personal Computer	168	4.2	24.4
Microwave	1010.2	0.4	14.9
Audio System	40	3.0	8.5

The second group of consumption occurs with seasonal electric appliances, such as the electric fan, air conditioner, humidifier, and electric blanket, as shown in Tables 3 and 4. For example, a typical Korean residential building has one air conditioner, which consumes 1725 W over 4.65 hr per day. However, this seasonal appliance is utilized only during the summer season (13 days for June, 15 days for July, and 27 days for August).

Table 3. Power consumption of seasonal electrical appliances.

Appliance	Power Consumption (W)	Daily Usage Hours (hr)	Yearly Usage Days (days)
Electric Fan	60	7.20	95
Air Conditioner	1725	4.65	55
Humidifier	99	5.12	126
Electric Blanket	230	5.42	146

Table 4. Monthly usage of seasonal electrical appliances.

Appliance	Days of Use in Each Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Electric Fan	0	0	0	0	14	16	23	25	16	0	0	0
Air Conditioner	0	0	0	0	0	13	15	27	0	0	0	0
Humidifier	23	21	17	0	0	0	0	0	0	17	23	24
Electric Blanket	27	25	20	0	0	0	0	0	0	20	24	27

The third group of consumption occurs with lighting appliances, such as fluorescent, incandescent, and halogen lights, as shown in Table 5. For example, a typical Korean residential building has one stand-alone (stabilizer-included) fluorescent lamp, which consumes 25.86 W over 7.9 hr per day.

Table 5. Power consumption of lighting appliances.

Appliance	Power Consumption (W)	Daily Usage Hours (hr)
Fluorescent Tube (20 W)	20	7.9
Fluorescent Tube (32 W)	32.09	7.9
Fluorescent Tube (40 W)	40.18	7.9
Fluorescent (Compact)	37.90	8.1
Fluorescent (Circular)	39.85	5.6
Fluorescent (Stand-Alone)	25.86	7.9
Incandescent	71.48	1.7
Halogen	94.17	1.3

The final group of consumption occurs with stand-by power from various appliances, as shown in Table 6. Normally it accounts for approximately 10% of total household power consumption.

Table 6. Consumption amount of stand-by power.

Appliance	Average Stand-By Power (W)	Daily Stand-By Power Amount (Wh)
Two TV sets	8.6	147.1
Audio System	9.1	191.1
DVD	12.2	269.6
Microwave	2.8	66.2
Air Conditioner	2.8	54.2
Personal Computer	3.2	63.4
Computer Monitor	2.6	51.5

If we aggregate the above-mentioned four types of consumption, we can obtain a monthly power consumption graph, as shown in Figure 2. Here, it should be noted that a consumption amount of 2.2 kWh/day for any additional appliance was added to each monthly amount.

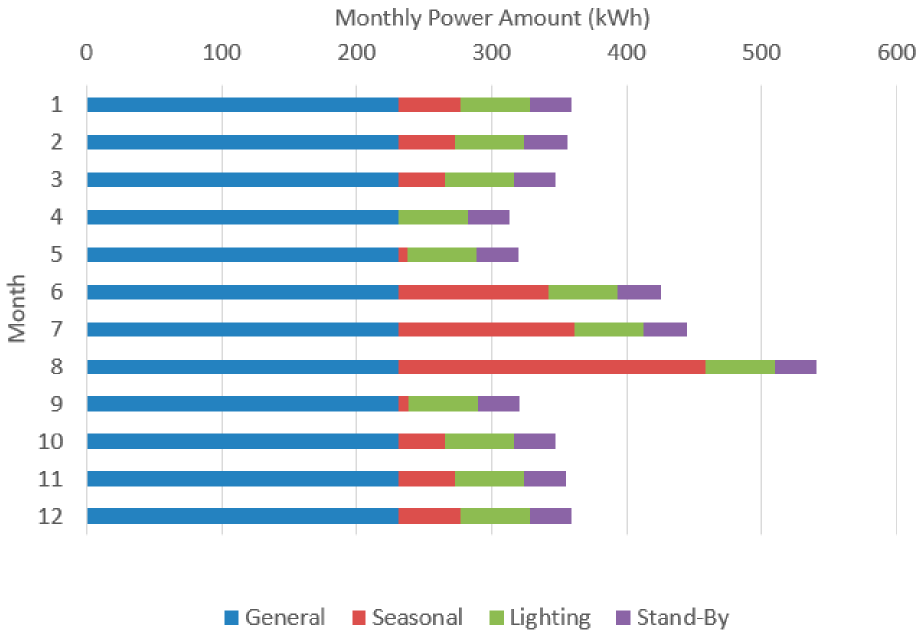

Figure 2. Monthly power consumption for a typical Korean house.

So far, the monthly power consumption of a typical Korean house has been assessed based on four different types of consumption. Now let us assess the monthly power generation amount from the PV system ($PV^m_{Electric}$).

The monthly PV generation amount is affected by two major decision variables (PV angle, A^{PV}, and PV size, S^{PV}). The first affecting factor is the tilted angle of the PV panel, as shown in Figure 3. As seen in the figure, the lowest angle (15°) generates the highest amount in June, while the highest angle (60°) generates the highest amount in December. The highest amounts in March and September occur in the middle.

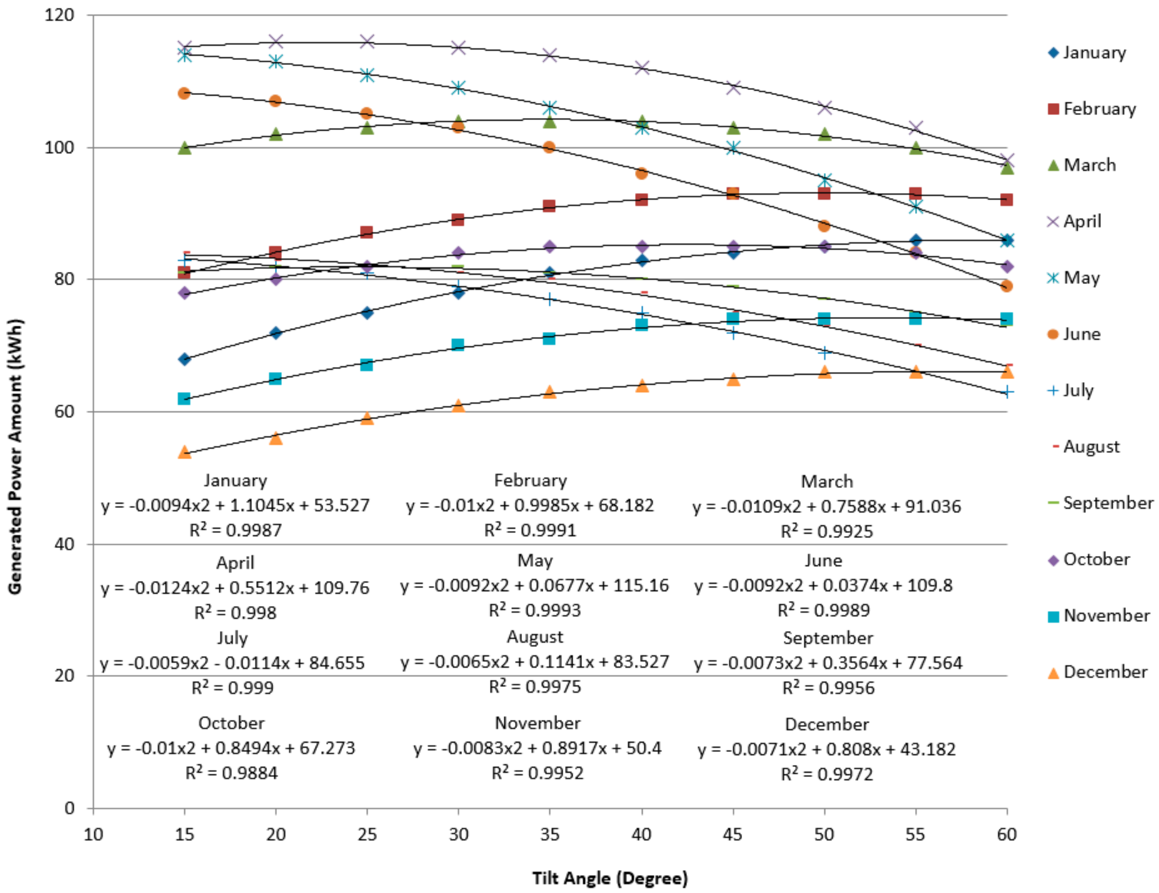

Figure 3. Monthly photovoltaics (PV) generation amounts with different tilt angles.

For this study, in order to estimate the energy production of the residential PV system, the PVWatts calculator [9], which was developed by the National Renewable Energy Laboratory (NREL) in the U.S. Department of Energy, was utilized. After inputting various PV system specifications such as the DC system size (unit size (1 kW) in this study), array type (fixed in this study), array azimuth (180° (full south) in this study), system losses (14% in this study), inverter efficiency (96% in this study), and PV tilt angle (A^{PV}) into the software, we could obtain an estimation of the month-average solar radiation (kWh/m^2/day), and the monthly unit-size PV generation amount (kWh) for a specific location.

For the specific location, this study selected Seoul, the capital city of South Korea. However, PVWatts provided the PV generation data of Incheon, as the nearest location from Seoul (24 miles west from the center of Seoul), whose latitude is 37.48° N and longitude is 126.55° E, as shown in Figure 4.

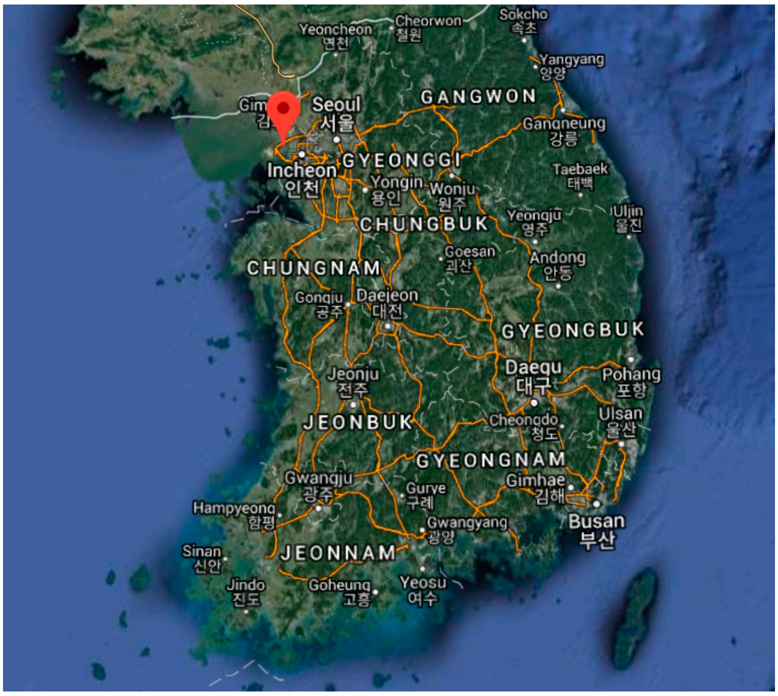

Figure 4. Location of the solar data source (Incheon) from Google Maps.

The influencing factor, PV size (S^{PV}), can be multiplied by the unit-size generation amount (kWh/kW) at a certain PV angle (A^{PV}), to calculate the monthly PV generation amount ($PV^{m}_{Electric}$).

The PV-related construction cost (C_{Cst}) in Equation (1) is the function of PV size (S^{PV}). The original PV construction cost is 7,210,000 KRW/kW in this study. However, after considering the Korean government's subsidy (60% of the original cost = 4,326,000 KRW/kW) and the building materials cost savings ($462,500/kW), the PV-related construction cost (C_{Cst}) becomes 2,421,500 KRW/kW (=7,210,000 − 4,326,000 − 462,500) multiplied by the PV size (S^{PV}).

The PV-related annual maintenance cost (C_{Mtn}) in Equation (1) is 12,105.7 KRW/kW (0.5% unit C_{Cst}) multiplied by the PV size (S^{PV}).

4. Computational Results

The residential PV design model is optimized with various practical data, as proposed in the above sections. Figures 5 and 6 show the total PV design cost, as specified in Equation (1), with different PV sizes ($0 \leq S^{PV} \leq 3$ kW, by 0.2 kW) and tilt angles ($15° \leq A^{PV} \leq 60°$, by 2.5°). In this resolution, 639,919 KRW, with a PV size of 1.2 kW and a PV tilt angle of 27.5° is the minimal design solution for the system.

When we narrowed down the PV size ($0.95 \leq S^{PV} \leq 1.3$ kW) and the tilt angle ($26.4° \leq A^{PV} \leq 28.6°$), and then divided them into finer intervals (0.05 kW for the PV size and 0.1° for the tilt angle), Figures 7 and 8 were obtained. At this resolution, we obtained a better solution (639,901 KRW with PV size of 1.2 kW and PV tilt angle of 28.3°~28.4°) than that with coarse resolution (639,919 KRW with PV size of 1.2 kW and PV tilt angle of 27.5°).

Size (kW)	Angle (°)																		
	15	17.5	20	22.5	25	27.5	30	32.5	35	37.5	40	42.5	45	47.5	50	52.5	55	57.5	60
0	717,546	717,546	717,546	717,546	717,546	717,546	717,546	717,546	717,546	717,546	717,546	717,546	717,546	717,546	717,546	717,546	717,546	717,546	717,546
0.2	694,407	694,068	693,802	693,608	693,487	693,438	693,462	693,558	693,727	693,968	694,282	694,668	695,130	695,693	696,330	699,032	699,818	700,679	701,613
0.4	676,073	675,374	674,811	674,386	674,097	673,944	673,929	674,050	674,308	674,702	675,234	675,902	676,707	677,648	678,727	679,942	681,293	682,782	684,407
0.6	655,356	654,280	653,440	652,774	652,282	651,964	651,820	651,849	652,052	650,439	650,990	651,720	652,712	656,881	658,233	659,758	661,457	663,375	671,050
0.8	650,905	649,663	648,643	645,858	645,366	643,126	643,114	643,356	643,807	644,468	645,339	646,418	647,708	649,206	650,915	652,832	654,959	657,296	659,841
1	645,787	644,538	643,544	642,803	640,325	640,115	640,214	640,559	641,153	642,038	643,787	645,182	646,831	648,735	650,893	653,306	655,974	658,896	662,073
1.2	644,412	642,952	641,770	640,864	640,235	639,919	641,952	642,284	642,903	643,810	645,005	646,488	648,284	651,081	653,564	656,342	659,415	662,784	666,449
1.4	649,777	648,075	646,695	645,638	644,905	644,494	644,407	644,642	645,201	646,082	647,286	648,814	650,664	652,838	655,411	660,475	663,885	667,631	671,713
1.6	655,106	653,274	651,792	650,659	649,875	649,441	649,356	649,620	650,233	651,196	652,509	654,170	656,181	658,541	661,250	664,309	667,754	672,223	676,439
1.8	659,033	656,847	655,027	653,571	651,333	650,833	652,761	653,050	653,690	654,682	659,183	661,101	663,387	666,041	669,064	672,456	676,216	680,344	684,841
2	669,794	667,668	665,888	664,455	663,369	662,630	662,812	662,305	662,883	663,822	665,108	666,741	668,722	673,245	676,680	680,161	684,137	691,727	696,724
2.2	684,973	682,556	680,506	678,364	677,246	676,482	676,072	676,137	676,701	677,627	678,907	680,543	682,585	685,633	688,601	691,938	695,645	701,895	706,652
2.4	700,831	698,455	695,872	694,443	692,950	692,331	692,066	692,153	692,593	693,386	694,532	696,030	698,614	701,622	704,567	707,900	711,543	715,991	721,451
2.6	717,795	715,595	713,778	712,344	711,292	710,621	710,334	709,891	710,484	711,447	712,779	714,482	716,554	718,996	721,807	725,012	729,510	733,784	738,444
2.8	736,695	734,433	732,543	730,527	729,563	728,958	728,712	728,825	729,298	729,719	731,393	733,197	735,370	738,480	741,517	744,932	748,725	752,895	758,276
3	756,136	754,161	752,071	749,926	749,009	748,364	748,061	748,073	750,994	752,061	753,468	755,216	757,305	759,735	762,506	766,006	769,782	773,924	779,091

Figure 5. The total PV design cost.

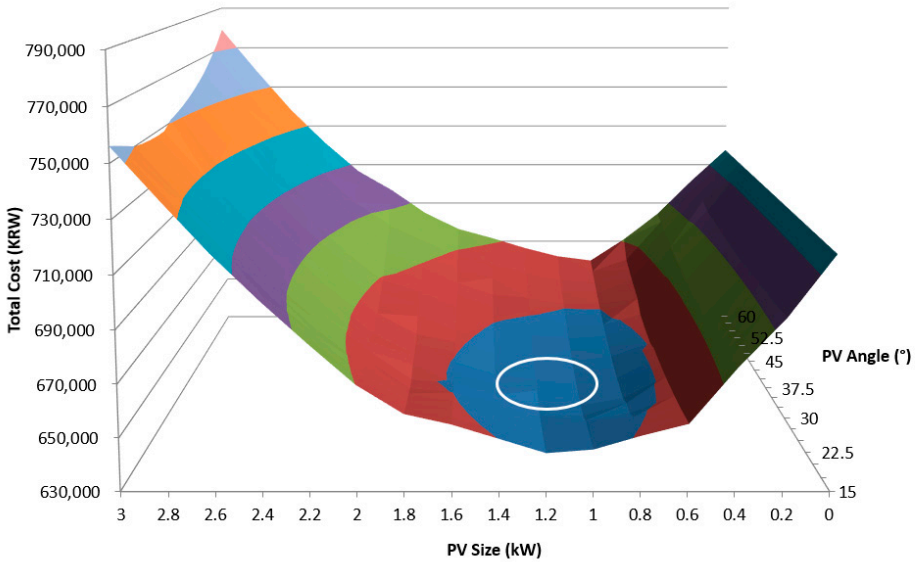

Figure 6. Map of the total PV design cost.

Size (kW)	Angle (°)																						
	26.4	26.5	26.6	26.7	26.8	26.9	27	27.1	27.2	27.3	27.4	27.5	27.6	27.7	27.8	27.9	28	28.1	28.2	28.3	28.4	28.5	28.6
0.95	642,782	642,775	642,768	642,761	642,754	642,748	642,743	642,738	642,733	642,728	642,724	642,721	642,717	642,715	642,712	642,710	642,709	642,707	642,706	642,706	642,706	642,706	642,707
1	640,162	640,153	640,145	640,138	640,131	640,128	640,125	640,122	640,119	640,118	640,116	640,115	640,114	640,114	640,114	640,114	640,115	640,116	640,118	640,120	640,122	640,125	640,128
1.05	640,587	640,581	640,576	640,572	640,568	640,564	640,561	640,558	640,555	640,553	640,552	640,551	640,550	640,549	640,549	640,550	640,551	640,552	640,554	640,556	640,558	640,561	640,564
1.1	640,504	640,496	640,488	640,481	640,474	640,467	640,461	640,456	640,450	640,446	640,441	640,438	640,434	640,431	640,428	640,426	640,424	640,423	640,422	640,422	640,421	640,422	640,423
1.15	641,242	641,234	641,226	641,218	641,211	641,204	641,198	641,192	641,187	641,182	641,177	641,173	641,170	641,166	641,164	641,161	641,159	641,158	641,157	641,156	641,156	641,157	641,157
1.2	640,004	639,991	639,978	639,966	639,958	639,951	639,945	639,939	639,933	639,928	639,923	639,919	639,915	639,912	639,909	639,906	639,905	639,903	639,902	639,901	639,901	641,892	641,892
1.25	641,162	641,148	641,135	641,122	641,110	641,098	641,086	641,075	641,065	641,055	641,045	641,036	641,027	641,019	641,011	641,004	640,997	640,991	640,985	640,980	640,975	640,970	640,966
1.3	642,320	642,305	642,291	642,278	642,265	642,253	642,241	642,230	642,219	642,208	642,198	642,189	642,180	642,171	642,163	642,156	642,148	642,142	642,136	642,130	642,125	642,120	642,116

Figure 7. The total PV design cost at a finer resolution.

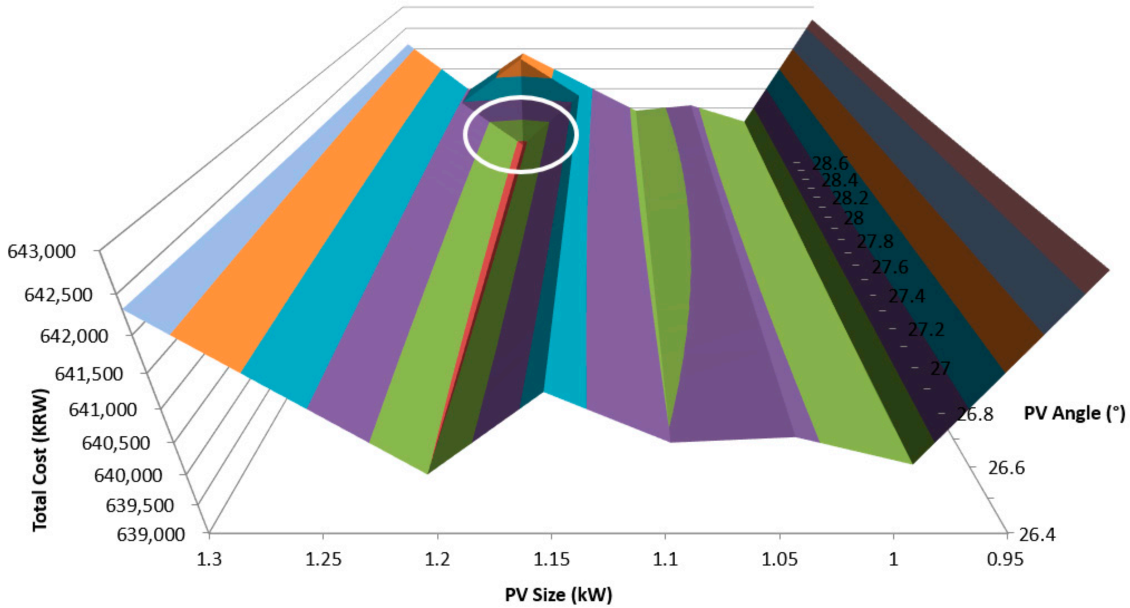

Figure 8. Map of the total PV design cost at a finer resolution.

In order to find a global optimal solution, we applied a genetic algorithm [10] as a global search meta-heuristic algorithm [11] to this PV design problem. When this meta-heuristic optimization algorithm was applied, we obtained an even better solution (639,824 KRW) at different solution spot (a PV size of 1.1904 kW and a PV tilt angle of 26.7013°) than those at the previous two resolutions. This phenomenon means that there exist local optimal solutions within the solution space.

Here, it should be noted that this PV design problem cannot be solved by using calculus-based approaches, because the monthly electric bill, as a part of the objective function, possesses stepped piecewise linearity, as shown in Figure 1. At certain stepped points such as 100, 200, 300, 400, and 500 kW, this cost function is not differentiable. Although a previous research [6] tackled this problem with a gradient-based approach, named SQP (Sequential Quadratic Programming), it had to sacrifice the accuracy of the objective function by smoothing out this step function with polynomial curve fitting.

In order to compare our approach by using a genetic algorithm with the old approach, using SQP, we first performed a polynomial regression based on the electrical rate data in Table 1, and obtained the following second-order polynomial function:

$$C^{m}_{Electric} = 0.5632x^2 - 76.207x + 7612.3 \text{with} R^2 = 0.9947 \quad (6)$$

Then, based on Equation (6), the SQP optimization was performed, obtaining an optimal cost of 617,529 KRW, with a PV size of 1.3935 and a PV tilt angle of 29.7229°. It appears that the solution (617,529 KRW) from SQP was better than that (639,824 KRW) of our approach. However, when we verified the SQP solution with a real cost table (Table 1), we obtained 644,252 KRW, which is worse than our solution.

5. Conclusions

This study proposes a design optimization model for the residential PV systems in South Korea, where the objective function to be minimized consists of three costs, such as the monthly electric bill, the PV-related construction costs, and the PV-related maintenance cost. Here, the monthly electric bill has six ranges in the form of a stepped piecewise linear function. The PV-related construction costs also include the government's subsidy and the building-material cost savings. The initial construction costs, and the annually occurring maintenance costs are fairly compared by introducing the capital recovery factor.

Regarding residential electrical consumption, four consumption types, such as year-round electric appliances, seasonal electric appliances, lighting appliances, and stand-by power, were considered. Also, regarding residential PV generation, the monthly generation amount was calculated by considering different solar altitude angles.

While local optimal solutions, this model could find the global optimal solution by using a genetic algorithm. We hope that this optimization model will be practically used in residential PV system designs in South Korea.

For future study, we plan to construct more detailed PV design optimization models by considering discrete PV size variables [12–14], ESS (energy storage systems) [15,16], AC–DC conversion [17], and more energy-efficient lighting devices (light-emitting diodes). Normally, the size of PV is discrete, because a PV system consists of an integer number of panels. Thus, we would like to consider this discrete nature of the PV size after gathering sufficient data in the future. In order to efficiently utilize surplus energy from the PV system, we may install an ESS and optimally schedule it [15].

The climate change cast over in Korea has made its summers hotter than before, which has led to more energy consumption in the summer months, and higher energy bills. Thus, the Korean government is about to reform the multi-stage progressive electric rate, in order for lower-income groups to be able to afford to pay it. Once all-new data, including billing, panel capacity and costs, ESS capacity & costs, etc., are obtained, we will correspondingly construct a more detailed and up-to-date model design.

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References

1. EIA (U.S. Energy Information Administration). Country Analysis Brief: South Korea. Available online: https://www.eia.gov/beta/international/analysis.php?iso=KOR (accessed on 4 February 2019).
2. Geem, Z.W.; Roper, W.E. Energy Demand Estimation of South Korea Using Artificial Neural Network. *Energy Policy* **2009**, *37*, 4049–4054. [CrossRef]
3. Geem, Z.W.; Kim, J.-H. Optimal Energy Mix with Renewable Portfolio Standards in Korea. *Sustainability* **2016**, *8*, 423. [CrossRef]
4. Kang, K.-S.; Kim, M.-S.; Kwak, J.-Y. Renewable Energy Scenarios for 2030 in Korea. *J. Wind Energy* **2017**, *8*, 5–10.
5. MOTIE (Ministry of Trade, Industry and Energy). *White Paper on Trade, Industry and Energy (Energy Section)*; Korean Ministry of Trade, Industry and Energy: Sejong, Korea, 2018.
6. Jeon, J.-P.; Kim, K.-H. An Optimal Decision Model for Capacity and Inclining Angle of Residential Photovoltaic Systems. *Trans. Korean Inst. Electr. Eng.* **2010**, *59*, 1046–1052.
7. Renewable Energy Certificate. Available online: https://en.wikipedia.org/wiki/Renewable_Energy_Certificate_(United_States) (accessed on 4 February 2019).
8. Mays, L.W.; Tung, Y.K. *Hydrosystems Engineering and Management*; McGraw-Hill: New York, NY, USA, 1992.
9. NREL (The National Renewable Energy Laboratory). PVWatts® Calculator. Available online: https://pvwatts.nrel.gov/ (accessed on 4 February 2019).
10. Goldberg, D.E. *Genetic Algorithms in Search Optimization and Machine Learning*; Addison-Wesley: Reading, MA, USA, 1989.
11. Saka, M.P.; Hasançebi, O.; Geem, Z.W. Metaheuristics in Structural Optimization and Discussions on Harmony Search Algorithm. *Swarm Evol. Comput.* **2016**, *28*, 88–97. [CrossRef]
12. Geem, Z.W. Size Optimization for a Hybrid Photovoltaic-Wind Energy System. *Int. J. Electr. Power Energy Syst.* **2012**, *42*, 448–451. [CrossRef]
13. Askarzadeh, A. A discrete chaotic harmony search-based simulated annealing algorithm for optimum design of PV/wind hybrid system. *Sol. Energy* **2013**, *97*, 93–101. [CrossRef]
14. Askarzadeh, A. Developing a discrete harmony search algorithm for size optimization of wind–photovoltaic hybrid energy system. *Sol. Energy* **2013**, *98*, 190–195. [CrossRef]
15. Geem, Z.W.; Yoon, Y. Harmony Search Optimization of Renewable Energy Charging with Energy Storage System. *Int. J. Electr. Power Energy Syst.* **2017**, *86*, 120–126. [CrossRef]
16. Aryani, D.R.; Kim, J.-S.; Song, H. Suppression of PV Output Fluctuation Using a Battery Energy Storage System with Model Predictive Control. *Int. J. Fuzzy Logic Intell. Syst.* **2017**, *17*, 202–209. [CrossRef]
17. Fitri, I.R.; Kim, J.-S. An Optimal Current Control of Interlink Converter Using an Explicit Model Predictive Control. *Int. J. Fuzzy Logic Intell. Syst.* **2018**, *18*, 284–291. [CrossRef]