Economic Evaluation of Exploiting Solar Energy to Provide Electrical Energy

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ABSTRACT:
Providing electrical energy is one of the main concerns when constructing a new building for business, agricultural, or residential purposes in remote areas. On these occasions, an economic analysis should be done to make an appropriate decision for providing electrical energy to these areas. In this paper, an approach is proposed for economic evaluation of a plan to exploit solar energy in order to provide electricity for those consumers who have not access to the national electricity grid. On the other hand, those consumers who have access to the national grid may also use a variety of techniques and methods such as solar energy exploitation to manage their consumption and cut their electricity costs. Besides for generating electrical energy, solar energy may be used for direct provision of heat requirements, and this will lead to a cut in fossil fuel costs. In this paper, a method is also proposed for economic evaluation of using solar energy in buildings which are close to the national grid in order to manage electricity consumption and also to decrease fossil fuel costs. Related numerical studies are presented along with analysis of the sensitivity to changes in economic parameters.

KEYWORDS: economic evaluation, electrical energy, photovoltaic systems, sensitivity analysis, solar energy

1. INTRODUCTION
In early years of generating electrical energy, power companies had focused on particular geographical areas and generated and distributed electrical energy locally. Then, the issue of national grids and central large power plants was introduced to form large interconnected systems for more economical and more secure generation. A few years later, idea of central generation by large power plants lost many of its advocates mostly because of an increase in costs of transmission and distribution, worsening of environmental issues, technological changes, and different legislations. In recent decades, issues of restructuring and privatization have been raised in power industry and put into action in some countries. In the restructured environment of power industry, convincing market players to invest in multi-billion dollar projects of power generation and transmission is not easy, because capital recovery may be possible only after a very long period. These issues led to introduction of distributed generation (DG) as a proper choice for generation and as a response to the increase of electricity demand. DG is generating or storing of electricity in a small scale which is located close to the consumer. DGs can be connected to the grid or be used independently. Those DGs which are connected to the grid are usually located in the distribution level [1]-[4].

In many developing countries, there are lots of residential and business buildings which are located in places that are far from the inter-connected system and don’t have access to electrical energy [5]. Also, providing electrical energy is one of the main concerns when constructing a new building for business, agricultural, or residential purposes in remote areas. On these occasions, economic analysis should be done to make an appropriate decision for electrifying these areas. First solution is extending the grid into the area where these consumers are, which can be expensive. Another solution is using DG to make it possible to improve life quality in the remote areas quickly [5].

In addition, consumers who have access to the national grid may use a variety of techniques and methods such as changing their time of consumption to off-peak periods, using more energy efficient equipments, and employing DGs to manage their consumption and cut their electricity costs. In some cases, because of existing limitations, it is not possible to use methods such as changing the consumption times to off-peak periods and replacing equipments with their more energy efficient kinds; on these occasions, using...
DGs may be a more economical and more proper option. Some DG technologies, in addition to generating electrical energy, can be used to produce the heat needed in buildings which in turn will lead to a cut in fossil fuel costs.

DGs are of different kinds some of which are: internal combustion engine (ICE), combustion or gas turbine, fuel cells, micro-turbine, wind turbine, hydraulic turbine, solar photovoltaic (PV), battery, capacitor storage, geothermal, superconducting magnetic energy storage (SMES) [6]. PV units, in addition to all their benefits regarding environmental considerations and usage of renewable energies, provide a chance to improve life quality and also to manage consumption.

In this paper, a method is proposed for economic evaluation of projects in which PV units are used to provide electricity for consumers who are far from the national electricity grid. A remote consumer’s features are presented and the plans including the use of solar energy and the expansion of grid for providing electricity for this consumer are evaluated and compared economically. Also, a method is proposed for economic evaluation of the use of PV units in the buildings which are close to the national grid in order to manage the generation of needed electricity and also to cut fossil fuel consumption. A numerical example of calculating the cost of electricity generated by a PV unit is presented. In this effort, all of the related numerical studies are presented along with analysis of the sensitivity to changes in economic parameters.

2. SOLAR PHOTOVOLTAIC (PV)

PV technology provides an appropriate solution for resolving accessibility and environmental problems. In spite of the fact that solar energy is free, the equipment needed to convert it to useful electrical energy is fairly expensive. Considering technological advances and mass production of the related equipments, it is predicted that costs of generating electrical energy from solar energy will fall considerably [8].

From the year 1976 to 2008, the cost of initial installation of PV modules for each watt of generation capacity decreased from about 58 $/W to 4 $/W. Accordingly, the electrical energy which was generated by PV units became cheaper during this period [9]. In recent years, price of fossil fuels has gone up. From the year 1999 to 2006, the average cost of generating electrical energy from fossil fuels such as gas, oil, and coal has increased from about 0.025 $/kWh to 0.075 $/kWh [10]. If this trend continues, in near future, the cost of electrical energy generated by PV units can compete directly with the cost of electrical energy generated from fossil fuels. So, it seems that solar energy will certainly have its own place in generating electrical energy in near future. According to the estimation of International Energy Agency, 11% of the whole electrical energy of the world will be generated by using solar energy in 2050. However, veracity of this estimation depends on adopting incentive policies by different countries in the next 5 to 10 years so that the cost of initial investment goes down [10].

Environmental considerations, motive of finding alternative unlimited energies, and motive of benefiting the advantages of DGs are some of the reasons which cause different countries to adopt incentive policies to promote usage of PV units [11].

In general, four different modes can be considered for employing PV units, as follows [11]:

a) Domestic and business PV systems which are not connected to the national grid.
b) Very small PV systems which are not connected to the national grid. This mode is used for loads such as those of telecommunication equipments which are far from the national grid and their consumptions are very low.
c) PV systems in the form of DGs which are connected to the national grid. These systems provide the whole or part of the load which is needed. In this usage, it is not necessary to use batteries for saving electrical energy; so the initial cost of these systems can be lower than the modes (a) and (b).
d) Centralized large PV systems which are connected to the national grid. These systems are alternatives for old power plants which burn fossil fuels.

In this paper, the modes (a) and (c) are considered and studied.

The main parts included in a PV unit are the PV array, battery (if needed), load controller, and inverter. Lots of studies have been done to cut costs of using PV technology in business and residential buildings. In this respect, PV arrays have been incorporated into materials of facades of buildings’ walls and roofs. These PV systems, which are called building integrated photovoltaic (BIPV), are more economical through sharing a part of PV cost with usual building costs. However, designing, procurement, installation, and maintenance of BIPV systems include costs which are higher than usual [12]. Rise of temperature in PV cells decreases the efficiency of energy conversion. Hybrid photovoltaic-thermal (PVT) system, includes PV modules with air channels. In this system, surrounding air is usually circulated in the air channels so that the PV modules are cooled. Thermal energy which is
produced in this way can be used to meet building’s need for heat. In fact, in a PVT system, both the electrical and thermal energies can be produced at the same time by using a series of installed equipments. In such a system, PV modules act as a part of heat absorption system. Usage of PV in the form of combined heat and power production can economically improve this technology [12], [13]. Building integrated photovoltaic-thermal (BIPVT) systems are new systems in which BIPV and PV technologies are combined [13]. In BIPVT systems, both electrical and thermal energies needed in a building are produced simultaneously. Meanwhile, the installation cost of related collectors is shared with usual building costs and as a result it becomes more economical.

3. ELECTRIFICATION OF REMOTE AREAS

Here, two plans are considered to electrify areas which are distant from the grid. The first plan is to extend the national grid into the consumption area and the second plan is to install DG units in the area. However, a plan to install DG in the area itself can include several plans, because there are different DG technologies any of which may be used. Here, for electrification by DG, just PV technology is considered. The economic technique which is used for economic evaluation and comparison of the plans is that of present value method [14].

3.1. Plan of Grid Expansion

If the transmission or distribution grid or both of them are extended to provide the energy needed by the remote consumers, the present value of the project can be computed as:

\[ LCC_{Grid} = C_i^{Grid} + \sum_{k=1}^{nG} [(C_{k,OKM}^{Grid} + C_E^{Grid}(k)) \times (P|F,k,i)] \] (1)

where, \( LCC_{Grid} \) is the present value of plan of grid expansion ($), \( C_i^{Grid} \) is the initial investment and installation cost of the grid ($), \( C_{k,OKM}^{Grid}(k) \) is the operation and maintenance cost of the new lines and substations in the year \( k \) ($), \( C_E^{Grid}(k) \) is the electrical energy cost of the grid for the remote consumer in the year \( k \) ($), \( P|F,k,i \) is the factor of present value of uniform amounts over the period of \( nG \) years and with the real interest rate of \( i \) (see Appendix).

It is worth noting that the real interest rate, \( i \), can be calculated on the basis of the bank interest rate and the inflation rate. If the annual cost of maintenance and operation of the grid and also the annual cost of consuming electrical energy from the grid is considered fixed for the remote consumer for all years, the present value of the plan can be computed as:

\[ LCC_{Grid} = C_i^{Grid} + [(C_{k,OKM}^{Grid} + C_E^{Grid}) \times (P|A,nG,i)] \] (2)

where, \( P|A,nG,i \) is the factor of present value of uniform amounts over the period of \( nG \) years and with the real interest rate of \( i \) (see Appendix).

Annual cost of electricity consumption from the grid, \( C_E^{Grid} \), can be calculated as:

\[ C_E^{Grid} = COE_{gen}^{Grid} \times \frac{1}{1-\delta_{T&D}} \times Load \times 365 \] (3)

where, \( COE_{gen}^{Grid} \) is the cost of electrical energy generation by large power plants ($/kWh), \( \delta_{T&D} \) is the distribution and transmission loss factor, and \( Load \) is the amount of load that is consumed daily by the consumer (kWh/day).

3.2. Plan of Exploitation of PV Technology

If, instead of extending the grid, a PV unit is installed at the place of consumption to meet the need for electric energy, the present value of the plan for using the PV can be calculated as:

\[ LCC_{PV} = C_i^{PV} + \sum_{k=1}^{nP} [C_{k,OKM}^{PV}(k) \times (P|F,k,i)] \] (4)

where, \( LCC_{PV} \) is the present value of the plan of PV unit installation ($), \( C_i^{PV} \) is the initial investment and installation cost of the PV unit ($) and \( C_{k,OKM}^{PV}(k) \) is the operation and maintenance cost of the PV unit in the year \( k \) ($), \( P|F,k,i \) is the factor of present value of amount in the year \( k \) and with the real interest rate of \( i \) (see Appendix), and \( nP \) is the economic life of the installed PV unit (years).

The cost of initial investment and installation includes the initial value of equipment, the cost of design and engineering, and the cost of installation. If the annual cost of maintenance and operation of the PV unit is considered fixed for all years, the present value of the plan can be computed as:

\[ LCC_{PV} = C_i^{PV} + \sum_{q=1}^{nP} [C_{q,OKM}^{PV} \times (P|A,nP,i)] \] (5)

where, \( P|A,nP,i \) is the factor of present value of uniform amounts over the period of \( nP \) years and with the real interest rate of \( i \) (see Appendix).

3.3. Economic Comparison of Plans

If \( nG = nP \); then for economic comparison of the two foresaid projects, it is enough to compare \( LCC_{Grid} \) with \( LCC_{PV} \). If \( nG \neq nP \); then a common life or the smallest common multiple of lives should be chosen for the two plans and the present value of plans should be computed on the basis of that common life [14]. The comparable present values for the two plans are as follows:

\[ LCC_{Grid} = C_i^{Grid} \sum_{q=0}^{nG} (P|F,q \times nG,i) + (C_{k,OKM}^{Grid} + C_E^{Grid}) \times (P|A,B,i) \] (6)
LCC_{PV} = C_{PV}^{\text{first cost}} + \sum_{q=0}^{B_{q}} (P | F, q \times nP, i) + C_{PV}^{\text{installation cost}} \times (P | A, B, i) \quad (7)

where, \( B \) is the common life chosen for two plans and \( \alpha = B/nG \) and \( \beta = B/nP \). The present values considering the common life, i.e., \( \text{LCC}_{\text{Grid}} \) and \( \text{LCC}_{\text{PV}} \), should be compared with each other. The smaller one indicates the more economical plan.

3.4. Numerical Study

Here, it is intended to evaluate and compare the two plans of grid expansion and exploitation of PV units to electrify areas which are distant from the grid.

**Table 1.** Needed data for economic evaluation of electrification plans for the consumer being studied

<table>
<thead>
<tr>
<th>Plan of grid expansion</th>
<th>Investment and installation cost of a distribution substation (20/0.4 kV, 15 kVA)</th>
<th>350 $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan of grid expansion</td>
<td>Investment and installation cost of medium-voltage lines (20 kV)</td>
<td>14.9 $/m</td>
</tr>
<tr>
<td>Plan of grid expansion</td>
<td>Electrical energy generation cost of large power plants</td>
<td>0.046 $/kWh</td>
</tr>
<tr>
<td>Plan of grid expansion</td>
<td>Operation and maintenance cost of a grid based on a percentage of its initial cost</td>
<td>1% per year</td>
</tr>
<tr>
<td>Plan of grid expansion</td>
<td>Distribution and transmission loss factor</td>
<td>12%</td>
</tr>
<tr>
<td>Plan of grid expansion</td>
<td>Life of grid expansion plan</td>
<td>25 years</td>
</tr>
<tr>
<td>Plan of exploitation of PV unit</td>
<td>Cost of purchase of a PV and related accessories</td>
<td>8000 $/kW</td>
</tr>
<tr>
<td>Plan of exploitation of PV unit</td>
<td>Design and installation cost of a PV unit</td>
<td>1600 $/kW</td>
</tr>
<tr>
<td>Plan of exploitation of PV unit</td>
<td>Annual cost of operation and maintenance of a PV unit</td>
<td>80 $/kW</td>
</tr>
<tr>
<td>Plan of exploitation of PV unit</td>
<td>Life of PV unit plan</td>
<td>10 years</td>
</tr>
</tbody>
</table>

The remote consumer which is studied here consists of a farm with its equipments and some residential buildings. The total electrical load power of the farm is 14 kW. If the coincidence factor of the farm’s electrical loads is assumed to be 0.7, the peak of consumption load will be about 10 kW. Daily electrical energy consumption of this farm is about 100 kWh. Needed data for economic evaluation of the electrification plans is brought in Table 1. It is worth mentioning that the studies are done with the real interest rate of 15%. In addition, considering the existence of a low-voltage grid in the both plans, its cost is ignored in comparing the two plans.

3.4.1. Sample plan of grid expansion

The farm is about 40 km distant from the closest 63/20 kV high-voltage substation. However, because of topography of the region; if a medium-voltage line (20 kV) is extended to the farm, length of this new medium-voltage line will be about 48 km.

It is assumed that expansion of a medium-voltage grid into consumption place will be enough and there will be no need to increase the capacity of high-voltage substations, to extend the high-voltage lines, and to increase the capacity of power plants.

As mentioned before, there is a common low-voltage grid in the both plans; so, its costs are ignored. However, it must be noticed that a 20/0.4 kV transformer is needed only for the grid expansion plan and the PV unit can generate the consumer’s needed voltage. Therefore, costs of investment and installation of medium-voltage lines must also include cost of 20/0.4 kV transformer.

Considering Table 1, regarding the investment and installation cost of every one meter length of medium-voltage lines and also the investment and installation cost of a 15 kVA distribution substation, the total initial cost of grid expansion plan is 715550 $.

In Table 1, the operation and maintenance cost of grid is brought according to a percentage of its initial cost; so, the annual operation and maintenance cost of the new substations and lines is 7155/5 $.

As mentioned before, daily consumption is 100 kWh. Using (3), the annual cost of electrical energy consumption from the grid can be calculated as:

\[ c_{\text{grid}} = 0.046 \times \frac{1}{1-0.12} \times 100 \times 365 = 1907.95 $ \quad (8) \]

Using (6) and considering the common life \( B=50 \) and the number of terms \( \alpha = 50/25 = 2 \), the present value of grid expansion plan can be calculated as:

\[ LCC_{\text{Grid}} = 715550 \times \sum_{q=0}^{B_{q}} (P | F, q \times 25, 15\%) \quad (9) \]

\[ + (715550 \times 1907.95) \times (P | A, 50, 15\%) = 7.97654 \times 10^5 $ \]

3.4.2. Sample plan of exploitation of PV

In this plan, a PV unit with the generation capacity of 10 kW is used to supply the consumer. According to the data of Table 1, the investment and installation cost of the PV unit is 96000 $. Also, the annual operation and maintenance cost of the PV unit is 800 $.

Using (7) and considering the common life \( B=50 \) and the number of terms \( \beta = 50/10 = 5 \), the present value of PV plan can be calculated as:

\[ LCC_{\text{PV}} = 96000 \times \sum_{q=0}^{5} (P | F, q \times 101.5\%) \quad (10) \]

\[ + 800 \times (P | A, 50, 15\%) = 1.32732 \times 10^5 $ \]

3.4.3. Comparison of the two sample plans

By comparing the present values of two plans, which are computed as (9) and (10), \( LCC_{\text{Grid}} \) and \( LCC_{\text{PV}} \), the more economical plan can be determined.
Considering the fact that the present value of grid expansion plan is about 6 times as much as the present value of PV plan, it can be concluded that the PV plan is more economical.

3.4.4. Sensitivity analysis

Considering the possibility of changes in the economic parameters and possibility of errors in estimation of these parameters, economic analysis should be done considering uncertainties. One existing solution is sensitivity analysis through which effects of changes in the parameters on the results of analysis can be studied. Sensitivity analysis is repetition of a financial computation process with changing main parameters, and comparing obtained results with those obtained by the initial data. The sensitivity analysis can help decision-makers so that it will be promising if the initial parameters change but the results of analysis and comparison of plans don’t change [14].

Here, the sensitivity analysis of the economic evaluation, which was done in the numerical example, is performed. When a parameter changes, other parameters is assumed to be unchanged according to the data of Table 1.

In Fig. 1, the ratio of \( \frac{LCC_{Grid}}{LCC_{PV}} \) is drawn versus different interest rates. As it is shown in this figure, the ratio of \( \frac{LCC_{Grid}}{LCC_{PV}} \) is reduced in the lower interest rates. In other words, in the lower interest rates, the grid expansion plan gets economically closer to the PV plan.

In Fig. 2, the ratio of \( \frac{LCC_{Grid}}{LCC_{PV}} \) is drawn according to different capital costs for every one meter length of a medium-voltage line. As it is presented in Fig. 2, economic evaluation of the two plans shows a high sensitivity to the initial cost of medium-voltage line. In the cost of about 2.3 $ for every one meter length of a medium-voltage line, the values of \( LCC_{Grid} \) and \( LCC_{PV} \) are almost equal.

The ratio of \( \frac{LCC_{Grid}}{LCC_{PV}} \) versus different investment and installation costs of every one kW power of PV is shown in Fig. 3. As it is presented in this figure, even with the initial cost of 25000 $ for every one kW, the PV plan is more economical. Meanwhile, it can be understood from this figure that the economic evaluation has high sensitivity to the capital cost of PV.

In Fig. 4, the ratio of \( \frac{LCC_{Grid}}{LCC_{PV}} \) is drawn according to different electricity generation costs of large centralized power plants. As it is shown in Fig. 4, even if the electricity generation cost of large power plants is close to zero, considering the fact that other parameters are fixed, the PV plan is more economical. Also, it is shown that the economic analysis does not have high sensitivity to the electricity generation cost of large power plants. This is due to the small amount of consumption load.

One of the parameters which can have a considerable effect on the results of economic analysis is the consumer’s distance from the grid and the required length of the line if the grid is to be extended. The ratio of \( \frac{LCC_{Grid}}{LCC_{PV}} \) is drawn according to different lengths of new medium-voltage line in Fig. 5. As it can be observed in this figure, in the shorter line lengths, the grid expansion plan gets economically closer to the PV plan. However, even with a line as long as 10 km, the PV plan is more economical.
4. EXPLOITATION OF PV SYSTEMS IN BUILDINGS NEAR THE GRID

The PV systems which are connected to the grid can be very efficient for consumption management in houses on hot summer days. In this situation, a PV unit supplies all or part of the load demand which is needed by the consumer who is connected to the grid. In this application it is not necessary to use a battery to store electrical energy, therefore initial cost of this kind of systems can be lower. At present, considering the conditions of building industry, it is possible to use PV and PVT units in majority of developing countries. So, in this section, economic analysis and computation of cost of electrical energy generated by PV and PVT units is dealt with. Uniform cost technique [14] is used to compute cost of electrical energy generated by PV and PVT units. If the cost of electrical energy generated by PV and PVT units is less than the electrical energy cost of the grid, then the PV and PVT are economical to use.

4.1. Cost of Electrical Energy Generated by PV

One of the factors which influence the electrical energy generation cost of PV units is the number of hours that these units are in operation per year. The electrical energy cost of PV units can be calculated as:

\[ COE_{PV} = \frac{C_I}{h} (A|P,n,i) + \frac{C_{O&M, Annual}}{h} \]  

(11)

where, \( COE_{PV} \) is the cost of electrical energy generated by the PV unit ($/kWh), \( C_I \) is the initial investment and installation cost of the PV unit ($/kW), \( C_{O&M, Annual} \) is the annual cost of operation and maintenance of the PV unit, \( h \) is equivalent to the hours of supplying full load per year (hours), and \( (A|P,n,i) \) is the capital recovery factor for the capital recovery time of \( n \) year(s) and with the real interest rate of \( i \) (see Appendix).

4.2. Cost of Electrical Energy Generated by PVT

As mentioned before, in a PVT system, needed thermal and electrical energies are produced through one installed system. If the heat recovery process does not take place in a PV system, needed heat must be supplied through another way, such as usage of a boiler, and by burning fuel. This amount of fuel can be economized through the process of combined heat and power production in PVT systems. If the profit of using the heat which is recovered in the PVT unit is called \( B_{PVT} \), the cost of electrical energy generated by the PVT unit can be calculated as:

\[ COE_{PVT} = \frac{C_B}{h} (A|P,n,i) + \frac{C_{O&M, Annual}}{h} - B_{PVT} \]  

(12)

where, \( COE_{PVT} \) is the cost of electricity generated by the PVT unit ($/kWh).

The profit of using the heat which is recovered in the PVT unit can be computed as:

\[ B_{PVT} = \frac{C_{fuel}}{\eta_k \times k \times HV} \]  

(13)

where, \( B_{PVT} \) is the profit of using the heat which is recovered in the PVT unit ($/kWh), \( C_{fuel} \) is the price of every one cubic meter of delivered fuel ($/m^3), \( HV \) is the thermal value of delivered fuel (kcal/m^3), \( k \) is the coefficient of conversion of kcal to kWh (k=1/860.425 kWh/kcal), and \( \eta_k \) is the thermal efficiency of a typical boiler or another heat source which can be substituted for production of the recovered thermal energy.

4.3. Numerical Study

4.3.1. Computation of electrical energy cost of a PV unit:

Here, a numerical example of computation of cost of electrical energy generated by a PV unit is presented. In this example, a sensitivity analysis is done regarding the changes in operational and economic parameters. Data concerning the price and characteristics of a sample PV and also data concerning the interest rate is brought in Table 2. The cost of electrical energy generated by the PV unit can be computed using (11). Fig. 6 shows the changes in the cost of delivered electrical energy by the PV unit according to different annual operating hours. In all computations, the capital recovery time of PV plan is assumed equal to the life of PV unit (10 years).

Table 2. Data needed for computation of cost of electrical energy generated by a sample PV

| Cost of purchase of a PV unit and related accessories | 4500 ($/kW) |
| Cost of design and installation | 500 ($/kW) |
| Annual cost of operation and maintenance | 45 ($/kW) |
| Approximate life of a PV unit | 10 years |
| Real interest rate | 14% |

As it can be seen in Fig. 6, the electrical energy of PV unit with the operating hours of 365 hours per year (on average, 1 hour a day) is very expensive (2.75 $/kWh). With the average operating hours of 2 hours a day, the electrical energy cost of PV unit decreases to
half the cost of the mode with the operating hours of 1 hour a day.

Fig. 6. Changes in cost of electrical energy generated by the sample PV unit versus annual operating hours.

Fig. 7. Changes in cost of electrical energy generated by the sample PV unit versus different costs of purchase.

Fig. 8. Changes in cost of electrical energy generated by the sample PV and PVT units versus their operating hours per year.

4.3.2. Computation of electrical energy cost of a PVT unit

Here, a numerical example of computation of cost of electrical energy generated by a PVT unit is presented. Based on the assumption that the extra cost, which is due to process of combined heat and power production in the PVT system, is compensated for by the cost of purchase and installation of heat production equipment which itself is due to lack of such a process; data concerning the example of Section 4.3.1, brought in Table 2, is also be used for the PVT system. Data concerning fossil fuel (in this case, natural gas) and the boiler, which will be needed if the heat recovery is not done, is also brought in Table 3.

Table 3. Data of fossil fuel and boiler

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal value of delivered natural gas</td>
<td>9000 (kcal/m³)</td>
</tr>
<tr>
<td>Price of delivered natural gas</td>
<td>0.2 ($/m³)</td>
</tr>
<tr>
<td>Efficiency of a typical boiler</td>
<td>70%</td>
</tr>
</tbody>
</table>

The cost of electrical energy that is generated by the PVT unit can be computed using (12) and (13). Fig. 8 shows the changes in the electrical energy cost of the PV of Section 4.3.1 and also presents the changes in the cost of electrical energy of PVT system versus operating hours per year. In all computations, the capital recovery time of PV and PVT plans is assumed equal to the life of the units (10 years). As it is shown in Fig. 8, the simultaneous production of heat and electrical energy causes a decrease as much as 0.0273 $/kWh in the electrical energy cost of the PVT unit compared to that of the PV unit. If the units being studied will be in operation for about 8000 hours a year, then the cost of electrical energy of the PV and PVT units will respectively be 0.1254 $/kWh and 0.0981 $/kWh.

If it is assumed that the PV units are used only during the peak load hours, that is, when the electricity price of grid is the highest; considering the two numerical examples mentioned in this section and Section 4.3.1, they are not assumed to be capable of direct competition with the price of electricity of the grid. However, in the economic studies, the environmental advantages of usage of solar energy are ignored. By taking these advantages into account, PV units will sound more economical. Also, under the present conditions that the generation cost of electrical energy through PV units is not directly capable of competition with the cost of electricity generated using fossil fuels; some countries have adopted incentive...
policies for the users of this clean technology. If these incentive policies are taken into account, the PV or PVT plans will be even more economical.

5. CONCLUSIONS
In this paper, a method is presented for economic evaluation of the plan of exploitation of PV in comparison to the plan of grid expansion to provide electricity for consumers who have not access to the national grid. The presented method is used to choose the economical plan to provide electricity for a sample consumer who is far from the grid. Considering the results of sensitivity analysis done for the system under study, it seems that the plan of exploitation of PV, in majority of cases and situations, is more economical than the plan of grid expansion. Also in this paper, a method is presented for economic evaluation of usage of solar energy to produce heat and electrical energy demand in buildings which have access to the national grid. The numerical examples are presented for the method of computation of electrical energy cost of PV and PVT units. According to the analysis done in the system under study, it seems that the cost of electrical energy generated by PV and PVT units is not capable of direct competition with the price of electricity of the grid. At present, it may seem that usage of other technologies of distributed generation such as diesel generators and gas turbines are more economical because of their lower investment cost; however, it must be noted that access to fuel and its transportation to remote areas is one of the most important concerns in using these technologies. Furthermore, in many countries there are some charges for polluting environment. These charges should be added to the cost of electrical energy generation by fossil fuels. Also, in some countries there are incentive schemes for the users of clean and renewable energies like solar energy. This adds to economic motives for exploiting the PV technology to supply the electricity demand.

6. APPENDIX
The present value of $P$ regarding the future value of $F$ in the year of $k$ and with the real interest rate of $i$ can be calculated as:

$$P = \frac{1}{(1+i)^k} = F \times (P | F, k, i) \quad (14)$$

Hence, the future value of $F$ can be calculated as:

$$F = P (1+i)^k = P \times (F | P, k, i) \quad (15)$$

The real interest rate of $i$ can be calculated on the basis of the bank interest rate ($i_b$) and the inflation rate ($d$) as:

$$i = \frac{(1+i_b) - 1}{(1+d)} \quad (16)$$

The present value of $P$ regarding the uniform amounts of $A$ over the period of $n$ years and with the real interest rate of $i$ can be calculated as:

$$P = A \sum_{t=1}^{n} \left(\frac{1}{(1+i)^t}\right) = A \left[\frac{1(1+i)^n - 1}{i(1+i)^n}\right] = A \times (P | A, n, i) \quad (17)$$

Hence, the uniform amounts of $A$ can be calculated as:

$$A = \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] = P \times (A | P, n, i) \quad (18)$$

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