Investigation of PV System Cable Losses

Sami Ekici*‡, Mehmet Ali Kopru**

*Department of Energy Systems Engineering, Faculty of Technology, Firat University, 23119

**Department of Electrical and Energy, Vocational School of Technical Sciences, Bingol University, 12000

(sekici@firat.edu.tr, makopru@bingol.edu.tr)

‡ Sami EKICI; Firat University, Faculty of Technology, Department of Energy Systems Engineering,

Tel: +90 424 237 0000, sekici@firat.edu.tr.

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Abstract- Photovoltaics (PV) are the systems which produce electrical energy from the solar energy directly. The components of a PV system are inverters, batteries, charge controller and connectors. Energy losses due to these components affect the system performance adversely. In this study, the PV system cable losses and the effects of these losses are investigated. PV system losses and especially cable energy losses for different cable cross sections are investigated in PVsyst6.2.6 software by simulating experimental setup. According to observed results from the simulation study, it has been shown that thermal losses are 5.7%, module quality losses are 3%, invertor losses are 18%, module array mismatch losses are 1% and shading losses are 33%. Cable losses also affect the system performance as 1.7%, 0.6% and 0.2% for the cross sectional areas of 1.5 mm^2, 4 mm^2 and 10 mm^2 respectively. In experimental study, it has been shown that the usage of solar cables with different cross sectional areas and different lengths do not affect the PV system performance significantly in the small PV systems. Solar cable losses can be observed more clearly in a system which is installed on a wide area with precise measurement. The present time value of money table has been obtained by using inflation and discount rates for the next 25 years and the optimum cross sectional area of cable has been calculated for the PV system installed in the experimental study.

Keywords Photovoltaics; cable losses; solar energy; PVsyst.

1. Introduction

The changes in people's daily lives depending on the growing technological development during the second half of the twentieth century, increasing the number of equipment using electrical energy and becoming an indispensable object of life are gradually increasing the energy demand. To meet the ever-increasing energy needs, it necessary to seek new and renewable energy sources as an alternative to fossil fuels considering environmental, social and economic factors. Recently, exhaustible fossil fuels are gradually replaced by renewable energy sources [1]. The most important feature of renewable energy sources is that they are permanent in nature. As renewable energy technologies have no negative effect on the environment, the interest in this energy sources has increased day to day.

Today, the production of electricity from renewable energy sources has gained even more importance. There are a number of advantages of solar energy over other types energy sources. One of the techniques for producing electrical energy from solar energy is the usage of photovoltaic (PV) systems. Electricity generation from PV systems is increasing every day. 10-20% of the PV system efficiency can be achieved with today's technology. Environmental factors like solar radiation level, weather conditions etc. and losses arise from the incorrect installation, which will affect the efficiency of PV systems have led to a reduction of the total energy efficiency. Hence, elements of PV system must be designed carefully in the installation stage to minimize system losses and maximize output energy. Measuring and analyzing of those losses due to dust, dirt, shading, inverters and cables used in the PV systems are of great importance. Detection of components, which cause the losses and be possible to correct technologically will increase the efficiency of the system by working in this area. Especially, the solar cables are needed to investigate and perform serious studies to show the direction to researchers working in this field. Losses in cables both cause a loss of energy in PV systems and also negatively affect the economic cost of the system.

The studies related to the analysis of cable losses generally remain in the simulation phase. There isn't enough study related to the investigation of cable losses on real PV systems. In this study, both the simulation and the actual implementation of a PV system were performed to examine cable losses occurring in the system. Also, impact of cabling cost on the total system cost was investigated. Optimal cable cross-section in order to minimize losses caused by the choice of cabling is calculated mathematically. Although this study particularly dedicated to the cable losses, other losses occurring in the system were examined by using PVsyst 6.2.6 software.

In this study, it is aimed to give an idea to the scientists and companies working in this area by examining effects of solar cables on the whole PV system output which are generally selected by rough computations without considering both system efficiency and total system cost. In the second section of the study, PV system losses explained briefly. A simulation study performed by using PVsyst 6.2.6 software, representing a 150 Wp stand-alone experimental PV system which is installed on the terrace of the main building of Technology Faculty of Firat University are explained in the third section. In the fourth section, the experimental work has been cited and system output current, voltage and power were measured for different lengths and cross section of solar cables. In the fifth section, the cross-sections of solar cables are optimized. The sixth and final section is the conclusion section.

2. Losses Occurred in The PV System

Due to low energy yield of the PV systems, it is essential to transmit the produced energy to the consumers with minimum losses as possible. Therefore, it necessary to minimize these losses by eliminating the factors that cause the losses occurred in PV systems. Factors that may cause losses in PV systems are environmental factors such as shade, dust, snow, rain, temperature and such losses due to system components such as cables, inverters and batteries. PV systems should be installed taking into account the losses and the produced energy should be consumed in local areas where it was produced as much as possible. Figure 1 shows some losses occurred in a PV system.

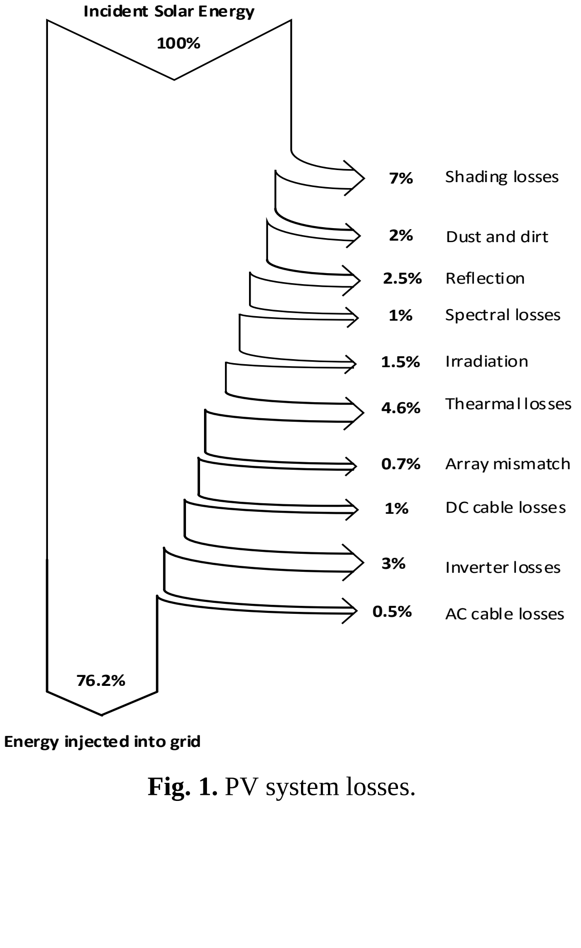

Fig. 1. PV system losses.

The power loss can vary between 10% to 70% depending on different reasons which effect the PV system performance [2]. About 25% of the produced energy by the PV system is lost due to some system losses as shown in the above figure.

2.1. Shading Losses

One of the most important factors affecting the performance of the PV panels is shading. Factors that may cause shading are neighboring buildings, shrubs and energy transmission towers etc. [3, 5]. Generally, buildings are built very close together especially in the city centers and this cause shading on PV modules especially installed on the rooftops [3, 6]. Sometimes due to the wrong designing of PV system array, self-shadowing is also possible. Because of the fact that these cases will reduce the performance of the panel, it should be given the right decisions in the design phase. The location where the PV system is installed must be selected carefully. Another factor that can widely cause the losses is trees especially in rooftop applications as depicted in Fig. 2. So, the surrounding trees should be well analyzed when the PV system is designed. If a PV system is planned to install close to the trees, leaf-shedding trees should be preferred. Therefore, it can be facilitated from the incoming solar radiation onto the panel at lower angles especially in the winter seasons [3, 4].

2.2. Dust Losses

These losses are caused by pollution of PV module surface due to any reason or decreasing the incoming solar radiation due to snow accumulation on the module surface [2]. The research results made for losses caused by dusting show that, especially in areas where there is little rainfall, these losses reach 15% in extraordinary cases [2, 7]. Figure 3 shows a solar panel which is contaminated due to dust [8]. To improve system efficiency, the module needs to be cleaned regularly. But in the big solar power plant, especially in areas with water shortage, this process is very costly [2].

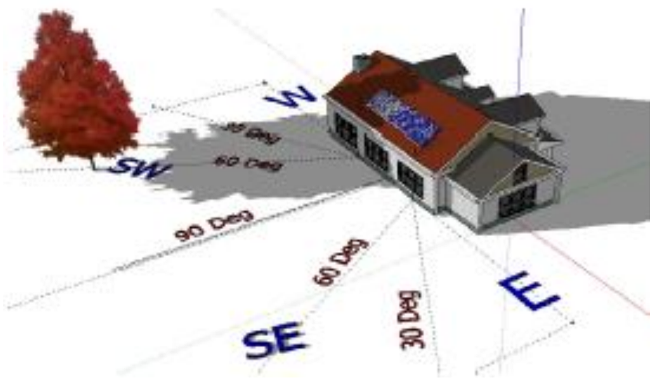

Fig. 2. A solar panel exposed to shading

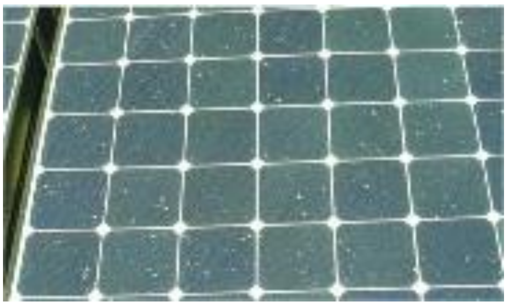

Fig. 3. Dirt accumulated on solar panels.

2.3. Reflection Losses

While the PV module absorbs some of the solar radiation, a certain amount of solar radiation is reflected back from the module surface. This is called the reflection losses due to the back-reflected radiation [2]. To reduce reflection, the module surfaces are coated with an anti-reflecting film.

2.4. Thermal Losses

Solar panels are tested under standard test conditions corresponding 25 °C, 1000 W/m^2 solar radiation and AM 1.5 (air mass). The efficiency of the panel is calculated according to the standard test conditions. Producing electricity starts with receiving solar radiation on the PV module surface. While some of the incident solar radiation is transformed into electrical energy, a portion of solar radiation is converted into heat energy [9]. PV performance is decreasing with increasing temperatures that occur in the panel. PV panels can't convert the entire solar energy into electrical energy. The conversion rate of PV panels is about in the range of 5-25%. Therefore, more energy that the solar modules can’t convert it to the electrical energy causes heating of the modules and so thermal losses [5, 10].

2.5. Module Mismatch Losses

One of the major sources of losses in the photovoltaic system is that different energy amount produced by two or more arrays in the module. This mismatch is caused by factors such as partial shading and pollution that can cause losses [11].

2.6. Direct Current Cable Losses

Normally the cable losses for a well-designed installation should be less than 2% and this proportion shouldn't rise over time. The cause of some of the losses occurring in the cables is corrosion and overheating [12].

In a PV system installation, solar cables are used to connect PV modules and inverters. The cable power losses can be expressed as follows depending on time. Here r_{DC} is DC resistance of the cable, V_{DC} voltage between cable ends, P_{loss} is DC power loss.

$$P_{loss}(t) = 2.I^2_{DC\_cable} r_{DC} \tag{1}$$

$$P_{loss}(t) = 2.(\frac{P_{DC\_cable}(t)}{V_{DC}})^2 r_{DC} \tag{2}$$

Energy losses due to resistive loads are proportional to the increase of wiring resistance. Electricity generation in PV systems needs to minimize system losses because it is expensive. A significant portion of the system losses occurs in the electrical parts. These losses occur largely in cables and inverters.

PV system characteristics are obtained under the standard test conditions (STC). But PV system output is always variable and rarely works in the STC. Therefore, solar cables carry the different amount of electrical current. So, the calculated cross sections of solar cables under STC may be unsuitable. The cable voltage drop occurring due to the cross-section leads to energy loss and also reduces the efficiency. Because of aforementioned reasons, the cross-section of the cable must be calculated carefully to minimize losses that may occur in PV systems [13].

3. Simulation Study

In this study, the losses occurring in the PV systems and the energy losses caused by the solar cables were investigated. In this section, a simulation study of experimental setup which will be explained in the next section is performed by using PVsyst 6.2.6. PVsyst software contains very useful tools for sizing, simulation and data analysis of PV systems [14]. PVsyst gives opportunity to users to choose panels and values of inverter which will be used in the installed PV system depending on manufacturers and nominal powers.

In this PV system, one solar panel, one inverter, charge controller, battery and solar cables are used. A 150 Wp Shenzhen Topray (TPS-105) monocrystalline solar panel is used both in the simulation and also experimental study. To be suitable for solar power planned to be established, a Nordic brand WT-30SN-12E inverter is provided. ProVista Technology brand ISC3020 charge controller is used for the installed standalone PV system.

3.1. Simulation Results

In the Fig. 4, the top view of the simulation environment performed with PVsyst software according to experimental PV system installed on the terrace of the main building of Technology Faculty at Firat University is shown. The simulation study is performed to be similar as much as possible to the experimental setup.

The monthly average solar radiation between 1990-2012 years of the province of Elazig which is calculated by using equivalent sun hours obtained from Turkish General Directorate of Meteorology, outdoor temperature data and geographic location information are transferred manually to the software [15]. In simulation studies, the tilt angle of the panel is 30 degrees and it is directed to the south side (azimuth angle = 0). The slope and direction of the module are shown in Fig. 5.

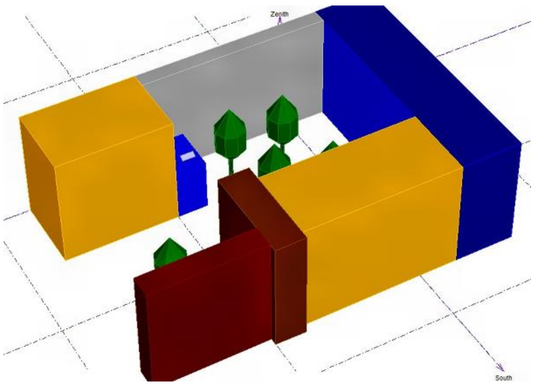

Fig. 4. Top view of simulation environment.

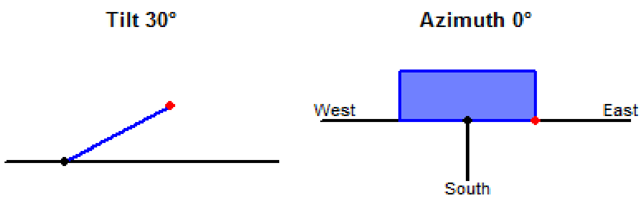

Fig. 5. Tilt and direction of the module.

Voltage-power curve of 150 Wp monocrystalline module used in the experimental and simulation study and power produced at the maximum power point depending on the solar radiation are shown in Fig. 6.

As seen in Fig. 6, while PV module voltage doesn't change, the generated power decreases significantly depending on the variation in solar radiation. The current-voltage characteristics of the solar panel change depending on the temperature and radiation. The voltage and current change of the PV module are shown in Fig. 7.

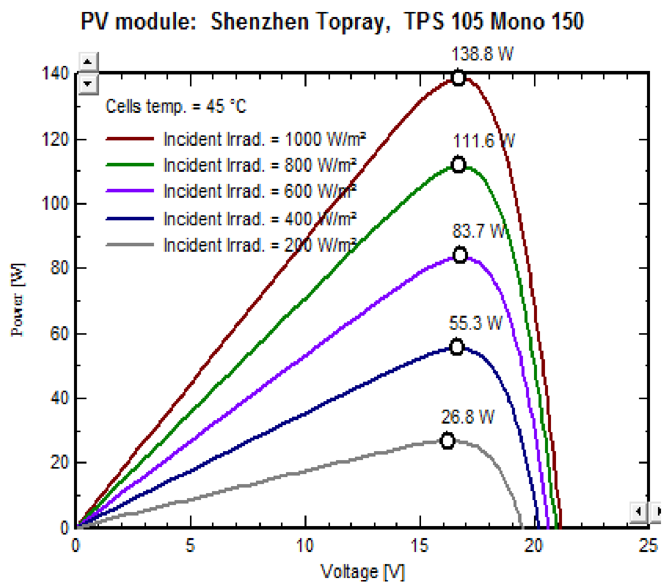

Fig. 6. Power and voltage curve of selected PV module.

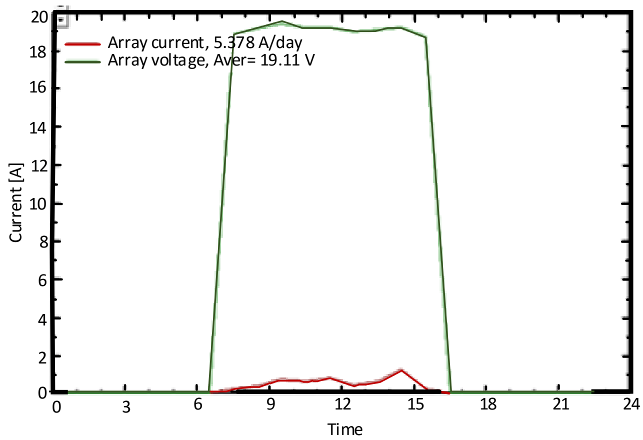

Fig. 7. Current and voltage curve of selected PV module.

Both cable and the other system losses are examined using different cross sections of cables between the panel and the inverter. The PV system efficiency under the standard test conditions (1000 W/m^2 solar irradiance, 25 °C temperature and AM 1.5) is 14.90%. In Fig. 8, loss diagram of simulated PV system for solar cable, which has 4m-length and 1.5 mm2 cross-sectional area, is shown. As seen in Fig. 8, the system temperature losses are 5.7%, module quality losses are 3%, inverter losses are 18%, mismatch losses are 1%, shading losses are 33% and losses caused by the used cable are 1.7% for one year. The annual energy produced by the PV system is 185.4 kWh but the total amount of energy transferred to the network in a year is 136.5 kWh. The total annual energy loss caused by cable, temperature, inverter, array mismatch and module quality is 48.9 kWh.

As seen from the Fig. 9, cable loss occurred is 0.6% when a solar cable of 4 mm^2 cross sectional area is used. When the cross-section of the cable is changed losses depending on it is also changing. As expected, while the cable cross section is increased, energy losses occurring due to the solar cable has decreased. As can be seen from Fig. 8 and 9, the losses occurring in the PV system significantly affect the efficiency of the system. The annual system losses obtained from PVsyst software depending on the selected cable cross-sections used in the simulation studies are presented in Table 1.

ModQual in Table 1 represents losses arising from the quality of modules, MisLoss is array mismatch losses, OhmLoss is resistive cable losses, InvLoss is inverter losses and EArrMPP virtual available energy at the maximum power point (MPP). As clearly seen from Table 1, the energy loss due to the solar cable used in the system is change dramatically when we used cables with the different cross-sectional area. For example, if someone wrongly calculates and uses a cable which has 1.5 mm^2 cross sectional area while an optimal section is 4.0 mm^2, the cable losses increase as much as 2-3 times in this PV system.

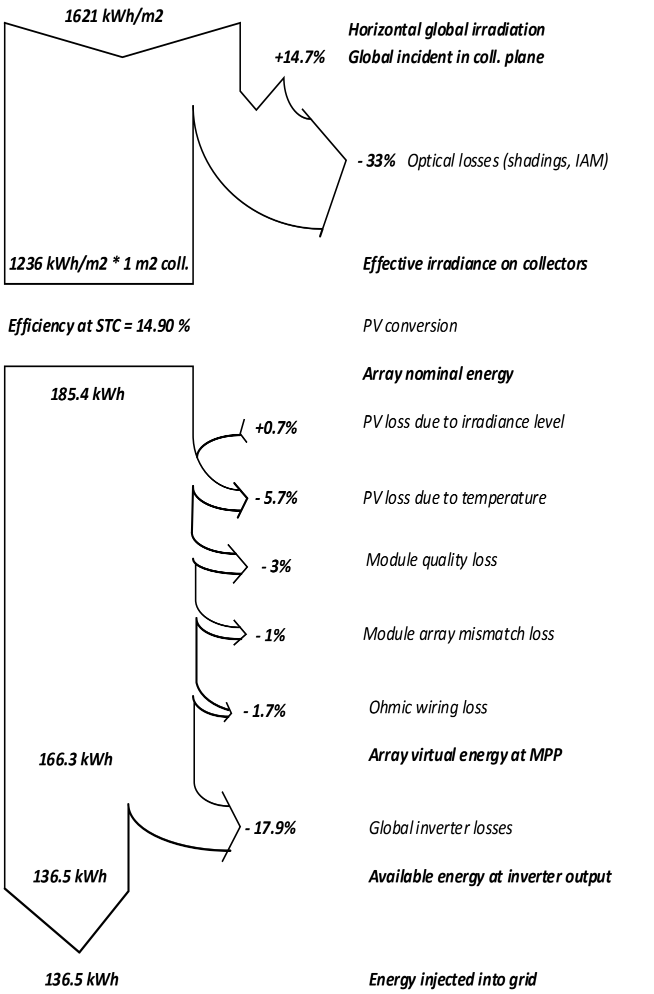

Fig. 8. System loss diagram of conductor which has 1.5 mm2 cross sectional area.

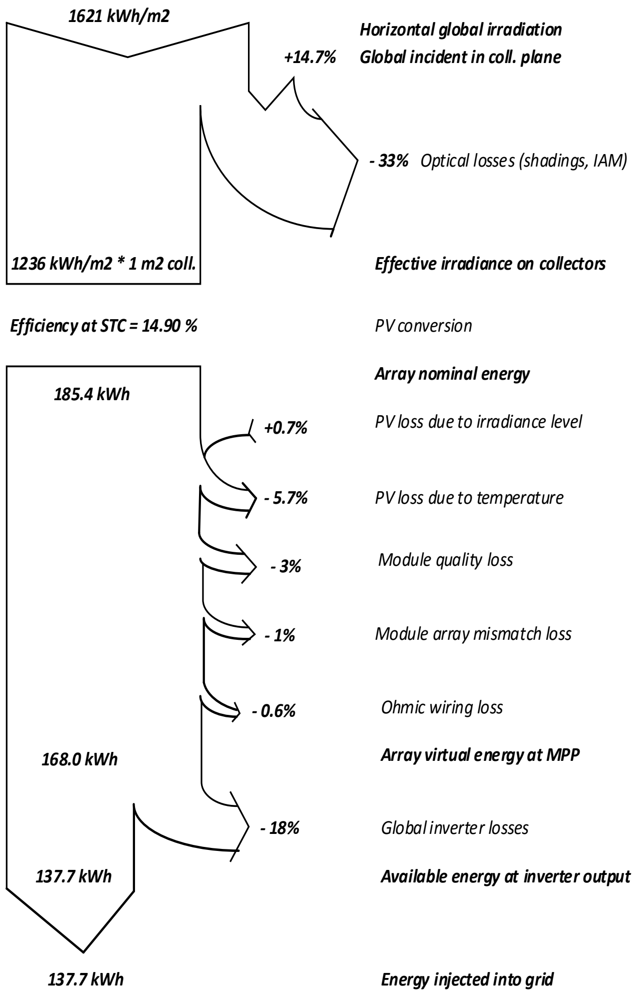

Fig. 9. System loss diagram of the conductor which has 4 mm2 cross-sectional area.

In Fig. 10, energy losses occurring in the simulated PV system are depicted for different sections and cable lengths. As shown in Fig. 10, when cable length increases or cross sections decreases energy loss increases. It can be suggested to increase cable cross-section to reduce the energy losses but in that case, system cost will also increase. Therefore, it is necessary to calculate the most proper cable size to be used in the PV system before the installation phase.

Table 1. Annual energy losses of installed PV system

Losses		Annual energy losses (kWh)
ModQual		5.282
MisLoss		1.708
EArrMPP		166.26
InvLoss		29.795
OhmLoss	1.5 mm2	2.795
	4.0 mm2	1.048
	10 mm2	0.419

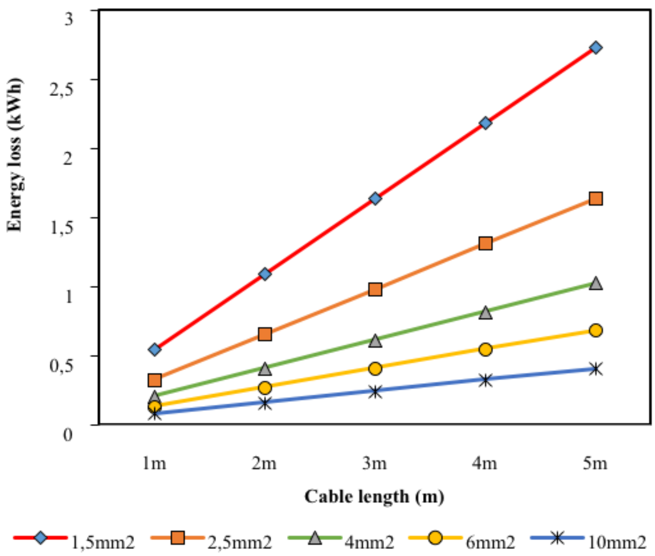

Fig. 10. Energy losses for different cable length and cross-sectional area.

4. Experimental Study

In the previous section, the energy losses occurred in different cross sections and lengths of the solar cables are simulated by using PVsyst. In this section, an experimental study will be carried out for the PV system simulated. The PV system is tested by connecting a 100 W bulb to the inverter output for 2.5 mm^2 cable size and a 75 W bulb for the cable sizes of 4, 6 and 6 mm^2 respectively. In Fig. 11, the PV system set up installed on the terrace of the main building of Technology Faculty of Firat University is illustrated. After the completion of the system installation and connection stage, it has switched to measuring steps for each cable section and length.

First of all, energy losses for solar cables with 2.5 mm^2 cross-sectional area have been investigated. PV panel output current and voltage and load current and voltage is measured for 5 different lengths of 2.5 mm^2 cable. Table 2 shows the measurement results obtained by the use of 2.5 mm^2 solar cable. When we look at the measured panel and inverter output voltage, it is seen that the results obtained for different lengths are very close to each other. The reason for this is that the internal resistance of the solar cable is very small. The internal resistance of 2.5 mm^2 cable is about 5.09 Ω/km. The maximum cable length is selected as of 5 m.

Fig. 11. PV system installed in experimental study.

Table 2. Measurement results of 2.5 mm^2 solar cable.

Length (m)	Solar panel		Inverter output	
	Voltage (V)	Current (A)	Voltage (V)	Current (A)
5.0	20.66	5.73	233.8	0.45
4.0	20.59	6.82	233.8	0.45
3.0	20.64	6.96	233.8	0.45
2.0	20.67	6.92	233.8	0.45
1.0	20.61	5.36	233.8	0.45

The internal resistance of the cable about is 0.025 Ω for this length. It has been also seen that the output power of solar panel is close to the output power of inverter. This can be explained as the load corresponds the power need from the solar module directly, not from the battery.

Table 3 shows measurement results obtained by the use of 4 mm2 solar cables of 7 different lengths. When we look at the panel and inverter output voltage, it is seen that measured values are very close to each other. The internal resistance of 5 m length and 4 mm^2 cross-sectional area is about 0.016 Ω. In particular, a large voltage drop caused by solar cables can be seen more clearly in the solar power plants which are installed on a wide area. A quite sensitive measuring device is required to obtain more accurate results.

The voltage drop of solar cable which has 4 mm^2 cross sectional area and 4 m-length can be calculated according to voltage and current measurements in Table 3 as shown in Eq.(3). Where L is the cable length, I is the DC current, U is the DC voltage output of the PV panel, k is the self-conductance of the aluminum conductor and S is the cross-sectional area. The total voltage drop can be calculated as;

$$\%e = \frac{2.L.I}{k.S.U}.100 = \frac{2x4x0.49}{35x4x19.85}x100 = 0.14\% \tag{3}$$

$$u = \frac{U.\%e}{100} = \frac{19.85x0.14}{100} = 0.0277V \tag{4}$$

Although the voltage drop in this example is very low, a considerable high voltage drop will occur in a big solar power plant where a thousand meters of solar cable are used.

The third experimental study was performed by using a 6 mm^2 solar cable. This solar cable was tested for 7 different lengths. The measured results of these cable lengths are shown in Table 4. To reduce or prevent voltage drop, often larger cross-sectional cables are used in the electrical installations. Here, the purpose is to reduce the voltage drop to the desired level by increasing the cross-sectional area. To observe this situation, finally, we test a solar cable which has 10 mm^2 cross sectional area. The obtained measurement results are given in Table 5.

Table 3. Measurement results of 4mm^2 solar cable

Length (m)	Solar panel		Inverter output	
	Voltage (V)	Current (A)	Voltage (V)	Current (A)
5.0	19.18	0.55	233.9	0.52
4.5	18.92	0.50	233.9	0.57
4.0	19.85	0.49	233.9	0.50
3.5	18.84	0.55	233.8	0.50
3.0	18.95	0.50	233.9	0.47
2.0	19.15	0.52	233.8	0.41
1.0	19.32	0.43	233.8	0.52

When we observe Table 2-5, we can see that the output power of solar panel is not equal to output power measured from the AC side (inverter output). The reason for different output powers is that the power produced by the solar panel is not adequate for the load especially because of cloudy weather and partial shading and some of the power that the load needs is provided by the battery.

Table 4. Measurement results of 6 mm^2 solar cable.

Length (m)	Solar panel		Inverter output	
	Voltage (V)	Current (A)	Voltage (V)	Current (A)
5.0	19.45	0.45	233.7	0.50
4.5	19.43	0.45	233.7	0.51
4.0	19.38	0.49	233.7	0.45
3.5	19.40	0.50	233.7	0.46
3.0	19.44	0.45	233.7	0.47
2.0	19.28	0.47	233.8	0.47
1.0	19.30	0.38	233.8	0.47

Table 5. Measurement results of 10 mm^2 solar cable

Length (m)	Solar panel		Inverter output	
	Voltage (V)	Current (A)	Voltage (V)	Current (A)
4.0	19.29	0.47	233.8	0.66
3.5	19.53	0.45	233.8	0.49
3.0	19.63	0.50	233.9	0.53
2.5	19.59	0.51	233.9	0.52
2.0	19.67	0.53	234.0	0.50
1.5	19.58	0.52	234.0	0.41
1.0	19.12	0.52	234.0	0.51

The most important findings emerged from both PVsyst simulation and the actual implementation can be expressed as follows:

✓ Selection of a large cross-sectional cable to reduce the voltage drop has not large effect on PV system where the distance between inverter and panel is short. In particular, the impact of the cable losses can be felt even more dramatically in large-scale solar power plants.

✓ When the section is decreased or the cable length increases, the energy loss increases. The expansion of cable cross-section can be suggested to reduce the energy losses but this selection will increase the system cost. A more precise calculation of the optimal cable size is required including all required parameters. If the conductor cross-section is selected as too small, it will increase power losses. If you select a very large conductor cross-section of the conductor, the system cost will increase and thus the unit cost of energy obtained from the solar system will increase significantly. Because of the fact that the cost of PV systems is already high, adding extra cable cost is not an acceptable situation.

In the next section, an optimization study will be performed to determine more suitable cross section for our PV system including parameters such as power losses and system cost.

5. Sizing of the DC Cables

Because designers already know what kind of anomalies will occur in the system, they try to reduce system losses caused by voltage drops and increase cable sizing considering system cost. Many designers try to keep the voltage drop below 1.5% due to national and international standards [16].

Gershony et al. [16] proposed a mathematical method for the selection of a suitable cable cross-section in the PV system. In this method, tariff rates have been calculated using the system components and certain parameters belonging to the location of which the PV system will installed in terms of the unit energy produced by the PV system. By this way, it can be provided to reduce losses relating to produced energy amount and system cost by preventing selection of incorrect cable cross sections and calculating optimal cable size. This tariff has also considered as critical tariffs. Generally, the critical tariff is calculated by using the well-known or easily obtainable parameters as shown in Eq. (5). Detailed information about obtaining the Eq. (5) to (7) can be found in [16]. Firstly, the cross-sectional area S_{SA} is calculated depending on allowable current intensity. After then, installation devices, selected cable type and labor cost, equivalent sun hour to calculate form factor K, the current I_{mp} at the maximum power point, the unit conductance of selected conductor r and g_{25} parameter calculated by using expected inflation and discount rates are obtained for the next 25-year. Critical tariffs T_C and the appropriate cable cross-section S are calculated as follows:

$$T_C = \frac{S_A(U+W)}{K.I_{mp}^2.8760.r.g_{25}} \quad (5)$$

where U is the unit cost of selected conductor ($/m) and W is the labor cost ($/m). To calculate effective usage of conductor, we need to calculate form factor K as;

$$K = \frac{\sum_{h=1}^{h=8760} I_h^2}{I_{mp}^2.8760} \quad (6)$$

where I_h is the hourly current passing through the conductor and can be obtained by using a computer software such as PVsyst. h in the Eq. (6) represents total hours in one year. the optimal cable cross-section can be calculated as;

$$S = S_A \sqrt{\frac{T}{T_C}} \qquad (7)$$

As we can see clearly in Eq.(7), the optimal cable cross-section S_A can be calculated by using allowable conductor size, local tariff T ($) and critical utility tariff T_C ($).

5.1. Calculation of Optimal Cable Cross-Section

As mentioned in section 4, and 5, one of the most important processes to set up a PV system is to select appropriate cable sizing in order to reduce system losses. In this section, a real World example will be performed to obtain optimum cable cross-sectional area for a cost-effective PV systems installation.

Firstly, it is required to determine short circuit current of the PV module to calculate conductor size depending on the allowable current value. The appropriate cable cross-section is found according to I_{SC} current generated by the panels. The short-circuit current of the 150 Wp solar panel used in this study is 8.820 A. When we look at 2014 NEC (National Electrical Code) 310.15 (B) (16) table, it is convenient to use 12 AWG (American wire gauge) aluminum cable according to this current value. The selected cable sectional area is 3.31 mm^2 according to NEC Chapter 9, Table 8. The production cost of THWN aluminum cable is 1.388 $/m and the labor cost is 1 $/m. All these parameters that will be used in the calculation of tariffs are shown in Table 6. The critical tariff is calculated by using Eq. (5) depending on the parameters given in Table 6 for 5 m-length as follows:

$$T_C = \frac{S_A(U+W)}{K.I_{mp}^2.8760.r.g_{25}}$$

$$T_C = \frac{3.31(6.94+5)}{0.74x8.42^2x8760x0.0382x17.53} = 0.12\$/kWh$$

Table 6. Parameters used in the critical tariff calculation

S_A	3.31mm^2
U	1.388 $/m
W	1 $/m
K	0.74
I_{mp}	8.42 A
ρ	0.0382 $W.mm^2/m$
g_{25}	17.53 $

The yearly inflation rate and discount rates are selected as 2% and 5% per year respectively. These rates are used to obtain time value of money tables and so the g_{25} parameter which represents the present value of a 25-year as a single value. The more detailed information to calculate the time value of money table can be obtained in [16].

The most appropriate cable cross-section can be calculated based on the critical tariff. The 12.8 ℂ/kWh value can be obtained by converting critical tariff value from $ to ℂ. If the local electricity tariff is accepted as 13 ℂ/kWh [16], the most appropriate cable section is calculated by using Eq.(7) as follows:

$$S = S_A \sqrt{\frac{T}{T_C}} = 3.31\sqrt{\frac{13}{12.8}} = 3.33mm^2$$

According to Eq. (7), the most appropriate cable section is found as 3.33 mm^2. Since there isn't cable production in these sections, the closest upper section having 4mm^2 cross-sectional area should be selected for our PV system.

6. Conclusion

In this study, the losses occurring in the cables used in PV systems are investigated. Before going into the simulation and application studies, some information is given about the losses encountered in PV systems. Then PV system simulation is performed with PVsyst software.

The simulated physical area is plotted in the software as close as the actual implementation performed. Then information such as position and tilt angle of the panel is entered to the package. The average monthly direct and diffused solar radiation values calculated by using sun hours and outdoor temperature values between 1990-2012 years obtained from General Directorate of Meteorology for Elazig province are entered the PVsyst manually. The PVsyst software gives an opportunity to the users to choose inverter and solar panel models with their specifications that are widely used in the actual implementations around the world. Thus, Shenzhen Topray TPS-105 solar panel which has 150 Wp output power and Lintech brand pure sinewave inverter which has 300 Wp nominal power are used in the simulation studies same as actual practice. The cable in cross section of 1.5, 4 and 10 mm^2 have been simulated and the cable losses examined in the system. The other system losses are also investigated. According to simulation studies, it has been shown that heat losses are 5.7%, the module quality losses are 3%, inverter losses are 18% array mismatch losses are 1%, shading losses are 33%. The cable losses are 1.7%, 0.6% and 0.2% for the cables of 1.5, 4 and 10 mm^2 cross sections. The PVsyst package also offers the opportunity to draw hourly, monthly and yearly-generated power, current and voltage values and gives detailed information about other losses.

After the simulation studies performed, an actual PV system installed on the terrace of the main building of Firat University, Technology Faculty. The cases in the simulation studies for different cable cross sections are repeated in the experimental studies. The output powers are affected partial shading due to near buildings, trees and incoming solar radiation level for different experiments. In the experiment performed by using a solar cable of 2.5 mm^2 cross sections, the weather was clear and the load energized by solar panel directly. In this case, the output power of solar panel was 140.42 W. But in the experiments performed by using the other cable cross sections, the solar panels exposed to shading completely and load energized by the battery. The output powers of the solar panel were 9.23 W, 9.49 W and 9.06 W fort the cables of 4, 6 and 10 mm^2 cross sectional areas. It was observed that the voltage drops on solar cables with different sections and lengths were very small. It is concluded that these losses will much more affect the PV system efficiency, especially in the big solar power plants.

One of the most important points to be considered before the installation of PV systems is the cost accounts. The use of cables with a larger cross section than is required will cause lower resistance and voltage drop but this selection increases system installation cost unnecessarily. In this case, it should be determined the most appropriate cable cross-sections considering both system security and unnecessary cost increases. For this purpose, an optimization method mentioned in [16] is applied to the experimented PV system to calculate the most appropriate cable cross-sections. By choosing annual inflation and discount rates as 2% and 5%, respectively, present time value of money table is obtained and by using the final equations mentioned in section 5 the appropriate cable cross-section is calculated as 4 mm^2 for our PV system installed.

If someone selects a cross-sectional area of 6 mm^2 instead of 4 mm^2, 0.696 $ of economic loss will occur for every meter of that cable. When the critical tariff is calculated again for 6 mm^2 cross sectional cable, it is obtained as 16.58 ₵ / kWh. In this case, local tariff remains below the critical tariff and this PV system will be uneconomic.

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