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Design and Implementation of Off-Grid Micro Solar Power Plant

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Abstract: In this study, detailed information about off-grid micro solar power plant established in Tracim Cement factory in Vize district of Kirklareli province is given. Three 320Wp Gazioglu GSE 320 MP model solar panels are used as the energy source in the system. Voltronics VM3000-24 model inverter is used to control the power drawn from the panel, charge the battery and transform the DC voltage into AC voltage. While a 150W led projector is used as a load at the system output, sixteen BSB Power DB12-65 gel batteries with 12 V - 65 Ah label values are used as energy storage unit. The electrical data measured by the inverter in the installed system are transferred to the SCADA program with the help of Arduino Mega. Thus, while the data can be monitored instantly, it is also recorded. The results of simulation and implementation are compared and verified for a month of Sep-2020. The results show that simulation and implementation results verify each other.

Keywords: Solar Energy, Off-Grid Photovoltaic System, Photovoltaic Panel.

Şebekeden Bağımsız Mikro Güneş Santrali Tasarımı ve Uygulaması

Özet: Bu çalışmada Kırklareli ilinizi Vize ilçesinde bulunan Traçim Çimento fabrikasında kurulmuş olan şebekeden bağımsız mikro güneş enerji santrali hakkında detaylı bilgi verilmiştir. İlk olarak PV*SOL programı ile sistemin simülasyonu yapılmış ve ardından uygulama sistemi kurulmuştur. Sistemde enerji kaynağı olarak 3 adet 320Wp gücünde Gazioğlu GSE 320 MP model güneş paneli kullanılmıştır. Panelden çekilen gücün kontrolü, akü şarjı ve DC gerilim AC gerilime dönüştürülerek AC yükün beslenmesi için Voltronics Axpert VM3000-24 model inverter kullanılmıştır. Sistem çıkışında yük olarak 150 W led aydınlatma kullanılırken enerji depolama birimi olarak 16 adet 12 V - 65 Ah etiket değerlerine sahip BSB Solar12-65 akü kullanılmıştır. Kurulan sistemde inverter tarafından ölçülen elektriksel veriler Arduino Mega yardımıyla Scada programına aktarılmıştır. Böylece veriler anlık olarak izlenebilirken aynı zamanda kayıt altına da alınmıştır. Simülasyon ve uygulama sonuçları Eylül-2020 ayı için karşılaştırılmış ve simülasyon sonuçları doğrulanmıştır. Sonuçlar yapılan simülasyondan ve uygulamadan elde edilen sonuçların tutarlı olduğunu göstermiştir.

Anahtar Kelimeler: Güneş Enerjisi, Şebekeden Bağımsız Fotovoltaik Sistem, Fotovoltaik Panel

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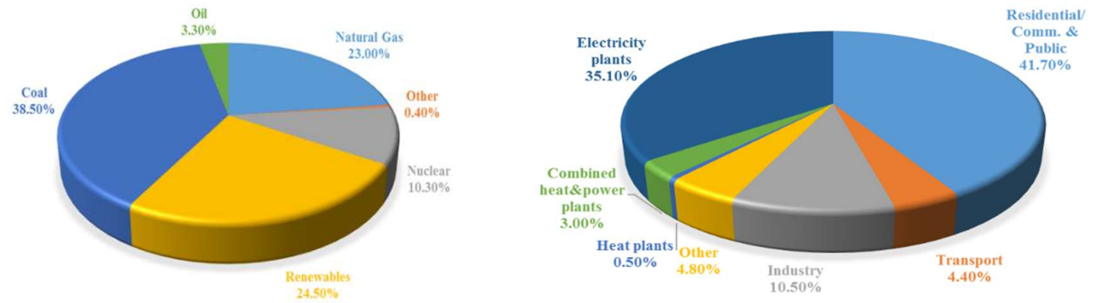
1. Introduction

The use of alternative energy sources in the production of electricity in the world is rapidly increasing. According to 2017 data, when the types of fuels used in electricity generation in the world are examined, coal has the highest share with 38.5%, while the share of renewable energy sources is 24.5%. The share of energy resources in electricity generation in the world is given in Figure 1a. As can be seen from the figure, the share of renewable energy sources ranks second after coal [1].

The consumption places of the renewable energy sources in the world are given in Figure 1b. As seen in the figure, the highest consumption is used in domestic and commercial applications with 41.70%, while the share of electricity generation is at the level of 35.10% [1]. Therefore, the use of renewable energy sources in domestic applications is important. Solar energy is important for domestic applications, especially due to the ease of installation. In addition to domestic applications [2], the use of solar energy is also widely used in rural areas where fishing [3], animal husbandry [4], and agriculture [5] are carried out. Off-grid solar systems are installed in a rural area where there is no electrical energy, with the capacity to generate the energy required to supply the necessary energy [6], [7].



a) Fuel share in electricity production **b)** World sectoral consumption of renewable sources

Figure 1. Statistics of energy world in 2017

Increase in the use of renewable energy sources in recent years in Turkey occur. While solar energy use increased by 107.81% in 2019 compared to the previous year, wind energy use increased by 8.33%. Fossil fuel uses such as natural gas, lignite, fuel oil also changed by 0.79%, 5.25% and -56.86%, respectively. Solar energy in terms of having a high potential to increase the use of solar energy in Turkey is important in terms of electricity production. The share of total installed power of renewable energy sources in Turkey in 2019 is 45.23%. The power values of the energy sources are shown in Table 1. Although the use of fossil fuels in electricity production in Turkey is high, the use of alternative energy sources is increasing. As seen in Table 1 and Figure 2, while natural gas has the highest share with 25,935.41 MW (30.53%) installed power, wind energy has 7,520.33 MW (8.85%) installed power and solar energy has 169.70 MW (0.20%) installed power [8].

Table 1. Resources in installed power

Source	Total Installed Power (MW)
Natural Gas	25,935.41
Hydro Dam	20,642.51
Coal	20,283.7
Run of River	7,851.85
Wind	7,520.33
Geothermal	1,514.68
Solar	169.7
Others	1,039.58

In the literature, there are studies in standalone systems based on PV power. Therefore, the simulation and experimental studies are realized in the papers. The modelling of panels with single diode [9] and two diode [10] is studied. The models are always developed to estimate the performance of PV panels. As it is known, power of PV panels is controlled by a DC/DC converter in standalone systems. Different types of converters such as SEPIC, buck, boost, buck-boost, flyback-boost are used in different applications [11]. The converters are controlled with maximum power point algorithms to extract maximum power from PV panels [12-[14]. PV panels are combined with wind turbines, and a hybrid system occurs. In addition to PV power, wind power is used in the system when the sun irradiation is inadequate to feed the load or battery [15]. In standalone renewable energy systems, reliability analysis is realized to ensure the load is always energized [16].

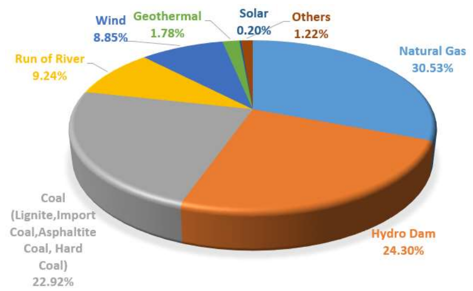


Figure 2. Fuel shares in Turkey installed power in 2019.

In this study, the design and installation of an off-grid photovoltaic system required to meet the energy requirement of the led projector used in the lighting of the cottage located at the entrance door of the Tracim Cement Factory is carried out. The system is designed in PV*SOL software. Depending on the results obtained from software, 960Wp three PV panels, sixteen 12 V – 65 Ah gel batteries, an inverter and a 150 W led projector as a load are used in the system. The measurements taken by the inverter in the system are transferred to the SCADA program with the help of Arduino, and all measurements are remotely monitored and recorded.

2. System Description

The system that is seen in Figure 3 is built in the Tracim campus in Vize. The block diagram of the system is given in Figure 4. It includes three parallel connected 320Wp Gazioglu GSE 320MP photovoltaic panels, so total system power reaches 960Wp. As the system is off-grid, it includes sixteen 12V-65Ah BSB VRLA Solar12-65 batteries. There are four parallel branch, and each branch has two series connected batteries. Thus, total battery bank has 24 V – 520 Ah electrical specifications. The battery bank is used to store the excess energy, and to feed the load when the produced solar energy is inadequate. In the system, Voltronics Axpert VM3000-24 inverter is utilized to control the power flow. It includes 1000Wp power maximum power point tracking (MPPT) controller, and 3000Wp inverter. A 150W led light is used as a load at the output which is fed by the inverter. As the light is used to illuminate the entrance cabin of the factory, the load runs from 08:00 pm and 08:00 am. The system charges the battery bank outside the specified hours. The load is controlled by a relay that is connected to the Arduino Mega. It is utilized to protect the battery against deep discharge. The voltage level of the batteries is lower than the deep value, the relay disconnects the load from the system, and batteries begin to charging from PV panels. The microcontroller converts the measurement signals that are in RS232 protocol of the inverter to TLL by MAX232 IC. The TTL signal is given to Arduino, and it transmits the signal to SCADA system. Thus, the measured current and voltage signals are transferred to SCADA, and they are recorded and monitored at the remote location.

Figure 3. The installed system

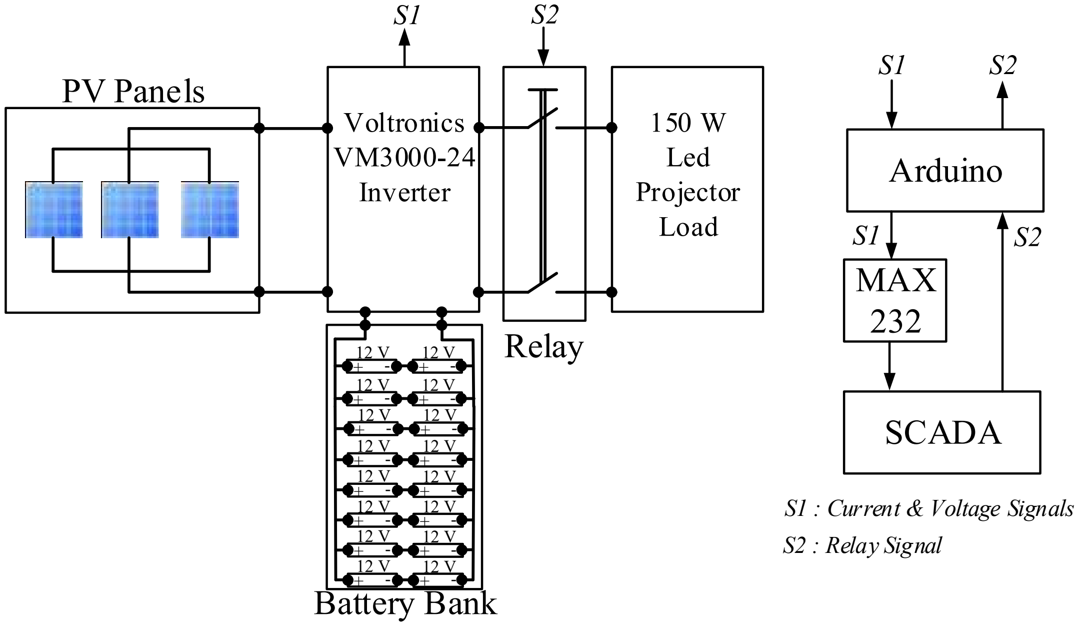


Figure 4. Micro solar power plant

Electrical specifications of the panels are given in Table 2 [17]. The maximum power of the panel which is seen in Figure 5 is 320 Wp, and as three panels are used, total system power is 960 Wp. Three panels are connected in parallel, thus maximum power point current is 28.77 A. As the panels are connected parallel, the output voltage of the system is the same with the panel. The maximum power point voltage is 33.4 V. The characteristic curves of the PV panel is seen in Figure 6. The maximum power points for 1000W/m^2, 800W/m^2 and 600W/m^2 irradiation are 320W, 258W and 194W, respectively.

Table 2. Electrical specifications of the panel (STC: 1000W/m^2, 25^{0}C)

Quantities	Value
Maximum Power (P_{max})	320 Wp
Open Circuit Voltage (V_{oc})	40.9 W
Maximum Power Point Voltage (V_{mpp})	33.4 W
Short Circuit Current (I_{sc})	10.15 A
Maximum Power Point Current (I_{mpp})	9.59 A
Panel Efficiency	19.17%

Figure 5. PV panels in the system

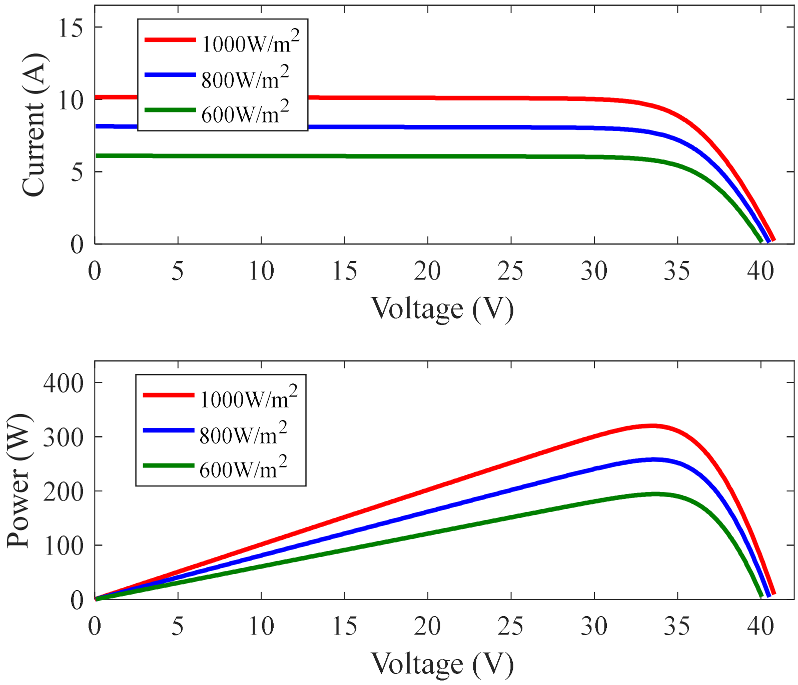


Figure 6. Characteristic curves of the panel

Off-grid PV systems should have battery bank to store the energy from PV panels. The moments that the irradiation is not enough for the producing required energy of a load, battery bank starts to feed the load. When the produced power by PV panels is higher than the required load energy, a battery bank charges, especially in the morning hours. The used battery in the system is BSB Solar12-65 seen in Figure 7a. It has 12V and 65Ah electrical specifications [18]. Sixteen batteries are connected as two are in series, and eight parallel branches. The output voltage of the battery bank is 24V.

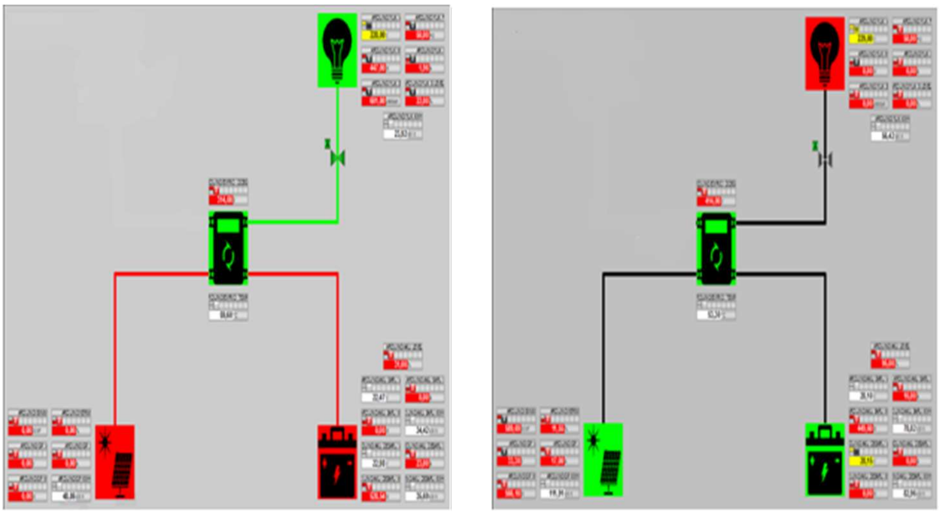
A PV system needs power electronics converter. The used converter in the system is Voltronics VM3000-24 inverter that is seen in Figure 7b. It has 3000W MPPT solar charger and AC charger [19]. It has also utility input connection. Depending on the power balance of the system, battery bank can be charged or the load can be feed by utility. However, this input is not used in the proposed system. Input power only provides from PV panels.

The load is a 150 W led projector in the system [20]. The projector is used for to lighting the entrance cabin between 8:00 pm and 8:00 am. The picture of the load is given in Figure 7c. In order to disconnect the load from inverter, a relay is used between them.

a) BSB Solar12-65 battery **b)** Voltronics Axpert VM3000-24 inverter **c)** Led projector

Figure 7. The used components in the system

SCADA interface of the system is seen in Figure 8. The picture on the left side is shows the night operation status. There is no energy flow from PV panels, and the load feeds from the battery bank. On the right side, the figure shows the morning operation. As the adequate irradiation, PV panels produce energy, and it is transferred to the battery. The load is out of operation.



a) Night **b)** Morning

Figure 8. SCADA interface of the system

3. System Design in PV*SOL

PV*SOL is a software that realize a dynamic simulation with 3D visualization for photovoltaic systems. In the software, different types of photovoltaic systems can be simulated, whether rooftop photovoltaic systems, whether large solar parks or large industrial halls. Lifelike system design can be made with the panel, power electronics converters, battery and load samples in the database. In addition, thanks to the database containing climate conditions, the amount of energy that can be produced by using meteorological information such as temperature and radiation can be calculated for the location where the system will be installed. As a result of the system parameter input, the software calculates various electrical results such as the amount of energy that can be produced in the system, the amount of energy that can be transferred to the load, losses and efficiency. The system installed in the software environment is given in Figure 9. As can be seen, all components in the system are placed in the software.

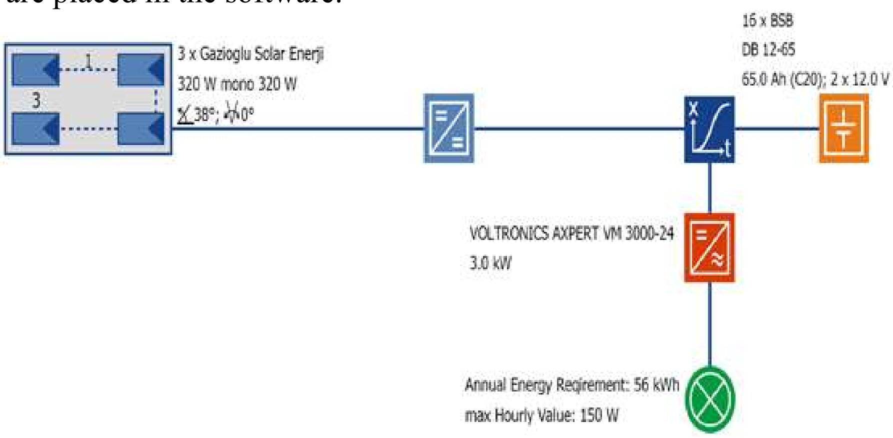


Figure 9. The system in PV*SOL

When the system simulation is completed, the software prepares a result report for a year as shown in Table 3. PV array provides 960 Wp in 4.9m^2 area. While it is possible to produce 7,541.6 kWh of energy from solar panels under meteorological conditions at the system location, only 1,278.3 kWh of energy is produced. Therefore, PV array efficiency is 16.9%. While consumption requirement energy is 657 kWh, the energy covered by solar is 613.07 kWh.

Table 3. The output annual data in PV*SOL

Parameter	Value
Location	Tracim Cimento
PV Output	960 Wp
Active PV Surface Area	4.9 m^2
PV Array Irradiation (E_{in})	7,541.6 kWh
Energy Produced by PV Array (E_{PV})	1,278.3 kWh
Consumption Requirement (E_{Last})	657 kWh
Consumption Covered by Solar Energy (E_{PVuse})	613.07 kWh
System Efficiency (E_{PVuse}/E_{in})	8.1%
PV Array Efficiency (E_{PV}/ E_{in})	16.9%

The variations of daily energy values of the components are given in Figure 10. The waveforms are obtained from PVSOL software for a month of September. As can be seen in the figure, the energy produced by PV array is 113 kWh, battery charge and discharge energies are 82 kWh and 53 kWh, respectively. Solar fraction value is 100% that means the consumption requirement is fed by the system.

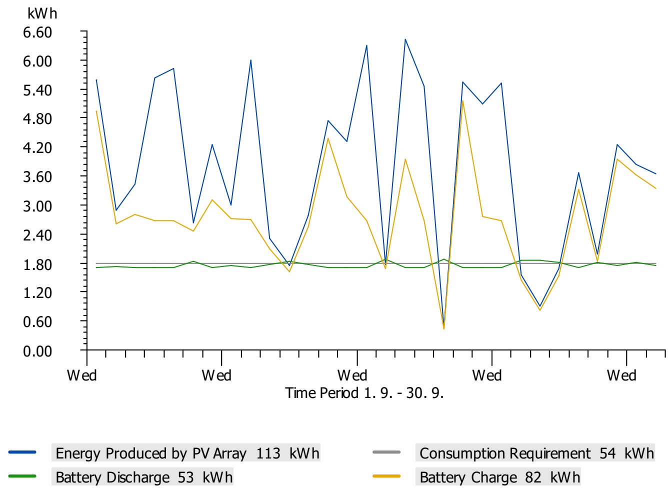
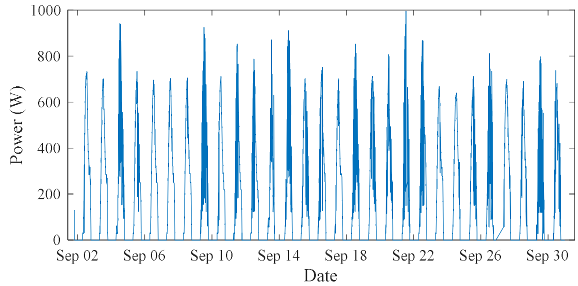


Figure 10. Energy variations of the components

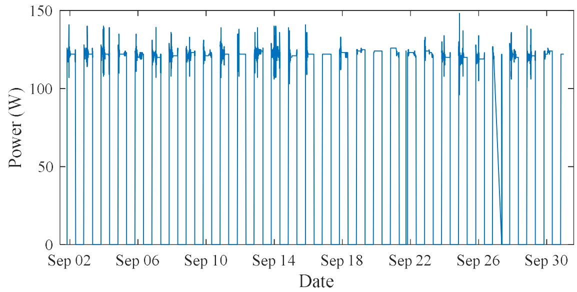
4. Measurement Results

Measurements taken from the system can be monitored and recorded in SCADA software at 1 second intervals. The measurements are made by the inverter, and the values are taken using the RS232 communication protocol. Power and energy values are calculated by measuring the current and voltage values of solar panels. In addition, battery current and voltage are other measurements. Different types of power and energy values can be calculated depending on these measurements. Current and voltage measurements of the load at the output of the system are made by the inverter. Figure 11 shows the instantaneous PV power, load power, battery charge and discharge power waveforms, respectively. As seen in Figure 11a, maximum produced power value changes depending on the weather conditions. Figure 11b shows the load power that is consumed around

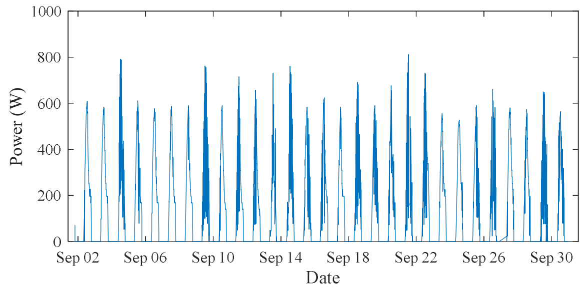
125 W. The load works between 08:00 am-08:00 pm in every day. Battery charge and discharge power variation are given in different figures. Figure 11c and Figure 11d shows battery charge and discharge power, respectively. When the produced energy is examined 113 kWh energy is produced by PV array as calculated in PV*SOL software. Battery charge and discharge energy values are measured as 82 kWh and 69 kWh, respectively. The produced energy by PV panels is 113 kWh in Sep-2020 as calculated in PV*SOL simulation. The daily variation of the energy is seen in Figure 12a. As seen in Figure 12b, the total charge energy is higher than the total discharge energy values. It provides uninterruptable energy transfer to the load.



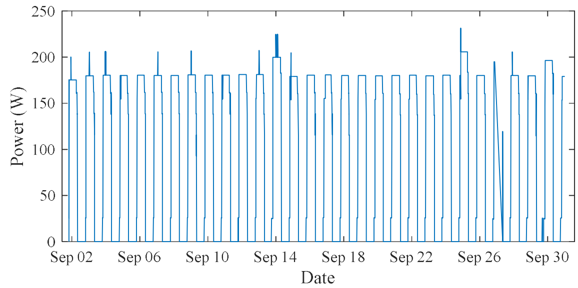
a) PV power variation



b) The load power

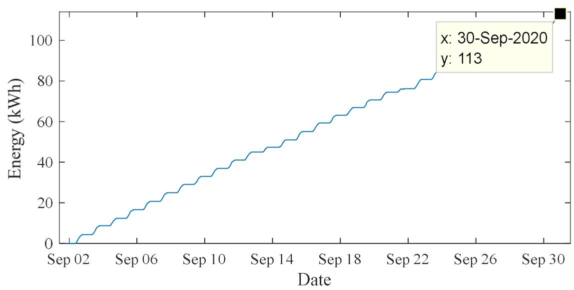


c) Battery charge power

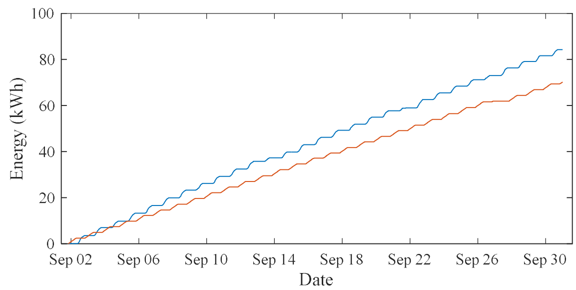


d) Battery discharge power

Figure 11. Power variations of the system



a) PV energy variation



b) Battery charge (blue) and discharge (red) variations

Figure 12. Energy variations of the system

5. Conclusions

In this study, a photovoltaic system, that consists of 3x320W PV panels that are connected in parallel, 16x12V-65AH batteries, an inverter and led projector as a load, is designed in PV*SOL software, and installed in Tracim Cimento in Vize, Kirklareli. The system is used to light the entrance of the factory. The projector is works between 08:00 am-08:00 pm. The system is remote monitored, and measured quantities are recorded and monitored by Scada. The annual report of PV*SOL software, and calculation results for month of September are given in the study. The simulation result for the month of September is verified by the measurement results. The total produced energy is 113 kWh, and the load is fed uninterruptable. The software can be used to design for this type of systems. The actual results may not be the same with simulation results certainly because of weather conditions, panel pollution, etc. The software uses the past weather conditions that are in databases, therefore the future weather conditions effect the system performance. However, if the simulation options are set detailed, very similar results can be obtained.

Acknowledgment

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