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# ENERGY STORAGE APPLICATION FOR PHOTOVOLTAIC ARRAYS ON DISTRIBUTION NETWORKS FOR DAILY LOAD

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**Abstract**: Because of the many disadvantages of classical energy production systems as production and transmission cost, air pollution, raw material problem (natural gas, coal etc.), reliability etc., the integration of Renewable Energy Sources (RESs) to distribution network is one of the most important goals for new energy strategies. Photovoltaic (PV) Arrays as RES is widely used at distribution networks nowadays. DC voltage is produced with PV arrays based on solar irradiation and temperature. Because of the solar irradiation PV arrays cannot produce power all day. Therefore Energy Storage Systems (ESSs) is an important part for RESs. Energy can be stored with ESSs and can be used at the peak time. In this way the peak power and energy cost can be decreased with usage of ESS with PV arrays. In this work, total load power, power losses and energy coast are analysed at 30 bus distribution network (DN) for the integration of RESs and ESSs, and optimum usage of ESS for producers is examined.

***Keywords:*** PV arrays, energy storage systems, distribution network, daily load

## Introduction

Emerging technology and increasing energy demand have made it necessary to modernize the traditional distribution networks. As the settlement areas are widened, DNs cause many disasters, energy loss and time loss and DNs do not respond to today's needs. New distribution network system as smart grid (SG) makes it possible to connect RESs to the DNs. RESs are an important part of the new energy production strategies for SG [1-5].

SG allows bi-directional energy transmission. Fuel cells, wind tribunes, PV arrays can be used for this purpose. RESs can produce safe, efficient and environmental energy for DNs. RESs can be installed closer to settlements for cheaper energy production than the conventional power plants. RESs as distributed generation become widespread and PV panels are being used widely as RES. PV arrays are a DC power source, ambient temperature and solar irradiation level are the basic variable for voltage production. One diode mathematical model is used for this work [6-10].

After the development of the RESs, continuity problem became a new research area. PV arrays and wind turbines generate electricity depending on weather events. Especially PV arrays cannot produce power at the peak time. Energy storage has become necessary for decreasing the peak power. For this purpose, ESSs can be used in different ways. Charge-discharge strategy should be set for optimum ESS usage. Therefore, ESSs can minimize the peak power demand and decrease power losses [11-14].

The aim of this paper is propose an optimum usage of ESS for PV arrays. For this purpose, two suggestions performed for unlicensed producers. First, PV arrays are connected directly to the DN, ESS is charged and discharged at the determined power levels. Then, PV arrays are only used for charging the ESS and ESS is connected to the DN at the peak time. Especially the energy cost and power losses are compared and the results are discussed for the optimum ESS usage.



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**Pv Arrays**

PV cells consist of semiconductor materials and produce DC voltage depending on ambient temperature and solar irradiation. The working principle of PV cells is similar to the p-n junction diode. PV cell can be modelled with current source, parallel diode, and parallel and series resistance. One diode model electrical equivalent circuit for PV cell is given in Figure 1. Output current which is depending on photon current, diode current and parallel resistance current is given in (1).

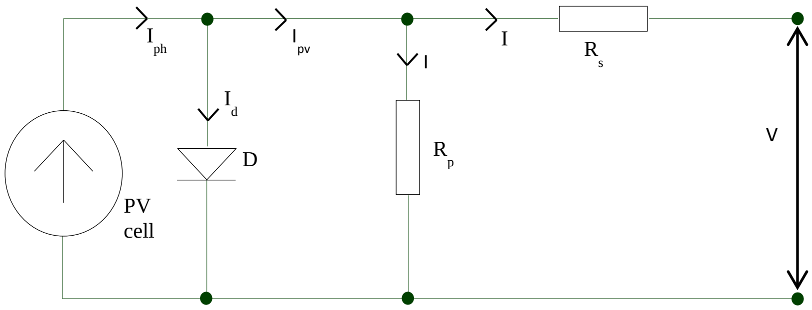


Figure 1. P V Cell electrical equivalent circuit [15]

Photon current, diode current and parallel resistance current in (1) can be calculated with (2), (3) and (4). Eq. (5) and (6) are necessary to calculate (2) and (3).

$$I = I_{ph} - I_d - I_p \tag{1}$$

$I_{ph}$ is photon current whish is given in (2), $I_d$ is diode current which is given in (3) and $I_p$ is parallel resistance current which is given in (4). Eq. (5) and (6) are necessary to calculate (2) and (3). PV nomenclature is given in Table 1.

$$I_{ph} = N_p * \frac{G_T}{G_{Tref}} * \left[I_{ph_{ref}} + K_i\left(T_C - T_{C_{ref}}\right)\right] \tag{2}$$

$$I_d = N_p * I_s * \left[e^{\frac{q\left(V + I\frac{N_s}{N_p}R_s\right)}{N_s nkN_c T_C}} - 1\right] \tag{3}$$

$$I_p = \frac{V + I\frac{N_s}{N_p}R_s}{\frac{N_s}{N_p}R_p} \tag{4}$$

$$I_s = I_{s_{ref}} * \left[\left(\frac{T_{C_{ref}}}{T_C}\right)^3 * e^{\frac{qE_g}{nk}*\left(\frac{1}{T_{C_{ref}}} - \frac{1}{T_C}\right)}\right] \tag{5}$$

$$I_{s_{ref}} = \frac{I_{sc_{ref}} + K_i(T_C - T_{C_{ref}})}{e^{\frac{q\left(V_{oc_{ref}} + K_v\left(T_C - T_{C_{ref}}\right)\right)}{nkN_s T_C}} - 1} \tag{6}$$

Table 1. PV nomenclature

| | | | |
|---|---|---|---|
| I | PV Cell Output Current | $T_C$ | Cell Temperature |
| $I_{ph}$ | Photon Current | $T_{C,ref}$ | Reference Cell Temperature |
| $I_d$ | Diode Current | $K_i$ | Short Circuit Current Temperature Coefficient |
| $I_p$ | Parallel Resistance Current | $K_v$ | Open Circuit Voltage Temperature Coefficient |
| $I_s$ | Diode Saturation Current | $R_s$ | Series Resistance |
| $I_{s,ref}$ | Reference  Saturation Current | $R_p$ | Parallel Resistance |
| $I_{ph,ref}$ | Reference Photon Current | $N_p$ | Parallel Module Number |
| V | Output Voltage | $N_s$ | Series Module Number |
| $G_T$ | Solar Irradiation | $N_c$ | Cell Number |
| $G_{T,ref}$ | Reference Solar Irradiation | $V_{oc,ref}$ | Reference Open Circuit Voltage |

| | | | |
|---|---|---|---|
| q | Electron Charge-1.6021*$10^{-19}$ C | $I_{sc,ref}$ | Reference Short Circuit Current |
| k | Boltzmann's Constant-1.38065*$10^{-23}$ J/K | n | Ideality Factor |
| $E_g$ | Bandgap Energy | | |

Kyocera KC200GT PV module is used at this work and electrical specifications are given in Figure 2. Three PV array is created with 13 series modules. Two of them have 10 parallel modules and one PV array has 13 parallel modules. Solar irradiation and ambient temperature at 21 august 2016 is used with one minute time interval for Kayseri in Turkey. Sunrise time is 05.54 and sunset time is 19.28. The modelled PV arrays are simulated and daily power of three PV arrays is shown in Figure 3.

**Specifications**

| Electrical Performance under Standard Test Conditions (*STC) | |
|---|---|
| Maximum Power (Pmax) | 200W (+10%/−5%) |
| Maximum Power Voltage (Vmpp) | 26.3V |
| Maximum Power Current (Impp) | 7.61A |
| Open Circuit Voltage (Voc) | 32.9V |
| Short Circuit Current (Isc) | 8.21A |
| Max System Voltage | 600V |
| Temperature Coefficient of Voc | $-1.23\times10^{-1}$ V/℃ |
| Temperature Coefficient of Isc | $3.18\times10^{-3}$ A/℃ |

*STC : Irradiance 1000W/m², AM1.5 spectrum, module temperture 25℃

| Cells | |
|---|---|
| Number per Module | 54 |

Figure 2. KC200GT PV module electrical specifications [16]

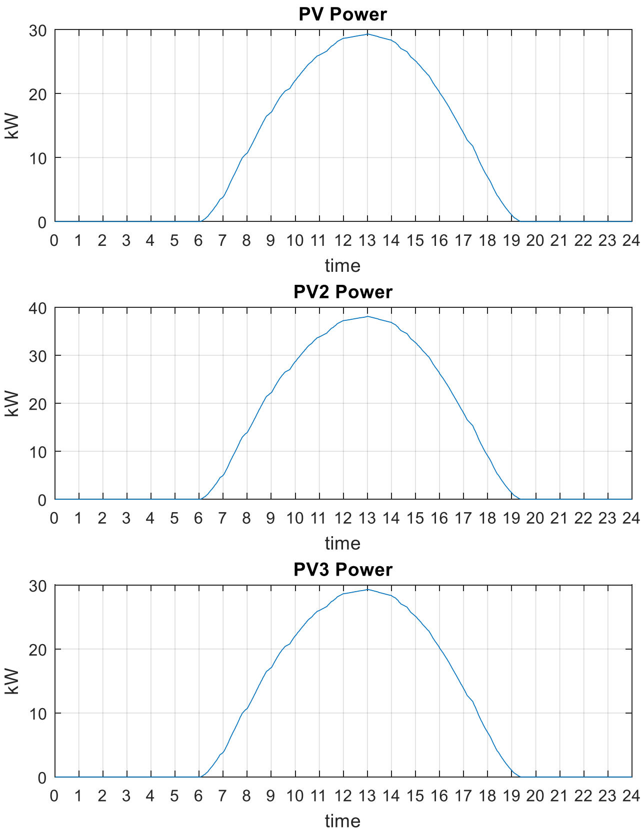


Figure 3. Generated power of PV arrays

## Results and Findings

Figure 4 shows the 30 bus DN which is used in this work and line data of 30 bus is given in Table 2. Three buses as 6, 11 and 21 are selected randomly for the unlicensed producers and 30 kW, 40 kW and 30 kW PV arrays are connected respectively. Besides 60 kW and 420 kWh DESSs (Distributed Energy Storage Systems) is connected to the same bus with PV arrays. Daily load is created in one minute interval for daily simulation.

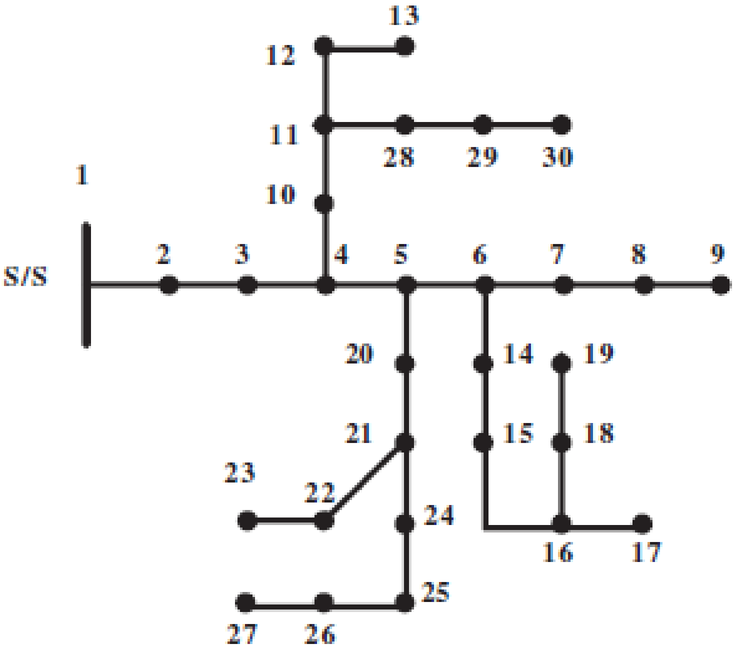


Figure 4. 30 Bus distribution network [17]

Table 2. Line data of 30 bus DN

| 30 Bus DN | Line Data | | | |
|---|---|---|---|---|
| | Sending Bus | Receiving Bus | R | X |
| 1 | 1 | 2 | 1.632 | 1.1019 |
| 2 | 2 | 3 | 1.088 | 0.7346 |
| 3 | 3 | 4 | 0.544 | 0.3673 |
| 4 | 4 | 5 | 0.272 | 0.1836 |
| 5 | 5 | 6 | 0.544 | 0.3673 |
| 6 | 6 | 7 | 1.376 | 0.3896 |
| 7 | 7 | 8 | 2.752 | 0.7792 |
| 8 | 8 | 9 | 4.128 | 1.1688 |
| 9 | 4 | 10 | 3.6432 | 1.5188 |
| 10 | 10 | 11 | 0.9108 | 0.3797 |
| 11 | 11 | 12 | 0.4554 | 0.1898 |
| 12 | 12 | 13 | 0.4554 | 0.1898 |
| 13 | 6 | 14 | 0.9108 | 0.3797 |
| 14 | 14 | 15 | 1.8216 | 0.7594 |
| 15 | 15 | 16 | 1.8216 | 0.7594 |
| 16 | 16 | 17 | 0.9108 | 0.3797 |
| 17 | 16 | 18 | 1.376 | 0.3896 |
| 18 | 18 | 19 | 1.376 | 0.3896 |
| 19 | 5 | 20 | 0.9108 | 0.3797 |
| 20 | 20 | 21 | 1.8216 | 0.7594 |
| 21 | 21 | 22 | 2.7324 | 1.1391 |
| 22 | 22 | 23 | 0.9108 | 0.3797 |
| 23 | 21 | 24 | 2.752 | 0.7792 |
| 24 | 24 | 25 | 3.0272 | 0.8571 |
| 25 | 25 | 26 | 2.752 | 0.7792 |
| 26 | 26 | 27 | 2.752 | 0.7792 |
| 27 | 11 | 28 | 1.376 | 0.3896 |
| 28 | 28 | 29 | 1.376 | 0.3896 |
| 29 | 29 | 30 | 4.128 | 1.1688 |

In first case study, DESS is charged and discharged based on the total load level. ESS charge level is determined as 800 kW and DESS discharge level is 1400 kW. Thus, peak load and peak-off load get closer to each other. Peak load can be decreased with DESS discharging and peak-off load can be increased with DESS charging. Besides PV arrays feed the DN at day time. Peak power is decreased from 1593 kW to 1423.7 kW with load level based (LLB) DESS charging. Total daily energy of base DN is 22919 kWh and daily energy is decreased to 22371 kWh. Daily energy cost is decreased from 7993,463 TL to 7561,301 TL.

Second case study is about storage of PV power with DESS. In this case, DESS is charged with PV power and discharged at the peak time (17.00-22.00). Peak power is decreased from 1593 kW to 1415.9 kW and daily energy is 22061 kWh. Daily energy cost is decreased from 7993,463 TL to 7576.332 TL.

Total load power comparison is shown in Figure 5 and total power loss comparison is given in Figure 6. Figure 6 shows the importance of RES and DESS about power loss. Peak power loss is decreased from 143,9778 kW to 108,6754 with RES and DESS usage. Total energy lost is 1368 kWh for based DN. Total energy loss is decreased to 1172 kWh with LLB DESS charging and 1176 kWh with PV charge.

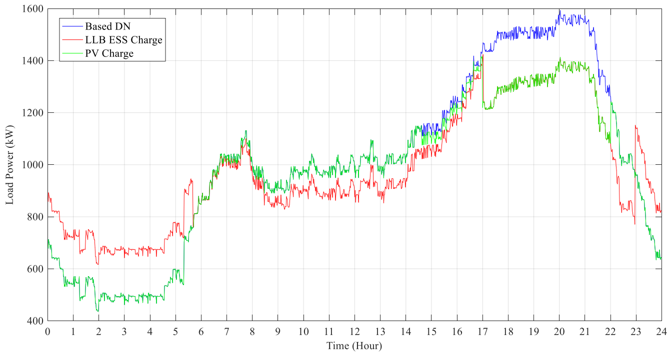


Figure 5. Load power results for 30 bus DN

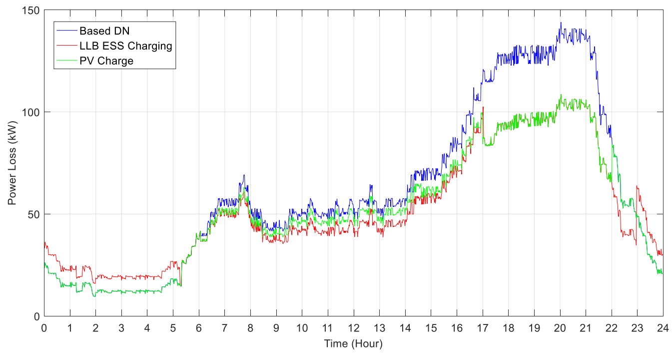


Figure 6. Power loss results for 30 bus DN

Apart from these studies, DESS is not used for 30 bus DN and only PV arrays are added. In this study, daily energy is 22156kWh, daily energy cost is 7734,727 TL and peak power is 1593 kW. This study is not shown in Fig. 5 and Fig. 6.

Electric price tariff of TEDAS (Turkish Electricity Distribution Company) is given in Table 3 and Table 4 shows the energy cost comparison for 30 bus DN.

Table 3. Electric price tariff of tedas [18]

| Electric Price Tariff with Distribution Fee (₺/kWh) | | |
|---|---|---|
| **Day** | **Peak** | **Night** |
| 0,330447 | 0,499784 | 0,208112 |

Table 4. Energy cost comparison

| **Energy Cost** | **ESS Charging Status** | | |
|---|---|---|---|
| | **Based DN** | **LLB Charge** | **PV Charge** |
| Day (₺) | 3807,41 | 3568,167 | 3784,609 |
| Peak (₺) | 3108,656 | 2715,326 | 2714,327 |
| Night (₺) | 1077,396 | 1277,808 | 1077,396 |

| Energy Cost | ESS Charging Status | | |
|---|---|---|---|
| | **Based DN** | **LLB Charge** | **PV Charge** |
| Total (₺) | 7993,463 | 7561,301 | 7576.332 |

## Conclusion

After the development of Smart Grids, RESs are widely used at DN and unlicensed production is supported in Turkey for below 1000 kW. RESs cannot produce electricity in all day. So that PV arrays can give energy to DN at day time. At peak time, solar irradiation level is low or zero and PV power is at the minimum levels. Because of this, PV arrays cannot help about decreasing the peak power but DESSs have an important place for this purpose. In this paper, two ESS charging status is studied for the PV arrays, and total load level, daily energy, total power loss and daily energy cost are examined. Peak power is decreased nearly %10, daily energy is decreased %3 and daily energy cost is decreased nearly %5 in both studies with RESs and DESSs. These results are closer to each other but total energy without DESS is lower than LLB ESS charging. So PV charge is more efficient way to use DESS.

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