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# Active and reactive power of solar electric vehicle chargers system

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**ABSTRACT**

Increasing the number of electrical vehicles determine an increasing of electrical vehicle chargers number too. The best situation is reach when the zero emission vehicles are charged with electrical energy produced by solar panels or another green energy. This paper presents a solar electric vehicle charger system with energy storage capabilities. The system should be considered as a combination of three systems: solar energy production system, energy storage system and electric vehicle charger system. One of the novelty of the system is that for energy storage is used a 2nd life Nissan Leaf electric vehicle battery. The paper gives information about, simulation and measurement of the annual solar energy production of the system, measurements results of the currents, voltages and powers of the system, and a distribution of the maximum daily energy production.

**KEYWORDS**

solar inverter, solar panels, battery management system, active and reactive power, power factor, electric vehicle charger

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## 1. INTRODUCTION

At the end of October 2021 in Hungary the number of Electric Vehicles (EV) was around of 40,545 [1]. In conformity with The Hungarian Energy and Public Utility Regulatory Authority at the end of second quarter of 2021 the number of public EV chargers in Hungary was 1,627. During this period time from this chargers 2,248 MWh energy was used for EV charging. The used energy amount was with 68.2% higher than the charged energy in second quarter of 2020 and with 22.6% higher than the charged energy in first quarter of 2021 [2]. The above data show a rapidly increasing of the EV number and the EV chargers number, which determine an increasing of the energy consumption too. In August 2021 the electrical energy production in Hungary was 2,905 GWh. This energy production was with 9% higher that the energy production in August 2020. From energy source point of view, the renewable energy was 22.4%. In case of renewable energy production, 68.8% of it was given by the solar energy [3]. It is important to know that in Hungary the capacity of photovoltaic systems on second quarter of 2021 was 2,621 MW. From solar energy production point of view, the capacity of small household size solar power plants was 944 MW and the rest of 1,677 MW capacity was represented by big size solar power plants [4]. On February 1, 2022 at 10:06 the measured energy production of Paks nuclear power plant was: 2,043 MW [5]. According to International Renewable ENergy Agency (IRENA) report on 2030 the global installed capacity of solar systems will be increased by six times compare to 2018, and in 2050 that will reach 8,519 GW [6]. One of the biggest advantages of the solar systems is that the energy produced by it is a green energy, and the carbon footprint is reduced. Unfortunately, the increasing of the number and the capacities of the PhotoVoltaic (PV) systems determine some problems for the Distribution Network Operators (DNOs) as pass over the upper limit of voltage, voltage unbalances, fluctuations, and thermal overloads. This kind of technical challenges is determinate by increasing of amount of power generated by solar systems [7].

For example, a combination of higher solar energy production and a lower level consumption from power grid point of view could cause reverse power flow [8]. The rise of voltage should be determined by reverse flow of power. Voltage rises on Low-Voltage (LV) power supply line determine a limitation of higher number of solar systems connection to the LV grids.

## 2. EFFECT OF REACTIVE POWER COMPENSATION AND SOLAR ENERGY ON LOW VOLTAGE POWER SUPPLY LINE

In Fig. 1 a simple LV circuit is presented. The power consumption of the single consumer is $P_L$ and $Q_L$. The connection of the consumer to the distribution power supply line is done through a line with $R + jX$ impedance. To the same connection point as the consumer is connected a PV system with $Q_{PV}$ reactive power and $P_{PV}$ active power.

$$\Delta V = V_1 - V_2 = I^* \cdot (R + jX), \tag{1}$$

where,

$$I^* = \left(\frac{(P_L - P_{PV}) + j(Q_L - Q_{PV})}{V_2}\right)^*. \tag{2}$$

If $I^*$ is substituted to Eq. (1)

$$\Delta V = \left(\frac{(P_L - P_{PV}) + j(Q_L - Q_{PV})}{V_2}\right)^* \cdot (R + jX), \tag{3}$$

$$\Delta V = \frac{(P_L - P_{PV})R + (Q_L - Q_{PV})X}{V_2} + j\frac{(P_L - P_{PV})X - (Q_L - Q_{PV})R}{V_2}. \tag{4}$$

The $\Delta V$ from imaginary and real part could be written as in Eq. (5) as

$$\Delta V = \Delta V_d + j\Delta V_q, \tag{5}$$

where,

$$\Delta V_d = \frac{(P_L - P_{PV})R + (Q_L - Q_{PV})X}{V_2}, \quad \Delta V_q = \frac{(P_L - P_{PV})X - (Q_L - Q_{PV})R}{V_2}. \tag{6}$$

The magnitude of $V_1$ can be calculated as

$$V_1 = \sqrt{(V_2 + \Delta V_d)^2 + \Delta V_q^2}. \tag{7}$$

The (X/R) reactance-to-resistance of LV circuit is lower that means $(\Delta V_q \approx 0)$, $V_2$ should be written in a new form:

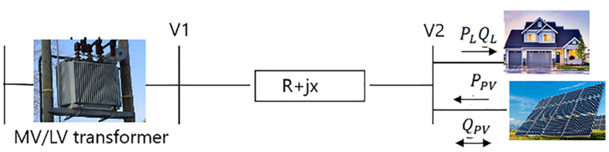


*Fig. 1.* Example of a simple LV power supply line

$$V_2 = V_1 - \Delta V_d. \tag{8}$$

If $V_2$ is substituted by $V_1$ the $\Delta V_d$ can be written as

$$\Delta V_d \approx \frac{(P_L - P_{PV})R + (Q_L - Q_{PV})X}{V_1}. \tag{9}$$

At the common coupling point, the voltage $V_2$ should have the next form:

$$V_2 \approx V_1 - \frac{(P_L - P_{PV})R + (Q_L - Q_{PV})X}{V_1}. \tag{10}$$

When the energy requirement is higher than the supplied energy, the voltage drops on the power line as in Eq. (10). When the generated solar energy exceeds demand, then the voltage is increasing. The voltage at the Point of Common Coupling (PCC), is given by Eq. (11),

$$V_2 \approx V_1 + \frac{(P_{PV} - P_L)R + (Q_{PV} - Q_L)X}{V_1}. \tag{11}$$

This situation becomes a problem when the voltage limits is reach by the voltage growing due to increasing of number of PV systems ($P_{PV} \gg P_L$). Eqs (10) and (11), show that the reactive power produced by PV inverter and the situation of the consumer influence the PCC voltage. If the PCC voltage reaches the lower limit voltage, then the PV inverter should start to produce reactive power to increase the voltage. If the voltage at the PCC reaches the upper voltage limit, then PV inverter should stop to produce the reactive power and start to consume it to reduce the voltage.

## 3. SOLAR SYSTEM WITH ENERGY STORAGE AND ELECTRIC VEHICLE CHARGING CAPABILITIES

The solar system and electric vehicle charging with energy storage capability from Óbuda University contains: 24 glass-glass solar panels, a solar inverter, a charger/inverter which supply the Battery Management System (BMS) role too, two EV chargers and used Li-Ion Nissan Leaf batteries.

### 3.1. Solar panels

The efficiency of a typical commercial PV module is about 13–20% [9]. For construction of this system the used solar panel is SoliTek glass-glass, mono-crystalline 320 W solar panels. The total solar panels capacity is 7680 W.

### 3.2. Solar inverter

The solar inverter is an 8.2 kW Fronius Symo inverter. The highest amount of produced power was around of 7 kW for short time. In general, the best energy production for longer time is around of 6.5 kW. The reason why the power of the solar inverter has to be higher than the power of the solar panels is that the inverter has to produce not only active power but reactive power too. The production of the reactive power should not decrease the production of the active power, in case of maximum solar energy production. In Figs 2 and 3 the diagrams of input DC voltage and current and the output AC voltage of solar inverter are presented. The differences between two figures are that in first figure is presented the measurement results of a sunny day. The total energy production in Sept. 9, 2021 was 45.38 kWh. The diagram of DC current is quite the same with diagram of the AC current and power output of the inverter. This diagram form is typically for a sunny day. In both cases the level of the DC voltage decreases with increasing of the DC current. The output AC voltage is around of 235 V.

## 3.3. Battery management system

The role of Battery Management System (BMS) is done by a Victron charger/inverter. Another role of it is to interconnect the solar system, EV chargers, batteries and the power supply network. The connection to the internet gives the possibility to use the online Victron Remote Management (VRM) portal. Through the portal not only the momentary information regarding the system should be known, but the historically information too. In Fig. 4 the momentary information of the system through VRM is presented.

The status of the system is as follows: the solar system produces 1,135 W, 939 W is fed in the power system, 68 W is used by the EV chargers, which are in standby mode, because no EV on chargers, 75 W is used for charging the batteries.

## 3.4. Electric vehicle charger

The system contains two Wallbox EV chargers. In Fig. 5 the all energy supplied to the EV charging and the charging time is presented. The 124.97 kWh energy means 53.65 kg $CO_2$ saved.

Figure 6 shows a nighttime status of the system after a typical day. The PV system operated normally, the energy was fed in the grid into the network. Midday a car arrived

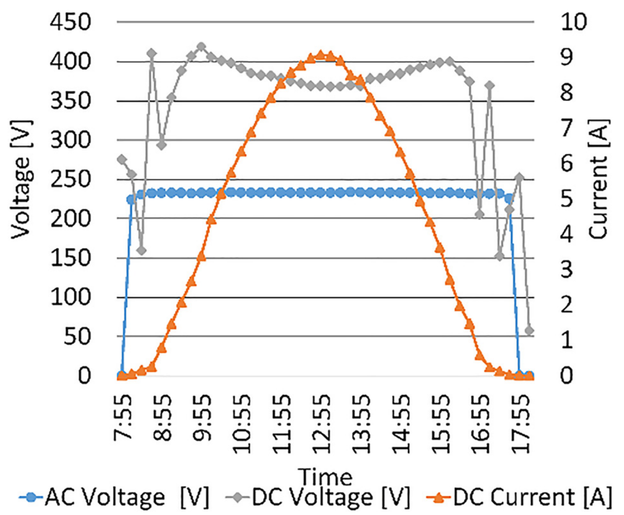


*Fig. 2.* The diagrams of input, output of voltage and current in a sunny day

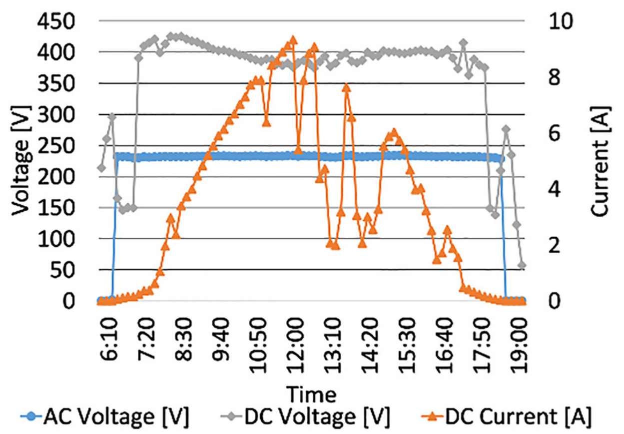


*Fig. 3.* The diagrams of input, output of voltage and current in a cloudy day

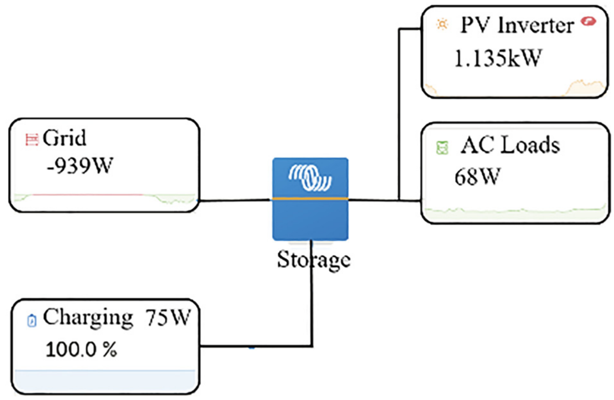


*Fig. 4.* Momentary status of the system, feed into the grid

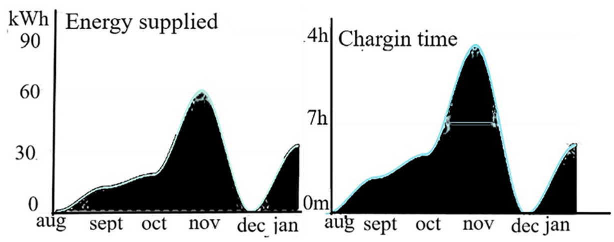


*Fig. 5.* The energy supplied by the EV chargers

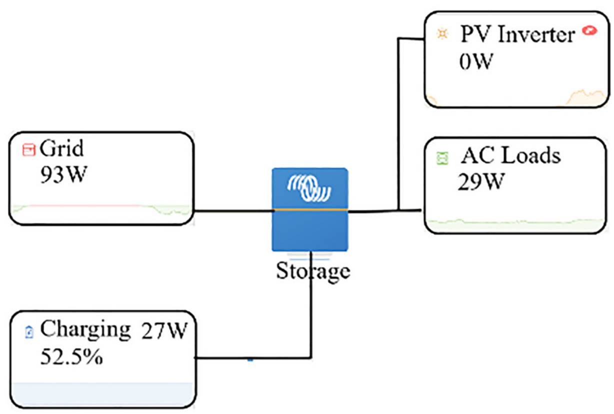


*Fig. 6.* Day after an EV charge

for charging so the whole PV production + grid source + the battery supplied the energy for the car charging.

### 3.5. Storage batteries

The batteries are used batteries from Nissan Leaf first generation car. This is an important fact because the reduced storage capacity of the batteries is not enough for EV, but for energy storage (electro-chemical storage) in a solar system is acceptable [10].

## 4. MEASUREMENT RESULTS

### 4.1. Energy production of the system

It is well known that the solar energy is not a constant energy source. In this case the nominal capacity of the system is 7.68 kW. The energy production of the solar system presented in this paper was simulated with help of Photovoltaic Geographical Information System (PVGIS) program. In Fig. 7 the result of the simulation and the measured solar energy production is presented. In general, the simulated and the measured energy production are quite equal. Some differences should appear, because of weather from that month.

Month with the biggest difference in simulated and measured energy production was May. In Fig. 8 is presented the measured daily energy production of May and June

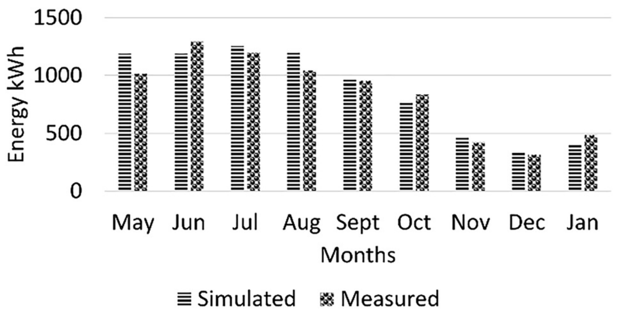


*Fig. 7.* Comparison between simulated and measured solar energy production

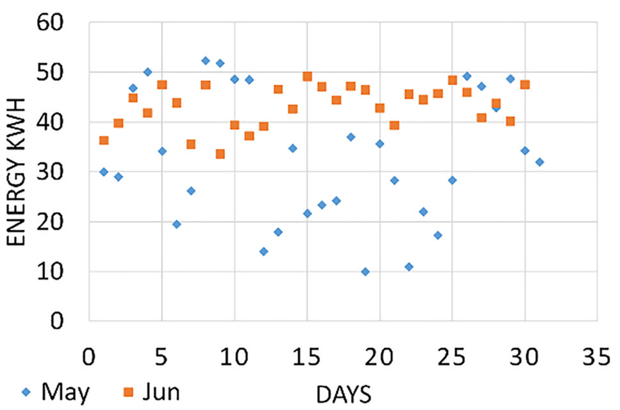


*Fig. 8.* Distribution of energy production for May and June 2021

2021. The measurement results show that in May was a changeable weather, with a lot of cloudy days.

The energy production was very unpredictable for that month. In the sunniest day the maximum energy production was 52.6 kWh. In the lowest energy production day, the total energy amount was 9.91 kWh. The total simulated energy production for May was 1,186.8 kWh, and the measured energy production was 1,014.72 kWh. Compare to May, June was a quite stable month, where the measured energy production was higher that the simulated one. The variation of the energy production was much lower compare to May. The maximum daily energy production was 49. 11 kWh and minimum 33.55 kWh. From minimum energy production point of view in June it was three times higher than in May. The total simulated energy production for June was 1,188.1 kWh, and the measured energy production was 1,294 kWh. The difference between the total simulated and the measured energy was 210.55 kWh that is less than 3% of total measured energy production which was 7,556.85 kWh.

It is well known that the PV systems fed energy in power network systems only if the grid voltage is within specified limits. Peaks of energy production should determine the voltage to reach the upper limit. Reaching of the upper or lower voltage determine a switch down of the solar inverter. In case of Fronius inverter it is switch off at 260 and 180 V.

The voltage stability can be influenced by monitoring the reactive and effective power transmission to the grid. One solution is to reduce the active power generation, but that determine a reduction of the electrical energy supplied to the power supply network [11–15]. Another solution is to manage the reactive power [16–25]. Managing of the reactive power can cause the level of the voltage to rise and to fall. This regulation of the voltage levels can be solved by using of the inverters with smart capabilities.

There are listed some reactive power controls technics:

- Fixed power factor control;
- Scheduled power factor control;
- Power factor control as a function of injected active power;
- Voltage-dependent reactive power control (volt-var control).

In case of solar inverter presented in this paper the volt-var control method are used for reactive power output management. In Fig. 9 the measurement results of active power $P$ (W), reactive power $Q$ (var), apparent power $S$ (VA) and the power factor $\cos \varphi$ in a sunny day is presented.

Because the power factor is 1, the active power is equal with apparent power. This is the reason why in Fig. 9 only the three wave forms, but four vertical axis ($S$, $P$, $Q$, $\cos \varphi$) should be seen. The total energy production was 28.97 kWh. The diagram of the reactive power follows the diagrams of active and apparent power. The amount of produced reactive power is 1% of amount of active power. That is meaning in this case the amount of reactive, was around of 290 var.

In Fig. 10 the measurement results for a rainy day is presented. In this case when the energy production is very low, the power factor is lower than 1, and the inverter start

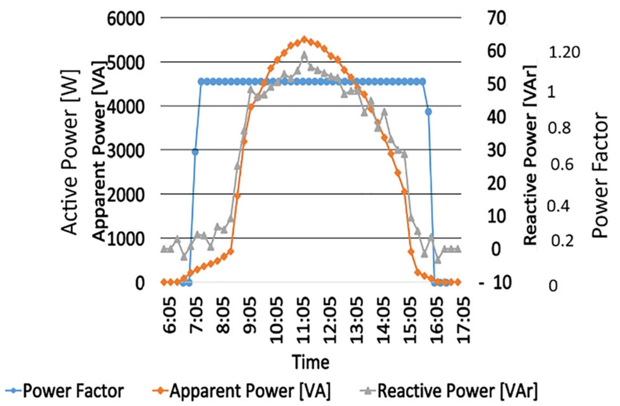


*Fig. 9.* Active, reactive, apparent power and power factor in a sunny day

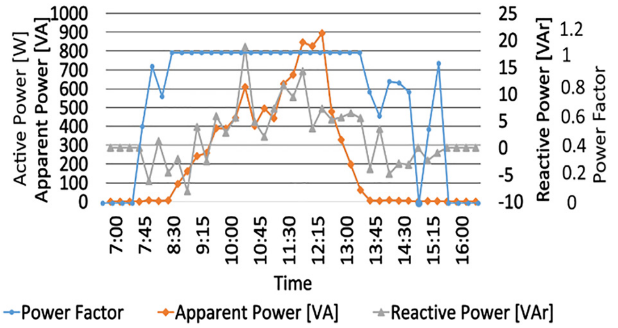


*Fig. 10.* Active, reactive, apparent power and power factor in a rainy day

to consume the reactive power. The total energy production for that day was 2.31 kWh.

In Fig. 11 a simulation of voltage drop, which should appear due the reactive power injected by a solar system on a power system line is presented. For the simulation was used a typically 3 phase power supply line, 95 $mm^2$ 3 core aluminum, $r = 0.397\,\Omega\ km^{-1}$, $x = 0.0762\,\Omega\ km^{-1}$. The injected powers by solar system is $P = 6{,}696$ W, $Q = 65.83$ var and the current $I = 9.57$ A.

In Fig. 11 it can be seen that at the end of the line the voltage drop should be 1.6 V. If on this power supply line only 20 solar systems with 7 kW capacity are connected, then the voltage drop should be 32 V at the end of line. This

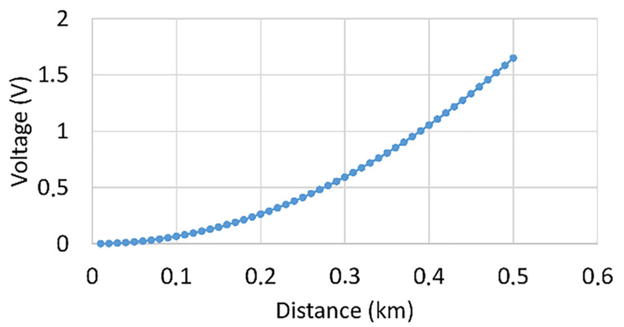


*Fig. 11.* Voltage drop on power supply line due to reactive power

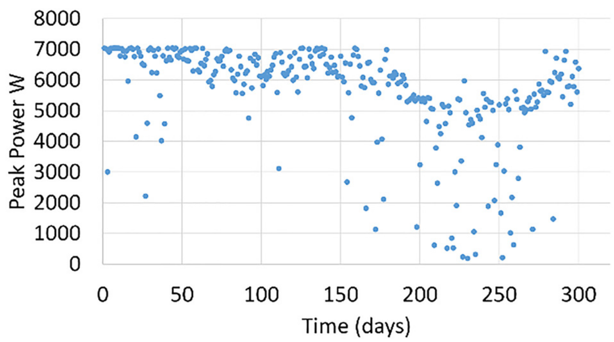


*Fig. 12.* Distribution of daily peak power production

kind of problem appear on streets from villages and cities where the most of buildings are family houses where are solar systems installed.

Figure 12 presents the measurement results of daily peak power production from middle of May 2021 till middle of March 2022. Between May and October the daily peak power production is between 6 and 7 kW and the dispersion, is not so significant. Start with end of October the daily peak power decrease and the dispersion become more significant.

## 5. CONCLUSION

This paper presents an electric vehicle charging system where the energy for charging is coming from multiple sources: as solar panels, storage batteries, and power supply network. The measurements on the system give information about output voltage and current of the solar panels, and the output voltage of the inverter in a sunny and cloudy day too. There is presented a comparison of the simulated and measured solar energy production also. The results of the simulation and measurements are quite same. Bigger differences are coming if the weather in a month is different compare to typical weather in that month, rainier and cloudy days, which determine less energy production.

Measurement results about active ad reactive powers and the dependence between them are presented too. In a sunny day the reactive power consumption of the solar inverter is on a low level. This consumption appears in the morning and in the evening when the energy produced by the solar panels is in a low quantity. In a rainy day, the consumption of the reactive power is higher, because the energy produced by the solar panels is lower for longer time. At the end of the paper a distribution of the maximum daily energy production is presented too. Between October and March, the energy production decreasing and the dispersion of the maximum energy production is more significant.

## REFERENCES

[1] Electric cars in Hungary are breaking new records one after another. [Online]. Available: https://villanyautosok.hu/2021/12/

10/sorra-huzzak-be-az-ujabb-rekordokat-az-elektromos-autok-magyarorszagon/. Accessed: Jan. 31, 2022.
[2] MEKH, prepared a map of domestic electric charging stations, the number of which increased by 45 percent in one year. [Online]. Available: http://www.mekh.hu/terkepet-keszitett-a-mekh-a-hazai-elektromos-toltoallomasokrol-melyek-szama-45-szazalekkal-nott-egy-ev-alatt. Accessed: Jan. 31, 2022.
[3] In August, almost a quarter of domestic electricity generation came from renewable energy sources. [Online]. Available: http://www.mekh.hu/augusztusban-a-hazai-villamosenergia-termeles-csaknem-negyedet-biztositottak-megujulo-energiaforrasok. Accessed: Jan. 31, 2022.
[4] The next few years may be about solar panels combined with energy storage. [Online]. Available: https://greendex.hu/energiataroloval-kombinalt-napelemekrol-szolhatnak-a-kovetkezo-evek. Accessed: Feb. 1, 2022.
[5] Hungarian Atomic Energy Authority. [Online]. Available: http://www.haea.gov.hu/web/v3/oahportal.nsf/web?OpenAgent&article=paksnpp. Accessed: Feb. 1, 2022).
[6] Future of Solar Photovoltaic: Deployment, Investment, Technology, Grid Integration and Socio-Economic Aspects, International Renewable Energy Agency: Abu Dhabi, United Arab Emirates, 2019. Available: https://www.irena.org/publications/2019/Nov/Future-of-Solar-Photovoltaic. Accessed: Feb. 1, 2022.
[7] D. W. Almeida, A. H. M. S. M. S. Abeysinghe, and J. B. Ekanayake, “Analysis of rooftop solar impacts on distribution networks,” *Ceylon J. Sci.*, vol. 48, no. 2, pp. 103–112, 2019.
[8] D. Almeida, S. Abeysinghe, M. P. Ekanayake, R. I. Godaliyadda, J. Ekanayake, and J. Pasupuleti, “Generalized approach to assess and characterise the impact of solar PV on LV networks”, *Int. J. Electr. Power Energy Syst.*, vol. 121, 2020, Paper no. 106058.
[9] A. K. Abdulrazzaq, G. Bognár, and B. Plesz, “Combined electro-thermal model for PV panels,” *Pollack Period.*, vol. 16, no. 1, pp. 7–13, 2021.
[10] I. E. Haber, G. Bencsik, B. Naili, and I. Szabo, “Building thermal capacity for peak shifting, based on PV surplus production,” *Pollack Period.*, vol. 16 no. 2, pp. 117–123, 2021.
[11] R. Tonkoski, L. A. C. Lopes, and T. H. M. El-Fouly, “Coordinated active power curtailment of grid connected PV inverters for overvoltage prevention,” *IEEE Trans. Sustain. Energy*, vol. 2, no. 2, pp. 139–147, 2010.
[12] S. Ghosh, S. Rahman, and M. Pipattanasomporn, “Distribution voltage regulation through active power curtailment with PV inverters and solar generation forecasts,” *IEEE Trans. Sustain. Energy,* vol. 8, no. 1, pp. 13–22, 2016.
[13] S. Alyami, Y. Wang, C. Wang, J. Zhao, and B. Zhao, “Adaptive real power capping method for fair overvoltage regulation of distribution networks with high penetration of PV systems,” *IEEE Trans. Smart Grid*, vol. 5, no. 6, pp. 2729–2738, 2014.
[14] R. Tonkoski, L. A. C. Lopes, and T. H. M. El-Fouly, “Droop-based active power curtailment for overvoltage prevention in grid connected PV inverters,” in *2010 IEEE International Symposium on Industrial Electronics*, Bari, Italy, July 4–7, 2010, pp. 2388–2393.
[15] S. Paudyal, B. P. Bhattarai, R. Tonkoski, S. Dahal, and O. Ceylan, “Comparative study of active power curtailment methods of PVs for preventing overvoltage on distribution feeders,” in *2018 IEEE Power & Energy Society General Meeting*, Portland, OR, USA, August 5–10, 2018, pages 1–5.
[16] J. F. Gómez-González, D. Cañadillas-Ramallo, B. González-Díaz, J. A. Méndez-Pérez, J. Rodríguez, J. Sánchez, and R. Guerrero-Lemus, “Reactive power management in photovoltaic installations connected to low-voltage grids to avoid active power curtailment,” *Renew. Energy Power Qual. J.*, vol. 1, no. 16, pp. 5–11, 20181.
[17] T. Stetz, F. Marten, and M. Braun, “Improved low voltage grid-integration of photovoltaic systems in Germany,” *IEEE Trans. Sustain. Energy*, vo. 4, no. 2, pp. 534–542, 2012.
[18] D. Almeida, J. Pasupuleti, J. Ekanayake, and E. Karunarathne, “Mitigation of overvoltage due to high penetration of solar photovoltaics using smart inverters volt/var control,” *Indones. J. Electr. Eng. Comput. Sci.*, vol. 19, no. 3, pp. 1259–1266, 2020.
[19] M. A. Ishimaru, H. Tamachi, and S. Komami, “Positive effect of PV’s constant leading power factor operation in power system,” *IEEJ Trans. Power Energy*, vol. 132, no. 7, pp. 615–622, 2012.
[20] N. Gökmen, W. Hu, and Z. Chen, “A simple PV inverter power factor control method based on solar irradiance variation,” in *2017 IEEE Manchester Power Tech*, Manchester, UK, June 18–22, 2017, pages 1–6.
[21] P. Chirapongsananurak and N. Hoonchareon, “Grid code for PV integration in distribution circuits considering overvoltage and voltage variation,” in *TENCON 2017, 2017 IEEE Region 10 Conference*, Penang, Malaysia, November 5–8, 2017, pp. 1936–1941.
[22] J. W. Smith, W. Sunderman, R. Dugan and B. Seal, “Smart inverter volt/var control functions for high penetration of PV on distribution systems,” in *2011 IEEE/PES Power Systems Conference and Exposition*, Phoenix, AZ, USA, March 20–23, 2011, pp. 1–6.
[23] P. Jahangiriand and D. C. Aliprantis, “Distributed Volt/VAr control by PV inverters,” *IEEE Trans. Power Syst.,* vol. 28, no. 3, pp. 3429–3439, 2013.
[24] I. Abdelmotteleb, T. Gómez, and J. P. Chaves-Avila, “Benefits of PV inverter volt-var control on distribution network operation,” in *2017 IEEE Manchester PowerTech*, Manchester, UK, June 18–22, 2017, pages 1–6.
[25] M. Juamperez, G. Yang, and S. B. Kjær, “Voltage regulation in LV grids by coordinated volt-var control strategies,” *J. Mod. Power Syst. Clean Energy*, vol. 2, no. 4, pp. 319–328, 2014.