DISTRIBUTION NETWORK PERFORMANCE ANALYSIS: BY INTEGRATING PHOTOVOLTAIC, WIND, ELECTRIC VEHICLE GENERATORS AND STORAGE

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Abstract. Energy is the foundation of a developing economy. In general, new energies provide a discontinuous flow of energy. For this reason, it is very difficult to match supply and demand according to production and consumption rates. Renewable energy sources, as useful as they are, require a backup energy storage system to store energy for times when the sun is not shining or the wind is not blowing. Unlike fossil or nuclear fuels, the amount and timing of renewable energy inputs are often beyond human control. Energy storage is one of the most important known human technologies for meeting needs. Pay special attention to the issue of energy storage. In this paper, to investigate the effect of renewable energy sources in evaluating the reliability of electricity distribution networks first, Quasi-Dynamic analysis was performed on the studied system. In this simulation, first, the characteristics of some elements are presented in the form of a table and then the simulation results for a group of other elements are expressed graphically. Transient stability for single-phase fault modes has been investigated for the batteries contained in DIgSILENT and electric vehicles. Also, harmonic analysis was performed on the PCC bus in the presence of three solar, wind, and electric generators. Finally, an EV collector battery model is designed. DIgSILENT Power Factory is used to perform the simulation analysis.

Keywords: Vehicle-to-grid, Integration of solar and wind system, DIgSILENT, Storage battery.

چکیده: انرژی زیربنای اقتصاد در حال توسعه است. به طور کلی، انرژی‌های جدید یک جریان ناپیوسته انرژی را فراهم می‌کنند. به همین دلیل تطبیق عرضه و تقاضا با توجه به میزان تولید و مصرف بسیار مشکل است. منابع انرژی تجدیدپذیر، به همان اندازه که مفید هستند، به یک سیستم ذخیره انرژی پشتیبان نیاز دارند تا انرژی را برای مواقعی که خورشید نمی‌تابد و یا باد نمی‌وزد، ذخیره کند. برخلاف سوخت‌های فسیلی یا هسته‌ای، مقدار و زمان‌بندی انرژی‌های تجدیدپذیر غالباً خارج از کنترل انسان است. ذخیره انرژی یکی از مهم‌ترین فناوری‌های شناخته شده بشر برای رفع نیازها است و باید به این موضوع توجه ویژه‌ای بشود. در این مقاله به منظور بررسی تاثیر منابع انرژی تجدیدپذیر در ارزیابی قابلیت اطمینان شبکه‌های توزیع، ابتدا تحلیل شبه دینامیکی بر روی سیستم مورد مطالعه انجام شده است. در این شبیه‌سازی ابتدا ویژگی‌های برخی از عناصر در قالب جدول ارائه شده و سپس نتایج شبیه‌سازی برای گروهی از عناصر دیگر به صورت گرافیکی بیان شده است پایداری گذرا برای خطای تک فاز در باتری‌های موجود در DIgSILENT و وسایل نقلیه الکتریکی بررسی شده است. همچنین آنالیز هارمونیک بر روی باس PCC با حضور سه ژنراتور خورشیدی، بادی و الکتریکی انجام شده است و در نهایت یک مدل باتری کلکتور EV طراحی شده است. برای انجام تحلیل شبیه‌سازی از DIgSILENT Power Factory استفاده شده است.

کلمات کلیدی: وسیله نقلیه به شبکه، ادغام سیستم خورشیدی و بادی، DIgSILENT، باتری ذخیره سازی.

1- Introduction

Iran's geographical location has provided unique conditions for the production of new energy. 300 sunny days in the country, having 5 hours of sunshine a day, and the windy weather of many southern cities are an important capacity in the development of new energy compared to large European countries. In our dear country Iran, the share of types of renewable power plants until December 2021 is 904/07 MW Of this number, solar energy is about 5.455 MW, which is 38.50%, and wind energy is 2.310 MW, which is about 21.34% of the share of renewable energy. Saving fossil fuel consumption on this date is reported 2092 million square meters of natural gas and non-emission of CO_2 greenhouse gas 5.49 thousand tons [1].

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Due to its geographical location, Iran has a large capacity in the field of new energy such as solar and wind but unfortunately, seasonal decisions and managerial changes cause insecurity in investing. Therefore, energy storage is one of the most important known human technologies for meeting these needs. Among the study sources in this article, Reference [2], has used a hybrid vehicle to adjust the frequency in the system including the battery and the electric vehicle, and has also investigated the controller of the electric vehicle to the network. Reference [3] examines vehicle charge control in the network. A collector is proposed for vehicle-to-grid (V2G) frequency tuning for grid-scale power generation. Finally, it shows the optimality of the proposed method. In the Danish power system [4], it uses electric vehicles (as a battery storage system) and wind. It has been stated that V2G is much cheaper than public generators.

In [5], hybrid electric motor plugins were examined in the smart grid. The obtained results indicate that the penetration level of hybrid vehicles will continuously increase to 30% by 2030. Reference [6], the integration of plug-in hybrid electric vehicles into the network to save battery costs has been done in MATLAB software. Since MATLAB is not able to "manage a large number of calculations". To save calculation time, the Monte Carlo simulation method has been introduced. In [7] the distribution system, unbalanced charging of electric vehicles has been investigated. [7] believes that in the future, electric vehicles will be charged in residential houses due to the increase in their number, and this will bring load imbalance in the system. In [8], energy management of electric vehicles has been researched on transient voltage stability. [9] considered electric vehicle batteries as energy storage units for the grid and discussed the economic benefits of using these batteries. In [10], hybrid vehicles are integrated into distribution networks. Furthermore, it recommends using renewable energies to improve voltage levels, including wind. [11] analyzed the extensive control structure for an advanced smart home with a microgrid that includes renewable energy sources, a battery, and an electric vehicle.

Reference [12], Introduces a framework for running an electric vehicle on the grid. A hybrid system including electric vehicles and wind has been added to the grid. DIgSILENT software is used to simulate a hybrid system that includes an electric vehicle in storage mode with a wind system [13]. A hybrid system that includes a battery and photovoltaic energy storage system is used for electric vehicle charging stations [14]. [15] has proposed a control system for voltage regulation in poorly distributed high-voltage photovoltaic distribution systems. This system includes a photovoltaic and an energy storage system simulated with MATLAB software. [16] has investigated the effect of distributed generation sources and electric vehicles on the voltage supply and states that distributed generation sources provide more power to the system, which can increase current and voltage supply when demand is low. Reference [17] has designed a system including photovoltaic generators, wind turbines, diesel generators, and battery energy storage systems in order to optimize shared capacity.

In [18] a system including a photovoltaic generator and V2G of electric vehicles in the parking lot has been designed for EV charging. Reference [19], wind and solar generators and electric vehicles have been added to the distribution network and it has been shown that these three generators can be good complements to each other. The reliability and consistency of the transient stability in the network have been investigated in different faults.

In the second part of the paper, system modeling is explained. The mathematical equations are presented in the third section. The fourth part is system modeling and simulation analysis, the fifth part is simulation and finally conclusions and references are given.

2- System Modeling

A simplified distribution network is used as a test case for simulations. The system under study is a 110 kW distribution network including a wind turbine, solar system, load, two electric vehicles, and battery storage. The installed capacities of the solar system and wind turbine are 15 MW. In this system, two generators each with a capacity of 1 MW and a 90 MW battery are used.

3-Mathematic equations

3-1-EV collector battery model

Figure 1 shows the designed battery. Thevenin's model shown in the figure, consists of a parallel RC network with an ideal voltage source in series with internal resistance.

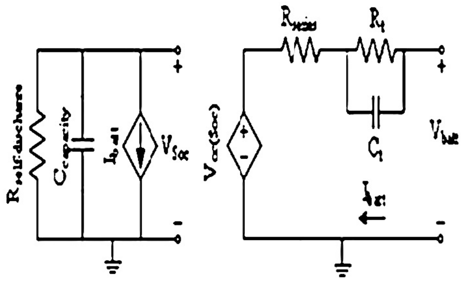


Fig. 1. Electric battery model [3]

Lithium-ion batteries are used in systems including renewable energies and electric vehicles due to features such as high power, high energy density, and high voltage, less pollution, no memory effect, "less self-discharge" and longer life. Also, a Lithium-ion battery is used in this project. The status of battery charge (SOC) can be estimated in real-time using a variety of methods.

The Ampere-Hour Integral Method counting technique is the most common technique for calculating SOC [20]. The status of battery charge (SOC) is determined using Coulomb counting in this project. An input and output current are measured with Coulomb counting to determine the SOC. In this case, by integrating the current over time (in charging or discharging mode), it is added or subtracted from the initial charge CR(t), and finally, the final SOC is obtained as shown in figures (1-6).

The amp-hour integral method requires a knowledge of the battery's maximum capacity in order to measure its current accurately. According to equation (1), the amp-hour integral method can be calculated using equation (1).

$$CR\left(t+1\right)=CR\left(t\right)+\int i\left(t\right).dt \tag{1}$$

$$\text{SOC}=\text{SOC}\left(0\right)-\int\frac{I\left(t\right)dt}{Q} \tag{2}$$

A battery's load current is I(t), its maximum capacity is Q, and its state of charge is SOC(0).

$$P=I*V_{batt} \tag{3}$$

$$V_{batt}=V_{oc}\left(SOC\right)+V_{transient}+V_{series} \tag{4}$$

$$V_{series}=R_{series}I_{batt} \tag{5}$$

$$OCV\left(t\right)=a*SOC\left(t\right)+b \tag{6}$$

Open circuit voltage (OCV) and SOC of lead-acid batteries are approximately linearly related. The values of "a" and "b" parameters can be found experimentally during battery charging when fully charged SOC=100% and when fully discharged SOC=0%. "b" is the battery terminal voltage when SOC=0% [21-22]. Battery energy is given by (7).

$$EC = \int_0^t V(i, SOC)\, i(t)\, dt \tag{7}$$

4-System modeling and simulation analysis

4-1-Electric vehicle

In Figure 2, the EV has four slots, a PLL, a PQ measuring block, an EV controller block, and a power controller block [13].

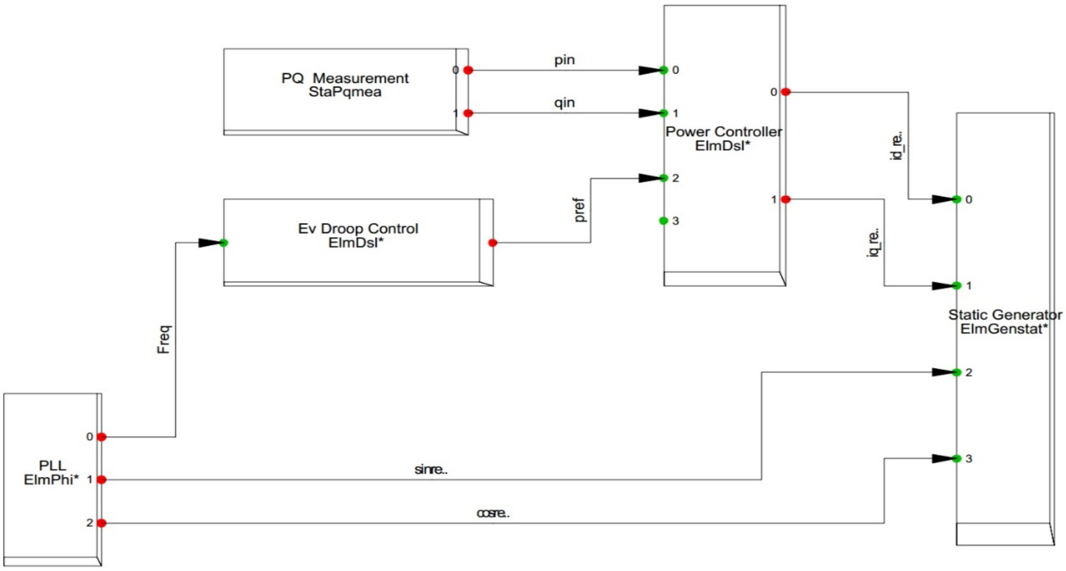


Fig.2. Static generator control block diagram used to simulate electric vehicle.

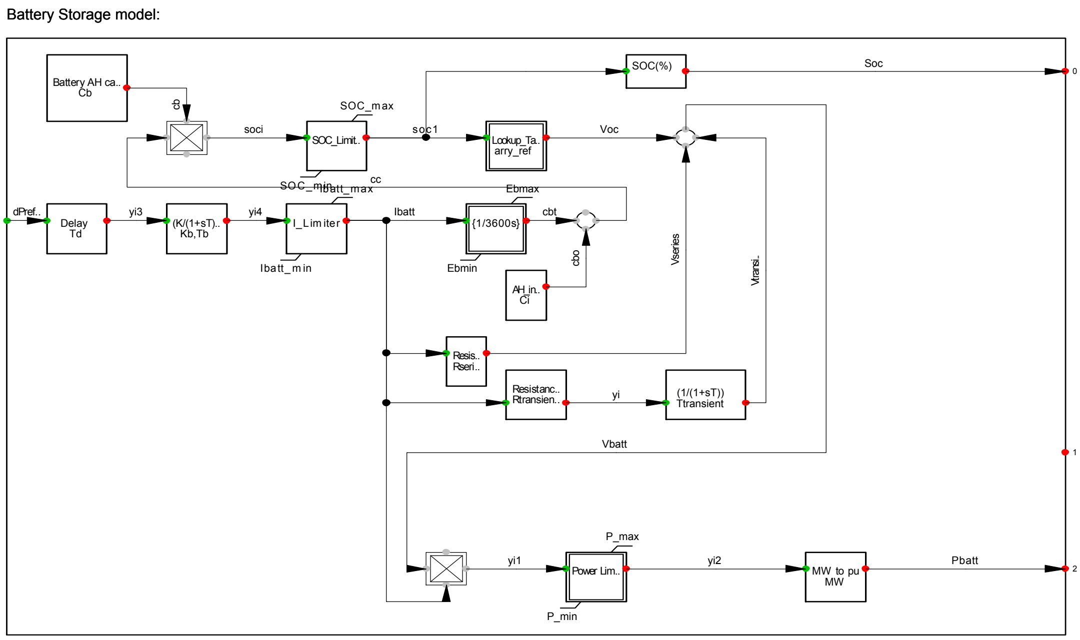


Fig.3. EV collector battery diagram block [3]

4-2-Battery

The battery designed in Figure 3 is a 90MW or 360MW/h battery that charges in 4 hours. The battery has one "dPrefb" input and two "SOC" and "Pbatt" outputs. The "dPrefb" input signal enters the battery with a delay, and this delay is the wireless connection between the electric vehicle and the collector, which is less than 2 seconds. This delay value passes through a controller block and a current is generated inside the battery. This current is multiplied by resistance and a voltage is obtained. To obtain SOC, the amount of ampere-hours is obtained from the battery current, and this value is added to the initial ampere-hour value. Lastly, the value obtained is multiplied by the battery-hour ampere to obtain SOC. This amount enters electric vehicles. Then all the voltages are added together and the battery voltage is obtained. This battery is connected to a load, which is the load of an electric vehicle.

5- Simulation

5-1- Quasi-dynamic analysis

Quasi-dynamic analysis allows us to examine the behavior of a power system at a specific time interval and at specific time steps that are determined. As part of the study, we added two solar and wind generators, an electric vehicle and a battery to the grid in order to perform a quasi-dynamic analysis. Tables I and II present a text report after applying quasi-dynamic analysis to the studied system.

5-1-1-Voltage Ranges

In Table I, LV, LV (1), LV (2), LV (3) are the bus bars to which the generators of photovoltaic, wind, battery and electric vehicles are connected, respectively. The main network is connected to bus bar B1.

Table 1. Voltage ranges quasi-dynamic simulation report

Terminal	LV(1)	B1	LV	LV(2)	LV(3)
Voltage Max. [p.u.]	1.04	1.04	1.04	0.00	0.00
Time Point Max	2022.03.01 00:00	2022.03.01 00:00	2022.03.01 00:00	2022.03.01 00:00	2022.03.01 00:00
Voltage Min. [p.u.]	1.02	1.03	1.02	0.00	0.00
Time Point Min	2022.03.01 20:00	2022.03.01 20:00	2022.03.01 20:00	2022.03.01 00:00	2022.03.01 00:00

5-1-2- Loading Ranges

In Table II, "winding transformer" is a transformer that connects a wind turbine to the grid. MV-K3 is a transmission line. Winding transformer (1) is a transformer that connects a photovoltaic generator to the grid. NT1 is a transformer that connects to the bus bar that is connected to the main network. Winding transformer (2) is the transformer that connects the battery to the grid. Winding transformer (3) is a transformer that an electric vehicle is connected to the grid.

Tabe1 2. Loading Ranges Quasi-Dynamic Simulation Report

Elements	PV Generator	EV	Winding Trans. (2)	Battery	Winding Trans. (3)	Winding Trans.	MV-K3	Winding Trans. (1)	NT1	WTG
Max. Loading [%]	62.5	90	40.01987	76.5	48.2	543.5	78.2	689.8097	30.67	66.6
Time Point Max	2022.03.01 14:00:00	2022.03.06 16:00:00	2022.03.06 14:00:00	2022.03.02 16:00:00	2022.03.06 20:00:00	2022.03.02 10:00:00	2022.03.03 10:00:00	2022.03.06 14:00:00	2022.03.05 10:00:00	2022.03.04 10:00:00
Min. Loading [%]	0.0	90	23.66945	45	46.7	0.1611616	5.01	0.1590999	2.36	0.0
Time Point Min	2022.03.01 00:00:00	2022.03.04 22:00:00	2022.03.05 00:00:00	2022.03.03 22:00:00	2022.03.05 16:00:00	2022.03.02 04:00:00	2022.03.04 04:00:00	2022.03.05 20:00:00	2022.03.04 04:00:00	2022.03.01 04:00:00

5-1-3-Network losses in the presence of Ev

As shown in Figures 4 and 5, an electric vehicle results in a network loss of 0.096 MW and reactive power losses of 0.671 MVAr. If the battery is in the network, this value will be equal to 0.098 MW and 0.658 MVAr.

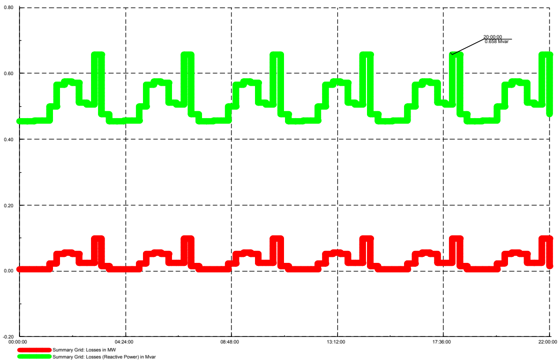


Fig.4. Network losses in the presence of battery

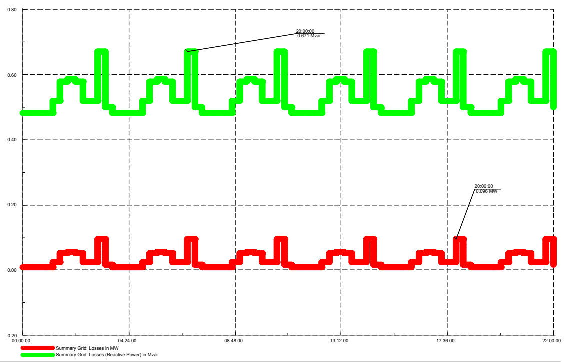


Fig. 5. Network loss in the presence of electric vehicle

5-1-4- Network voltage in the presence of Ev

In Figures 6 and 7, the grid maximum voltage reaches 1.044 p.u. when there is an electric vehicle present, but 1.042 p.u. when there is a battery present.

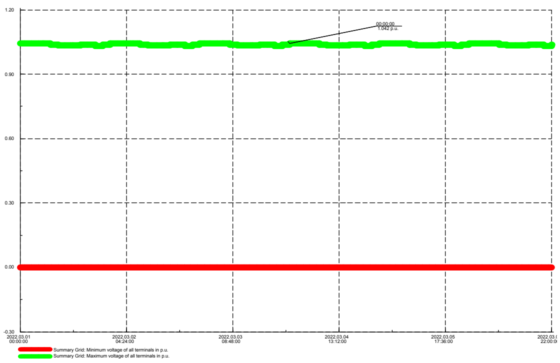


Fig. 6. Network voltage with battery

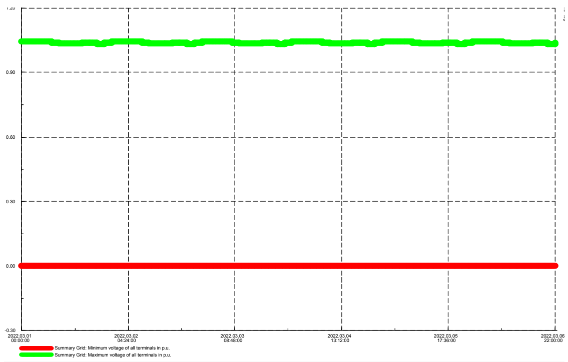


Fig. 7. Network voltage with the presence of the electric vehicle

5-1-5- Network losses in the presence of PV and wind generators

Figures 8 and 9 show that the maximum active power loss resulting from PV and wind generators is 1.182 MW and 9.339 MVAr, respectively. Moreover, the maximum active power loss of the network without PV and wind generators is 0.082 MW, and for reactive power, the maximum is 0.638 MVAr and the minimum is 0.447 MVAr.

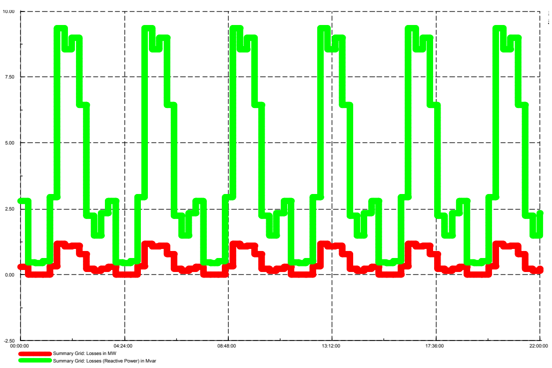


Fig. 8. Loss of the network in the presence of PV and wind generators

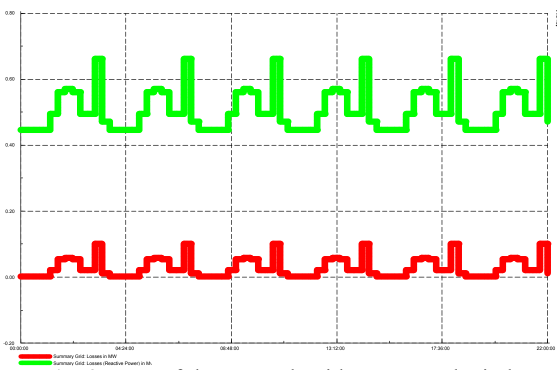


Fig. 9. Loss of the network without PV and wind generators

5-1-6-Network voltage in the presence of PV and wind

In Figures 10 and 11, the mains voltage reaches 1.358 p.u. with PV and wind present. This will amount to 1.041 p.u., if these two generators are not present in the network.

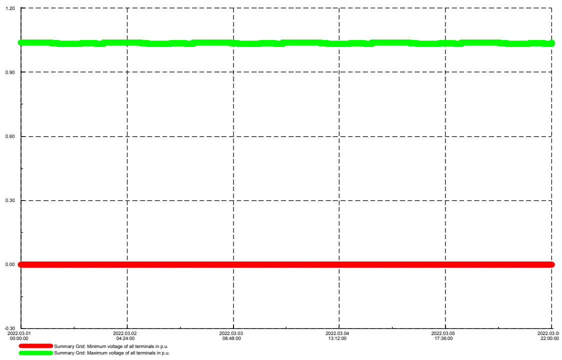


Fig. 10. Voltage without the presence of PV and wind

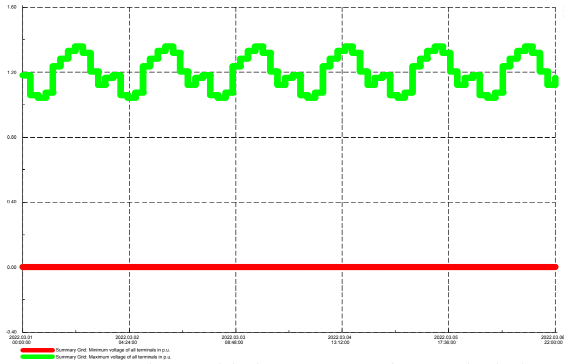
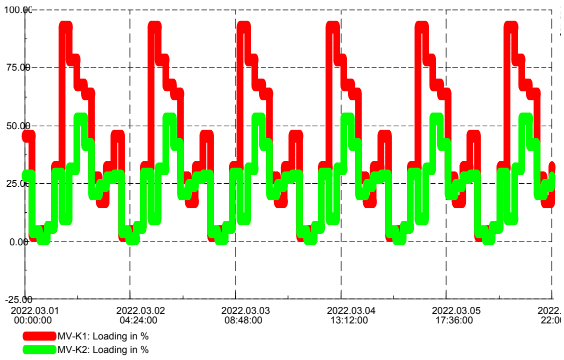


Fig. 11. Voltage with the presence of PV and wind

5-1-7- Loading MV-K1 and MV-K2 (transmission lines) and busbar voltage of Airport and West in the presence of PV and Wind

Figures 12 and 13 illustrate the MV-K1 and MV-K2 transmission lines that connect the wind generator and solar generator to the grid. The airport bus bar is connected to the wind generator and the West bus bar is connected to the solar generator. Throughout this section, loading and voltage were compared with and without wind and solar generators. In the presence of PV and Wind, the maximum loading of MV-K1 and MV-K2 are equal to 92.763% and 53.455%, respectively. Furthermore, in this case, the maximum voltages at the Airport and West are 1.062 p.u. and 1.064 p.u., respectively.



Fig, 12. Loading MV-K1 and MV-K2 (transmission lines) in the presence of PV and Wind

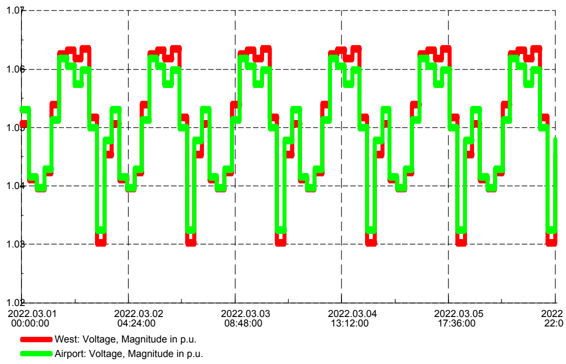


Fig. 13. Voltage of Airport and West in the presence of PV and Wind

5-1-8- Loading MV-K1 and MV-K2 (transmission lines) and busbar voltage of Airport and West Without the presence of PV and Wind

MV-K1 and MV-K2 have maximum loading values of 41.609% and 5.492%, respectively, and Airport and West have maximum voltages of 1.040 p.u., based on Figures 14 and 15.

5-2-Comparison between the battery and the Electric Vehicles

A fault is applied to the MV-K1 line connected to the PCC bus at t = 0.3 S and lost at t = 0.4 S in this section. The RMS simulation has been done at t = 10 S. Electric vehicle and battery performance were examined as a result of this fault. The frequency deviations of electric vehicles are tracked more closely than those of batteries. This is illustrated in Figures 16 and 17.

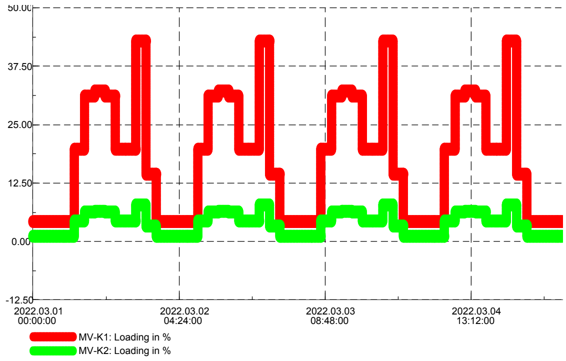


Fig. 14. Loading MV-K1 and MV-K2 without the presence of PV and Wind

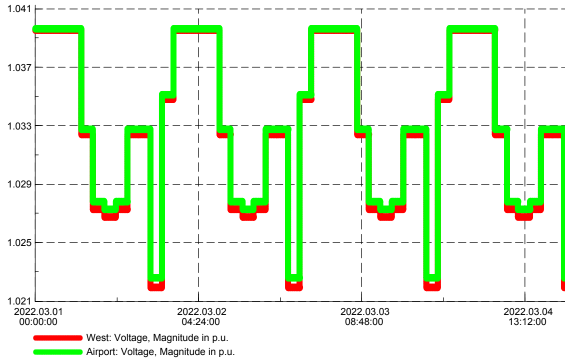


Fig. 15. Busbar voltage of Airport and West Without the presence of PV and Wind

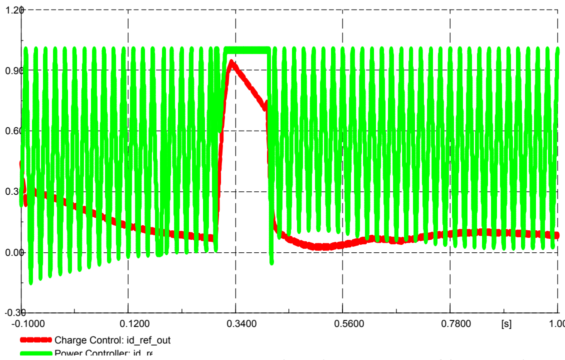


Fig. 16. Output current and active power of battery in single-phase fault mode at t=10s

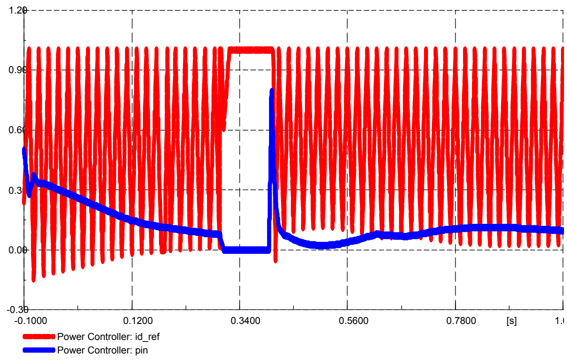


Fig. 17. Output current and active power of EV in single-phase fault mode at t=10s

5-3-Analysis of harmonics in PCC bus

One of the factors that contribute to harmonic production is the connection of solar and wind power plants to distribution systems. As a result of connecting the car, wind and solar generators at the PCC point, the network THD decreased from 2.004188% to 2.000392%. The HD value in harmonics 13 and later is reduced when all three generators are connected, as shown in Figure 18.

5-4-Battery

In this section, electric vehicles [23-26] are considered a load. Power is provided for the connected load by renewable sources that charge the designed battery. The battery is charged in figure 19.

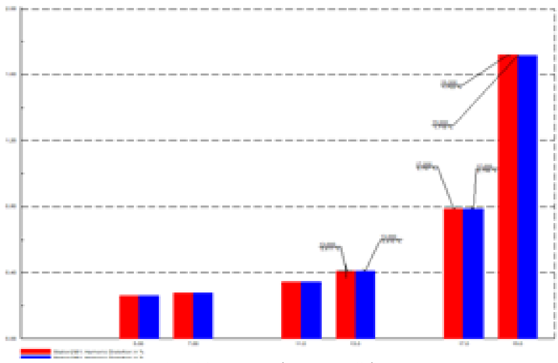


Fig. 18. HD value on PC bus

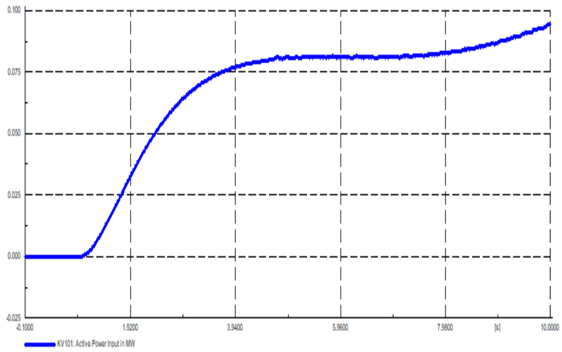


Fig. 19. Active load power connected to the battery

6- Conclusion

- Since renewable resources are variable, combining them can eliminate this problem.
- A hybrid system is the best way to overcome the periodicity of renewables given the growing energy demand and limited fossil fuel reserves.
- Compared to conventional generators, vehicle-to-grid systems provide faster and more reliable frequency control.
- Wind and solar power plants can be combined to increase energy production, and fluctuations from these sources can be eliminated when used alone by combining them with batteries.
- In addition to their many advantages, renewable energy sources cause changes in load flow, short circuit current level, harmonics, protection equipment, voltage level, transient stability, etc.
- In the Quasi-Dynamic simulation, renewable sources and batteries increase grid reliability.

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