# The Impact of Electric Vehicles on Voltage Symmetry

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*Abstract* — **Voltage asymmetry is one of the indicators by which the quality of electric energy in three-phase electric networks with a voltage of 0.4 kV is evaluated. According to these standards, the voltage asymmetry coefficient in the zero sequence should not exceed 2%. With the proliferation of electric vehicles, the load increases significantly, which is a variable, depending on the time of day and season, due to which voltage asymmetry may occur during operation. In this paper, we simulate a real network with a gradual increase in the number of connected electric vehicles, as well as a possible solution to the problem of asymmetry.**

*Keywords* — **Smart Grid, computer simulation, quality of electric energy, electric cars.**

## I. Smart Grid Concept

Smart Grids are an automated system that independently monitors and distributes electricity flows to achieve maximum energy efficiency. The concept of smart grids focuses not on the modernization of certain technologies and equipment, but on the revision of the principles of development and creation of new, innovative technical equipment for the power industry. It should provide a much more complete satisfaction of the requirements of consumers and other stakeholders through a significant change in the physical and technological characteristics and functional properties of all components of the energy system [1].

- Measuring instruments and devices for storing information, including in particular smart meters and smart sensors.
- Improved control methods: distributed intelligent control systems and analytical tools to support communication at the level of real-time energy system objects, enabling the implementation of new algorithms and techniques for controlling the energy system, including the control of its active elements.
- Advanced power grid technologies and components: Flexible alternative power transmission systems (FACTS), DC transmission, superconducting cables, microgrids, semiconductor power electronics, power storage, etc.
- Improved interface and methods of adopted solutions - technologies and tools that enable the transformation of data obtained from various network objects into information for decision-making.

Integrated communications that allow the elements of the first four groups to ensure interconnection and interaction, which is in fact an intelligent network as a technological system. In recent years, there has been a clear trend towards electrification in the automotive industry. Virtually all global manufacturers plan to release new cars that will be driven by electrical power plants. Moreover, according to numerous experts, electric cars have a future. That is, in the coming years, more and more cars with zero emissions of harmful substances will begin to appear on the roads, which, according to predictions and forecasts, should eventually completely force out classic cars [2].

According to Wood Mackenzie, about 3.3% of sales of new passenger cars in China accounted for “clean” electric cars in 2018, compared to 0.7% in 2015 [3]. According to the international consulting company Frost & Sullivan, in 2018 two million electric vehicles were sold worldwide, and by 2025 their sales will increase to 25 million, which is expected to be 20 22% of all cars [4]. In March 2019, analysts at

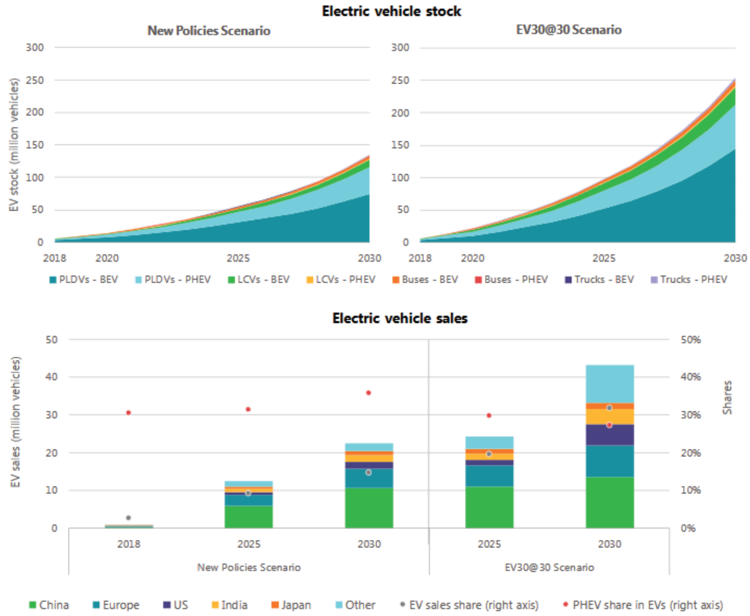

Fig. 1. Future global EV stock and sales by scenario, 2018-30 [5]

Bloomberg New Energy Finance provided data that in 2018 around 1.3 million all-electric cars were sold worldwide (excluding hybrids), and 60% of the volume fell on the Chinese market. According to Bloomberg New Energy Finance, by 2025 almost half of all buses in the world will be electric. The leader in this regard is China. He will have 99% of electric buses. One of the first cities where all buses are electric was Chinese Shenzhen - this is about 16.3 thousand urban electric buses [6].

## II. Effect of Voltage Unbalance

One of the reasons for the deterioration in the quality of electric energy is the asymmetry of voltages in the electric network [4]. If the three-phase voltage has the same magnitude and is in a phase shift of 120 °, then the three-phase voltage is called symmetrical. If the symmetry of the multiphase system is violated, the latter can be decomposed into three symmetric components — the direct sequence system, the inverse, and zero sequence systems superimposed on it [7]. As a rule, a three-phase voltage balance is an ideal situation for a power system. However, single-phase loads, unbalanced three-phase equipment and devices, poor connections to electrical connectors and many other factors cause voltage unbalance in the power system and reduce the quality of electricity. Thus, voltage asymmetry is one of the urgent problems of electric power systems.

In addition to the above, the cause of voltage unbalance can be emergencies in networks, such as asymmetric short circuits or phase failure [8]. Consider the main consequences of stress asymmetry.

1. Additional power loss. Voltage asymmetry always causes additional power loss in the power system. The higher the voltage unbalance coefficient, the greater the power dissipation. This ultimately leads to increased costs when paying for electricity [9], heating the motor windings, which can lead to the destruction of their insulation.
2. Decrease in equipment life cycle. High temperatures exceeding the nominal values for devices significantly reduce the service life of these devices and accelerate the cycle of their replacement, which significantly increases the cost of operation and maintenance of the equipment.
3. The effect on the operation of the relay. High zero sequence current resulting from voltage unbalance can lead to disturbance of the relay or reduce the sensitivity of the ground relay. This can lead to serious problems in terms of security of the power system.
4. Inaccurate measurements. The reverse and zero sequence of voltages or currents lead to inaccurate measurements in many types of measuring instruments. The inaccuracy of the measured values may affect the suitability of the settings and the coordination

of relay protection systems, the correctness of the decisions of some automatic functions of the system.

5. Influence on the operation of the transformer. Three-phase voltage with a high coefficient of voltage unbalance can lead to the fact that the flow inside the core of the transformer is asymmetric. This unbalanced flux will cause additional magnetic losses in the core, an increase in the temperature of the windings and may even damage the transformer.

In general, the consequences of voltage asymmetry in power systems are wide and serious. Voltage asymmetry can significantly shorten the life cycle of equipment, speed up its replacement and increase the cost of operating and maintaining the system. To eliminate non-random voltage asymmetry in the power system, it is necessary to develop a uniform load connection scheme even in the early stages of design. In this case, it is necessary to take into account their capacities and work schedules. Now, many electric cars are powered through 1 or 2 phases. Cars that are powered through 3 phases are extremely small. In addition, with an increase in the number of phases, the cost of charging also increases, which leads to the fact that consumers will prefer more affordable solutions [7]. Table 1 shows the charging parameters of various electric vehicles using various charging solutions [9].

Table 1
Supported charging options for electric vehicles [9].

| Parametrs | Volkswagen e-Up | Skoda CITIGOe IV | Nissan Leaf | Hyundai Kona Electric | Citroen C-Zero |
|---|---|---|---|---|---|
| Battery Useable, kWh | 32.3 | 32.3 | 36 | 39.2 | 14.5 |
| 3-phase 16A (11 kW) | 7.2 | 7.2 | 3.7 | 11 | 3.7 |
| 3-phase 32A (22 kW) | 7.2 | 7.2 | 6.6 | 11 | 3.7 |
| 3-phase 16A (11 kW), A | 2x16 | 2x16 | 1x16 | 3x16 | 1x16A |
| 3-phase 32A (22 kW), A | 2x16 | 2x16 | 1x29 | 3x16 | 1x16A |
| CCS (50 kW DC), kW | 30 | 30 | 46 | 35 | 30 |

## III. ELECTRIC NETWORK MODEL

Modeling is a very effective process of testing theoretical knowledge and the most accurate design in practice [10]. To study the effect of charges on the distribution system, a model was created on data from a classical village, where we know the load, approximate distances and types of power lines, and parameters of transformers. To create a model of the electric network, the parameters of real equipment were used [11]. The model was created using the Python programming language. Approximate distribution scheme of the village can be seen in Figure 2.

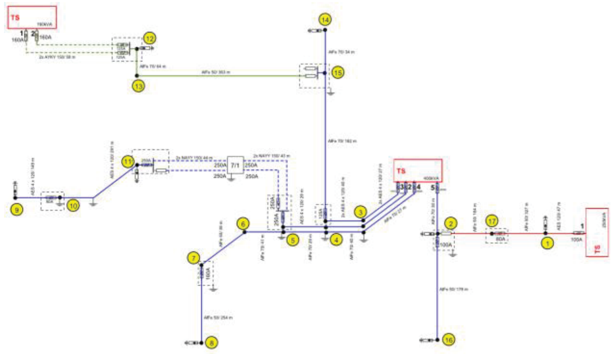

Fig. 2. Schematic single-line diagram of a distributed network of a village

To create a load model, an annual load schedule for each house was used. In Fig 3. You can see the total load curve of the whole village. Loads are represented mainly by private small houses.

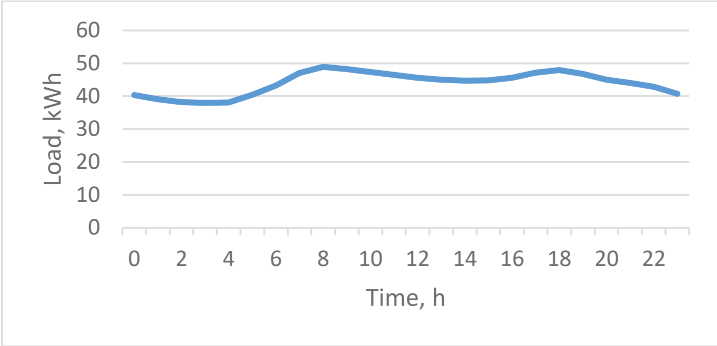


Fig. 3. Annual load schedule

To create a model of the charging station, the parameters of the charging station from Schneider Electric were used: the most affordable EVlink Wallbox Plus - T2 socket outlet - 1 phase - 16A/3.7kW (fig.4) [12] with the declared power of 3.7 kW (single-phase solution). To calculate the duration of charging, an Nissan Leaf electric car was used. The declared battery capacity of this car is 24 kWh [13]. It takes about 7 hours to fully charge this car. The model of the charging station is a load that is included in the given time intervals. For the time the machine was turned on for charging, three periods were selected at 17:00, 19:30, and 22:00. The timing and connection point are made randomly. The number of connected machines increases in increments of 5% of the total number of network loads.

Fig. 4. Charge for electric vehicle (EVlink Wallbox Plus) selected for modeling [12]

## IV. Simulation Results

As part of the simulation, a smooth increase in the number of connected electric vehicles was carried out. The increment was 5%, as can be seen in graph 5, the maximum current in the network increases with an increase in the number of electric vehicles. When connecting 35% of the total number of consumers, the maximum current value exceeded the permissible value for the cable. Thus, modern networks can only allow electric cars to have 35% of consumers.

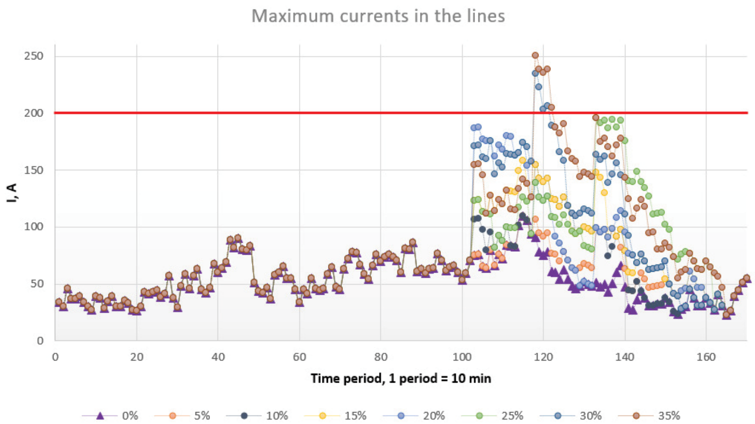


Fig. 5. Graph of maximum currents in the network.

Since the model is three-phase, it is possible to calculate the asymmetry coefficient of the voltage in the network. Since the time it takes to connect an electric vehicle to charge can be different, as well as the charging time (by how many percent the battery was discharged per day), the effect of asymmetry is manifested even when the charges are evenly distributed over the phases [14]. To control the voltage asymmetry in three-phase systems, we used the voltage asymmetry coefficient in the reverse sequence $K_{2U}$ and the voltage asymmetry coefficient in the zero sequence $K_{0U}$. The voltage asymmetry coefficient in the reverse sequence is [11]:

$$Ku = (U_{2\,(1)} / U_{1(1)}) \cdot 100 \tag{1}$$

Where $U_{2\,(1)}$ - is the effective value of the voltage of the reverse sequence of the fundamental frequency of the three-phase voltage system, V; $U_{1\,(1)}$ - is the effective value of the voltage of the direct sequence of the fundamental frequency, V.
The calculation of asymmetry parameters was carried out for the most difficult mode, that is, when the number of electric vehicles was 35% of the total number of consumers. You can see the results of the calculations on graphs 6 7 8. The phase selection algorithm for the connection has the following steps [15]:

1) Phase current load measurement;
2) Measurement of the asymmetry coefficient;
3) Selection of the least loaded phase;
4) Check the asymmetry coefficient whether the phase is selected correctly;
5) Load connection.

As can be seen in Figure 8, a simple algorithm for selecting the phase for the connection significantly reduced the voltage unbalance coefficient.

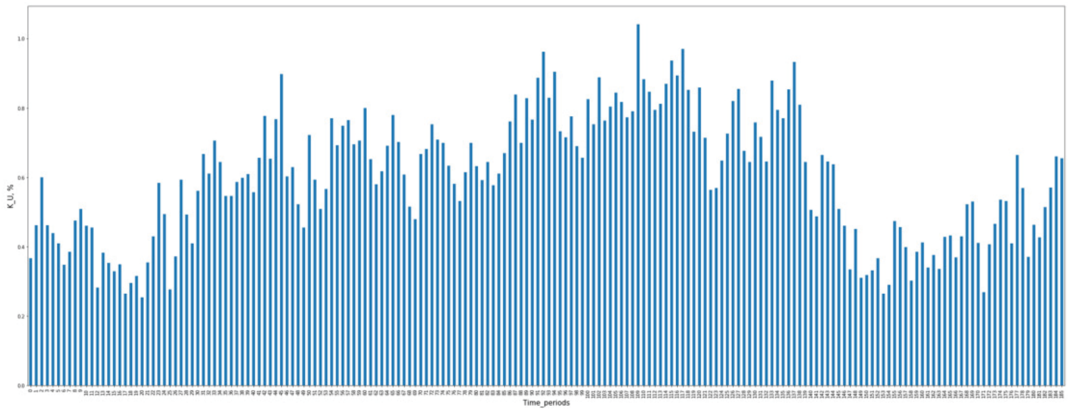

Fig. 6. Asymmetry factor for a network without the use of electric vehicles.

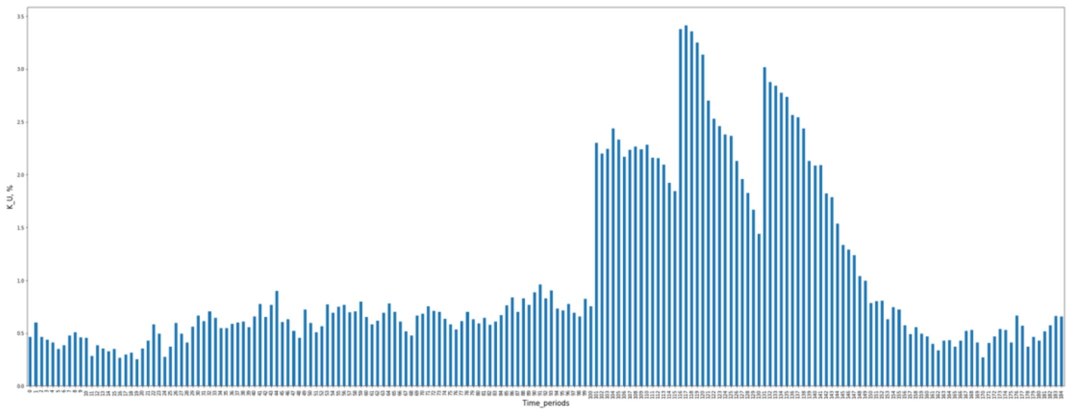

Fig. 7. Asymmetry factor for a network with the use of electric vehicles.

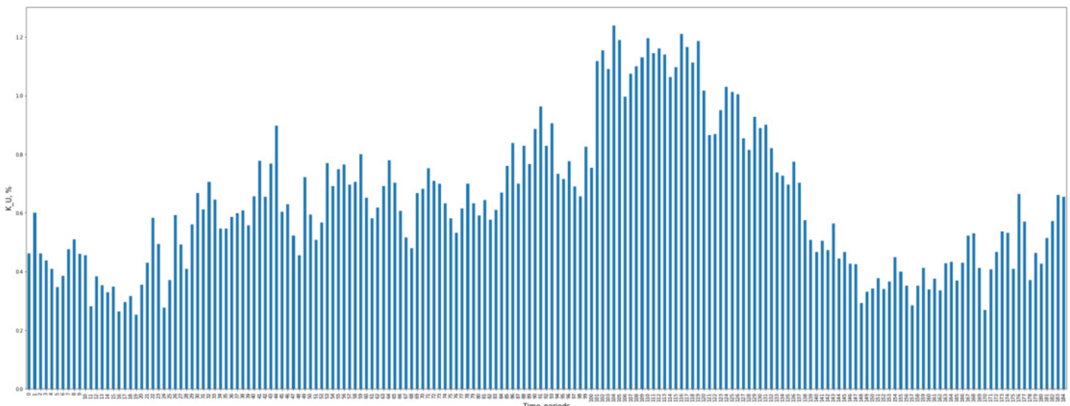

Fig. 8. Asymmetry factor for a network with the use of electric vehicles using the phase distribution algorithm.

## V. CONCLUSION

An increase in the number of modern smart elements does not always positively affect the parameters of the electric network, as well as the quality of electric energy. So the increase in the number of electric cars, creates not only an overload of power lines, but also an increased load on the rest of the equipment, but also worsens the quality of electricity. In this regard, modern networks require an integrated approach to modernization. It is the comprehensive implementation of the Smart Grid concept that will allow avoiding the deterioration of the operation of electric networks, increase reliability, and for network companies will avoid unforeseen additional costs.

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