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Analysis of the problems of electrical network operation with the wide distribution of electric vehicles

Abstract: This article examines the impact of increased elements of Smart Grid and an increase in the number of electric cars. The increase in the number of these new elements in the network creates problems with such parameters as permissible losses of active power, excess of permissible currents in electric lines, as well as voltage losses in certain sections of the network. This article discusses how to solve these problems by changing the cross-section of wires in power lines.

Keywords: Smart Grid; Electric Vehicle; Power lines cross-section; Microgrid.

I. INTRODUCTION

Smart grids are a modernized power supply network. Smart Grid networks combine comprehensive marketing and control tools, as well as advanced information technologies with communication tools. With their help, it is possible to detect in the automatic mode the most vulnerable, emergent and dangerous parts of the power grid. After that, the network carries out changes in the characteristics and design of the network itself to minimize losses and the risk of emergencies. All this guarantees a high level of performance and the provision of high-quality electrical energy to the consumers. Based on this, it can be concluded that intelligent networks are self-controlling and automatically balancing energy systems that allow the efficient transfer and distribution of energy. Its technical apparatus are digital control systems that solve various problems of artificial intelligence [1].

The emergence and development of the Smart Grid Concept is a natural stage in the formation of an electrical energy system. This is due to the need for the energy market, in which consumers and producers actively interact. This is also due to the availability of technical capabilities to solve these problems (the use of new computers and telecommunication technologies).
Various advanced features define the Smart Grid concept, such as [2]:

- Implementation of two-way interaction through the exchange of data between all existing network elements.
- This system works with each element of the technological chain of production (solar panels, hydroelectric power plants, wind generators, thermal power plants, various energy storage devices, nuclear power plants, etc.) and end-users.
- The use of digital communication in networks makes it possible to exchange information in real-time.
- Each element of the Smart Grid is obliged to be equipped with special technical means providing information interaction.
- This system ensures optimal operation of the power grid.

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 [3].

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 [4].

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 [5].

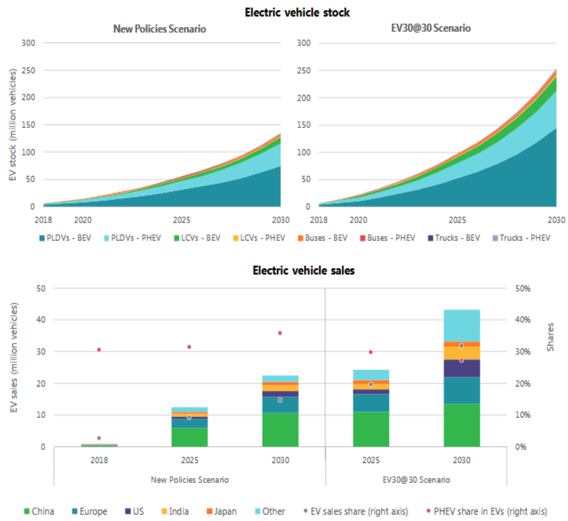

Fig. 1. Future global EV stock and sales by scenario, 2018-30 [3]

In March 2019, analysts at 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 rating is China. It 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. MODELLING MICROGRID

To analyze the influence of new smart elements and electric cars on the electrical network, a model was created. Modeling a small network is an effective method for predicting the impact on an existing network. To create a model, we used mathematical models of new elements that are involved in the creation of a Smart Grid, as well as a mathematical model of an electric vehicle and charging stations. The model is based on data from ordinary village parameters, such as load, distance, and types of power lines. After creating the base model, Smart Grid elements were introduced into it. The number of different elements can be seen in Table I [7].

TABLE I.
The number of elements in the model

Elements	***Numbers***
Line	91
Loads	58
Charging for Electric Vehicles	58
Photovoltaic	58
Transformer	2

1. Loads

The load model is presented by the average value of household electricity consumption. Each place of consumption within the model represents a real home. A small village was selected for analysis, and therefore the number of homes is not very large. The main task of this study is to show the effects of additional equipment.

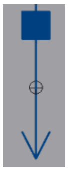

Fig. 2. Load model in the software.

2. Renewable Energy Sources

More and more households are starting to use small alternative sources of energy. The most common and efficient renewable energy source in Slovakia is the sun. That is why solar panels were used to simulate the distributed generation. Based on real data on solar radiation and Parameters of photovoltaic, a model of a photovoltaic was created. Figure 3 shows the appearance of the photovoltaic in the software space.

Fig. 3. Model of PV panels in software.

The parameters of photovoltaic are presented in Table II [8].

TABLE II.
Parameters of photovoltaic [8]

Parameters	***value***
Nominal Max. Power (Pmax	300 W
Opt. Operating Voltage (Vmp)	32,5 V
Opt. Operating Current (Imp)	9,24 A
Open Circuit Voltage (Voc)	39,7 V
Short Circuit Current (Isc)	9,83 A
Module Efficiency	18,33%
Operating Temperature	-40°C ~ +85°C
Max. System Voltage	1000 V
Module Fire Performance	TYPE 1 (UL 1703) or CLASS C (IEC 61730)
Max. Series Fuse Rating	15 A
Application Classification	Class A
Power Tolerance	0 ~ + 5 W

3. Electric car charger

An 11kW charger was used to simulate the charging of electric vehicles. The charging of electric vehicles will significantly affect the distribution system. The number of chargers is identical to the number of loads and is presented in the model as an AC source. The electric vehicle model operates in two modes: load mode and power mode. The mode of operation of the electric vehicle depends on the need of the electrical network manager now, as well as on the level of battery charge in the car. As a prototype electric car was used Nissan Leaf 24kWh [9]. Fully charging this vehicle with the selected charging station takes about 7 hours.

III. NETWORK ANALYSIS

To analyze the electrical grid, several models of operation scenarios were used:

1. Current network status;
2. The scenario considers an increase in the number of electric vehicles;
3. The scenario is considering increasing the number of photovoltaics;
4. The scenario considers increasing the number of electric cars and photovoltaics simultaneously.

To analyze the network status, the following parameters will be considered:

1. Losses of active and reactive power in the network;
2. Line current values;
3. Line voltage losses.

1. Losses of active and reactive power in the network

Power loss in the network is an important indicator of the correctness of the design of the transmission system of electrical energy. According to the norms, power loss in the transmission of electricity should not exceed 5%. In connection with the increase in the number of electric vehicles acting in the role of the consumer and the increase in production on solar panels, the transmitted power also increases. The results of the model calculations can be found in Table III.

TABLE III.
The losses of active power and reactive power in the network

Number of devices	***Charging for Electric Vehicles***		***Photovoltaic***		***Charging for Electric Vehicles with Photovoltaic***	
	Active power loss	***Reactive power loss***	***Active power loss***	***Reactive power loss***	***Active power loss***	***Reactive power loss***
	ΔP, kW	***ΔQ, kVar***	***ΔP, kW***	***ΔQ, kVar***	***ΔP, kW***	***ΔQ, kVar***
0	0,45	2,33	0,45	2,33	0,45	2,33
6	3,05	5,61	0,29	2,13	2,35	4,37
12	9,68	12,53	0,64	2,41	5,65	7,83
17	14,01	17,95	0,74	2,63	11,16	13,11
23	24,59	29,72	1,2	3,17	18,26	20,46
29	37,13	43,33	1,55	3,7	26,65	29,31
35	56,01	63,36	2,34	4,56	35,9	39,9
41	86,14	94,57	3,3	5,64	55,81	59,67
46	115,74	126,41	4,42	6,82	67,88	72,91
52	160,26	170,26	5,66	8,29	93,69	98,17
58	237,94	246,71	6,94	9,85	127,98	132,48

As we see in the figures below, as the number of smart elements increases, power losses in the network increase. In the case of electric vehicles, this is explained by the fact that the amount of energy consumed increases. Since the electric car acts as a load. In the case of solar panels, this phenomenon is caused by so-called reverse power flow. Reverse power flow occurs when the energy in the solar panels is produced more than the local load consumes. As a result, the energy flows in the opposite direction, that is, in a 22 kV network. Reverse power flow is a negative phenomenon and they are trying to avoid it [10].

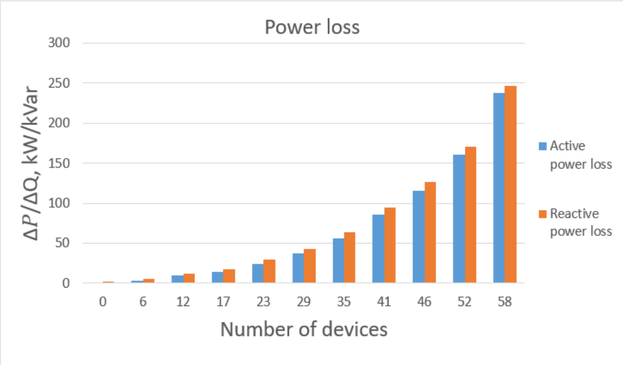

Fig. 4. Changes in active and reactive power loss values in scenario 1.

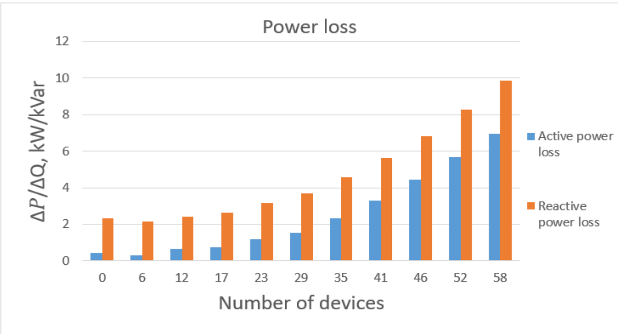

Fig. 5. Change of active and reactive power loss values in scenario 2.

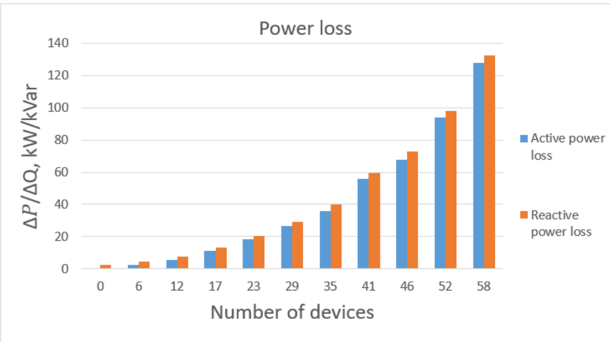

Fig. 6. Change of active and reactive power loss values in scenario 3.

As we see in the graphs, the losses have increased quite strongly. To reduce losses, you can use the following methods [11]:

1. Use of batteries. Charging them in a period of low load or high-energy production on the solar panels;
2. Replacing power lines;
3. Creating a system of management of electrical energy. To charge electric cars during a low load period or in time of excess energy production on solar panels.

2. *Line current values*

Each wire has a permissible current load. With an increase in the transmitted power, the current load in the lines also increases. With the increase of new smart elements increases and the transmitted power increases correspondingly and the value of the currents in the lines. The main increase in the value of currents is observed at the beginning of the lines. I will list the main sites in Table IV.

TABLE IV.
Comparison of currents in lines under different scenarios

Type	***Size, mm***	***Imax, A***	***I_1, A***	***I_2, A***	***I_3, A***	***I_4, A***
ALFe	35	138	7,1	184	29,3	130,7
ALFe	50	168	25,8	505,7	83,2	369,4
ALFe	70	213	19,5	693,9	98,2	470
AYKY	150	278	2,7	92,7	8,8	29,3
NAYY	150	281	4	127,9	21,7	91
NAYY	70	184	5,1	310,1	35,8	172,8
NAYY	50	149	3,3	78,5	12,4	55,9

According to table 4, in several lines in mode 1 and 3 currents flow that exceed the value of permissible, which is not allowed by the technical standards of operation.

3. *Line voltage losses*

Reducing the voltage at the consumer compared with the normal effect on the operation of the current collector, whether power or lighting load. Therefore, when calculating any transmission line, the voltage deviations should not exceed the permissible norms, the networks selected from the load current and calculated for heating, as a rule, are checked for voltage loss [12].

$$\Delta U = ((P \cdot r_0 + Q \cdot x_0) \cdot l) / U_{nom} \qquad (1)$$

Where P is active power (kW), Q is reactive power (kVar), r_0 is line resistance (Ohm / km), x_0 is line inductive resistance (Ohm / km), l is line length (km), U_{nom} is rated voltage (kV).

The results of the calculations of voltage losses are presented in Table V. As the model contains 91 sections of power supply lines, for clarity, the table shows the average value of voltage losses on the elements. According to the norms, the permissible loss value is 10%. In two modes, the loss value exceeded the allowable values.

TABLE V.
Average values of voltage

Mode (model)	***Average voltage***	***Difference with nominal***
	U, V	***U, %***
Current state	395,02	1,24
Charging for Electric Vehicles	274,44	31,39
Photovoltaic	405,17	-1,29
Charging for Electric Vehicles with Photovoltaic	304,65	23,84

IV. SELECTION OF THE OPTIMAL CROSS-SECTION OF LINES

The choice of the cross-section of power lines can be made according to the following parameters [13]:

1. The choice of the cross-section of the line by the allowable operating temperature of the conductor cores;
2. The choice of the cross-section of the line by the permissible current load;
3. The choice of the cross-section of the line by the allowable voltage drop;
4. The choice of the cross-section of the line by economic parameters;
5. The choice of the cross-section of the line by the mechanical strength;
6. The choice of the cross-section of the line depending on the thermal and dynamic effects of short-circuit currents;
7. The choice of the cross-section of the line by the proper protection of contacts.

In this article, the choice of sections will be made according to two criteria:

1. Permissible current load
2. Permissible loss of line voltage.

1. Permissible current load

The choice of line section by the current carrying capacity is based on the allowable operating temperature of the conductor cores, with the result that the impractical temperature calculation is replaced by a more convenient current calculation. Heat removal conditions are expressed using conversion factors. The following definitions are important in size according to the current-carrying capacity. The rated current carrying capacity (I_n) is the maximum allowable current for a given type and conductor or cable cross-section at basic installation and under basic conditions.

The permissible current capacity (I_{per}) is the maximum permissible current for a given type and cross-section of a conductor or cable, under which the specified basic conditions are not met. The allowable current capacity I_{per} is determined by calculating using the conversion factors k_1, k_2 ... k_n according to the equation [13]:

$$I_{per} = k_1 \cdot k_2 \cdot \ldots \cdot k_n \cdot I_n \tag{2}$$

Where k_1 - k_n are coefficients that take into account individual conditions.

According to the formula (2), new sections were selected that satisfy the load currents. For more details, see Table VI.

TABLE VI.
Selection of the section according to the permissible current load

Type	*Size, mm*	*Imax, A*	*Size, mm*	*Imax, A*	*I_1, A*	*I_2, A*	*I_3, A*	*I_4, A*
ALFe	35	138	70	213	7,1	184	29,3	130,7
ALFe	50	168	185	520	25,8	505,7	83,2	369,4
ALFe	70	213	2 x 150	735	19,5	693,9	98,2	470
AYKY	150	278	150	278	2,7	92,7	8,8	29,3
NAYY	150	281	150	357	4	127,9	21,7	91
ALFe	120	357	120	357	5,1	310,1	35,8	172,8
NAYY	50	149	50	149	3,3	78,5	12,4	55,9

2. Permissible loss of line voltage

The definition of the line section by the allowable voltage drop implies that the designed load should not lead to a voltage drop at the terminals of the device below the specified limits. Allowable voltage drops ΔU are usually indicated in percent. For a given allowable voltage drop, we can determine the cross-section S (mm2) using the following simple relation [13]:

$$S = \rho \cdot L \cdot (I_n / \Delta U) \tag{3}$$

Where ρ - the resistance of the conductor (W $\cdot$ mm^2 / m), L - the length of the line (m), I_n - is the rated current through the line (A), ΔU - the voltage drop (V).

The choice of the cross-section according to the criterion of permissible voltage loss was made for the most severe mode. For the calculation, we used sections chosen according to the method of permissible currents. The results can be seen in Table VII.

TABLE VII.
Selection of the section according to the permissible loss of line voltage

Mode (model)	*Average voltage*	*Difference with nominal*	*Active power loss*	*Reactive power loss*
	U, V	*U, %*	*ΔP, kW*	*ΔQ, kVar*
Charging for Electric Vehicles with Photovoltaic	304,65	23,84	237,94	246,71
Charging for Electric Vehicles with Photovoltaic	365,00	8,75	31,26	114,92

Selected sections are tested according to the norms of permissible losses. In addition to improving the quality of electricity, changes in the line sections also reduced the loss of active and reactive power.

V. CONCLUSION

This article deals with the impact of a low voltage smart grid on the distribution system. The results of the calculations confirmed our assumption that existing networks of distribution systems are not prepared to fulfill this new criterion given by EU legislation.

Concerning these results of calculations, we can conclude that the existing distribution networks are not ready to apply electromobility to a large extent. Thus, with the widespread use of electric vehicles, it becomes necessary to replace the infrastructure of electrical networks: power lines, transformers, and protection systems. Replacing the classic infrastructure is one of the solutions to the current problem. However, it is worth that the cost of replacing such a large amount of equipment is quite high. The best solution is to combine these methods:

1. Partial replacement of equipment
2. Introduction of smart electric energy management
3. Introduction of accumulation systems
4. Introduction of small generation systems

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