Choosing the solution to reduce losses in new generation networks (Smart Grid)

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***Abstract*—this article discusses the influence of smart elements that are part of the concept of smart networks on the distribution system. The latest European directives 2014/94 / EU, 2009/28 / EC, 2010/31 / EU and the wide distribution of electric vehicles set new challenges for distribution system operators. Existing distribution networks are not ready to meet these criteria. The article presents the results associated with the application of this new directive in existing distribution systems, as well as a comparison of possible solutions.**

Keywords—smart grids, electric cars, renewable energy sources, active power losses, SWOT analysis.

I. Smart Grid Next-Generation Electric Grid

The energy system based on the Smart Grid concept ("Smart Grid", "Actively-Adaptive Grids") is a single energy-information complex where managed objects should allow remote control and situation assessment and emergency automation systems should reduce redundant requirements for power and information reserves capacities. The emergence of such a system is an opportunity to provide new properties and new effects due to new methods and a new organization for controlling the functionality and development of the intellectual energy system [1]:

1. Survivability
2. Power quality
3. The possibilities of its accumulation,
4. Flow management and removal of unnecessary restrictions on the synchronous operation of all parts of the system,
5. Optimization of primary energy resources and investments used

Experts at zPryme Research & Consulting claim that in some U.S. states, Smart Grid implementation has reduced peak grid loads, reduced electricity bills by an average of 10%, while cost has increased by 15% and the use of Smart Grid technologies by 2020 it will save about $ 1.8 trillion by reducing energy consumption and improving the reliability of energy supply. According to a situation analysis by Cleandex, Europe plans to fund $ 750 billion worth of smart grid programs in Europe over the next 30 years. In Germany, Smart Grid has been implemented in electric meter systems that consolidate information on energy consumption and utilities in individual households with subsequent transfer to utility companies. Now, thanks to this, municipalities consume energy more efficiently and reduce their negative impact on the environment [2].

Experts point to a tendency to rapidly reduce the gap in the cost of traditional and non-traditional energy sources. The stimulating role for using alternative energy sources is likely to be played by the factor of rising oil and gas prices, as well as the strengthening of environmental requirements for the construction of traditional generating capacities. Thus, the commercial attractiveness of using alternative energy sources will develop under the influence of two multidirectional factors: higher prices for traditional hydrocarbon sources and lower prices for alternative sources. [3] However, it should be noted that the power generated by wind farms, solar power plants, cogeneration power plants (KHPPs) and other alternative energy sources is not constant and depends on natural conditions - the presence of wind, solar radiation activity, etc. In this case, such instability of renewable energy generation makes its negative adjustments to the stable operation of the power system. Smart Grid implies the use of the latest technologies and algorithms in the process of organizing and managing, such as virtual power plants (WPS), FACTS systems, phasors or PMU (Phasor Measurement Unit), DC inserts (HDVC), various types of energy storage devices (including electric cars), etc [4].

II. Electric Cars as One of The incentives for Changing Electric Networks

Today, the world is entering the era of the Fourth Industrial Revolution, the era of profound and rapid change. The new technological structure dramatically changes all processes in society, dictates the need for the active introduction of electric vehicles in the transport and communications complex of countries with the creation of the appropriate infrastructure. Almost all global manufacturers plan to produce new cars that will run on electricity. Moreover, according to numerous experts, electric vehicles have a future. Undoubtedly, the advantages of electric vehicles will make them the transport of the future:

1. Cost reduction - an electric car is a great way to save on fuel.
2. Local reduction (within the city) of environmental pollution - a working engine does not emit any harmful gases or other substances
3. Noise reduction - electric motors are quite capable of providing quiet and smooth acceleration, while being able to give great acceleration
4. Safety - road safety is a top priority for any sane driver.

This work was supported by the Scientific Grant Agency of the Ministry of Education of Slovak Republic and the Slovak Academy of Sciences by the projects VEGA No. 1/0372/18.

The main limiting factor for mass use is the high price of electric vehicles. However, the progress of electric vehicles is very fast, and in the near future, their cost will not particularly differ from the cost of hybrid and traditional cars. The largest market for electric vehicles will remain China. The government promotes their dissemination in order to reduce CO2 emissions. In tab II, we present the forecasts of various companies that show the rapid penetration of electric vehicles into our lives.

TABLE I. ELECTRIC VEHICLE FORECASTS [5][6][7][8][9]

Company forecast	***Year***	***Million pieces***	***Percentage of total cars***
Frost & Sullivan	2025	25	≈20-22%
Bloomberg New Energy Finance	2025	–	≈50% of buses
Deloitte	2030	21	≈20%
BNEF	2030	30	–
International Energy Agency	2030	21,5	–
J.P. Morgan	2030	–	≈39%

III. VILLAGE MODEL WITH SMART ELEMENTS

Based on the analysis, the new European standards [10][11][12] that relate to energy can suggest that the amount of energy consumed will increase in the future, and electric cars will make a significant contribution to this growth. It is also planned to widely disseminate renewable energy sources, which also have a specific effect on the electric network. In order to analyze the influence of new smart elements on the network, a model of a small village with real network parameters was created. After that, smart elements were added to the finished network. The following programs were used for modeling: Matlab, Neplan, Excel, and Python. The block diagram of the model of the electric network of the village is shown in Fig. 1. You can see the number of different elements in tab II [13].

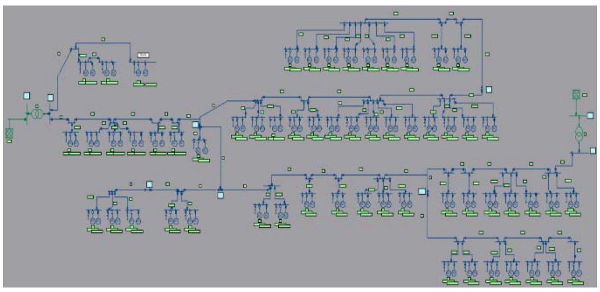

Fig. 1. Model of a villag's network

TABLE II. THE NUMBER OF ELEMENTS IN THE MODEL

Type of elements	***Numbers***	**Installed power, kW**
Power Lines (0.4 kV)	91	
Loads (Households)	58	
Charging for Electric Vehicles (AC)	58	
Photovoltaic Systems	58	191,4
Transformer (22/0,4 kV)	2	
Electric energy storage system	2	100

A. Load model

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 [14].

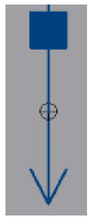

Fig. 2. Load model in the software.

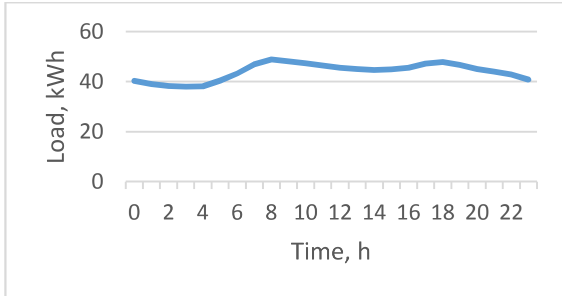

Fig. 3. Annual load schedule

B. Photovoltaic Systems model

To create a model of the solar panel, the real parameters were used, which are presented in table 3. To simulate the operation of the solar panel, we used data obtained as part of measuring the power produced by the solar panel installed at our department. The measurement interval is about 104 days. In this case, from July 27 to November 16. For the model, the average values of produced capacity per hour for a given period were used. The measurement graph can be seen in Fig 4.

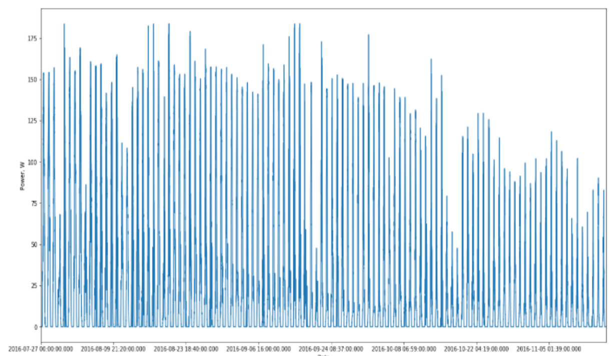

Fig. 4. Measuring the power produced by the solar panel

In Fig. 5 there is a presentation of the PV panel model in the software used. Although the PV panel is a DC power source, together with inverter is the AC power source. The parameters of the PV panel are in Table III

TABLE III. PARAMETERS OF PHOTOVOLTAIC [15]

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

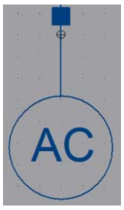

Fig. 5. Model of PV panels in software

C. *Model of electric energy storage system*

Tesla's battery parameters were used to create the model. Since the ultimate goal of this article is to find out whether it is possible to reduce the loss of active power in the network using batteries, a simplified model of the energy storage system was used. The parameters of the energy storage system are presented in table 4.

TABLE IV. PARAMETERS OF THE ENERGY STORAGE SYSTEM [16]

Parameters	***value***
AC Voltage	380 to 480V, 3 phases
Power	50kW (AC) per Powerpack
Depth of Discharge	100%
Energy Capacity	210 kWh (AC) per Powerpack
Operating Temperature	-22°F to 122°F / -30°C to 50°C

D. *Model of Electric car*

To analyze the influence of electric vehicles, a simplified electric vehicle model was created. The simplified model is a normal load whose value is set through the nominal charging power. This load will be connected to the network for a certain time, simulating the charging of an electric vehicle. An example can be seen in Fig. 5. A power of 3,7 kW was selected for the charger. This model was used to simulate charging electric vehicles. In this case, the charger acted as a load. Nissan Leaf was used to create the electric car model. The declared capacity of this car is 24 kWh [17]. It takes about 7 hours to fully charge this car. According to new European standards, every new home should be equipped with charging for electric vehicles [18]. In this regard, the number of chargers equal to the number of houses was added.

IV. Possible Solutions to Reduce Active Power Loss in the Network

To analyze the influence of smart elements on the network, their number was gradually increased, each step amounted to 10% of the total number of houses. Due to the lack of data on the installation time for charging electric vehicles, we are considering the option that the cars will be charged from 19:00 to 2:00 at night. In Figure 6, it is clearly seen that with an increase in the number of smart elements in the network, an increasing power appears. During the day, solar-powered power generation is observed, and at about 30%, the power begins to be excessive and we observe a reverse flow of power (from the 0.4 kV network to the 22 kV network), which is a negative phenomenon. However, during installation on charging electric vehicles, on the contrary, there is a hung up consumption, which increases the current load in the lines, which is also a negative factor [19].

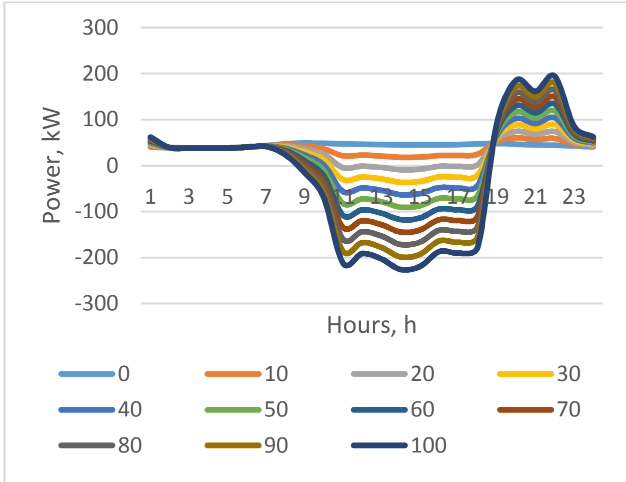

Fig. 6. Daily network load graph

Fig. 7 shows the loss of active power in the network without compensation methods. As you can see, with the increase of smart elements in the network, losses increase. In addition to an increase in active power losses, an increase in currents in power lines and a strong voltage drop in some sections of the network were also observed. Losses increased by almost 7 times [20].

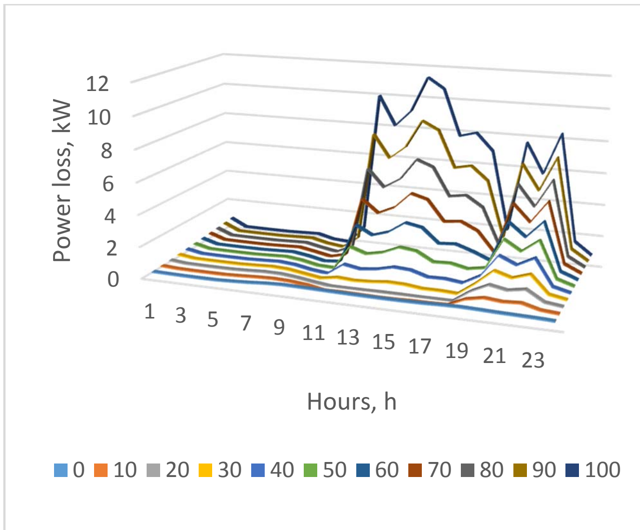

Fig. 7. Dependence of an increase in active power losses with an increase in the number of smart elements.

In Figure 8, you can see the positive effect of installing electrical energy storage systems. In the model, we used two large batteries, which were placed in the nodes of the highest load /generation. Different lines represent different capacities of installed batteries. The batteries worked in charging mode during a sunny day, for charging from solar panels and in discharge mode while charging electric vehicles. As can be seen from the figure, the discharge mode is more efficient because the charging cycle is shorter and more power can be consumed. During the charging cycle, you have to take less power from the network to cover a whole sunny day. For greater efficiency, it is better to use a large number of small batteries, so the batteries can be placed closer to the sources of consumption / generation, which will further reduce losses [21].

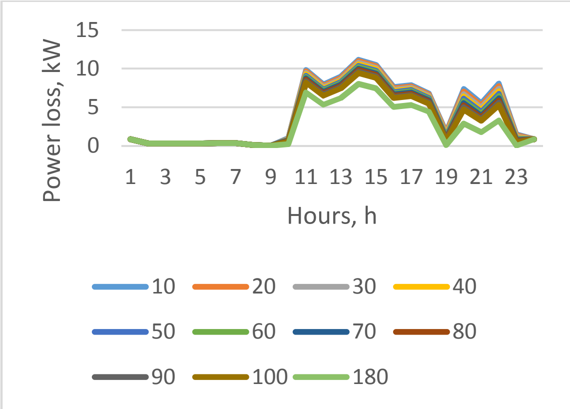

Fig. 8. The dependence of active power losses when using storage systems with a capacity of 10-100 and 180 kW

Table 5 presents some parameters of the lines that were used in the model, as well as the currents that flow through them. The modes are arranged in order:

1) A mode without smart elements
2) The hardest possible mode.

In this table, you can also see which lines were replaced, and that they satisfy the conditions for checking the maximum current.

TABLE V. SELECTION OF THE SECTION ACCORDING TO THE PERMISSIBLE CURRENT LOAD [17]

Type	*Size, mm*	*Imax, A*	*Size, mm*	*Imax, A*	*I_1, A*	*I_2, A*
ALFe	35	138	70	213	7,1	184
ALFe	50	168	185	520	25,8	505,7
ALFe	70	213	2 x 150	735	19,5	693,9
AYKY	150	278	150	278	2,7	92,7
NAYY	150	281	150	357	4	127,9
ALFe	120	357	120	357	5,1	310,1
NAYY	50	149	50	149	3,3	78,5

Table 6 summarizes the average network parameters after changing the cross-sections of the lines that did not satisfy the permissible current. As you can see the loss of active power has decreased visibly, the voltage drop across individual elements has also decreased. From which we can conclude that this method of reducing active power losses is quite effective [22].

TABLE VI. SELECTION OF THE SECTION ACCORDING TO THE PERMISSIBLE LOSS OF LINE VOLTAGE

Mode (model)	***Average voltage in model***	***Difference with nominal***	***Active power loss in Grid***	***Reactive power loss in Grid***
	U, V	***U, %***	***ΔP, kW***	***ΔQ, kW***
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

V. Choosing The Best Solution to Reduce Network Losses

To select the best solution to reduce active power losses in the network, we present a SWOT analysis of each of the presented solutions. Therefore, SWOT analysis is a strategic planning method [23]. It is used to help a person or organization identify its strengths and weaknesses, opportunities and threats associated with competition or project planning. SWOT analysis is a flexible tool; therefore, it is suitable for assessment in completely different areas. SWOT is an abbreviation that consists of the following concepts [24]:

- S (**Strengths**) - strengths, business characteristics that distinguish it against competitors;
- W (**Weaknesses**) - weaknesses that make a company vulnerable to other players;
- O (**Opportunities**) - opportunities, environment elements that the company can use for development;
- T (**Threats**) - threats, environmental elements that can harm the business.

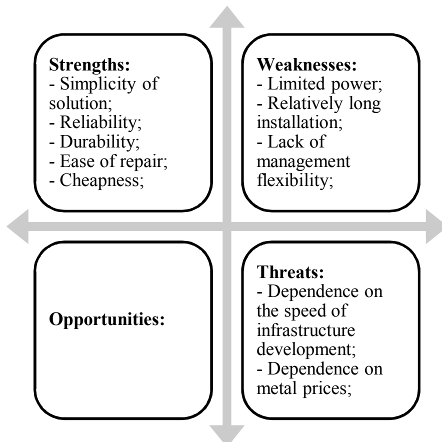

Fig. 9. SWOT analysis of a method for reducing active power losses by replacing power lines

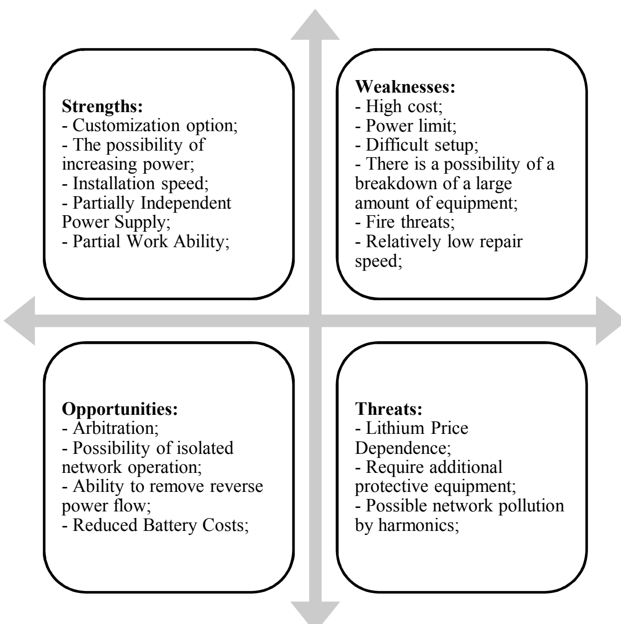

Fig. 10. SWOT analysis of a method for reducing active power losses by installing energy storage systems [18]

As it can be seen from the SWOT analysis, a more promising method is to reduce losses by installing storage systems. Since this method has a fairly wide flexibility for the future possible increase in power, as well as additional features such as arbirtrage and energy management. However, at the moment, this method loses in the cost of solving the main problem, as well as in durability.

VI. Conclusion

According to analysts, in the coming decades we will see a rapid increase in the number of electric vehicles. The rapid spread of electric vehicles is facilitated by:

1) Laws for the protection of climate
2) Subsidies from the state
3) Increase in energy prices
4) Reduction in energy costs
5) Reduction in battery costs

Analysts also predict an increase in the number of autonomous small power plants that will be used at home. Every year, the price of such stations decreases, and the efficiency increases.

It is not possible to confirm the operation of the whole model; however, individual elements were confirmed by measurements, for example, the measurement of the received power from the solar battery, the electric vehicle is charging power and speed, and the operation of the village's classic electric network. As it can be seen in the simulation results of our model, the wide and rapid spread of smart elements will have a significant negative impact on small power supply systems. In addition, with confidence we can say that the energy system that exists now is not ready for such a huge amount of Smart elements. Our next goal in the study in this direction will be the refinement of the model. As part of this, additional data collection will be carried out such as charging time of electric vehicles of different models, and the generated solar power for a whole year. In addition, we plan a more sophisticated model of the energy storage system, a dynamic change in power in the network.

This article analyzed two ways to maintain the durability of the system. A classic way is to change the installed power equipment to a more powerful and expensive one, which sometimes is necessary only at a specific time. This method is effective and reliable, but in the end, it is losing, since with increasing power you will have to change equipment repeatedly. In addition, the modern method, which is an integral part of Smart Networks. This method is much more flexible. However, now it has a number of disadvantages, the main of which are high cost and durability. After eliminating these shortcomings, this method will be more widely used.

The article presents the results associated with this new European directive. The results of this article can be used to predict the impact of this directive on the development of the distribution network.

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