The impact of a low-voltage smart grid on the distribution system

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***Abstract*—This paper deals with the impact of a low voltage smart grid on the distribution system. The last European directives 2014/94 / EU, 2009/28/EC and 2010/31 / EU, bring new problems to solve for distribution system operators. The existing networks of distribution systems are not prepared to fulfill these criterions. Paper shows results related with application of this new directives on existing distribution systems.**

Keywords—smart grid, electric vehicle charging, microgrid

I. Introduction

Nowadays is the word "Smart" used more often then before. It usually refers to different products with an increasing degree of computational efficiency - intelligence. We know intelligent products such as smartphone, smart watch, smart TV or other intelligent electronics with various features and applications which are currently on the rise. Electric energy is currently an important and strategic "raw material" and its importance in the future years is clearly growing. For this reason, increasing emphasis is placed on the stability, safety and security of electricity supply to final customers. Therefore, computer technology is increasingly being introduced into the electrical system. Very popular is also the new term, that refers to more intelligent grid - "Smart Grid".

Many articles, projects and publications focus on Smart Grid as well as on domestic and foreign conferences. Despite the great popularity, there is considerable contradiction in the definition of this term. An intelligent network is often referred to as a network capable of using more renewable energy sources and distributed production than the current network.

Understanding the current network of smart grids is costly and demanding. It is a long-term process that binds capital for many years. Therefore, it requires a strong commitment from all stakeholders. In addition, it is not fully verified how the Smart Grid technologies will work together.

In this paper is describing influence of future low -voltage smart grid to the distribution system. This smart grid is grid that consists from houses and renewable energy sources. The future distribution system must also contain a considerable number of electric car chargers.

II. IMPLEMENTATION OF THE SMART GRID

A. Basic differences between traditional and smart grids

The basic difference between intelligent and traditional electrical networks is in the structure of the networks themselves. [1] Traditional distribution consists of the production of electricity in large power plants, and subsequently, through transformation and transmission, it reaches the final consumer. [2] Intelligent network, besides these parts, also addresses the issue of communication and faster network management. Significant impact consists of renewable sources, accumulation, intelligent measurement and two-way communication. [3]

Other features include self-repairing the network, fast detection and fault localization. An increased number of sensors helps to accurately map real-time network status. [4] Thanks to the new features in the network, not only increases the comforter of the electricity supplier, but also increases the comfort of the customer who can monitor his consumption and also production at regular intervals. [5]

As mentioned above, electricity production passes from centralized production to decentralized. This can result in advantages and disadvantages, depending on the point of view. Decentralized sources of small production capacity across Europe are in harmony with European Union regulations. The question will also be the reliability of this network. [6]

B. Legislative changes in the energy sector

As in the last European Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure [7], Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources [8] and Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. [9] In article 6 about new buildings suggesting that all new building need to take into account:

- Cogeneration
- Heat pumps
- Block or district heating or cooling, particularly where it is partially or entirely supplied from renewable energy sources
- Decentralised energy supply systems on energy from RES

Article 9 is focused on Nearly zero-energy buildings committed to build only houses with nearly zero energy by 31.

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December 2020. To fulfil this criterion is needed to install to all buildings photovoltaic power plant, and there are suggestions to build on all new houses electro mobile charger.

III. Modelling Microgrid

Microgrid modeling is a very effective process for verifying the theoretical knowledge and for the most accurate design in practice. This modeling software is based on mathematical transitions and complemented by a graphical environment that facilitates modeling itself. [10]

This model is based on data from the classic village where we know the load, approximate distances and types of power lines. This model can then simulate behavior if the power grid is to be upgraded and supplemented by new energy appliances or production sources. [11]

To create a model of the electrical grid used the parameters of real equipment. The Table I shows the number of different elements that the model contains.

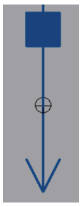
TABLE I. The number of elements in the model

Line	91
Loads	58
Charging for Electric Vehicles	58
Photovoltaic	58
Transformer	2

A. Loads

The load model is presented by the average value of household electricity consumption. Individual loads have different values and present a disproportionate load on the network. The number of loads is not high; the aim is rather to point to the impact of additional equipment.

Fig. 1. Load model in the software



B. Renewable energy sources

In order to determine the impact of renewable energy sources, each source of power generation was added to PV panels. Power of panels has been designed to use subsidies to promote renewable resources in the country. Eleven monocrystalline panels of the All-Black CS6K-300M type from Canadian solar [12] with a maximum output of 3.3 kW were selected for this model.

In Fig. 2 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 II.

Fig. 2. Model of PV panels in software

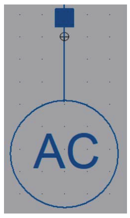


TABLE II. Parameters of photovoltaic

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

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C. Electric car charger

A 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 charging of electric cars is mentioned only partially, but research is already underway in this area. Just the idea that every household would recharge its car during the night is unimaginable with the current state of power lines. Therefore, the impact of such a load should be examined as the reconstruction of the power lines will not be negligible in terms of both time and finance. [13]

IV. Network Analysis

To analyze the electrical grid, several model operation scenarios were used [14]:

1. Current network status
2. Charging for an electric vehicle is connected in every house.
3. Each house contains 3.3 kW photovoltaics.
4. Every house has a Charging for Electric Vehicles and a photovoltaics.

A. Load flow

Power loss is an important parameter when operating an electrical network. According to the norm, power losses should not exceed 5% of the transmitted power. With an increase in electrical load, power losses begin to increase, according to equation (1)(2) [15].

$$\Delta P = \frac{P^2 + Q^2}{U^2} \cdot R \quad (1)$$

$$\Delta Q = \frac{P^2 + Q^2}{U^2} \cdot X \quad (2)$$

For the analysis of this mode of operation, the calculation of the power loss was made, with the connection of different amounts of new equipment. Table III presents the values of active and reactive power losses in scenario 1 with an increase in the number of connected elements. As can be seen in graph 1, the power loss increased significantly after the installation of the chargers.

TABLE III. THE LOSSES OF ACTIVE POWER AND REACTIVE POWER IN THE NETWORK WHEN RUNNING SCENARIOS 1

Number of devices	***Active power loss***	***Reactive power loss***
	ΔP, kW	***ΔQ, kW***
0	0,45	2,33
6	3,05	5,61
12	9,68	12,53
17	14,01	17,95
23	24,59	29,72
29	37,13	43,33
35	56,01	63,36
41	86,14	94,57
46	115,74	126,41
52	160,26	170,26
58	237,94	246,71

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

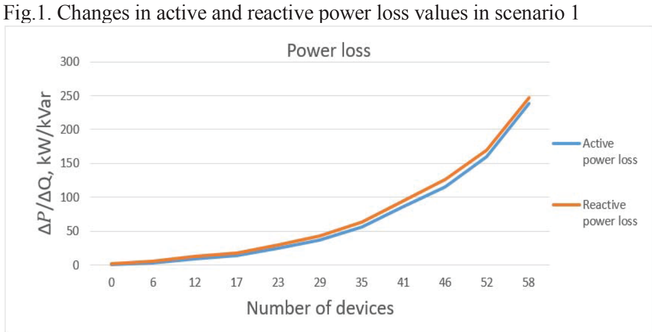


Table IV presents the values of active and reactive power losses in scenario 2 with an increase in the number of connected elements. When installing photovoltaics, there was initially a slight decrease in losses. But after the amount of generated power on photovoltaics exceeded the capacity of consumers, losses began to increase. This is due to the fact that the excess power began to flow from the 0.4 kV grid to the 22 kV grid. In order to avoid these energy flows, it is necessary to connect accumulation batteries.

TABLE IV. LOSSES OF ACTIVE POWER AND REACTIVE POWER IN THE NETWORK WHEN RUNNING SCENARIO 2

Number of devices	***Active power loss***	***Reactive power loss***
	ΔP, kW	***ΔQ, kW***
0	0,45	2,33
6	0,29	2,13
12	0,64	2,41
17	0,74	2,63
23	1,2	3,17
29	1,55	3,7
35	2,34	4,56
41	3,3	5,64
46	4,42	6,82
52	5,66	8,29
58	6,94	9,85

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

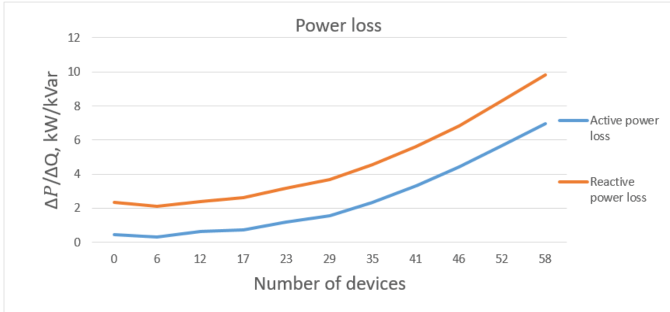
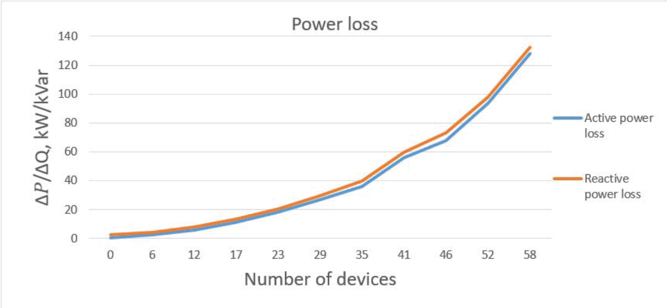


Table V presents the values of the losses of active and reactive power under scenario 3 with an increase in the number of connected elements. With simultaneous charging for an electric vehicle and photovoltaics, the loss values still remained fairly large, however, they are lower than under scenario 1.

TABLE V. LOSSES OF ACTIVE POWER AND REACTIVE POWER IN THE NETWORK WHEN RUNNING SCENARIO 3

Number of devices	***Active power loss***	***Reactive power loss***
	ΔP, kW	***ΔQ, kW***
0	0,45	2,33
6	2,35	4,37
12	5,65	7,83
17	11,16	13,11
23	18,26	20,46
29	26,65	29,31
35	35,9	39,9
41	55,81	59,67
46	67,88	72,91
52	93,69	98,17
58	127,98	132,48

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



On the table VI you can see the permissible values of the current load of each line. The values of currents in this line are also presented during grid operation in different operation scenarios. As can be seen, installing such a number of charging stations will lead to a significant increase in the currents in the lines, which will overload them. Installing a combination of photovoltaics and charging slightly reduces the current load, but the power of the panels is not enough to compensate for the increased currents. The output can be an increase in the cross sections (size) of lines.

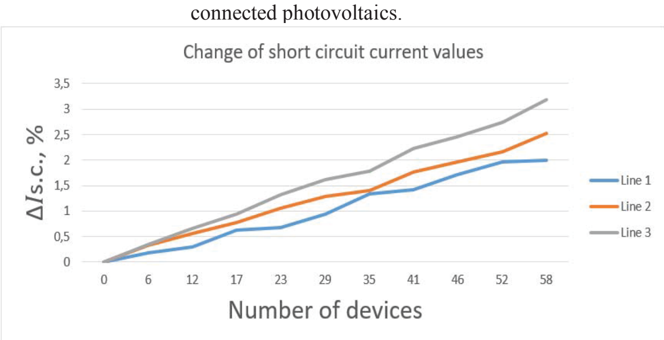
TABLE VI. COMPARISON OF CURRENTS IN LINES UNDER DIFFERENT SCENARIOS

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
NFA	120	280	40,7	956,1	145,6	684,9
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

B. Short circuit analysis

With an increase in the number of power supplies, short circuit currents in the grid also increase. As part of the study of the model, the calculation of short-circuit currents was made depending on the number of connected photovoltaics. [16] The calculation was made for the three main lines of the grid model, which are located directly in front of the transformer. As can be seen from the graph, with an increase in the number of photovoltaics, the short-circuit current began to increase, the maximum increase was 3.2%.

Fig. 4. Changes in short-circuit currents depending on the number of connected photovoltaics.



C. Transformer

The table VII shows the average values of voltage, currents on the elements in the model and shows the values of power consumption. [16] When using scenario 1, the values of the currents in the elements have increased, and the voltage does not meet the prescribed norms. In scenario 2, the currents increased slightly, the voltage value also increased, but the value was within the prescribed norms. In Scenario 3, the use of photovoltaics helped to reduce current in the lines by 31%, as well as improve voltage performance. Autonomous operation of this network is possible only in scenario 2.

TABLE VII. AVERAGE VALUES OF VOLTAGE, CURRENTS ON THE ELEMENTS IN THE MODEL

Mode (model)	Average voltage	Average line current	Grid power consumption	
	U, V	I, A	P, kW	Q, kVar
Current state	395,02	5,34	45,42	17,1
Charging for Electric Vehicles	274,44	144,71	953,91	482,03
Photovoltaic	405,17	22,45	-172,49	-98,37
Charging for Electric Vehicles with Photovoltaic	304,65	99,86	619,55	441,56

V. ACCUMULATION

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.

VI. CONCLUSION

This paper 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. Loses in the network increasing in all 3 scenarios. Loading of existing distribution lines during of scenarios exceeds the allowable limits. The short circuit analysis shows that the short circuit current increases with number of photovoltaic power plant. Calculation of current flows on distribution lines during scenario 1 shows that the values of the currents in the elements have increased, and the voltage does not meet the prescribed norms. In scenario 3 the use of photovoltaics helped to reduce current in the lines by 31%, and help to keep voltage in permissible limits.

With regard to these results of calculations, we can conclude that the existing distribution networks are not ready to apply electro mobility to a large extent. The amount of installable chargers for electric vehicles is limited. The possibility of increasing the number of chargers is the local application of photovoltaics, but the number of existing buildings is not prepared for the installation of photovoltaics. This means an increase in installation costs. The solution can also be the sharing of electricity produced from photovoltaics between households, or the use of batteries from electric vehicles as the accumulation for household.

REFERENCES

[1] M. Shamshiri, C. K. Gan, a C. W. Tan, “A review of recent development in smart grid and micro-grid laboratories”, v 2012 IEEE International Power Engineering and Optimization Conference Melaka, Malaysia, 2012, s. 367–372.

[2] Martinek, Z., Hromadka, A., Hammerbauer, J.: Reliability characteristics of power plants, In: Advances in electrical and electronic engineering, Vol. 15, Issue:1, Pg. 37-45, 2017, DOI: 10.15598/aeee.v15i1.2043

[3] N. Nikmehr a S. N. Ravadanegh, “Optimal Power Dispatch of Multi-Microgrids at Future Smart Distribution Grids”, IEEE Transactions on Smart Grid, roč. 6, č. 4, s. 1648–1657, júl. 2015.

[4] J.Pálfi, M. Tompa, P. Holcsik: Analysis of the Efficiency of the Recloser Function of LV Smart Switchboards ACTA POLYTECHNICA HUNGARICA 14 : 2 pp. 131-150. , 20 p. (2017)

[5] Bačík J., Perduková D., Fedor P.: Design of fuzzy controller for hexacopter position control. Advances in Intelligent Systems and Computing. Volume 347. Springer-International Publishing Switzerland 2015, pp. 193- 202. ISSN 2194-5357

[6] M. GONO, M. KNYCL, R. GONO, I. KŁOSOK-BAZAN: Experience with the production of electricity from biogas at sewage treatment plant in the Czech Republic, Przeglad Elektrotechniczny, Volume 89, Issue 11, 2013 r, pp 12-15

[7] Directive 2014/94/EU of the European Parliament and of the Council https://eur-lex.europa.eu/legal content/EN/TXT/?uri=celex%3A32014L0094

[8] Directive 2010/31/eu of the european parliament and of the council https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32010L0031&from=SK

[9] Directive 2009/28/EC of the European Parliament and of the Council https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32009L0028

[10] Borlase S., Smart Grids: Infrastructure, Technology and Solutions, 577, (CRC, 2013) ISBN: 978-1-4398-2905-9

[11] Momoh J., Smart Grid: Fundamentals of Design and Analysis, 216, (IEEE P., 2012) ISBN:978-0-470-88939-8

[12] Cimbala, R. ; Kiraly, J.; German-Sobek, M.; Bucko S.; Kurimsky, J.; Dzmura, J., Polarization Phenomena in Magnetic Liquids, CHEMICKE LISTY Volume: 109 Issue: 2 Pages: 117-124, ISSN 1213-7103

[13] Datasheet-All-black_CS6K-MS_EN

https://www.canadiansolar.com/upload/b46f34f7016c1aab/aeda548a15610168.pdf

[14] Pavlík, M.:“Measuring of dependence of shielding effectiveness of wet materials on the frequency of electromagnetic field in the high frequency range“(2013) Acta Electrotechnica et Informatica, 3, pp. 12-16.

[15] Z. Čonka, M. Kolcun: Impact of TCSC on the Transient Stability In: Acta Electrotechnica et Informatica. Roč. 13, č. 2 (2013), s. 50-54. - ISSN 1335-8243 Available on internet :www.versita.com/aei. (2013)

[16] Cimbala, R., German-Sobek, M., Bucko, S.:The assessment of influence of thermal aging to dielectric properties of XLPE insulation using dielectric relaxation spectroscopy (2015) Acta Electrotechnica et Informatica., 15 (3), pp. 14-17. ISSN 1335-8243

[17] Petras, J.; Kurimsky, J.; Balogh, J.; Cimbala, R.; Dzmura, J.; Dolnik, B.; Kolcunova, I., „Thermally Stimulated Acoustic Energy Shift in Transformer Oil“, In: ACTA ACUSTICA UNITED WITH ACUSTICA, Volume: 102 Issue: 1 Pages: 16-22, ISSN: 1861-9959

[18] Kolcunova, I.; Pavlik, M.; Lison, L. „Assessment of long thermal ageing on the oil-paper insulation“ In: ADVANCES IN ELECTRICAL AND ELECTRONIC ENGINEERING Volume: 14 Issue: 5 Pages: 506-511, DOI: 10.15598/aeee.v14i5.1836