Analysis of Smart Technical Measures Impacts on DER and EV Hosting Capacity Increase in LV and MV Grids in the Czech Republic in Terms of European Project InterFlex

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***Abstract*—The paper presents a methodology how to quantify a technical and economic impact of selected smart solutions on hosting capacity increase of DERs and EVs on LV and MV level in a large distribution area in the future. The official Czech government documents called National Action Plan for Smart Grids and Clean Mobility published by Czech Ministry of Industry and Trade present several scenarios of future expected development of DERs and EVs. Comparison of business as usual and smart grid solutions is presented and monetized.**

***Index Terms*--distribution grid models, DER hosting capacity, EV integration, investment cost, smart technical solutions**

I. INTRODUCTION

A necessary precondition to quantify an overall impact of the new generation and consumption on distribution grids is to divide the total numbers into smaller regions and districts. This was done for the Czech Republic based on climate conditions for renewables, population density, type of cities and villages, economic aspects, traffic infrastructure, etc. The applied granularity includes 50 district and about 200 HV/MV substations. Analysed DSO area includes more than 2500 MV feeders with more than 60000 secondary transformers MV/LV. As such huge topology of distribution grid could not be modelled and calculated due to its complexity, the whole grid was mapped, and the structures were divided into 15 MV groups and 18 LV groups. The groups are called "representative models" and they represent fixed grid structures with representative topologies and feeder's electrical parameters.

As the NAP predictions are very ambitious for both DERs and EVs, many districts are expected to have significant hosting capacity deficits. Therefore, implementation of smart technical measures was included in the hosting capacity calculations. Smart measures are represented by autonomous control functions Q (V) and P (V) in smart PV inverters on LV level, volt-var control in DERs installed on MV level, smart EV charging control and smart home energy storage. The paper compares how these smart solutions increase overall hosting capacities in all the country and how they can reduce the necessary additional DSO investment cost to integrate expected DERs and EVs into the distribution grids.

II. ENERGY POLICY AND FUTURE SCENARIOS IN THE CZECH REPUBLIC

National Action Plan for Smart Grids [1] and Clean Mobility [2] are strategic documents and concepts of development of network infrastructure to ensure reliable and safe operation with respect to the required development of distributed generation.

A. *DER scenarios*

According to NAP SG, the scenarios imply assumptions of the dominant share of DER at the LV level and most visible share in future years is supposed to realize with small roof PV installations and with micro CHP units in households.

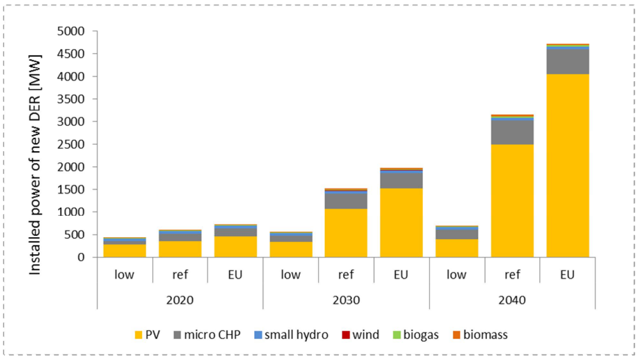

Figure 1. Comparison of three different DER development scenarios on LV

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n° 731289

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B. *EV and new loads scenarios*

NAP CM defines predicted EV sales in future years. Those numbers can’t be naturally used directly as an installed power of charging stations but could help to recognize how many EVs will be operated per day.

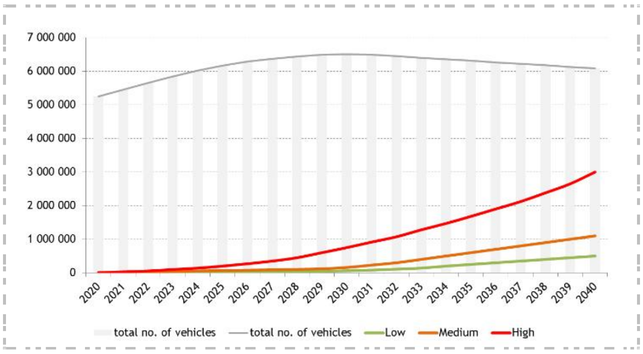

Figure 2. Predicted EV share on light vehicle market in three scenarios

III. LV AND MV GRID ANALYSIS

The basic idea for SRA (Scalability and Replicability Analysis) for European project InterFlex [3], [4] was to simplify whole distribution grid into less complex but still appropriate representative grid models. The analysis has been done for whole CEZ Distribuce areas and so it represents both urban and rural areas with different grid topology.

A. *Representative LV grid models*

For creation of representative grids and feeders technical and statistical data from the grid database and geographic systems were collected and analysed. To handle the analysis one common identifier were established, which represents code of municipality and beneath there is direct connection to different secondary substations and LV grids.

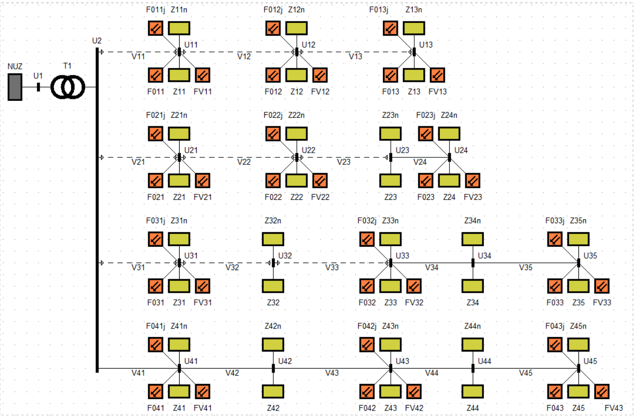

Figure 3. Representative LV grid model designed in calculation SW

Data describing municipality part of the grid are the size by number of populations, municipality status, type of connection to superior grid, number of buildings, number and parameters of existing DER, description of connected customers, number and details of secondary substations, LV feeder attributes (length, type, material, cross-section). To reach the largest number of real feeders, up to four variants of representative grids were selected for each municipality size. All designed 18 representative LV grid models are also made in variations for the years 2020, 2030 and 2040 – this covers the expected renewal and development of LV grids. In result there are 54 different representative LV models.

B. *Representative MV feeders*

Unlike LV representative models in MV grid topology the statistical approach to build representative models was not convenient due to high complexity of MV grid. Hence the grid dispatchers and employees of operation preparation were asked to identify most relevant real grids that fulfil conditions defined by the research team.

There are etc. 4000 different MV feeders in the grid, maximum of 20 representative feeders is requested with different parameters (length, material, type of the feeder, number and attributes of existing installed DER). Those feeders have particular real topology extracted from DMS/SCADA, its real load, generation from DER and real connection in HV/MV substation. Existing DERs are connected into representative feeders in the model. New DERs according to different development scenarios were divided in similar principle as in low voltage, with district granularity (which could be simply joined to HV substations). There are both 22 kV and 35 kV feeders (35 kV feeders are typically longer and used in mountain areas). At the end of the research set of 15 representative feeders were established (see example in fig. 4).

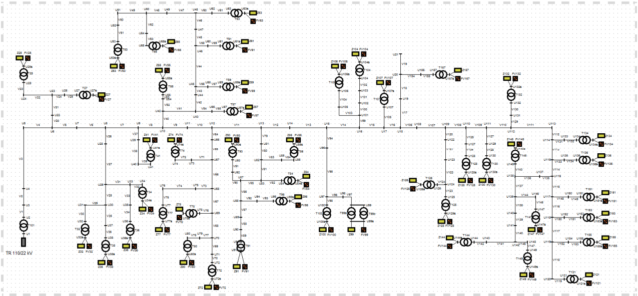

Figure 4. Representative MV grid model designed in calculation SW

IV. SCALABILITY AND REPLICABILITY METHODOLOGY FOR GENERATORS

The methodology for connection study described in [8] stipulates that the worst condition is about to be tested. Situation when DER is producing maximum power but in the same time there is no electricity consumption in the grid. This is only theoretical situation. In real operation before connecting any generator there is always at least nonnegative consumption. In SRA methodology this was taken into consideration. First year consumption and generation on LV was analysed and several significant season periods were found. Winter season (high consumption, high CHP generation, very low PV generation), summer season (low consumption, no CHP production, maximum PV generation), and mid-term season (average – rather low consumption, considerable CHP production, very high PV generation).

Due to rather little differences between summer and mid-term PV production (PV efficiency decrease with summer outdoor temperatures), the mid-term season was chosen, specifically 3rd Sunday in May 2017 2PM.

A. *Distribution of predicted DER power into representative LV models*

DER development scenarios are set for the whole Czech Republic, or for each DSO. In previous chapters about representative LV voltage feeders, the municipality unit was introduced. For division of overall scenario figures similar work needed to be done with the difference, that the administrative unit is district. In CEZ Distribuce there are 54 districts. There are criteria how those districts differ from each other, which radically refines the give out of connected DER installed power. Namely number of households, solar irradiation, gas connection availability, purchasing power of the population or existing power plants location.

B. *Distribution of predicted DER power into representative MV feeders*

Topology and number of elements in MV grids is more complex, so predicted energy sources are divided based on different rules. Total number of DER power on LV is distributed into districts, then HV/MV substations, representative feeders and into secondary substations by their installed power. Models respect existing DERs on MV installed power per MV feeder (from grid database). Distribution of new DERs installed power on MV is like existing ones, with exception of new DER 5 to 10 MW. Half of them are supposed to be connected directly into HV/MV primary substation. New storage on MV is considered as new generator with the same attributes as new DER (storage is expected to be operated based on owner needs and this will probably not correspond with DSO needs).

C. *Evaluation of hosting capacity for generators*

The calculation of DER hosting capacity of every representative LV model or MV feeder was done by valid methodology mandatory for all new connections in DG described in Distribution Grid Code [8]. Requesting connection of new generator brings duty to fulfil several conditions. DER must pass connection study for quality of electricity according to EN 50160. For purposes of SRA & CBA methodology only technical parameters influencing directly grid condition were considered.

In LV models, voltage in every node in the modelled grid after simulated connection with maximum current injection should not exceed limit of 110% Un (253 V in each phase). Voltage unbalance in every node should not exceed 2%. Difference between voltage before and after connection should not exceed 3% in every node of the tested grid. Lines, conductors and cables should not exceed 70% of their nominal current ampacity. MV/LV transformers should not exceed 70% of their nominal current load.

In MV models, voltage in every node in the modelled grid after simulated connection with maximum current injection should not exceed limit of 110% Un (24.2 kV or 38.5 kV). Difference between voltage before and after connection should not exceed 2% in every node of the tested grid. Overhead lines should not exceed 70% of their maximum current ampacity. Underground cables should not exceed 50% of their maximum current ampacity. HV/MV transformers should not exceed 70% of their nominal current load (if at least two transformers in primary substation are in operation). HV/MV transformers should not exceed 50% of their nominal current load (if at least two transformers in substation are in operation).

Usual connection request only concerns one specific DER. In this methodology all the DERs are tested simultaneously and all of them must succeed and pass the computation. If at least one PCC exceeds the limits, the hosting capacity of the grid is reached, and subsequent modification needs to be done. Modifications are subject of the chapter "CBA and economic impact" where also costs of those modifications are calculated and different BAU and SG scenarios are compared.

V. SCALABILITY AND REPLICABILITY METHODOLOGY FOR ELECTRIC VEHICLES

Unlike simulation of DER connection, the EV integration brings biggest issues in times of peak consumption. In this scenario, a few thousand of randomly selected secondary substation annual measurements were analysed and on 5th January 2016 at 6PM the average highest peak in LV was identified as 36.5% of secondary substation installed power. In next decades the load without EVs is expected to increase, in 2020 it is 38% in 2030 is 40.9% in 2040 is 43.3% (due to the increase of non EV loads). In MV level grid maximum winter consumption was found on 17th January 2017 (the MV analysis was done year after LV analysis). From all measured HV/MV primary substations 6PM as a load peak hour was identified. The percentage load of HV/MV installed power was 18.3% in 2017, so it is foreseen 18.9% in 2020, 20.32% in 2030 and 21.51% in 2040.

A. *Distribution of predicted EVs into representative LV feeders*

New loads development scenarios are set for the whole Czech Republic, for each DSO and districts. Criteria how those districts differ from each other, are different from DER example and refines the give out of connected loads connected power. Number of houses represents the theoretical potential EV purchase. Based on the Statistical Office data, the number of family and apartment houses was defined for each district. Gas connection availability helps to have more accurate presumptions about future micro CHP units distribution. The higher purchasing power of the district the higher probability to purchase a new DER.

B. *Distribution of predicted EVs into representative MV feeders*

Topology and number of elements in MV grids is more complex, so predicted new loads are divided. Total load on LV is distributed into districts, then HV/MV primary substations, representative feeders and into secondary substations by their installed power. In model LV loads are one 3-phase element per one secondary substation with power factor equal to 0.95 in 2020, 0.96 in 2030 and 0.97 in 2040 (inductive mode). New storage on MV is considered as new load. (Storage is expected to be operated based on owner needs and this will probably not correspond with DSO needs).

C. Evaluation of EV impact on distribution grid

The calculation of connection of new loads into representative LV model or MV feeder was done by valid methodology mandatory for all new connections in DG described in Distribution Grid Code [8]. Requesting connection of new load brings duty to fulfil a number of conditions such as quality of electricity according to EN 50160. For purposes of SRA & CBA methodology only technical parameters influencing directly grid condition were considered.

In LV models, voltage in every node in the modelled grid after simulated connection new load is not less than 90% Un (207 V in each phase). Voltage unbalance in every node is not to exceed 2%. Lines, conductors and cables should not exceed 80% of their nominal current ampacity. MV/LV transformers should not exceed 80% of their nominal current load.

In MV models, voltage in every node in the modelled grid after simulated connection with maximum current injection should not be lower than limit of 97% Un (21.34 kV or 33.95 kV), overhead lines should not exceed 70% of their maximum current ampacity, underground cables should not exceed 50% of their maximum current ampacity, HV/MV transformers should not exceed 70% of their nominal current load (if at least two transformers in substation are in operation) and HV/MV transformers should not exceed 50% of their nominal current load (if at least two transformers in substation are in operation).

If at least one node or line exceeds the limits, the hosting capacity for new loads of the grid is reached and subsequent modification needs to be done. Modifications are subject of the chapter “CBA and economic impact” where also costs of those modifications are calculated and different BAU and SG scenarios are compared.

VI. COST BENEFIT ANALYSIS AND ECONOMIC IMPACT

Cost-benefit analysis (CBA) in this document is based on technical and economical comparison of different business-as-usual (BAU) and Smart Grid (SG) solutions. Within InterFlex project only a few location, installations and customers are affected, but with scalability and replicability defined in previous chapters applied, those SG solutions could save inconsiderable costs for distribution capacity investments. CBA compare costs for distribution capacity investments for business-as-usual (BAU) and Smart Grid (SG) solutions. As the costs and benefits are business sensitive information, CBA results included in this document contain comparison in costs and benefits only in relative values.

A. Boundary conditions and parameters

This chapter refers to JRC “Guidelines for conducting a cost-benefit analysis of Smart Grid projects” methodology [9] and follows document’s structure. As for economic parameters, discount and inflation rate of 1.5% per year for CAPEX investment is set. Reference time perspective is for years 2020, 2030 and 2040. The reason for such long separation is the input data itself. Future scenarios from authorities, ministries and research organizations are looking to 2030, some to 2040 and only few to 2050. Implemented SG technologies covered by Work Package 6 in InterFlex project are described in detail in [5], [6] and [7]. Baseline scenarios contain grid development without SG solutions. Key assets and benefits are:

- Use case 1 – smart PV inverter with Q (V) and P (V) functions, increased DER hosting capacity in LV grids
- Use case 2 – volt-var control algorithm implemented in local DER control system, increased DER hosting capacity in MV grids
- Use case 3 - smart EV charging station, reduction of peak loads in distribution grids
- Use case 4 – smart PV inverter with residential battery, increased DER hosting capacity in LV grids

B. CBA Scenarios technical comparizon

SRA analysis quantified how much and which type of distribution capacity investments will be needed for selected time periods (up to year 2020, 2030 and 2040) for baseline as well as for SG scenarios. SRA results shows great potential of SG solutions for increasing DER and EV charging stations hosting capacity which results in reduced distribution capacity investments needs for SG scenario.

In figure 5 there is comparison of numbers and lengths of assets needed to be strengthened because of insufficient hosting capacity for connecting DERs (UC1, UC2, UC4) or EVs (UC3). For example, SG solution in case of UC1 in year 2040 needs 16 521 kilometres of LV lines to be refurbished, but without SG solution (BAU scenario) it is 20 110 kilometres. Expenditures for almost 4 thousand kilometres could be saved.

Solution	scenario	2020	2030	2040
UC1 LV [km]	BAU	0	0	20 110
	SG	0	0	16 521
UC2 MV [km]	BAU	1 261	5 37	1 507
	SG	898	155	463
UC3 EV [pcs transformer]	BAU	0	0	8 943
	SG	0	0	4 938
UC4 LV storage [km]	BAU	0	0	16 049
	SG	0	0	9 444

Figure 5. BAU and SG scenario comparison in length and pcs of assets

Example of impact of increase share of DER and EVs in CEZ Distribuce areas in the Czech Republic for selected scenarios for year 2040 is shown in figures 6 and 7 (insufficient hosting capacity in districts is coloured in red, green colour indicates sufficient hosting capacity).

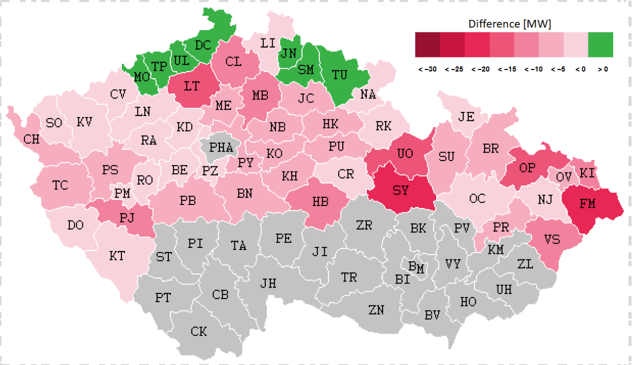

Figure 6. Areas without sufficient MV hosting capacity without SG

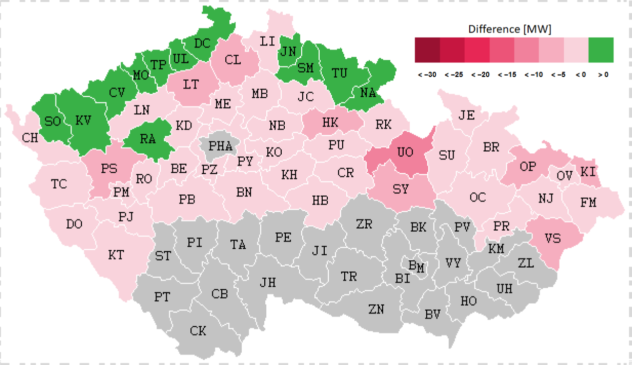

Figure 7. Areas without sufficient MV hosting capacity with SG solutions

C. *CBA Scenarios monetized comparizon*

Costs on CEZ Distribuce side are in OPEX category only and are marginal compared with CAPEX benefits. Minor OPEX costs for all use cases are caused by changes in existing internal DER and EV charging stations commissioning process or parameterization of existing communication paths between DER and EV charging stations. Due to this fact, OPEX costs are considered as 0 for this CBA purpose. There are no CAPEX costs on CEZ Distribuce side for implementation of SG solutions compared with business as usual or baseline (for all use cases). For some periods in selected use cases, no additional distribution capacity investments are generated due to the fact that predicted new installed capacity for DER and number of EVs in NAP SG scenarios are not so high to deplete hosting capacity. It's important to mention that for new DER and EV charging stations, solution tested within InterFlex, which are subject of SRA and CBA, could be easily integrated for costs less than 1% of original investment costs of DER or EV charging station installations. As the costs and benefits are business sensitive information, CBA results included in this document contain comparison in costs and benefits only in relative values.

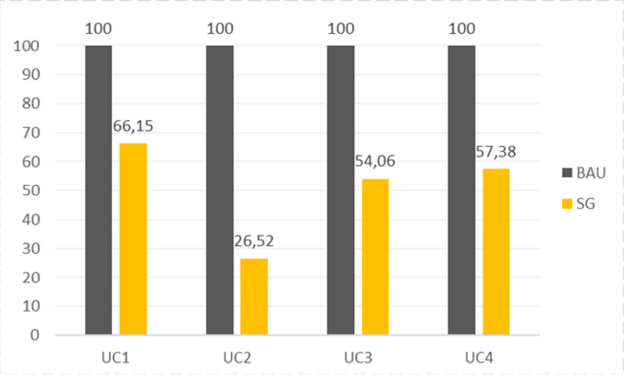

Figure 8. BAU and SG grid investment costs comparison in year 2040

VII. CONLUSIONS

This CBA analyse costs and benefits for SG solutions in case of large scale implementation in the Czech Republic. Based on positive CBA analysis CEZ Distribuce decided to use or promote these solutions to mitigate risks which are related to the expected future increased share of DER and EV charging stations in distribution grids. CBA analysis proved that in case of large scale implementation, SG solution is cost effective approach for DER and EV charging stations implementation, however some grid capacity investments will be still needed in the future. CBA is based on existing knowledge of legal, regulatory and technical boundary conditions and on inputs which are taken from the Czech government's initiative NAP SG.

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