MITIGATION OF REACTIVE POWER OVERFLOWS WITH ANCILLARY SERVICES

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Abstract

The paper summarizes changes regarding the execution of European directives (SOGL and EBGL) and their implementation into the Czech Republic regulatory system. It describes a portfolio of non-frequency ancillary services which are planned to be used or are already in operation in the local distribution, with a focus on reactive power management, which is generally considered as the most advanced of these services. The paper evaluates the reactive power overflow into the transmission system and indicates the most critical substations in the EG.D distribution grid in this regard. The paper also covers the analysis of existing resources in this particular area and evaluates their potential in reactive power management. Furthermore, it estimates the payment level for reactive power overflows from the distribution system into the transmission system.

1 Introduction

The increasing number of decentralized and distributed energy power sources, as a result of targets stated in a European Green Deal for the participating countries (amongst other factors), bears new challenges to the electricity distribution network and its operation. Most of the renewable sources are connected to the low and medium voltage levels which can result in power flow changes. Other changes in distribution grid operation, such as increasing share of cables, raise the reactive power flow in the distribution grids and lead to overflows into the transmission system [1].

The reactive power increases the transmission system losses and lowers their operational capacity. Consequently, the Czech Transmission System Operator (TSO) ČEPS a.s., needs to adjust the transmission system configuration or activate additional tools and services, which causes operational costs on their part. In case of lack of sources providing ancillary services connected to the transmission system, TSO is not able to compensate the exceeding reactive power without any additional devices.

In the current Czech regulatory system, the penalties for reactive power are set only for overflows into the distribution system, and there is no regulation for reactive power excess from the distribution to the transmission system. Due to the increasing occurrence and severity of overflows [2], a regulatory framework containing such penalties is discussed on national level platforms like the National Action Plan for Smart Grids [3]. Therefore, the highest potential in the usage of non-frequency ancillary services in the Czech Republic is generally seen in reactive power flow management.

1.1 Description of the Analysed Grid Section

EG.D is one of Czech Distribution System Operators (DSO) and its distribution area is situated in the southern part of the country as can be seen in Figure 1. The whole area is fed from nine primary substations. On the distributional area of EG.D are located six primary substations with a transformation 400/110 kV (Kočín, Dasný, Slavětice, Sokolnice, Čebín and Otrokovice) and two 220/110 kV substations (Tábor and Sokolnice). Substation Mírovka is geographically outside of the EG.D distribution area. Nevertheless, this substation presents an essential role in supplying the area of Vysočina region where major part belongs to the distribution area of EG.D. Besides above-mentioned substations, EG.D region is supplied from local power plants.

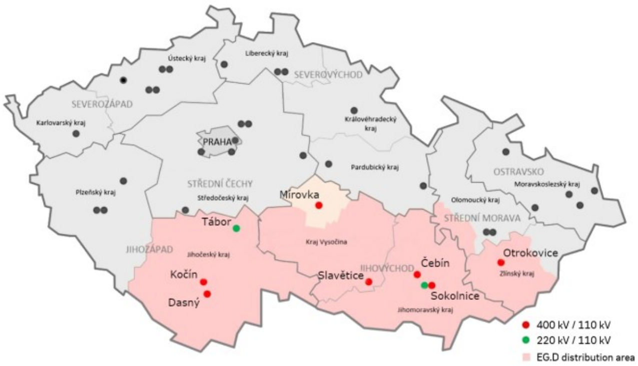

Figure 1 Distribution area of EG.D [4]

The distribution area of EG.D consists of urban areas with predominantly cable grids (like Brno, České Budějovice and Zlín) and as well of rural areas with a majority of overhead lines (Vysočina region). Due to the constantly increasing significance of reliability parameters, overhead lines in villages and district areas are replaced with cables; cable grid share is expected to rise continually. The share of cables varies with the voltage level. Presently there are 99.4 % overhead lines on the 110 kV level (only 14 km of a cable, which is located in the district of Brno), on high voltage level the share of overhead lines is 82 % and it reaches 38 % on low voltage level [5].

2 Reactive Power Flow Analysis

For the analysis, quarter-hour samples of reactive power measured at substations is used. The analyzed period is of one year (1st February 2019 – 31st January 2020), so that the end-of-year holiday period, atypical in its load profiles, is covered in its entirety. Measured values are averaged from all three phases so they do not demonstrate the possible influence of phase imbalance, but this is considered negligible on HV substation levels.

The data have been analysed for every primary substation in the EG.D distribution area. The paper uses sign convention where the minus sign (-) symbolizes the reactive power flow out of the distribution system (and into the transmission system) and correspondingly the positive numbers (+) stand for the opposite direction (from the transmission to the distribution system). The share of the time (in %) when the reactive power was flowing into the transmission system, has been calculated for every substation. Results are shown in Table 1. To have a better understanding of those shares, the median value of the reactive power for every substation throughout the examined period is also shown.

Table 1 Share of reactive power overflow and the median value of *Q*

Substation	Share of reactive power flow into the transmission system	The median value of reactive power (MVAr)
Dasný	59 %	-4.1
Kočín	99.9 %	-29.4
Tábor	59.2 %	-5.3
Mírovka	57.9 %	-5.3
Slavětice	79.1 %	-9.2
Sokolnice	76 %	-18.5
Čebín	99.2 %	-57.9
Otrokovice	56.8 %	-9.5

Results depicted in Table 1 indicate the most critical substations, with almost permanent overflows of reactive power into the transmission system. The worst situation is in the substations Kočín and Čebín, where the overflows of the reactive power occur practically throughout the whole period. Moreover, the median value in Čebín reveals that the overflow is in more than 50 % of the examined period surpassing 57.9 MVAr.

Table 2 Maximum measured values of *Q*

Substation	Max. measured value - overflow into transm. system (MVAr)	95th percentile of measured values (MVAr)
Dasný	-55	-31.2
Kočín	-101	-54.1
Tábor	-22.8	-13.7
Mírovka	-41	-26.7
Slavětice	-30	-22
Sokolnice	-66.4	-46.7
Čebín	-102.2	-87
Otrokovice	-79.9	-48

Table 2 depicts the maximal measured values throughout the analysed time. The 95th percentile of measured values eliminates the 5 % of maximal values which can occur as a result of an extraordinary situation in the grid. The highest values were measured in substations Kočín and Čebín. Relatively large values occurred in substations Otrokovice and Sokolnice. In those two substations the 95th percentile reaches almost 50 MVAr.

The data depicted in Tables 1 and 2 indicate the most critical substations in terms of reactive power overflows to the transmission systems. Regarding the results, the worst situation is in Čebín substation. The excess of reactive power occurs practically throughout the whole examined period, with typical values around 50 MVAr. Substation Kočín can be considered as the second-worst one. The excess of reactive power takes place almost through the whole period as well, but it does not reach such extreme values (typically around 30 MVAr).

The cause of the extremes in those two particular substations is different. The substation Čebín is located in the north of Brno and the main load of this substation covers the northern part of the city. Brno, as the second biggest city in the Czech Republic, has a high share of cables in its urban grid. Low-loaded cables generate a significant amount of reactive power. Moreover, in the region of Brno is situated a 17 km of 110 kV cable. The 110 kV cable has a higher impact on reactive power production than the MV cables due to immense loading output. Substation Kočín feeds mostly rural area and the grid works with a lower load in general. Furthermore, the excess of reactive power relates to the double overhead line from the adjacent nuclear power station Temelín to Kočín substation, which is used primarily as a backup. The low loading of this line contributes to the excess of reactive power in this substation.

2.1 *Load of the Grid and Its Impact on Reactive Power Flow Management*

Substation Otrokovice represents a different type of reactive power overflow pattern. At first sight, this substation could be qualified as one with a balanced ratio of overflow and consumption of the reactive power. According to the measurements throughout the period, the flow of reactive power from the transmission to the distribution system occurs in 43 % of the time and the other 57 % of the time occurs a reactive power overflow directed to the transmission system. The values reach a relatively high maximum in both directions (81.5 MVAr and -79.9 MVAr). The histogram of the measured *Q* values is shown in Figure 2. For easier orientation is coloured in blue the excess of the reactive power to the transmission system and the flow of the reactive power to the distribution system in green.

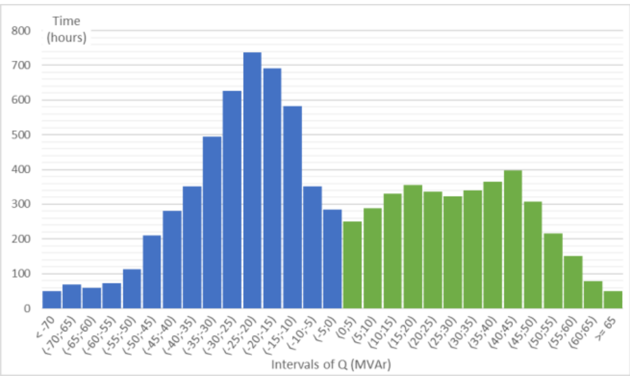

Figure 2 Substation Otrokovice – entire period histogram

For better recognition of the cause of these extreme values, data were divided according to the time in a week into two groups. The first one was for business days (Monday to Friday) from 6:00 to 22:00 and the second group was for weekends (Saturday and Sunday). This approach allowed to divide the data according to the load of the grid. In general, the load of the grid is higher during business days than over the weekends. The results of this analysis for Otrokovice substation are shown in Figure 3 (business days 6:00 to 22:00) and Figure 4 (weekends).

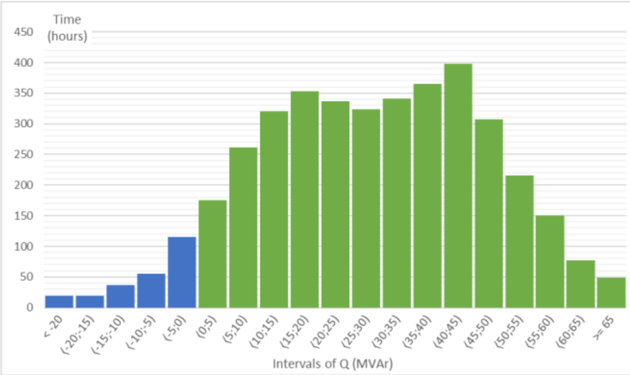

Figure 3 Substation Otrokovice – business days (6:00-22:00) histogram

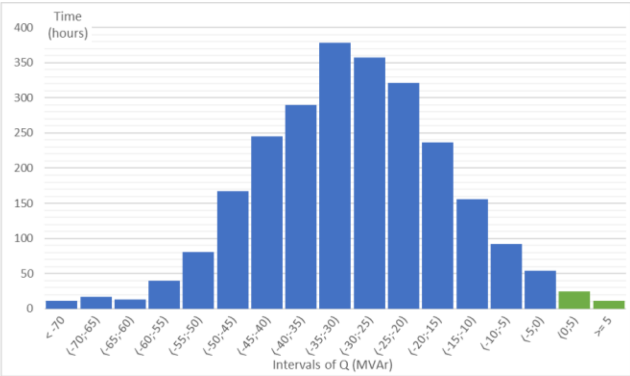

Figure 4 Substation Otrokovice – weekends histogram

The contrast between Figures 3 and 4 reflects the reactive power balance dependence on the load of the grid. The difference depicted above is amplified by the character of the Zlín region which is fed by the substation in Otrokovice. The region of Zlín is a distinguished industrial area and the maximum load of the Zlín region is comparable with the load of the whole southern Bohemia (substations Kočín, Dasný, Tábor). Above that, the load of the area varies during the day, reaching the maximum around 10 AM and significantly lower consumption over the night. This difference in the load is the reason for the substantial dispersal of the measured values. In this particular case, the impact of the grid load on reactive power balance is distinctly visible. In other substations, the difference was not so significant because of the lower variation of the load during the week.

3 Present Potential of the Reactive Power Flow Management in the EG.D Distribution Area

The previous chapter determined the most critical substations in terms of reactive power balance in the EG.D distribution area as well as its dependence on a time and day in the week. Building on this analysis, the reactive power flow management potential of the current power sources was analyzed. For purpose of the analysis, the sources with an installed capacity higher than 0.5 MW were considered. This limit has been chosen in accordance with the document National Action Plan for Smart Grids, where is this boundary defined for power sources aiming to participate in non-frequency ancillary services [3]. According to the location and grid configuration, all sources were assigned to the closest substation. For substation Mírovka, only sources located in the EG.D distribution area were included.

The sources were classified into three groups according to the type of the source to reflect on different production diagrams. The first group is photovoltaics (PV), which is closely linked to weather condition and particularly to the time of the day. The second group presents biogas and cogeneration power plants (BPP + CHP). The production diagram of these two sources is specific; in order to reach a subsidy (commonly named as "green bonus" in the Czech Republic), their operational time is reduced to 3000 or 4400 hours per year. The third group is presented with the remaining type of sources, including water, wind or gas turbines. The installed output of the existing sources was converted into the maximal potential in reactive power management with the power factor set to 0.95 inductive (this is used in the distribution grid operation guidelines as mandatory grid support). Results are shown in Table 3.

Table 3 Current potential for reactive power flow management; regulation with power factor 0.95L

Substation	PV *Q* (MVAr)	BPP+CHP *Q* (MVAr)	Others *Q* (MVAr)	Total *Q* (MVAr)
Dasný	45.4	16.7	72	134.1
Kočín	31.4	9.2	24.5	65.1
Tábor	9.7	3.6	29.4	42.7
Mírovka	2.7	6	7	15.7
Slavětice	26.9	10.3	10.2	47.4
Sokolnice	102.9	13.1	99.0	215
Čebín	24.8	14.1	87.7	126.6
Otrokovice	84.2	10.4	108.3	202.9

The results of the analysis together with the results shown in Table 2 (maximal measured values) indicate sufficient potential in already installed sources for most of the substations. The current capacity to cover the peak values is not satisfactory only for substation Kočín. The results shown in Table 3 take into account the ideal scenario when the delivery output is equal to the installed one and the entire potential can be used for the reactive power regulation. This can be seen as overtly optimistic regarding reliance on regulation of PV sources due to its intermittent character of generation.

3.1 Currently Used Tools with Reactive Power Flow Management

During the spring of 2020, extremely low loading of the grid occurred as a result of the world pandemic of Covid-19 and the strong restrictions such as the closure of shops, schools or limitations in industry production. Because of the lower consumption, TSO did not have enough tools and capacity to eliminate reactive power. Therefore the DSOs in the Czech Republic were appealed to use all possible resources to eliminate the overflow of the reactive power during the time of Easter holidays (Friday 10th April to Monday 13th April). Over this period, EG.D set all available power sources to the power factor of 0.95 inductive (so that the sources were consuming the reactive power) to limit the overflow of the reactive power from the distribution system. This reaction helped to reduce overflow by almost 80 MVAr in this distribution area during the daytime in comparison with the previous weekend (4th and 5th April) as depicts Figure 5. Unfortunately, the reactive power control is limited mostly on PV sources, which is visible on a higher overflow over the night. Higher values of reactive power during easter Monday (date 11.4.), in comparison to other days when the reactive power control tool was active, indicate worse conditions for PV sources (cloudy weather).

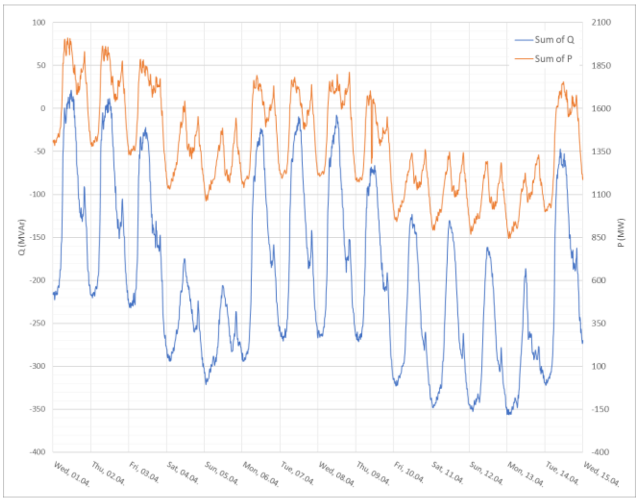

Figure 5 P and Q chart for the whole EG.D area over the Easter time, blue line represents *Q* and orange line represents *P*

4 Estimated Costs for Reactive Power Flow Management

In the previous chapter was analysed the regulation of currently operatin sources. Another option of reactive power overflow management is the installation of shunt reactors in the primary substations. This variant requires an initial investment. One of the objects of the thesis [6] was to find the optimal size of the shunt reactors to use its maximal potential and combine it with the utilization of current potential in the grid through ancillary services. The fee for approaching the ancillary service (reactive power flow management) was determined on a level of 1 €/MVArh, with respect to the durability of the compensators and constant values of reactive power overflow over their lifetime. The results of the optimization for every substation are depicted in Table 4. The calculated capacity of the compensators confirms the results presented in part 2.

Table 4 Optimal size of the compensator and yearly costs for acquired ancillary services N_{SERy} (Q flow management)

Substation	Q_{KOM} (MVAr)	$Q_{KOM}/Q_{5.perc}$	N_{SERy}
Dasný	20.8	66.5 %	13 600 €
Kočín	41	75.9 %	18 200 €
Tábor	9.1	66.3 %	5 800 €
Mírovka	16.8	62.9 %	12 400 €
Slavětice	16.1	73 %	7 700 €
Sokolnice	34.8	74.4 %	15 900 €
Čebín	75	86.3 %	15 100 €
Otrokovice	28.2	58.8 %	25 500 €

Provided that the amount of overflow stays in the next years approximately similar and the assumed price of the service would be multiple of the one here identified, appear the acquisition of shunt reactors for the DSO as a preferred variant.

5 Conclusion

Non-frequency ancillary services and especially reactive power flow management are expected to play an important role in the normal grid operation in the future. Subsequent necessary changes in the regulatory frame should aim to encourage the providers to offer these services on the market. The first step in this subject has been made at the beginning of the year 2021 with a change in the installed capacity limit for the power sources providing ancillary services to 1 MW (including the possibility of aggregation) [7].

As a priority in this field should be to operate tools, which are already implemented in the grid, and their utilization (despite the possible additional costs) than the installation of new devices. Present potential in already installed power sources is generally seen as sufficient. However, until now the DSO is not stimulated to limit the overflow of reactive power to the transmission system due to the missing penalties.

6 References

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