The Potential of Distribution Grid as an Alternative Source for Reactive Power Control in Transmission Grid

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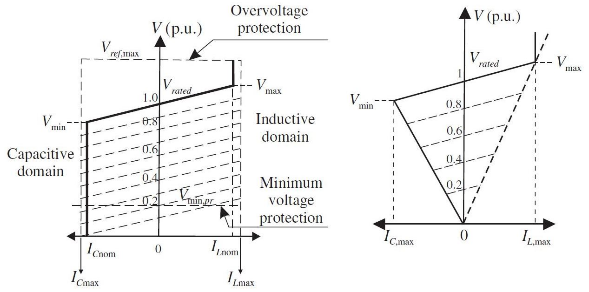
***Abstract*—Nowadays, the global trend in the energy sector is the spreading use of renewable energy, especially wind generators and solar panels. The high concentration of such sources in distribution grid increases the voltage in case of small load demands and high production which effects the voltage at connection point and, in turn, in transmission grid. To regulate voltage and control reactive power, system operators install costly equipment in transmission grids. This paper considers alternative way of voltage and reactive power managing and discovers possibilities of PV converters in MV and LV grids with different type of control to solve this problem.**

***Keywords*—DigSILENT, distributed generation, photovoltaic (PV) systems, reactive power control, PowerFactory, voltage control**

I. INTRODUCTION

Renewable sources are becoming the main type of fuel. Small and medium power plants operating by bio fuel, wind, and solar energy replace big plants firing fossil fuel with huge emissions. However, the first challenge is that in such regimes, when injection from Distributed Generation (further – DG) into the grid is maximum and loads in this area are close to the minimum, the reverse power flow and overvoltage in grid appear [1]. The second challenge is that the system reactive power requirements also depend on the configuration of generation and transmission. Consequently, the system reactive requirements vary in time as load levels and generation patterns change [2]. There are several technical solutions for the voltage problem. This could be the reconstruction of grid, which is global and long-term project. The managing voltage with tap changer leads to under voltage in neighboring feeders with low penetration of PV panels [3]. The implementation of batteries, which can store or inject power for support of voltage and frequency, is another option, but not very popular [4]. The most common solution nowadays is the changing reactive power flow through installation of devices in transmission grid such as static synchronous compensator (STATCOM) or the static VAR compensator (SVC) [5]. The main disadvantage is that these solutions lead to huge investments [6].

The aim of this paper is to examine the possibilities of converters of PV panels in LV and MV grids to control reactive power and voltage at the connection point of distribution grid to transmission (PCC – point of common coupling). If we look on V(I) characteristic of STATCOM and SVC presented at Fig.1 we can see, that such equipment can generate both inductive or capacitive currents and changing by this reactive power flow and correspondingly voltage at the node [7].



(a) (b)

Fig. 1. The V(I) characteristic of STATCOM (a) and SVC (b). [7]

At the same time, the converters in renewable sources are able to control voltage, reactive power or cos φ in local nodes where they connected to the LV or MV grid. Moreover, they have the same shape of characteristic and more variety. The example of Q(V) characteristic of a PV converter is presented at Fig.2.

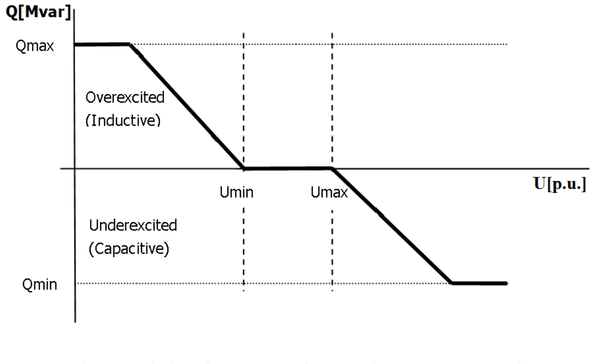


Fig. 2. Q(V) characteristic of converter for reactive power control. [8]

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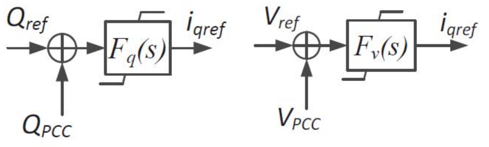
The question is, if any converter reproduces proper characteristic at local node, what would be the summation result of all converters at PCC? Is there any mismatch, can the set of inverters produce necessary amount of reactive power and deliver it to PCC? Is there any difference between control strategies? In this paper, some answers for these questions are presented as well as future directions for research in this area are declared.

II. CONTROL OF PV CONVERTERS

Generally, voltage and reactive power control can be organized in two ways [9]:

- the direct regulation in which reactive power is directly regulated to a preset value as shown in Fig. 3a;

- the indirect regulation or direct AC-bus voltage control in which AC voltage at the point of PV connection to the grid is directly controlled to a preset value as shown in Fig. 3b, and by doing so, reactive power is indirectly regulated.



(a) (b)

Fig. 3. Direct (a) and indirect (b) reactive power and voltage control implementation [9].

In this research, the PowerFactory software DigSILENT [10] (further – PowerFactory) is used for grid modelling and making of simulations. This software lets to implement different type of control for converters for steady state and dynamic simulations. For steady state simulations, PowerFactory provides following predefined controllers: a) constant V; b) voltage Q-droop control; c) voltage Iq-droop; d) constant Q; e) Q(P) control; f) Q(V) control; g) cosphi(P) control. Some of these controllers' types are an extended version of others; therefore, we introduce and use only some of them.

Constant Q control defines exactly the amount and direction of reactive power injecting/consuming from the grid. It could be defined like absolute value of Q (capacitive or inductive) or with cosφ. In the latter case, reactive power will proportional to active power generation.

Constant V control is done locally. Depending on voltage, the controller changes reactive power output to achieve set voltage at the node, while active power output is constant.

In case of Q(P) control, the local controller acts according to characteristic predefined for this node. For the specific amount of generated active power converter generates or consume reactive power as it presented at Fig. 4. It should be noticed, that in case of non-production at night, the converter can still provide reactive power for voltage regulation in the grid.

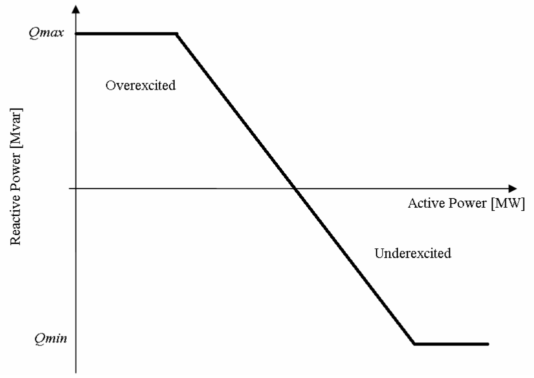


Fig. 4. Q(P) characteristic of converter [8].

The example of Q(V) control is already presented in Fig.2. The local controller acts as a reactive power controller with an adjustable setpoint. While the reference voltage is within the deadband, the entered reactive power setpoint is kept. If the reference voltage leaves the deadband, the reactive power setpoint is adapted according to the droop and the voltage deviation from the respective end of the deadband.

III. DESCRIPTION OF THE MODEL

For the investigation, the existing distribution grid in Germany is taken. The initial model in PowerFactory has developed by S. Geidel [11] from Energynautics, one of the collaborators of the SNOOPI project [12]. Then, this model was extended and reconfigured by KTH representatives and authors of this article. For this particular research, simulations for one 20 kV feeder "Gundersheim" connected to primary substation system is carried out. Most of the feeder is supplying 49 MV/LV substations via underground cables apart from a few overhead lines, interconnecting villages. The furthest substation is at the distance of about 22 km. All parameters of lines are taken into account in the model. Due to lack of space, it is not possible to show the system topology, but generally, "Gundersheim" feeder can be represented with the Table 1.

TABLE I. BASIC FACTS ABOUT THE 20KV "GUNDERSHEIM" FEEDER

Grid Parameter	Value
Number of small scale PV plants	278
Small scale PV capacity	4.4 MW
Number of large scale PV plants	1
Large scale PV capacity	7.3 MW
Maximum load (year 2015)	3.7 MW
Active power range at feeding point (year 2015)	-7.2 MW to 3.7 MW

Despite the available data for some LV grids, in the initial stage, all MV/LV substations represented as aggregated load and aggregated generation from PV panels. DSO has provided the measurements for the period from 18.06.15 00:00 to 25.06.15 00:00 with step of 15 minutes for loads and for output of the large-scale PV power plant at "fre08" node as well as voltages at primary substation. This period has had the most significant fluctuation in power flow. Since all PV panels are relatively in close distance from “fre08” node, their output was assumed based on large-scale PV power plant generation profile and their nominal power. Based on this, for each MV/LV substation load profiles and PV, generation curves were created using PowerFactory time-characteristic element.

As mentioned above, DSO provided measured voltage at the primary substation. However, to obtain characteristics with capacitive and inductive reactive power flow, voltage profile was randomly generated in diapason 0.95…1.10 p.u. It means that the distribution grid has to react and provide necessary amount of reactive power to the PCC according to the voltage settings and grid constrains. We emphasize that stabilizing of voltage at primary substation is not a task at this time; we will carry this kind of simulations out in the next stage.

Simulations were done for different operational scenarios, i.e. for different type of control of PV converters described above. Operational limits for small scale PV reactive power are ±0.41 p.u. as at the large-scale PV plant; power factor is 0.95.

For Q(P) control the Q(P) curve is defined as presented at Fig. 4. Parameters are set so that PV plant starts to consume reactive power, when generation exceeds 0.4 of nominal active power. The maximum amount of reactive power which can be consumed is 0.41 p.u. Generally, there is a possibility to inject reactive power into the grid, when PV panel has zero output and regulate voltage by this, but for householders it is not profitable; that is why usually the converter is switched off during the night.

The example of Q(V) characteristic is already presented at Fig. 2, but in PowerFactory, settings are in a numerical form and do not have graphical representation. However, it is easy to plot this characteristics after simulations. In addition, there is no possibility to define max and minimum reactive power output in p.u., here absolute numbers are based on operational limits, i.e. ±0.41 p.u. When voltage is in the range of 0.98-1.02 p.u., there is no regulation; when voltage exceeds settings, converter consumes reactive power and, on the opposite, generates reactive power, when voltage is under limits.

IV. SIMULATIONS AND RESULTS

For each of operational scenarios Quasi-Dynamic simulations were completed for the period mentioned above with the step of 15 minutes, total 576 iterations. To check the controllers operation, load profiles, P-Q and Q-U plots were created for all nodes. The results of simulations are presented below.

A. Constant Q, cos φ=0.95

This kind of regime is a typical for small scale PV plants. Fig. 5 and 6 present charts obtained for one of MV/LV substation “ghm01” and const. Q control. We can see that controller works properly. It always consumes reactive power, when PV generates active power. The P-Q characteristic has proper linear shape.

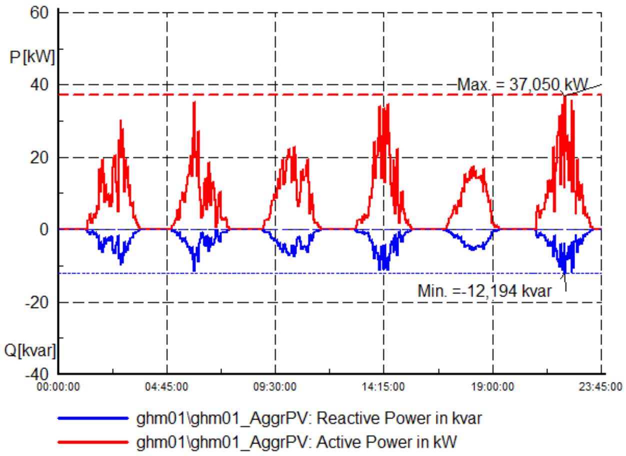


Fig. 5. Results of simulations for ‘ghm01’node with const. Q control. Power flow.

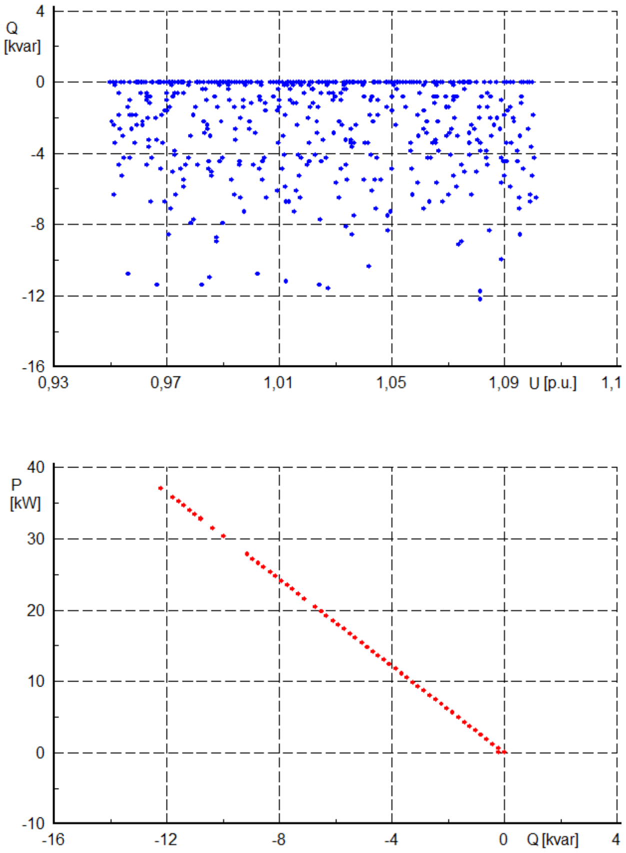


Fig. 6. Results of simulations for ‘ghm01’node with const. Q control. Q-U and P-Q diagrams/

At the primary substation, almost the same picture could be observed (Fig. 7). There is small dispersion in P-Q plot; distribution grid injects reactive power into the main grid most of the time. Here it should be noticed, that “-” before power means external grid receives power from the distribution grid.

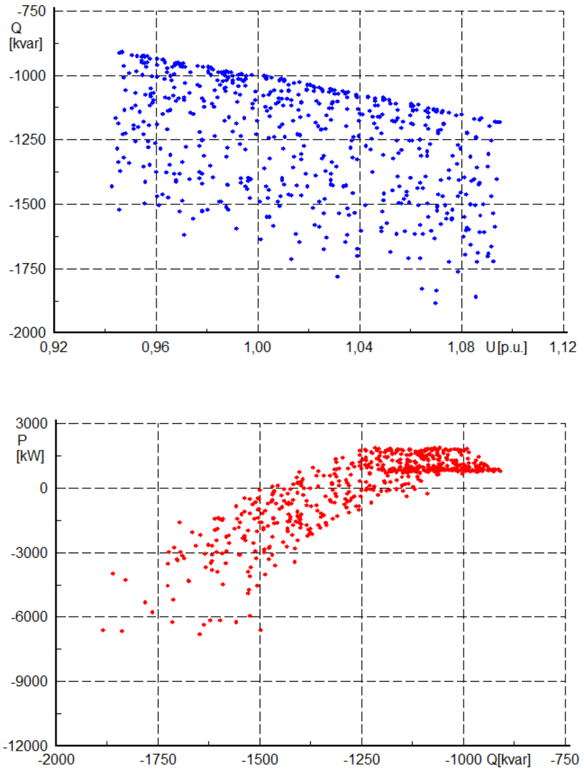


Fig. 7. Results of simulations at PCC with const. Q control. Q-U diagram and P-Q diagrams.

B. *Constant V*

At Fig. 8 the chart for MV/LV "fre01" is presented. We can see that converter literally has two regimes: it consumes maximum amount of reactive power in case of voltage is above setpoint of 1 p.u., and generates reactive power, when voltage is under 1 p.u.

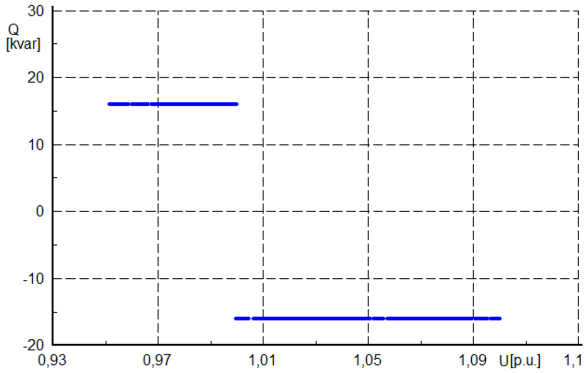


Fig. 8. Results of simulations for 'ghm01'node with const. V control. Q-U diagram.

From the results at the primary substation presented at Fig. 9 we can see that Q-U plot has more appropriate shape compare to local. In addition, external grid receives reactive power from distribution grid when voltage at PCC is less than 1 p.u. and, on the contrary, the distribution grid consumes reactive power to reduce voltage at PCC. However, significant fluctuations of reactive power and voltage can be observed. This can be explained by the fact that all controllers try to fix voltage locally, with the same set point and, as the result, such kind of disturbance appears in the grid.

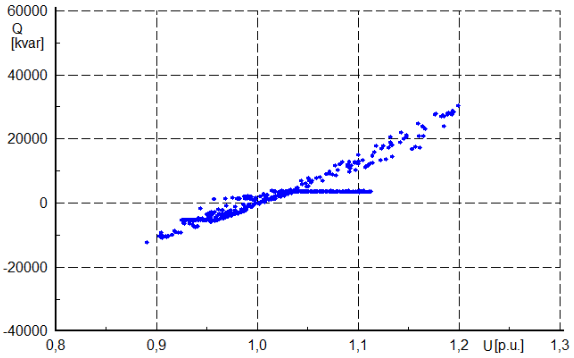


Fig. 9. Results of simulations at PCC with const. V control. Q-U diagram.

C. *Q (P) control*

The P-Q and Q-U diagrams for local MV node 'ghm01' are presented at Fig. 10. Here, it is possible to see the shape of Q(P) characteristic similar to Fig. 4 and that converter starts to consume reactive power when active power output is reaching a setpoint.

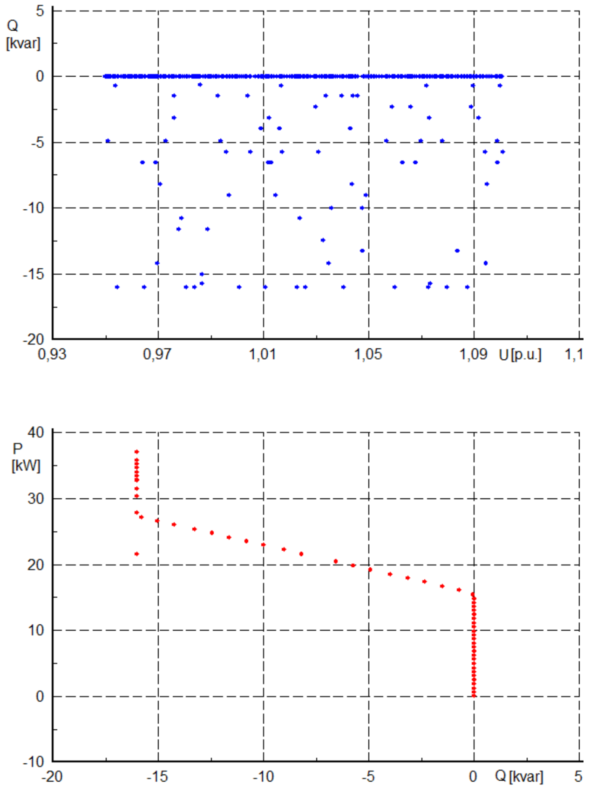


Fig. 10. Results of simulations for 'ghm01'node with Q (P) control. Q-U diagram and P-Q diagrams.

Since such kind of control is not a direct regulation of voltage, there is no influence of reactive power on voltage, and Q-V plot presented at Fig. 11 shows that. At the same time, it possible to see that the distribution grid provides almost the same shape of Q(P) characteristic to the transmission grid.

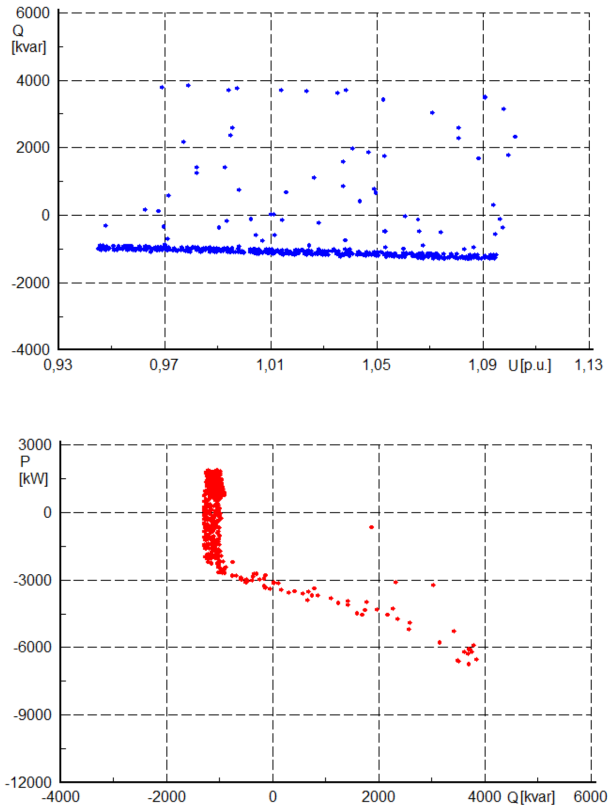


Fig. 11. Results of simulations at PCC with Q (P) control. Q-U diagram and P-Q diagrams.

D. Q (V) control

Fig. 12 and Fig. 13 show Q(V) characteristic and Q-P plot for MV/LV substation at the node 'ghm01'. We can see, that converter operates properly and within reactive power limits.

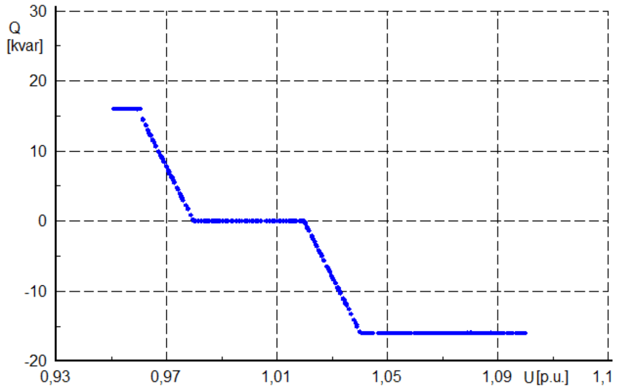


Fig. 12. Results of simulations for 'ghm01'node with Q(V) control. Q-U diagram.

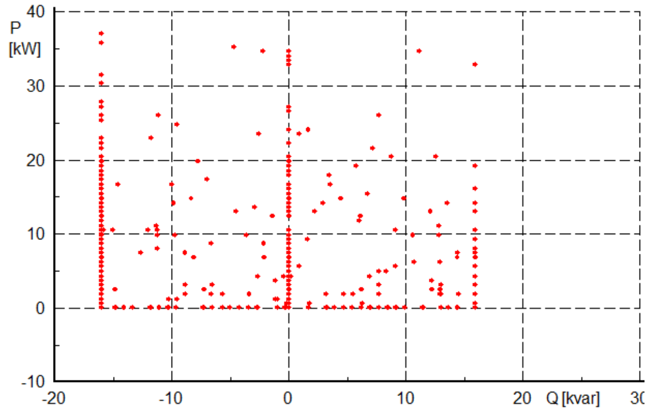


Fig. 13. Results of simulations for 'ghm01'node with Q(V) control. P-Q diagram.

The results of simulations for PCC are presented at Fig. 14 and Fig.15. We can see that reactive power flow through the node well balanced and voltage regulation goes well, has a proper shape and repeat settings of the local controllers.

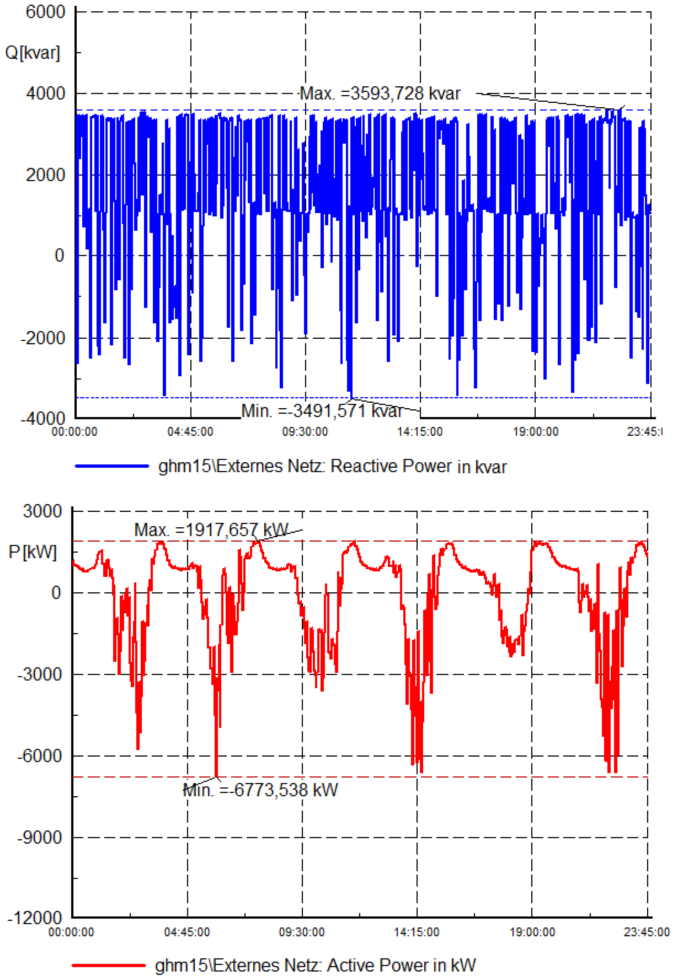


Fig. 14. Results of simulations at PCC with Q (V) control. Power flow.

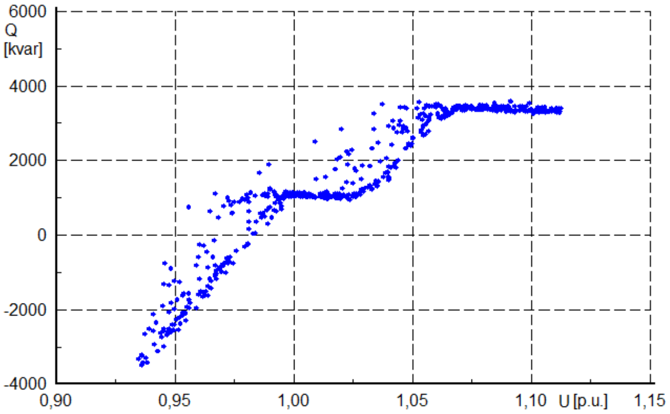


Fig. 15. Results of simulations at PCC with Q (V) control. Q-U diagram.

V. CONCLUSION

In this paper, the existing feeder of 20 kV distribution grid with high penetration of solar was considered. The aim of the research was to discover ability of different types of controllers at local nodes to manage the voltage and reactive power flow at the connection PCC, i.e. transmission grid. Simulations are performed for direct regulation (const. Q and Q(P) control) and indirect regulation (const. V and Q(V) control).

The results show that in all the investigated cases, even with rough settings, renewable sources are able to generate/consume reactive power according to the voltage set points at the primary substations, i.e. satisfy reactive power needs. Generally, P-Q characteristics of local controllers can be “transferred” to the PCC node. Some types of control such as “Constant V” and “Q(P)” needs additional tuning. The first one shows a good ability to regulate voltage through changing reactive power flow, but in some points conflicts appear because each node tries to keep the same voltage level. Since Q(P) control is an indirect regulation, for the best performance, Q(P) characteristic needs more accurate parameters determination with the final result to reduce voltage fluctuations.

The most accurate and flexible type of control is Q(V). The simulations show that with such a kind of control, it is possible to obtain Q(V) characteristic in PCC, which is very similar to the same characteristics of SVC or STATCOM. This is a very important fact, because due to this, new prospective of voltage regulation in transmission grid through renewable sources in distribution grid appear. It allows to increase the amount of renewable energy and may avoid huge investments for costly equipment in transmission grid.

VI. FUTURE WORK

In this paper, some possibilities of distributed generation to regulate voltage and control reactive power were shown, but still many questions require investigation. One of them is economic efficiency, because such an approach increases losses in distribution grid. For this reason, the authors plan to pay more attention for power flow and the detailed model with low voltage grids. Another question is how fast a response of converters in low and medium voltage level is. The authors plan to turn to dynamic modelling and perform simulations to investigate this problem. In addition, different combinations of control for large and small-scale PV plants are possible to consider as well as an implementation of central control for all renewables in the distributed grid. This direction will be also investigated in the nearest future.

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