LOCAL VOLTAGE CONTROL IN SMART GRIDS WITH TIME DEPENDENT POWER FACTOR

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ABSTRACT

This paper deals with the influence of a large share of distributed (dispersed) generation (DG) on a voltage profile in distribution networks. Until recently, the newly installed DG operated only with constant power factor, which was usually cosφ = 1. Countries around the world are now accepting the new rules and guidelines, which require that all DG participate in the voltage control, as they are the main reason for the voltage rise in distribution networks. Slovenia has already issued a document that prescribes different static characteristics Q(U), which determine the power factor of DG with respect to the voltage at the connection point.

As the new technologies nowadays allow bidirectional data flow in almost real time, more active participation of generators in voltage control is possible. Concept of voltage control which exploits these ideas is presented. At a certain intervals desired cosφ can be send to all generators in the network. Advantages of such a regulation are pinpointed out. Different solutions were evaluated by means of simulation on a real medium-voltage network, which demonstrates good flexibility when using such methods.

1. INTRODUCTION

Distribution utilities have to maintain network voltage between tight limits, which is essential for correct operation of customer loads. Control of the classical distribution system operates centrally; the last measured point in the system is at the secondary side of the on-load tap-changing (OLTC) transformer in the substation which determines the voltage level according to the measured voltage. The system is dimensioned in a way that the voltages are always in the statutory defined limits [1] - [3], [8]. By introduction of DG into the distribution grid, this concept of voltage control is not suitable anymore and new control schemes have to be developed. In [4] the authors say that until today the PV market has exhibited a quite constant evolution, so that it is often compared to the sector of microelectronics, governed by the Moore's law. The "PV Moore's law" postulates a 20 % PV costs reduction with every doubling of cumulative production capacity. Actually, the prices of PV devices reduce by about 8 % each year, therefore are halved in about eight years.

Distribution networks are designed in a way that they don't predict the dispersed generation. When planning, the maximum and minimal possible power consumption is assumed. Then the conductor intersection is determined in a way that the voltage always remains within the prescribed limits. In cases where there is a lot of DG in the network, voltage may increase locally, which cannot be detected by the measurements in the substation. This can happen during the time of high DG production and low consumption, for example:

- a strong wind at night in case of a large number of wind farms and
- high output from PV sources at the midday in the urban places.

Traditional solution to these problems would be reinforcement of the network with new power lines and thus its over-sizing. Such solutions are in a way reliable, but because of the environmental reasons and legal restrictions in most cases very expensive and not economically justifiable solution. One of the alternative approaches is the use of improved central voltage control with voltage measurements of multiple points scattered all around the network and local reactive power control of DG which can enable that kind of operation. Their correct and consistent operation solves several problems in the network. DG may have with a proper management a positive impact on the network. It may contribute to the postponement of the investments in the network, reduction of losses and increase of supply reliability.

The concept of smart grids is in a way an upgrade of traditional system operation and planning. It includes classical elements (large centralized production units, transmission and distribution networks) and new elements, such as dispersed generation, advanced metering, customers who participate in adjusting their power consumption, virtual power plants, infrastructure for electric vehicles and energy storage. This topic is one of the major research and development priorities in the EU's electricity area [6], which leads to its energy independence and the transmission to a low-carbon society.

Using present values, an effective operation requires an accurate evaluation of the situation in the network, which could be difficult in some cases. Data from the smart meters must be sent in to the control center where they are processed. From there, the calculated desired operating points are sent back to the all generations.

One of the promising technologies is Power Line Communication (PLC), which is a technology that uses the existing power lines as the communication medium to transmit high-speed data signals from one device to another by using different modulation techniques. The advantage of using electric power lines as the data transmission medium is that every building is already equipped with the power line and connected to the power grid [10]. Time delays are few tens of ms. China, for example, is planning to install millions of smart meters based on PLC technology by 2015 [11]. However, PLC technology also has some issues as the power line presents a difficult medium for transmission of information as of the unpredictable noise, interference and string damping.

2. LOCAL REGULATION – CURRENT PRACTICE

Until recently all DG operated with constant power factor ($\cos\varphi = 1$) and therefore did not participate in the voltage control. Given the fact that dispersed generation is the main reason for the voltage rise, it should take some share of responsibility and participate in ancillary services. Nowadays many countries have already set up rules for DG to use static $Q(U)$ characteristic. In 2011 Slovenia issued [7], which prescribes these characteristics to participate in voltage control. On the basis of local voltage measurement and current active power output of DG, its necessary reactive power is determined. The ration between necessary reactive and active power is determined as tgφ. Example of two different static characteristics is presented in the fig. 1.

Such a regulation has many disadvantages. Many times reactive power is injected to the system when this is not necessary (when the voltages are inside the limits) and thereby increasing the losses. Without communication links DG cannot participate in voltage control in the event of an emergency. Moreover, that kind of local regulation does not ensure fairness. If a customer lives in the place far away from substation where voltage deviations are more frequent, the inverters will be burdened more than those located there where the voltage deviations are minor. Also their location may change depending on how the entire distribution system is configured. As the retail customers typically have no choice where they are located along a feeder, it seems not right required of them to produce a large amount of reactive power and in that way take all the burden and responsibility for the voltage rise along the entire feeder. Example of unfair reactive power distribution is shown in the fig. 7 in chapter 4, where simulations with different control strategies were carried out.

Static way of helping in reducing the voltage rise is only temporary solution. Once smart meters and the communication infrastructure will be installed in the vast majority of the network, we will be able to exploit these advantages to create better and more effective controls.

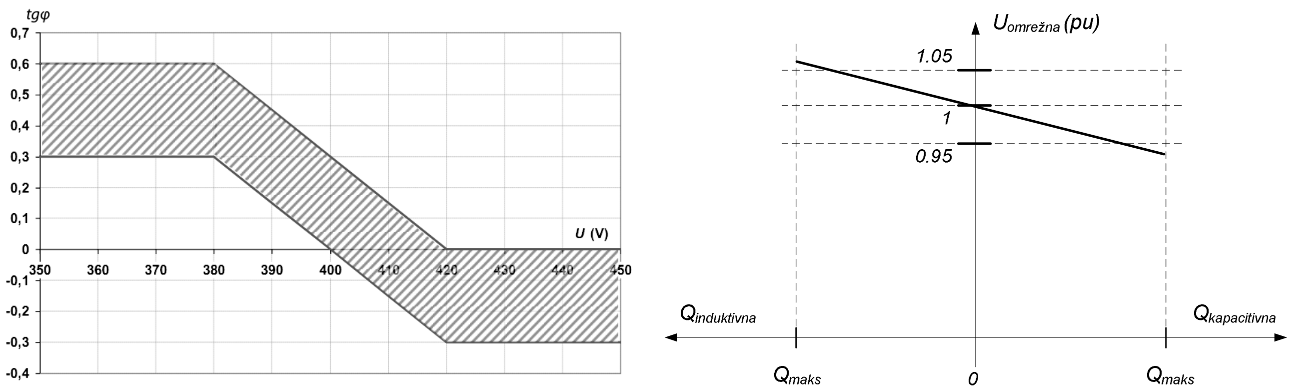

Fig. 1: Example of static $Q(U)$ characteristics for DG [7], [8].

3. LOCAL CONTROL SYSTEM DESIGN

In [12] the authors have dealt with the problem of optimization of capacitors in the network. By switching capacitors, they have reached minimal losses and corresponding voltage profile. They have also minimized the number of switches. Data from the monitoring sites were sent to a control center, where a load flow iteration procedure has been implemented to search for a best solution. In this article this idea has been upgraded by inclusion of local DG control in Smart grids.

Since in Smart grids we have the possibility of measuring the present values, this can be used for several types of optimizations, such as:

- to maintain the voltage within the limits,
- reduce network losses,
- minimize the investments in the network,
- minimize the number of switching of OLTC transformer,
- minimize the reactive power production,
- improve stability,
- relieve the operator’s burden,
- minimize the costs of network maintenance and
- Improve the monitoring of the network.

All this assuming a fair distribution of reactive power from DG is guaranteed. A fair distribution has been determined by the ratio of required reactive power and active power production. Single tgφ along entire feeder can be established. Participation in ancillary services is thus proportional to active power production.

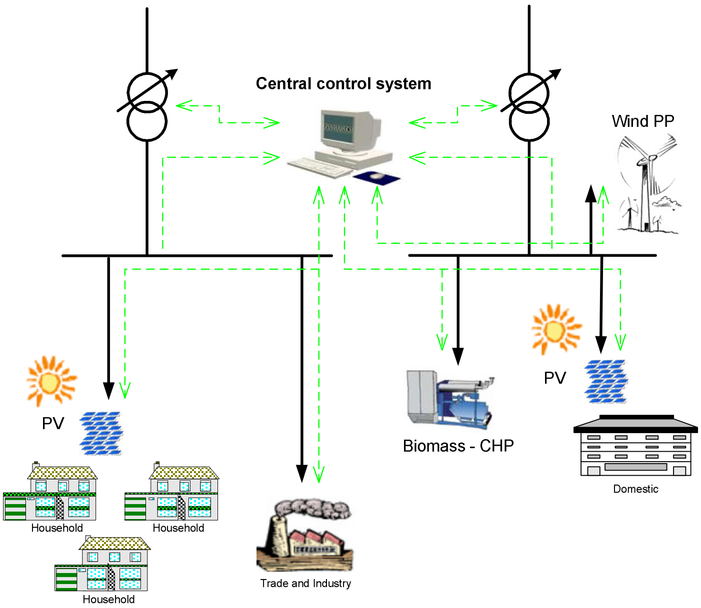

Fig. 2: Example of Smart grid.

Measured data is collected in the control center. The core of the algorithm is a simulation tool, which continuously runs simulations and determines optimal operation point based on the present measured values. Two criterions are taken into account: minimal network losses and minimal reactive power injection from DG. Which condition is more important is not anymore only a technical question.

Fig. 3 presents the calculated value of losses for one given moment of time (consumption situation) depending on common tgφ. Few load flow simulations are performed to find the minimum value. This tgφ value is then sent to all generators in the feeder. Of course this does not mean that they will all operate exactly with the desired set point, but will approach as close to this value as it gets.

Fig. 4 shows various possible tgφ trajectories of one feeder for one day. Red line is the desired set point of minimal losses. Because of the voltage limits in some cases during the day tgφ has to withdraw this trajectory. Similarly blue line presents tgφ where reactive power generation from DG is minimal with respect to the voltage limits. The figure shows that this has happened at the maximum solar activity, when the sources had to absorb some of the reactive power to reduce the voltage rise and in the evening when solar activity is low and consumption has risen. DG's have therefore produced a large amount of reactive power to obtain minimum threshold. Which of the operating point will be sent to the generators, as said, is a matter of economic evaluation.

It may happen that some DG are unable to produce required amount of reactive power or the minimal cosφ is defined and the deviations are so great that voltages are beyond the statutory defined limits. In that case obtaining voltage limits has priority over any other optimization.

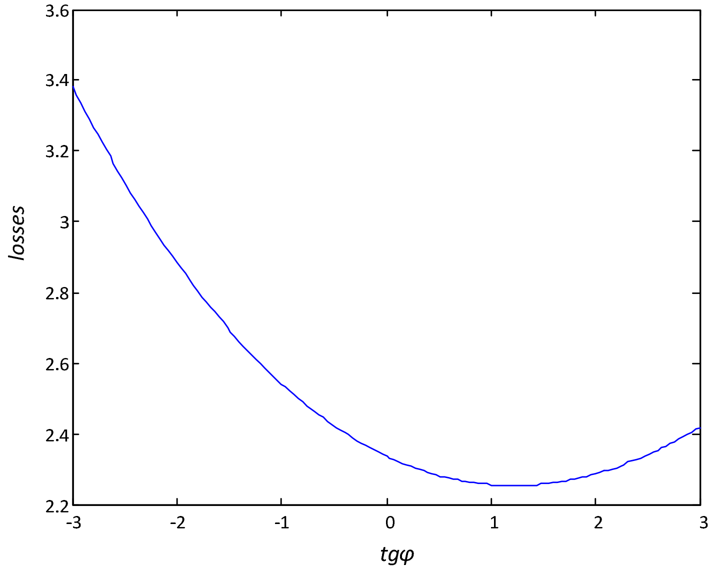

Fig. 3: Feeder losses as a function of uniform tgφ.

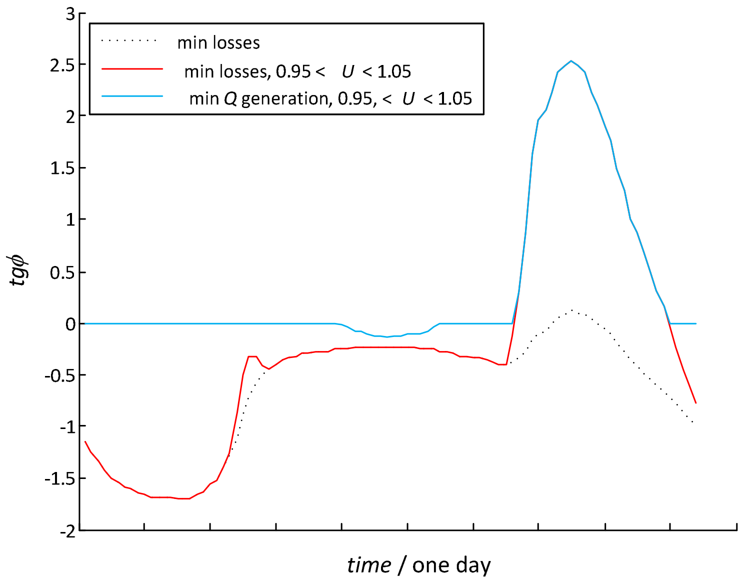

Fig. 4: Optimal calculated tgφ for all DG.

4. CONTROL SYSTEM PERFORMANCE EVALUATION

Fig. 5 presents single line diagram of one feeder of 20 kV medium voltage distribution network. The network was modeled in in the DIgSILENT Power Factory simulation program and the voltage regulation algorithm in Matpower 4.1, which is a package of Matlab m-files for solving power flow and optimal power flow problems [13].

Few typical daily load patterns were developed (residential, commercial and industrial loads). For loads a power factor cosφ = 0.95 was presumed. As the growth of DG in Slovenia is very fast, the network was modified by increasing the number of DG extremely (especially photovoltaic and cogeneration).

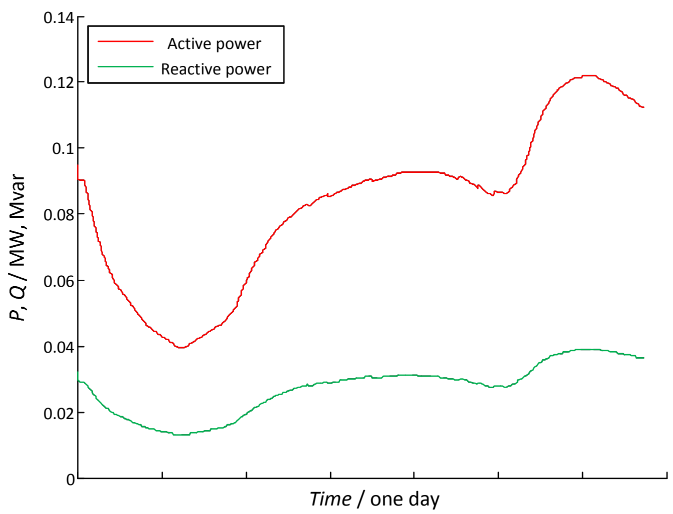

Fig. 5: Typical load pattern for residential area.

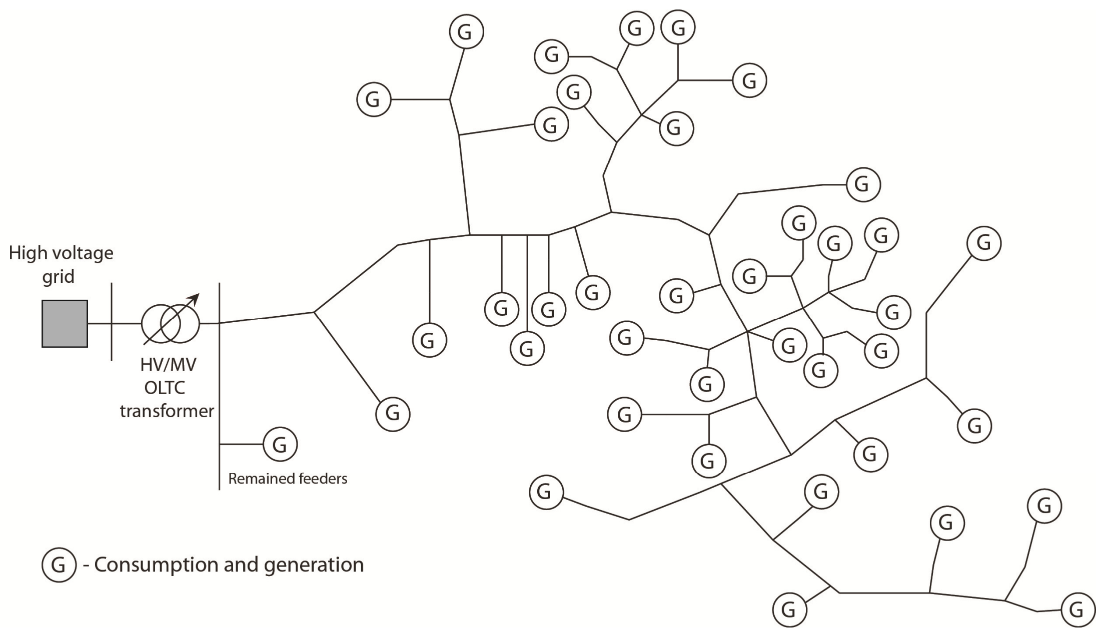

Fig. 6: Single line diagram of the distribution feeder.

The simulation results are shown next. Fig. 8 a) presents voltage profile when DG did not participate in the voltage regulation (cosφ = 1). Fig. 8 b) presents voltage profile, when static $Q(U)$ characteristic prescribed in [7] was used and fig. 8 c) presents voltage profile when DG followed the point of minimal losses.

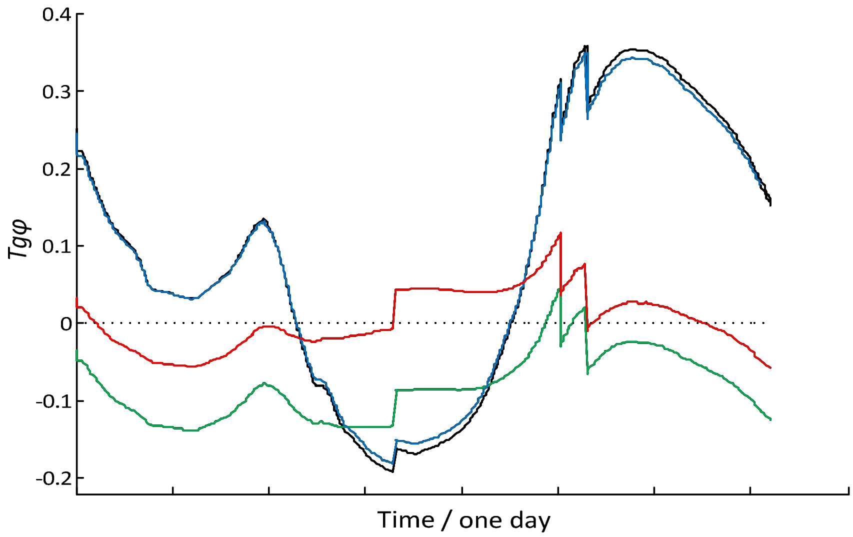

Fig. 7: Example of tgφ values for DG in the same feeder on different locations when static $Q(U)$ characteristic was used. Those located at the end of the feeder are burdened the most.

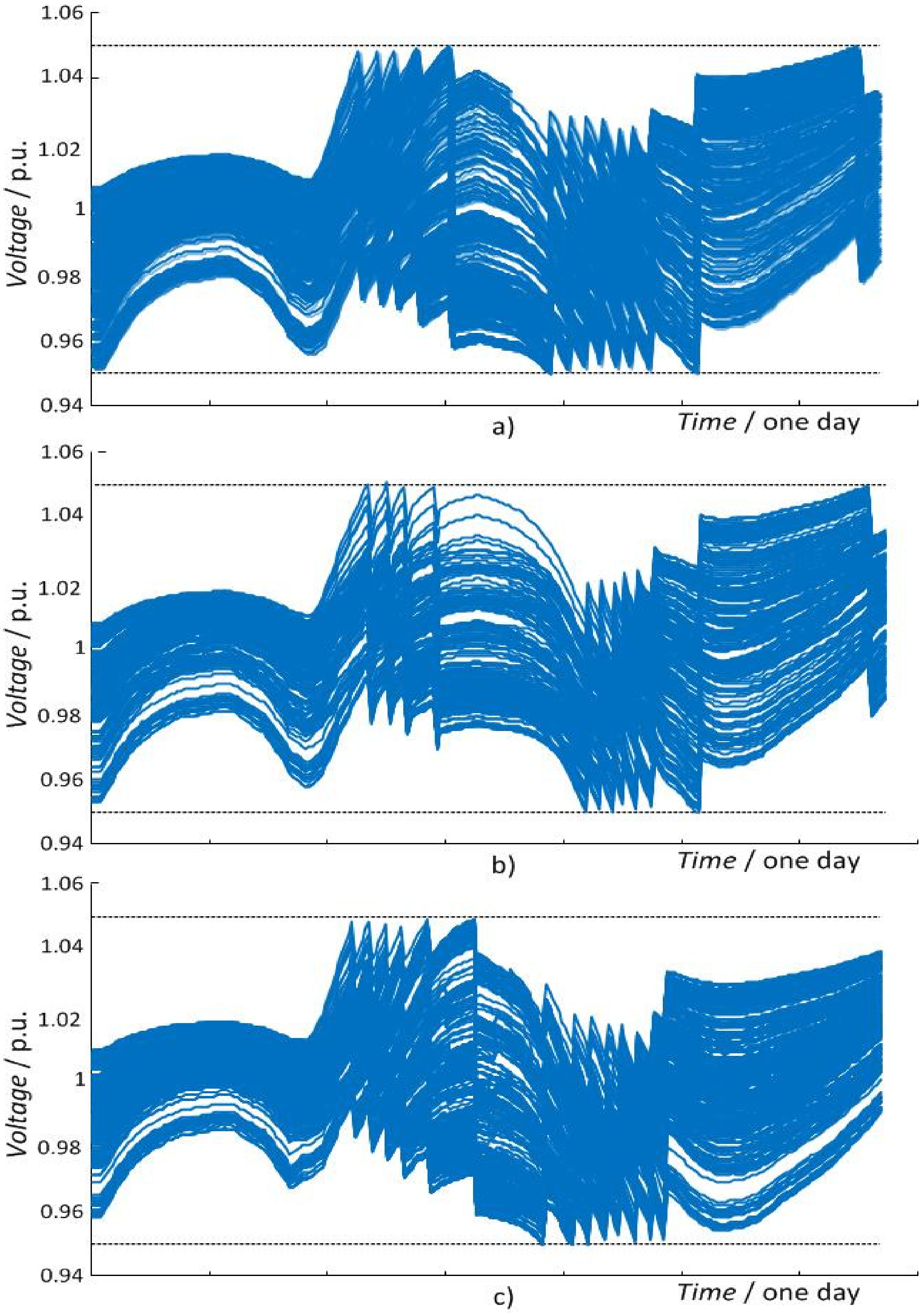

Fig. 8: Voltage profile of one day for different regulations.

4.1 Results evaluation

The proposed algorithm is validated by comparing the losses and tap-changer operations.

Table I: Simulation results

Regulation	*Tap operations*	*Losses* / kWh
Without DG	4	872
constant cosφ	14	565
static $Q(U)$ characteristic	12	553 - 578
Minimal losses set-point	14	492

The results from the Table I show that DG can reduce the network losses for cca. 35 % compared to the operation with constant power factor. This is due to the shorter transmission paths to the customers. In the case when DG's operated with cosφ = 1 the losses were still relatively high compared to time dependent power factor. When $Q(U)$ characteristic was used, the tap-changer operations were reduced. Within the zone prescribed in [7], the losses can differ, but generally they increase. It must be noted that the DG at the end of the feeder contribute significantly more to the system parameters control.

In the case of time dependent power factor, with subject to minimal network losses, the losses were reduced for cca.13 % compared to cosφ = 1 operation. It is noticeable that with the use of time-dependent power factor, the network operator has many benefits as the expense of lowering the cost for network maintenance (investment delay and maximization of DG operation.

5. CONCLUSION

This paper deals with the integration of DG in distribution networks. Until recently, the newly installed DG operated only with constant power factor, which was usually cosφ = 1. This situation is improving in many countries which have already prescribed static $Q(U)$ characteristics to contribute with voltage control.

With time dependent set point power factor the network can be optimized by many conditions. The chosen conditions were minimal network losses and minimal reactive power production from DG. On the basis of present values, the algorithm constantly searches for the optimal operating point. Furthermore, it ensures fairness by sending uniform tgφ to all generators on the same feeder.

Simulations with different control possibilities were carried out on one medium voltage distribution feeder. The results show that that distribution network together with ICT technologies can operate in a more flexible and reliable way than nowadays.

6. REFERENCES

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