THE IMPACT OF DISPERSED GENERATION ON DISTRIBUTION NETWORK

IMPACTUL GENERĂRII DISTRIBUITE ASUPRA REȚELEI DE DISTRIBUȚIE

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Abstract: *Since the European Commission has adopted the Green Deal Agreement, the environmental awareness has grown in all areas of economy, especially in energy. Thus, dispersed generation (DG), which includes, in general, renewables integrated in medium and low voltage networks, has already an important share in the electricity production – 38 % of the electricity generated in EU in 2020 [1]. Nevertheless, a large amount of DG units could cause some undesirable impacts on the distribution network related to power quality, such as overvoltage, voltage fluctuations and reverse power flow to the grid [2]. This paper aims to briefly analyze the main challenges created by DG penetration in distribution network and to propose practical solutions to maintain the grid stability and reliability in the same time with developing new renewable energy sources.*

Keywords: dispersed generation (DG), renewable energy sources (RES), voltage regulation, reverse power flow, demand response strategies, battery energy storage systems, smart inverters.

Rezumat: *De când Comisia Europeană a adoptat "Pactul Verde European", presiunile legate de reducerea emisiilor de gaze cu efect de seră au crescut în fiecare sector al economiei, în special în energie. Prin urmare, generarea distribuită (GD), care cuprinde, în general, surse regenerabile racordate la rețelele de medie și joasă tensiune, reprezintă deja o parte importantă din producția de energie electrică – 38 % din electricitatea produsă în UE în anul 2020 [1]. Cu toate acestea, un număr mare de unități de GD pot cauza efecte nedorite asupra rețelei de distribuție din punctul de vedere al calității energiei, cum ar fi supratensiuni, variații ale tensiunii și circulația curentului electric în sens invers celui normal [2]. Această lucrare își propune să analizeze succint principalele provocări la care este supusă rețeaua de distribuție ca urmare a integrării unităților de GD. De asemenea, sunt propuse soluții practice pentru*

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menținerea stabilității rețelei și siguranței în alimentarea consumatorilor, simultan cu dezvoltarea de noi surse regenerabile de energie.

Cuvinte cheie: generare distribuită, surse regenerabile de energie, reglarea tensiunii, strategii bazate pe cerere și răspuns, sisteme de stocare a energiei electrice prin acumulatori, invertoare inteligente.

1. Introduction

In the last years, DG experienced a tremendous growth due to the environmental constraints in energy sector, which directed most of the investments to "green" area. Dispersed generation technologies include, in general, renewable sources of energy, but also fuel cells, small & micro sized turbine packages and internal combustion engine-generators. Besides the positive effects in terms of environmental concerns, integrating renewables in the medium voltage or low voltage network could provide various advantages to the electrical distribution system such as improved power quality, grid reliability and reduction in the distribution losses, since it is generated locally [3]. However, due to continuous growth of DG without the proper development and adaption of the distribution network, the system is negatively affected [3]. Overvoltage, voltage fluctuations and reverse power flow are some of the challenges we must face to assure a reliable power grid with a high share of renewables.

Various types of researches describes, in general, the impact of dispersed generation on medium and low voltage networks in terms of voltage fluctuations outside the threshold values, reverse power flow, the contribution of renewables sources on short-circuit regime etc. Many studies also propose methodologies to determine the optimal place for DG units, in order to mitigate their impact on the network.

2. Analyzing DG Impacts

The rapid growth of renewable sources integrated in distribution network at medium or low voltage level comes with also advantages and challenges for the grid. Local generation of electricity from renewables reduces the power losses in the distribution system, due to short distances behind the source and the consumer and of the distribution capacity release. Nevertheless, a high share of dispersed generation units could negatively impact the distribution network. The increasing number of renewables, which induce volatility in the system, push the actual power grid to rapidly adapt to a more flexible behavior. Designed for a simple and unidirectional power flow, electricity network is facing serious challenges since the consumers become active participants in the grid. In the following paragraphs, a brief description of the impacts that DG has on distribution network is presented.

1.1. Voltage regulation

Power fluctuations of renewable energy at the point of common coupling could cause voltage regulation problems. This happens for instance when photovoltaic systems (PV) are installed in radial distribution networks. During the PV system operation in case of a weak power distribution network, the voltage variation may fall outside the admissible regulation band as defined by the connection standard, causing the intervention of the loss of mains relay and the unintentional disconnection of the plant [4]. Particularly in weak radial distribution networks, characterized by long lines, with high R/X ratio, the voltage rise can be considerable [4].

The voltage variation in the feeder is expressed by equation (1).

$$\Delta \boldsymbol{V} = \boldsymbol{V_1} - \boldsymbol{V_2} = \frac{\boldsymbol{R}(\boldsymbol{P} - \boldsymbol{P_g}) + \boldsymbol{X}(\boldsymbol{Q} \pm \boldsymbol{Q_g})}{\boldsymbol{V}} \tag{1}$$

- ✓ V – nominal voltage
- ✓ V_1 - voltage at the begin of the feeder
- ✓ V_2 - voltage at the end of the feeder
- ✓ R - resistance of the feeder
- ✓ X - reactance of the feeder
- ✓ P - active power absorbed by the load at the end of the feeder
- ✓ P_g - active power generated by DG at the end of the feeder
- ✓ Q - reactive power absorbed by the load at the end of the feeder
- ✓ +/- Qg - reactive power absorbed/generated by DG at the end of the feeder

In case of no-load condition (P=0 and Q=0), the equation can be written as follows:

$$\boldsymbol{V_2} = \boldsymbol{V_1} + \frac{\boldsymbol{R} \cdot \boldsymbol{P_g} + \boldsymbol{X}(\pm \boldsymbol{Q_g})}{\boldsymbol{V}} \tag{2}$$

As can be observed from equation (2), DG can provide voltage support to raise too low voltage V_2 at receiving end of the feeder [4]. Nevertheless, if there is no load demand or if it is very small, voltage at the end of the feeder could raise beyond the upper bound, limiting the capacity which can be installed or, in general, the active power that can be injected at the end of the line [4]. The PV power generation could not only offset the load, but also cause reverse power flow through the distribution system with operational issues, including overvoltage and loss of voltage regulation [4].

2.2 Reverse Power Flow

More and more consumers are becoming active consumers or prosumers, which means they can inject power in the grid, causing reverse power flow. This happens when power generated by dispersed sources exceeds the local consumption, so it is transferred back to the grid.

The major problem is that power grids were designed for the classic unidirectional power flow, from centralized production to end consumer. The greater penetration of dispersed energy sources is changing completely this well consolidated environment [4]. Thus, bidirectional power flow can cause unnecessary power flow from the distribution network to the transmission network, leading to instability and reduction in the system reliability. It has also harmful effects on the protection system, it changes the operation of the relay, instigating false tripping of circuit breakers [5].

Reverse flow is defined as the product of a voltage and current variance in magnitude and angle. These changes are due to the inclusion of another source of energy different from the initial generation for which the system was designed, which can cause changes of direction in active and reactive power in a line [11]. Physically, the reverse flow is observed as the change of direction of the active and reactive power in an electrical system [11].

In [12] it was analyzed the variation of active power in a distribution network with a 20 MW installed capacity in DG units for one month. In the graph bellow, there are represented the load profile (grey), the power generated by the dispersed units (blue) and the grid power (orange). The graph shows that reverse power flow occurred on each day because of the low load profile during nighttime.

To mitigate the impact of reverse power flow on the distribution network, there are necessary studies about the optimal location of dispersed generation and also about the optimal load installed in the dispersed generation nodes so that, at its peak, the dispersed generation does not produce such implications in the network.

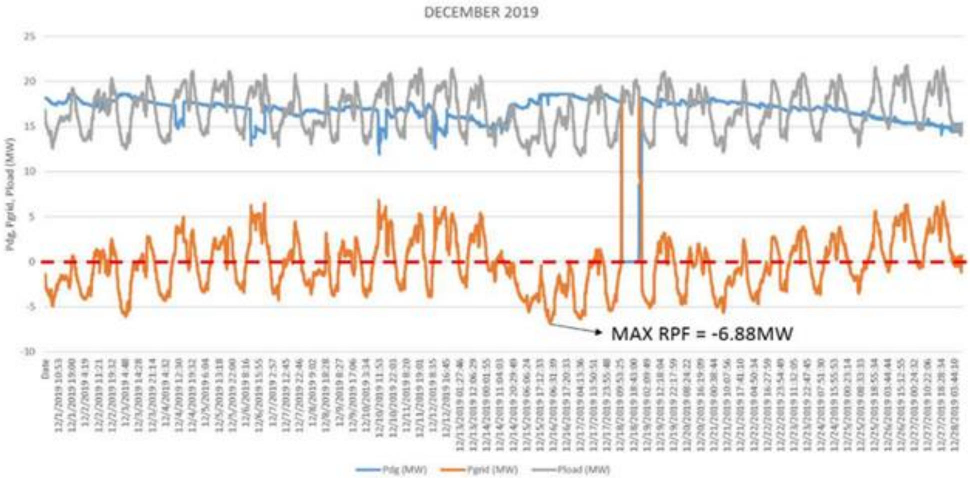

Figure 1. The variation of active power in a distribution network for one month.
Source: M. Turiman, B. Sarmin, Reverse Power Flow Analysis in Distribution Network.

3. Solutions for mitigating DG impact on distribution network

3.1. Smart inverters for voltage regulation

Voltage variations outside the admissible bounds are noticed by the relays which order the disconnection of the DG source. These actions are no longer considered the right approach to obtain an effective DG integration and network operation, due to equipment degradation, poor quality of power supply for the customers and reduction of energy production with related economic loss for the DG owner [6]. A more flexible way to control the DG output at the point of common coupling in accordance with the grid capabilities and needs would mitigate the problem. Smart inverters represent an emerging solution which can prevent the negative effects of DG in the distribution network. Their capabilities are described below.

Active power curtailment consists in limiting/curtailing the active power transferred through inverter to reduce the voltage at the point of common coupling of the DG plant [6]. Even if the inverter reduces the power injected into the grid, the benefits are also for the DG owner and for the DSO. On one hand, the voltage is maintained in the normal values and, on the other hand, the productivity of the DG units is improved, since no continuous disconnections and connections are needed.

Besides active power curtailment, smart inverters have several possibilities to influence the voltage at the point of common coupling, managing reactive power without losing the active power generated [6]. Reactive power management cos(u) = f(P) consists of reducing the cos(u) with the increment of the active power generated. In this operation mode, the smart inverter works as an inductive load absorbing reactive power from the grid. Consequently, the voltage at the point of common coupling can be reduced [6].

3.2. Battery energy storage systems

The distribution system operator is bound to take the electricity produced by prosumers or other DG units, even if the load demand is at minimum level and this could lead to grid overloading. Thus, another option to mitigate the problems caused by DG is electricity storage. Battery energy storage systems can increase the network capacity to integrate renewable energy sources and provide grid support functionalities for congestion management, Volt/Var support and backup power supply [7]. Owned by the consumer or by DSO, energy storage systems give the possibility to maintain the voltage into normal thresholds without disconnecting the DG units or reducing the active power delivered.

More than that, if owned by the DSO, energy storage systems can be used to deliver ancillary services to the distribution grid, like frequency control, voltage regulation, spinning and stand reserves, black start service, peak shaving, load leveling, islanding support etc.

Furthermore, if owned by consumers, energy storage systems show great capabilities for increased self-consumption of dispersed generation, industrial applications, uninterruptable power supply etc. [4]. As was mentioned in section 2.2, reverse power flow occurs when power generated by DG units exceeds the load demand. Therefore, the excess electricity could be stored during this period and delivered to the grid at peak load time, when electricity price is also higher. Thus, battery energy storage systems, combined with flexible prices of electricity, could mitigate the problems caused by DG penetration in distributed network: reverse power flow, overvoltage, voltage fluctuations etc.

The rapid growth of renewable energy sources imposes the development of the grid in a way that unexpected production or lack of production of DG shouldn’t affect the security and stability of the network. Electricity storage in batteries represent an efficient, but expensive, way to balance the production and consumption on short-term (seconds or minutes), medium-term (daily storage) and even long-term (weekly to monthly).

3.3. Demand Response Strategies in Distribution Networks

The traditional voltage control devices may fail to handle voltage control problems caused by high penetration of DG in distribution network. Thus, there are techniques for voltage control based on demand response [8]. With the rapid development of smart grid technologies, it is possible for both utility and end-users to exchange information. The customers can receive updated information about the electricity cost and then can adjust their power consumption according to the cost information [8]. Demand response can help smart grids to integrate high levels of renewable energy sources and reduce the supply pressure on the utility. Demand response offers several advantages such as peak load shifting, increased system efficiency, lower system capacity requirement, network investment deferral and increased network reliability [9]. The two most used demand response programs are incentive-based and price-based, which are explained below.

Incentive-based programs are direct and influence customer behavior by offering incentives for reducing demand during peak periods. Incentive-based programs charge a penalty to customers who fail to reach the assumed target [10].

Price-based programs influence customer behavior through different electricity price policies such as Time of Use, Critical Peak Pricing and Real Time Pricing. Participants benefit if they reduce their consumption during specific periods. Conversely, the customers pay higher electricity costs if they fail to reduce their consumption during these times [10].

4. Dispersed generation in Romania

In Romania, the biggest companies in electricity production understood the evolution trend of the energy system and took action, diversifying their portfolio. Thus, Hidroelectrica, the greater electricity producer from Romania and the operator of 182 hydropower plants, also own a wind farm with an installed capacity of 108 MW. More than that, the company plans to develop 600 MW in on-shore and off-shore wind farms and to install floating photovoltaic panels in the accumulation lakes basins.

One of the biggest electricity producers from fossil fuels, Complexul Energetic Oltenia, is going to build 8 photovoltaic parks with a total installed capacity of 735 MW during a reorganization process which aim to reduce the company’s GHG emissions.

Not least, Nuclearelectrica, the operator of the nuclear power plant from Cernavoda, is engaged in a pilot project, very important for the future development of nuclear technologies. The project consists in building 6 small modular reactors in Romania, each of them with a capacity of 77 MW. Thus, this initiative combines the advantages of dispersed power generation with the predictable and secure production of electricity, removing the challenges related to overvoltage and reverse power flow.

In the light of the challenges that decentralization faces, explained in this paper, and of the great potential that Romania has on this direction, we emphasize the fact that a correct functioning of the energy system can be realized just with the contribution of all stakeholders involved in this sector. From the Government and Parliament, who have to assure a predictable and attractable legislative environment for investors, to TSO and DSOs, which have the role of handling the tremendous growth in renewable generation by reducing their impact on the electricity grid, all of us should participate at this change. Not least, electricity suppliers play a significant role in the transition to this new paradigm, named dispersed generation. Through the introduction of supply contracts based on demand response strategies, suppliers could model the clients' behavior and determine them to adopt an efficient way of consuming. Thus, the consumption curve could be adapted locally in order to better integrate the renewable energy sources in the grid.

5. Conclusions

This study evaluates the main challenges that distribution network is exposed to, due to the rapid penetration of dispersed generation. There were presented the conditions for occurring some unwanted phenomena, like overvoltage and reverse power flow, and were also proposed solutions, applicable at consumer or DSO level, for mitigating these effects.

We saw that integrating new renewable sources of energy in the distribution network should happen simultaneously with grid transformation, from the traditional view to smart grid. The unpredictability introduced by photovoltaics and wind turbines make necessary the adoption of a more flexible behavior, characterized by demand response strategies, electricity storage and a better communication between all parties involved in the energy chain.

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