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Renewable Energy Sources Intrusion into Smart Grids – Selected Problems

Abstract. *The aim of the paper are selected problems resulting from Renewable Energy Sources (RES) intrusion into Smart Grids (SG) presentation. Upon considerations there are: wind turbines influence on power system operation, RES and microgrids operation with a Power System, new Energy Market for islanded and connected to power system microgrid, Energy Management System and ICT after intrusion RES. Conclusion presents perspective of RES development.*

Streszczenie. *Celem artykułu jest przedstawienie wybranych problemów spowodowanych dołączeniem odnawialnych źródeł energii (OZE) do sieci inteligentnej. Rozważono: wpływ turbin wiatrowych ma eksploatację systemu elektroenergetycznego, Współpracę OZE I mikrosieci z tym systemem, nowy rynek energii dla pracy wyspowej i mikrosieci współpracującej z systemem, Energy Management System i ICT po dołączeniu OZE. W zakończeniu przedstawiono perspektywy rozwoju OZE. (**Wybrane problemy spowodowane dołączeniem odnawialnych źródeł energii (OZE) do sieci inteligentnej**)*

Keywords: Renewable Energy Resources (RES), Smart Grid (SG), Energy Market, Microgrid.
Słowa kluczowe: Odnawialne Źródła Energii (OZE), Rynek Energii, Sieci inteligentne.

1. Introduction

According to the fifth property of Smart Grid (SG) [1]: “It accommodates all generation and storage options” all existing renewable energy sources (RES) have to be connected to the SG. Before consideration problems resulting from different RES intrusion into SG it is necessary to pay some attention to more general issues.

Distributed generation can positively or negatively affect the Smart Distribution Grids. For example [2], in radial distribution networks, distributed generators can cause bidirectional power flows, alter the existing voltage profiles, affect the operation and coordination of the existing protection devices such as relays, reclosers etc. and compromise safety. In particular they can cause energized electric islands within the host networks which can form due either to faults causing an upstream feeder breaker to open automatically, or to inadvertent opening of the breaker for maintenance operations.[1]

V. Hamidi et al. [3] composed the following list of barriers when implementing the SG technologies:

- Technology readiness and development of technologies still under development.
- Cost of SG technologies.
- Need of re-structuring the industry.
- Compatibility with current standards and technologies.
- Lack of market power (energy market [1]) - for smaller utilities.

In addition to the above list it has to remember that connection RES to weak distribution grid (MV or LV) sometimes it is not possible in result aging lines, too low thermal limitation and voltage rise effect [2]; the problem is especially important for wind farms.

2. Wind Generation

Significant wind generation growth in coming decade assure it’s dominating position among RES and implies challenges in power system operation due to intermittent nature of wind. Wind generators are increasingly connected to an electrical grid through power electronic based converters and differ significantly from conventional synchronous generators particularly in terms of their impact on the electromechanical stability of the grid. The inertia of synchronous machines is stabilizing the grid frequency during transients and it is important to design technologies improving the stabilizing effect of the wind generators [4].

In that paper the Authors consider addition of a control loop that would feed (draw) active power in response to a decline (rise) in the time derivative frequency, thereby seeking to mimic the inherent inertial response of conventional synchronous generator.

The idea of inertial emulation neglects two important limitations in bandwidths and in the magnitude of power change that can be applied. In order to overcome these limitations, a work being actively considered is to supplement the control available from energy storage devices such as batteries. Typically energy storage devices offer fast control action (high bandwidth) while having narrow limits on the magnitude of power and energy that can be absorbed or supplied. On the other hand, varying the mechanical input power to a wind turbine through changes in its blade pitch is a relatively slow control action (low bandwidth) but one which can have broad limits before saturation reached [4].

Another type of challenges arise with the offshore wind farms located a long distance from the coast. For decreasing high losses accompanying AC transmission, High Voltage Direct Current (HVDC) cables with Voltage Source Converters (VSC) are to be applied. Multi-terminal VSC-HVDC consisting of more than two converters has following benefits: bulk power transmission, AC network interconnection over a long or medium distance, and economical advantages[2] [5].

Great capacity of wind farms results that the traditional “fit and forget” approach where all technical limitations are satisfied in many credible operational scenarios has significantly reduced the ability of certain networks to integrate more generation capacity as the extra costs are not viable for most wind farm developers. In this context, it is envisaged that the true potential of distribution networks to accommodate large renewable generation capacities will only be realized by applying active management schemes. In [7] it is proposed the innovative use of synchrophasor technology to actively manage wind power generation output in congested distribution networks, resulting in the connection of more capacity and hence, the delivery of more energy as opposed to the “fit and forget” approach. This is achieved by applying an angle-based

[1] The IEEE and other organizations have identified anti-islanding standards. As such number of anti-islanding techniques have already been adopted commercially.

[2] The idea of the VSC-HVDC application has been used also in [6].

constraint that is determined according to the network characteristics (i.e. a proxy the thermal limits, voltage limits etc.) and using minimal communication. Results from a radial test feeder considering two wind farms demonstrate the effectiveness of the technique in exporting more energy, although at expense of smaller capacity factors, whilst keeping the system secure.

3. RES and Microgrids connected to the Smart Distribution Grid

According to [1] development of RES (except of wind farms) in Poland is a result of private activity what results in number of generators dispersed (DGs) in region. Each of these DGs ought to be connected to distribution network and realize its private schedule what means that DGs belong to Virtual Power Plant (VPP).

Individual DGs, partners in virtual power plants, with different technical characteristics connected to the distribution network implies serious technical – as well as organizational problems depending on their number, capacity, schedules etc. Introduction of controlling interface between DGs and distribution network will be valuable solution simplifying a distribution network operation. Of course the interface between separate DG and distribution network is too expensive and it is necessary to group together number of DGs located not far one from the another. When we can collect several DGs with suitable location we can compose them in Microgrid[3].

Microgrid - it is interconnection of small modular generation[4] to Low- or Medium- voltage distribution systems. Microgrids can be connected to the main power network or be operating islanded, in a coordinated, controlled way[5]. Microgrid connected to the distribution network (in future smart distribution grid) needs creation of Active Distribution Network (ADN) passing following stages:

- remote monitoring and control of DG and RES,
- determination of great number of DG and RES management,
- full active power management together with real time communication and remote control.

ADN operation implies necessity of application one of two different strategy: microgrids or virtual consumers. Concept of virtual consumer [1,12] is adaptation of a model similar to information and business ability of Internet. Electrical energy bought from conventional generators, RES or storage devices, according to demand is delivered to agreed nodes. The system would use new ICT technologies as well as advance power electronics and storing devices.

Diversity of RES and storage devices as well as architecture and collaboration with power system implies necessity to define control strategy in operation.

“Building Network “ strategy emulate “vacillatory source” in islanded network. DER unit realizing this strategy controls voltage in the connection with the system node setting up the system frequency.

Power and energy management strategy is very important in islanded microgrid and it is more critical than in power system because of specific characteristics of the microgrid. It is worth of mention that according chapter 1 microgrid is one of important part of smart grids.

[3] The same opinion concerning role of the microgrid in RES intrusion into the grid one can find in [8]

[4] It is worth of mention that to RES are included also all types of storage devices including also Electric Vehicles [9] and optimal integration of the energy storage systems in smart distribution grids has been considered in [10]

[5] Process of reconnection from Islanded state to connection with distribution network is considered in [11].

Microgrid being consortium of private owners is more convenient for distribution grid nevertheless it is still part of virtual power plant.

4. New Energy Market for Islanded and Connected to Power System Microgrid

The main question for a new shape of EM with microgrids is: What kind of business models would support the implementation of Energy Efficiency (EE) and dissemination of implementation RES and creation DER? The business models on which the European thematic projects works last year were focused are those which concern the aggregator of Demand Response (DR), Distributed Generation (DG) and Distributed energy Storages (DS), which have been together called - Distributed Energy Resources (DER). Aggregation functions can be taken care of by an independent organization or an existing market participant, e.g. an electricity supplier (retailer) other forms of selling activities or virtual Power Plants (VPP). In each case, these organizations have been called: the aggregators.

The aggregator is defined in the following brief way (according to the definition from SEESGEN_ICT European Project): The aggregator is a company who acts as a mediator between electricity end-users, who provide distributed energy resources, and those power system participants who wish to exploit these services [12,13]

Nowadays, the aggregators for complex business models integration for DER management on the Energy Market have been needed.

The main aggregator's job is to provide a link between the end-users, i.e., the providers of demand response, prosumers, DGs and the buyers. Where the consumer is alone to provide demand response, he should have a direct relationship with buyers of demand response services. Without an intermediary, this would lead to very many bilateral relationships between market participants. Their management is not in the interest of buyers of demand response services, such as TSO's. For example, small consumers do not have access to electricity exchange and arranging the access could be expensive.

Not all consumers on the new energy market with islanded and connected microgrids can also provide DER in a cost-efficient way. For example, their load flexibility may be too small or cause too much inconvenience. Alternatively the consumer may offer flexibility at a time of day or year when it is of low value. The aggregator must evaluate the above-mentioned parameters based on information of what kind of appliances the consumer has, and what is their usage pattern.

ICT tools specifically for this purpose have been developed e.g. in the EU-DEEP project and in other similar European projects. Their usage constraints are sometimes born from the physical characteristics of the appliance, their costs and sometimes from the consumer's desire of convenience. The aggregator will develop an understanding of the common usage constraints and time patterns of flexibility of different types of appliances over time and may agree about them individually with each consumer.

Signals in information area, like "above the market and energy grid" must be received, appliances controlled, and measurements sent in an automated manner using the new technology and ICT tools. The aggregator can take care of installing the proper control and communication equipment for whole system integration.

Smart meters along with their bidirectional communication and load control features can be exploited in mentioned functions of integration. However, these features have not been standardized. Also the measurement resolution may not be high enough and time delay of load control calls may not be low enough for the aggregator's purposes. The aggregator collects together different realized and forecasted requests for distributed energy services, and evaluates his contractual position, taken into account forecast of consumption based on existing retail contracts and forecast of variable-output generation. He combines the different requests and identifies their whole synergies. He then calculates how to best respond to these requests by load control. The aggregator can take advantage of economies of scale in controlling a large group of consumers and acquire sophisticated optimization software to support the load control decisions.

The aggregator also makes sure that the load control decisions do not cause problems for the electrical network. One possibility is that he does this validation by consulting system operators (DSO's and TSO). The aggregator sends his planned schedules for DER control to concerned DSO's with information about the involved network nodes. The DSO's then evaluate if power quality constraints will be violated by the load control actions, and send the validation result back to the aggregator.

Finally the aggregator must provide financial incentives to the consumers to participate in demand response provision. These could take many forms and there are many ways to set up the business. The consumers could be rewarded by being offered an availability payment, call payment (payment for flexibility energy provided), or percentage of the aggregator's profits. The aggregator monitors the consumer's performance and rewards him accordingly.

The idea of VPP is also useful for realization of Demand Response (DR) aggregator functionalities [14] (see also [15]).

The VPP can be defined as “an information and communication system with centralized control over an aggregation of distributed generation, controllable loads and storage devices”. Its main function is to control the supply and manage the electrical energy flow not only within the cluster (chosen local DER) , but also in exchange with the main grid. “It represents a single entity to the system operator and electricity markets and enables visibility and control over a cluster of distributed generation”. A VPP at a high-development stage can also offer ancillary system and power quality services. The VPP is thus a controlled operation of aggregated DG units. In such a VPP an active control is obtained through an ICT infrastructure which consists of intelligent devices and smart meters, wireless and cable connections, central control computer management system (CCCMS) and software applications see [13].

In present situation most DGs, controllable loads and storage devices are invisible to network and system operators. Their aggregation into a VPP will enable their visibility to the VPP operator (VPPO) in first place and finally to the network and system operator. At distribution level, the VPPO can be an independent system operator (ISO) or the distribution system operator (DSO). When more VPPs are developed in a service area of the transmission system operator (TSO), once again they can be aggregated by this TSO into a large scale virtual power plant (LSVPP) with central control computer system for coordination and management.

The control system of VPP of course involves huge data transfers between smart meters, agents and central ICT system in order to manage the available DG and deliver the contracted energy and services.

Recent developments like the broadband cable (glass fibre) or wireless (WMAX) communications can provide connections with enough speed and capacity to transfer the required data. With such an ICT system the VPP can be presented to the system operator as a single technical entity which is able to offer ancillary system services for all other market participants. In Poland, nowadays the Independent Operator of Measurement (IOM) has been established - it involves with high quality of data acquisition and data metering supported services for all market participants

The VPP represents all contracted DG units in the wholesale electricity markets as a single commercial entity. In order to participate in these markets, the VPPO needs to develop or make use of software applications that are able to forecast the power generation of the VPP.

In general, the VPP facilitates the visibility of the aggregated DG units and their impact on the distribution network to the VPPO as well as the DSO. In addition, the ICT infrastructure of VPP, which provides active control, can be employed to introduce active control to the passive distribution network.

In conclusion: mentioned new models of business - such can be the aggregator role on the energy market and special ICT for realization and work supporting is the main goal of planned shape construction of future, open and full competition energy market together with Smartgrid.

5. Energy Management System and ICT after Intrusion RES

For ISO or TSO and Reliability Coordinators, the following areas of focus are the most representative of new functional needs related to the integration of RES [8]:

- Provide the operator a central repository with advanced data processing and alarming for renewable prediction conditions and forecast management (RES Forecast Plan).
- Provide an estimate of non-telemetered production (frequent in Distributed Generation) using flexible and field-proven up-scaling algorithms (RES Estimation).
- Enhanced Generation Control & Dispatch to automatically counteract renewable production power balance disturbances, optimize reserve calculations and provide curtailment facilities (RES Generation Control to Dispatch).
- Enhanced Security and Simulation: fed by RES production forecast inputs and taking into account forecast accuracies to support dispatcher training and asses multiple renewable production penetration scenarios (RES Network Security and Simulator).
- Advanced User Interface: data at user's finger tips to help the operator efficiently assessing current and future renewable production and impacts (UI).
- Extended Historian: to support reporting and data archiving (Historian).

These functional requirements match SCADA/EMS functions.

Several factors affect the viability of Active Management (AM) schemes in distribution systems with distributed generation. One of the critical factors is the control system reliability. While a lot of work has been done on the technical and economic aspects of active distribution network management, almost no attention has been paid to the impact of the reliability of control and communication systems on the expected benefits of active management strategies. Investigation the impact of control system reliability on the benefits of AM are presented in [14] (see also [16]).

Utilization of RES has been receiving considerable attention in recent years what implies increasing information system requirements. Specially the reliability information system is more important for implementing the smart grid. In [18] a Web Based Online Real-time Reliability Integrated Information System WORRIS Version 1.0 has been presented. This system yields the chance for customer to choose the electrical energy resource under environment of variety kind of resources in future.

Data delivery in the power grid today is, in the most part, hard-coded, tedious to implement and change, and does not provide any real end-to-end guarantees. Application have started to emerge that require real-time delivery in order to provide a wide-area assessment of the health of the power grid. In [18] two novel communication infrastructures that facilitate the delivery of power data to intended recipients has been presented.

6. Conclusion

Complexity of the SG development implies necessity to investigate new solutions enabling to limit some of the barriers.

For example, to support a high penetration of intermittent solar and wind power generation, many regions are planning to add new high capacity transmission lines strengthing grid synchronization but also increasing the grid's short circuit capacity, and furthermore will be very costly. With a highly interconnected grid and variable RES, a small grid failure can easily star cascading outages resulting in large scale blackout.

In [19] has been presented "Digital Grid" where large synchronous grids are divided into smaller segmented grid which are connected asynchronously via multi-leg IP addressed ACs/DC/ACs converters called Digital Grid Routers. These routers communicate with each other and send power among the segmented grid through existing transmission lines which have been re-purposed to digital transmission lines. The Digital Grid can accept high penetration of renewable power, prevent cascading outages, accommodate identifiable tagged electricity flows, record these transaction and trade electricity as a commodity (see also [15]).

Interesting proposal of measures to integrate a city district with a high share of building integrated photovoltaic system into the electric grid has been presented in [20].

And the next issue: new business models of energy market activities with RES and islanded Microgrids - how to integrate and increase new functionalities of Smartgrids have been considered.

The above considerations enable a general conclusion that the SG development needs a very wide researches necessary for decreasing costs and efforts necessary for reaching success [21].

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Abbreviations:
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