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SMART GRIDS AND DISTRIBUTED GENERATION

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Abstract

This paper describes the main characteristics of Smart Grids and distributed generation. Smart Grids can be defined as a modernization of the power system so it monitors, protects and automatically optimizes the operation of its interconnected elements (power plants, transmission and distribution system, industrial and residential loads). Distributed generation (DG) refers to the production of electricity near the consumption place using renewable energy sources. A load flow analysis is performed for the IEEE14 system in which a DG source (a 5MW wind turbine) is added that is on-grid or off-grid. The power losses are determined for these two cases.

Key words: smart grids, distributed generation, renewable energy sources, load flow, power losses

1. Introduction

Today's power grids are dealing with environmental (e.g. global warming), financial (e.g. constructing new transmission and distribution lines or stations) and operational challenges (e.g. matching load demand with power generation).[1,4,6,7]

In order to overcome these problems today's grids must be improved using state-of-the-art technologies, therefore increasing the reliability, efficiency, security and quality of the delivered power. Also, new grids must consider the environment by using renewable energy sources, especially at the distribution system, therefore helping significantly reduce the carbon footprint. This grid must also allow the customer to control and monitor the amount of power consumption through modern technologies (e.g. smart meters).[1,2,3,4,6,7]

With current initiatives on Smart Grids (SG) and sustainable energy, distributed generation (DG) is going to play an important role in the future electric power system [15]. In order to fully exploit the potential advantages of distributed generation, it is necessary to rethink the basic philosophy governing the electricity distribution system. The future active network will effectively and efficiently link small and medium scale electric power sources with loads demands. Distributed generation is often used as back-up power to enhance reliability or as a means of deferring investment in transmission and distribution networks, avoiding network charges, reducing line losses, deferring construction of large generation facilities, displacing expensive grid-supplied power, providing alternative sources of supply in markets and providing environmental benefits. However, depending on the system configuration and management, these advantages may not be true. In recent years, DG has become an efficient and clean alternative to the traditional electric energy sources, and recent technologies are making DGs economically feasible.[4,8,10,12,13,19]

In this paper will be performed a case study for a system in which a distributed generation source is added. The load flow analysis will be performed for the cases when the distributed generation source is on-grid (connected to the system) and off-grid (not connected to the system). The power losses will be determined for these two cases.

2. Smart Grids

Smart Grids (SG) are able to analyze, detect and respond promptly to various perturbations by integrating smart devices, advanced control methods and digital telecommunication systems on electrical networks.[4,5,16]

The Smart Grids can manage the direct interaction between its interconnected elements, which include generators, loads and a combination of these two. The Smart Grids comprises new products and services, smart meters, communication technology equipment and self-healing technologies. This leads to a better connection and operation of the power system.[2,7]

The main characteristics of SG are self-healing, empowering the customers, improving power quality and ability to accommodate various distributed generation. In addition, advanced control methods, digital sensing and metering, advanced grid devices such as FACTS (Flexible AC Transmission Systems) and SCADA (Supervision Control and Data Acquisition) system are some of the major technologies involved in the implementation of SG. FACTS are used to enhance control ability and increase power transfer capability based on power electronic and other static controllers. SCADA systems are used for operation, monitoring and controlling of power system grids.[4,5,9,11,14]

The benefits of Smart Grids are:

- integrates consumers as active players in the power system;
- improves the physical and economic operation of the power system by making it more sustainable and robust;
- allows cost savings, achieved by reducing peaks in power demand;
- voltage regulation and load following enables reducing cost of operations based on marginal production costs;
- the balance between generation and consumption is optimized in order to achieve an increased efficiency.[13]

In Fig. 1 is presented the current power grid, in which the power flow is from the power plants to the commercial, industrial, and residential loads via transmission and distribution system.

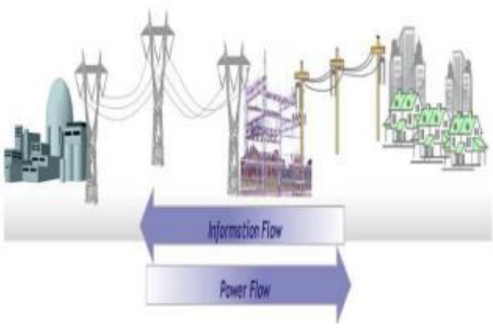

Fig. 1: Current power grid [10]

In Fig. 2 is presented the SG infrastructure, which is characterized by bidirectional power flow and two-way real-time communication. Also, the SG includes storage devices and smart meters. The SG also integrates renewable energy sources and electric vehicles.

Fig. 2: Smart Grids [10]

In table 1 is presented a comparison between the characteristics of the conventional grid and Smart Grids.

Table 1: Comparison between conventional grid and Smart Grids [4,10]

Conventional grid	Smart Grids
One way power flow	Bidirectional power flow
One way communication	Bidirectional communication
Passive consumer	Active consumer
Manual operation (based on predictions)	Automated operation (in real time)
Fossil fuel based power generation	Environmentally friendly generation
Centralized power generation	Distributed renewable generation

3. Distributed generation

The term "distributed generation" (DG) refers to the production of electricity near or at the consumption place. The distributed generation resources are renewable energy sources and cogeneration units (simultaneous production of heat and electricity).[17,18]

Renewable energy is energy from natural resources such as wind, sunlight, tides, waves, geothermal heat and biomass.

Distributed generation is characterized by some features which have not been present in traditional centralized systems: rather free location in the network area, relatively small generated power and variation of generated power dependent on the availability and variability of primary energy.[20]

One of the main advantages of DG is its close proximity to the consumer loads. DG has an important role in improving the reliability of the grid, reducing the transmission losses, providing better voltage support and improving the power quality. The distributed generation sources also help reduce the green house emission by providing clean and efficient energy.[17-21]

The most commonly used DG technologies and their typical module size are the following:

- small hydro: 1 - 100 MW;
- micro hydro: 25 kW - 1 MW;

- wind turbine: 200 W - 3 MW;
- photovoltaic arrays: 20 W - 100 kW;
- biomass gasification: 100 kW - 20 MW;
- geothermal: 5 - 100 MW;
- ocean energy: 100 kW - 5 MW.[19]

The operation of a distribution system with a large amount of distributed generation raises a number of issues:

- voltage profiles change along the network, depending on how much power is produced and consumed at that system level, leading to a behavior different from that of a typical unidirectional network;
- voltage transients will appear as a result of connection and disconnection of generators or even as a result of their operation;
- short circuit levels are increased;
- load losses change as a function of the production and load levels;
- congestion in system branches is a function of the production and load levels;
- power quality and reliability may be affected;
- utility protection and DG protection measures must be coordinated.[19]

4. Case study

The load flow case study is performed for the IEEE 14 system [22] from Fig. 3.

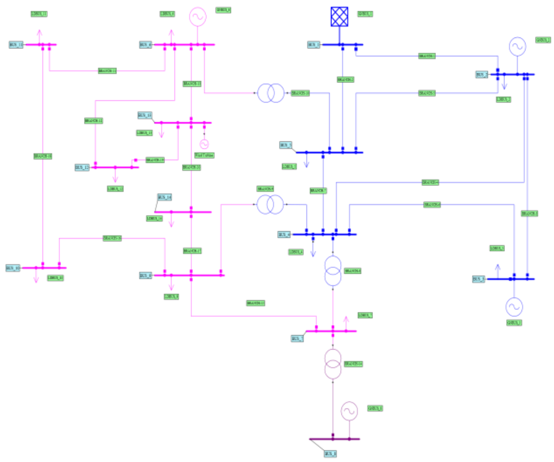

Fig. 3: One-line diagram of IEEE 14 system

A DG source (a 5 MW wind turbine) having the characteristics from Fig. 4 is added to this system, at bus 10.

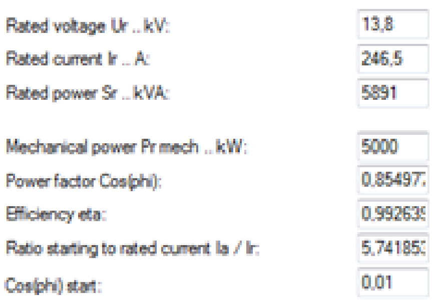

Fig. 4: Wind turbine characteristics

The load flow is performed for the cases in which the distributed energy source (wind turbine) is on-grid or off-grid.

The power losses are determined with the Neplan software [23], which uses the Newton-Raphson extended method.

The method starts from initial values of all unknown variables (voltage magnitude and angles at load buses and voltage angles at generator buses). A Taylor series is written, with the higher order terms ignored, for each of the power balance equations included in the system of equations. The result is a linear system of equations that can be expressed as:

$$\begin{bmatrix} \Delta\theta \\ \Delta|V| \end{bmatrix} = -J^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \tag{1}$$

$$\Delta P_i = -P_i + \sum_{k=1}^{N} |V_i||V_k| (G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}) \tag{2}$$

$$\Delta Q_i = -Q_i + \sum_{k=1}^{N} |V_i||V_k| (G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik}) \tag{3}$$

$$J = \begin{bmatrix} \dfrac{\delta\Delta P}{\delta\theta} & \dfrac{\delta\Delta P}{\delta|V|} \\ \dfrac{\delta\Delta Q}{\delta\theta} & \dfrac{\delta\Delta Q}{\delta|V|} \end{bmatrix} \tag{4}$$

where:

- $|V|$ - voltage magnitude;
- θ, θ_{ik} - voltage phase (θ), and voltage angle difference between the i and k buses (θ_{ik});
- P_i - net power injected at bus i;
- G_{ik}, B_{ik} - the real and imaginary part of the element in the bus admittance matrix corresponding to the i row and k column;
- ΔP, ΔQ - the mismatch equations;
- J - matrix of partial derivatives (Jacobian).

The linearized system of equations is solved in order to determine the next value (m+1) of voltage magnitude and angles based on:

$$\theta^{m+1} = \theta^{m} + \Delta\theta; |V|^{m+1} = |V|^{m} + \Delta|V| \tag{5}$$

The process continues until the norm of the mismatch equations are below a specified tolerance.

In table 2 are presented the results of the case study (the power losses for the cases in which the distributed energy source is on-grid or off-grid).

Table 2: Case study results

Wind Turbine	Active power losses ΔP (MW)	Reactive power losses ΔQ (MVAr)
Off-grid	13,59	27,43
On-grid	12,94	24,27

From the case study results it can be observed the power losses are lower when the distributed energy source (wind turbine) is on-grid.

5. Conclusions

The future of power systems is represented by Smart Grids and distributed generation.

Smart Grids is a new modern type of power system, being suitable for the operation of the power system in real time and able to react in a short time to various perturbations.

Distributed generation also provides many benefits, such as the fact that power is generated near or at the place of consumption, the power supply security is increased due to the variety of energy sources, the power losses in the network are lower (as shown in the case study), the greenhouse gas emissions are reduced.

These benefits and many more of Smart Grids and distributed generation will make them widely accepted in the near future.

The load flow case study was performed for the IEEE 14 system, in which a distributed generation source (a 5 MW wind turbine) was added.

The load flow was performed for the cases in which the distributed energy source (wind turbine) was on-grid or off-grid.

The power losses were determined with the Neplan software, using the Newton-Raphson extended method.

From the case study results it can be observed that the power losses were lower when the distributed generation source (wind turbine) was on-grid.

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