Scientific Bulletin of the „Petru Maior" University of Tîrgu Mureş
Vol. 11 (XXVIII) no. 2, 2014
ISSN-L 1841-9267 (Print), ISSN 2285-438X (Online), ISSN 2286-3184 (CD-ROM)

SCADA SIMULATION OF A DISTRIBUTED GENERATION SYSTEM WITH POWER LOSSES

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Abstract

In this paper we present the simulation of a distributed generation system. The simulation is performed using the facilities of CitectSCADA software considering the loads profile, the availability of the generating units and the power losses.
In order to cover the total load, the generating units are dispatched in ascending order of their power production costs, with the remark that if one of the distributed generation (DG) units is connected to the grid, then these DGs will be dispatched first due to the availability of their primary source.

Key words: distributes generation, simulation, SCADA, generation dispatch, power losses, power cost

1. Introduction

Distributed generation (DG) refers to the production of power near or at the consumption place. The distributed generation resources that are used for generating power are the combined heat and power or cogeneration (CHP) units and the renewable energy sources (RES). The location of these distributed generation resources in the power system depends on the presence and availability of their primary energy source (such as wind, water etc.).

The most common DG technologies and their typical module size are:

- Wind Turbine: 200 W - 3 MW;
- Photovoltaic Arrays (PV Arrays): 20 W - 100 kW;
- Small Hydro: 1 - 100 MW;
- Micro Hydro: 25 kW - 1 MW;
- Geothermal: 5 - 100 MW;
- Ocean Energy: 100 kW - 5 MW;
- Biomass Gasification: 100 kW - 20 MW;
- Battery Storage: 500 kW - 5 MW.

Distributed generation has several characteristics which are not present in traditional centralized power systems. The most important characteristic is the fact that the power generated by distributed generators is relatively small and has fluctuations dependent on the availability and variability of primary energy source. Another important characteristic is that the power flow is bidirectional (from the DG to the power grid or from the DG to the consumers), in comparison with the central generation system where the power flow is unidirectional.

The presence of DGs in a power system has an important role in improving the reliability of the grid, improving the power quality, reducing the transmission losses, reducing the greenhouse emissions and providing better voltage support.

The major impediment for a widespread acceptance of distributed generation has been the high cost of the power produced by these generators. However, this cost has decreased significantly over the past years.

This paper is a further study of the work presented in [1]. In [1] the simulation was performed for the IEEE 30 bus test system in which three DGs were included. In the simulation we considered all the loads as a single total load, and also the power losses were not considered. The simulation presented in this paper will be performed for a four bus test system.

The simulations presented in other papers ([2-14]), are focused on the analysis of power generated by distributed generators (usually photovoltaic, wind systems or small hydro systems) considering the wind speed, water flow speed etc. or dispatch of power in the electric grid. The distributed generators were connected to the power grid or isolated from the power grid. Also, in these papers the power losses were not considered in the simulations.

In this paper the simulation performed for the test system will consider the power losses, which will be subtracted from the total generated power.

2. Test system

In this paper we present a SCADA simulation of a distributed generation system, for the application test system in Fig. 1, considering the power losses.

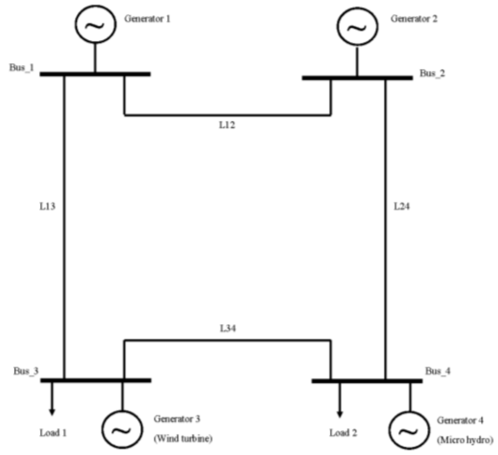

Fig. 1: Test system

The power losses will be determined with the Neplan software [15], using 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:

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

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

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

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

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:

$$\theta^{m+1} = \theta^{m} + \Delta\theta; |V|^{m+1} = |V|^{m} + \Delta|V| \quad (5)$$

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

The data for each generating unit are presented in table 1.

Table 1: Generators data

Type	Installed power (MW)
Generator 1 (G1) - Thermoelectric power plant	70
Generator 2 (G2) - Hydroelectric power plant	66
Generator 3 (G3) – Wind turbine	2
Generator 4 (G4) – Micro hydro	1

The power demand for the first load is 30 MW, respectively 45 MW for the second load.

The Romanian National Energy Regulatory Authority (ANRE) [16] sets the average prices for the production of electric energy from different sources that are presented in table 2.

Table 2: Average prices for the production of electric energy from different sources

Energy type	Average price [lei/MWh]
Nuclear energy	142
Hydroelectric energy	125
Thermoelectric energy	190
Producers beneficiaries of the bonus support scheme type that produce electricity from high efficiency cogeneration	189
Producers with dispatchable energy units	189

The power flow results considering different grid connections for the DGs are presented in table 3. The results will be considered in the simulation.

Table 3: Power flow results

Distributed generators connection	Active power losses (MW)
G3 (Wind turbine) and G4 (Micro hydro) are off-grid	0.465
G3 (Wind turbine) is on-grid and G4 (Micro hydro) is off-grid	0.450
G3 (Wind turbine) is off-grid and G4 (Micro hydro) is on-grid	0.456
G3 (Wind turbine) and G4 (Micro hydro) are on-grid	0.444

From table 3 it can be observed that the power losses are lower if the distributed generators are on-grid. These values will be used in the simulation presented further.

The distributed generators output, that will be used in the simulation is presented in Fig. 2.

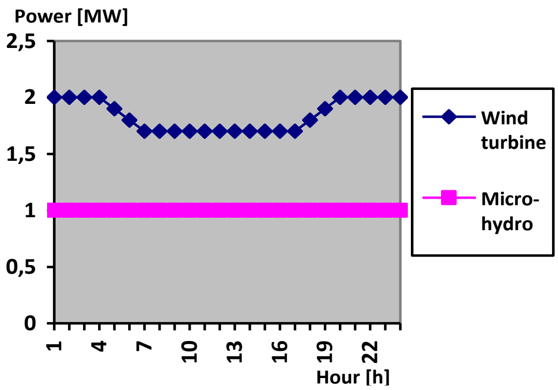

Fig. 2: Distributed generators output

3. Simulation of a distributed generation system

The simulation is performed using the CitectSCADA software [17].

In the simulation we considered the power demand of the two loads that is presented in Fig. 3.

The real power produced by the generators and the power losses are considered in this simulation.

The system's generating units will cover demand in order of their generating cost coefficient, with the observation that if the distributed energy sources are on-grid, they have priority access to the system. This is because the power generated by these distributed generators is variable in time due to the availability of their primary source.

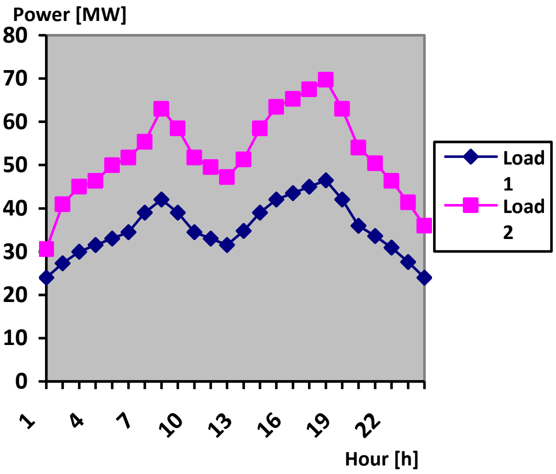

Fig. 3: Loads curve

The simulation flow chart is presented in Fig. 4.

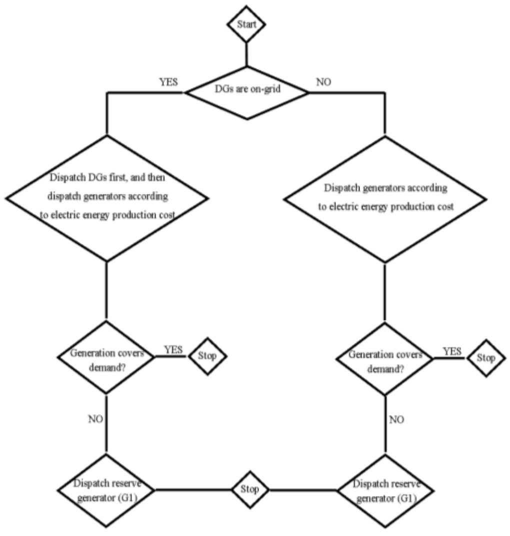

Fig. 4: SCADA simulation flow chart

The first step is to create the SCADA simulation interface (Fig. 5). The interface includes graphic symbols for the generators, loads, numerical objects ((####), slide bars, meters, charts, buttons and symbols (lights).

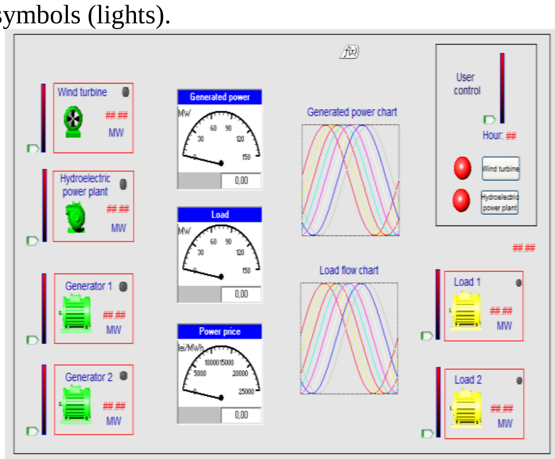

Fig. 5: Interface of SCADA system

Each of these components has assigned a corresponding tag.

The second step is to write the program functioning in Cicode Object (f(x)), which is comprised in the simulation interface. The Cicode Object (f(x)) automatically controls the system. Cicode is a programming language, similar with "C" or Visual Basic, which controls all the system components from the graphic page, like the tags (buttons, slide bar, numerical object etc.), local variables or the graphics.

The power dispatch (generation dispatch) is performed in ascending order of the power cost of the respective generator, with the observation that, if one of the distributed generation (DG) units is connected to the grid, then these DGs will be dispatched first due to the availability of their primary source. The dispatch order is presented in table 4.

Table 4: Generation dispatch order

Generator	Average cost for the production of electric energy [lei/MWh]
G3	189
G4	189
G2	125
G1	190

The Cicode Object comprises the main following functions:

- simulation: is composed of the loads demand from Fig. 3 and DGs generation output from Fig. 2 according to the hour of the day;
- dispatch: is composed of the generation dispatch order from table 4;
- power losses: according to the connection of the DGs (on-grid or off-grid), the corresponding values from table 3 are subtracted from the total generated power.

The only control that the user has is to connect or disconnect the DGs. This connection or disconnection of the DGs can be done by pressing the corresponding button of the DG from the user interface. Another control that the user has is to select the hour of the simulation. This can be done through the movement of the slide bar.

4. Simulation results

The results of the simulation (Fig. 6) emphasized that the system's generating units covered demand in order of their power cost coefficient, taking in consideration the power losses. Also, regarding the amount of power dispatched by each generator, the DGs dispatched their power according to their generation output, while the second generator dispatched all its installed power (except at 24:00 and 1:00).

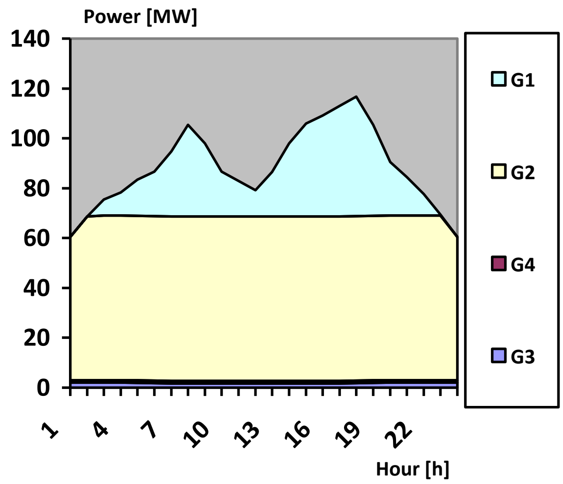

Fig. 6: Power dispatched by generators (DGs on-grid)

The power dispatched by these generators was enough to cover the total load only between 24:00 and 1:00. In order to cover the total load the reserve generator (first generator) had to be used. The first generator dispatched a smaller amount of power at the lowest demand, and dispatched a higher amount of power at the highest demand in order to cover the total load.

5. Conclusions

Distributed generation (DG) refers to the generation of power near or at the consumption point. The resources used for DG are the renewable energies and cogeneration units.

In this paper the simulation was performed for a test system in which two DGs were added and took in consideration the power losses. The power losses were determined by means of a specialized software, using the extended Newton-Raphson method.

The SCADA simulation emphasizes that the dispatch order selected according to the ascending order of power cost of each generator, with the observation that the DGs had priority access in the system although their power cost was higher, was respected.

The SCADA simulation emphasizes that the generation output of the DG sources (wind turbine and micro hydro generator) was too small to cover the total load alone, so the other generators had to be dispatched. The second generator had to be used to cover the load all the time. These three generators (G2, G3 and G4) managed to cover the load between 23:00 and 2:00. The load could be covered at 2:00 and 23:00 due to the power generated by the DGs. This emphasizes that DGs help cover the load. In the other cases (between 3:00 and 22:00) these three generators could not cover the load, so the reserve generator (G1) had to be used.

The reserve generator dispatched a smaller amount of power when the load was lower (between 3:00 and 6:00), and dispatched a bigger amount of power when the load was higher (between 21:00 and 22:00).

The SCADA simulation also emphasizes that the total power cost was higher when the DGs were connected to the system. The power cost increased even more when the reserve generator had to be used.

This increase of the power cost is determined by the high cost of power production associated to generators.

Acknowledgement

This paper is supported by the Sectoral Operational Programme Human Resources Development POSDRU/159/1.5/S/137516 financed from the European Social Fund and by the Romanian Government.

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