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Operation and Control of Distribution Systems with high level integration of Renewable Generation units

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Summary

Traditional power systems have a hierarchical vertical structure. This scheme is changing towards a horizontal structure because a large number of Distributed Generation (DG) units are being integrated into power systems at distribution level. Most of DG units are based on renewable energy sources (RES), which have a stochastic behaviour. Thus, it is better to investigate the impacts of DG integration in a probabilistic approach than a deterministic one, in order to help Distribution Network Operators (DNO) to develop strategies for both grid operation and control to keep high system availability and power quality.
As wind power technology has reached a great development and it is expected it will be widely introduced in power systems all around the world in a short term [7], wind generators will be studied with a special focus.
Real data from one Danish DNO will help to derive and verify the models.

Problem formulation

The design of new distributed energy systems must be considered as a modification of an existing centralized system by implementing DG units. This development lead to a radical shift in the philosophy of operation and development of distribution networks, from traditionally passive to increasingly active systems [2], because DG integration affects the network technically in a number of different ways [3] while DNO must maintain the responsibility of managing the grid and of giving service quality.

Most of DG units are based on RES, so their no-forecasting power production, because of their stochastic prime mover behaviour, may pose problems to DNO to control and operate the system in a suitable way when it is required to follow certain operation constraints. New challenges are also set up because most of the DG uses power electronics as energy converter interface between the prime source and the grid and this can affect, inter alia, the power quality and the protection scheme.

As distribution systems are spread in a given geographic area, it is necessary take into account some interdependencies from cyclic-deterministic phenomenon (time of day, day of week, season), considered location (city, rural, industrial) and random-stochastic phenomenon (weather conditions).

These interdependencies not only appear for DG, but also for the loads and the grid. The weather and the time frame in a specific geographic area have influence on both energy demand (because it depends on costumer behaviour) and grid availability, according to both DNO's restrictions and operation sets for a suitable network management.

Thus, it is necessary to set up probabilistic models with interdependencies [4, 5] of all stakeholders in the distribution systems with distributed generation integration in order to do a probabilistic analysis. This should be better than traditional deterministic analysis methods, since these may not be appropriate because they require specific values for loads, generation inputs and network conditions and they only calculate a specific state of the system, normally worst case situations, which are unlikely to happen. The deterministic approach also treats all these limiting scenarios as having the same risk. It does not give adequate consideration as to how likely or unlikely various contingencies are.

Probabilistic simulation models

Probabilistic methodologies are being applied to power system analysis since 70' [9] because the deterministic approach was not considered enough to cope with all power systems issues. And [10] already remarks that analysis techniques have to evolve if the system frameworks change in order to be able of dealing with the new matters. This prove the importance and usefulness of the probabilistic approach, and the reason why this research deals with it. Thus, power systems with a high level of DG units based on renewable source need a probabilistic approach mainly to deal with their stochastic power production. Moreover, there are other stochastic aspects, like failure and repair processes for any of the power system elements, which maybe should be included.

Probabilistic simulation methods are based on random sampling algorithms and are used to generate random samples that belong to a given stochastic model, and to compute expectations with respect to a given distribution function. The outcomes may be probabilities, discrete vectors or continuous fields of probabilities, in other words, probabilistic distribution functions (PDF).

And it is used to compare apparent effects of stochastic data set in order to determine the more likely effects in the system. This approach may be computationally intensive because the number of random variables and system complexities increase tremendously when uncertainty in renewable energy sources and load pattern are added to the system due to the fluctuating capacity levels of these sources. But it is possible with today's computing and analysis tools.

The probabilistic analysis when both generation and load have a stochastic behaviour can be performed through either a probabilistic load flow (PLF) or a Monte Carlo simulation (MCS) [1, 6, 8]. Both methods allow decisions to be based on objective data, i.e. probabilities of occurrence. Nevertheless, it is also possible to mix deterministic and probabilistic techniques to power system analysis [6].

When deriving probabilistic models one needs to have numerical data from the different elements which are parts of the system and which are to be modelled. Then, these data may need a previous treatment and analysis before it is used to build the probabilistic models [11]. And these data can be also used for validating the simulation models. However, there may be a problem with the data because they are not available or are costly to obtain.

The needed data to derive the models may be mainly from two different sources: existing public statistics or Distribution Network Operator request. Anyhow, both of them are complementary and it may be possible to develop models with the public statistics while data from DNO may be used to verify them. Both data sources are useful to obtain the probability density functions (PDF) that take part in the probabilistic models. However, each one of them presents advantages and disadvantages.

As Danish networks have a high level of DG units, then it is suggested that the models will be derived from real data provided by one of the DNO rather than public statistics. As Danish utilities are already operating their power systems under the circumstances described before, it would provide general results. It should be advisable to build a simulation model from a real network, rather than supposing different hypothetical scenarios. If hypothetical scenarios would be adopted, they could be unrealistic and then, the research work will not be used hardly ever.

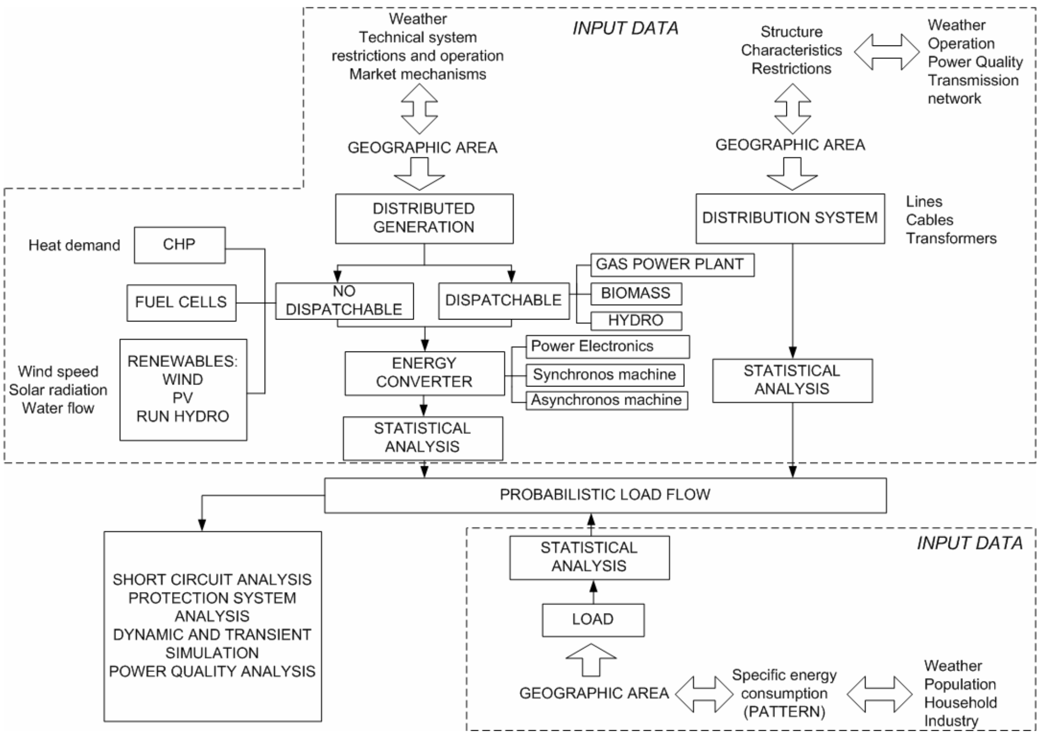

Fig.1. Distribution Power System Analysis Method

System Analysis Proposed

In order to solve the topics in the problem formulation, it is necessary to model the distribution power system [1] as shown figure 1, with the following main issues for the different blocks in the model:

- Probabilistic Power Flow (PLF): this processes the input data in order to analyze the steady-state of the distributed energy systems under uncertainty in energy generation and consumption. The input data are random variables with known probability density functions (PDFs) and the results are also PDFs, not fixed numbers, showing the range of the resulting quantities and the corresponding probability of each parameter occurring. As it has been quoted before, performing MCS is also possible. Even a mix of probabilistic and deterministic methods may be chosen. Power systems typically operate under slowly changing conditions; therefore they can be analyzed using power flow analysis that also provides the starting point for most other analyses, like fault and operational analysis, since power flow forms the core of power system analysis and emphasises on voltage levels, and load and power generation patterns.

- Input Data: the input data, which let the PLF provide the corresponding output values, are a probabilistic representation of the DG units power output, the load shape and the grid availability for a geographic area and time frame. It is formed by three entities:

    - Distribution system: probabilistic model for both the restrictions and the operation sets that may appear in transmission and distribution networks. The more important fact will be reliability of network elements.

    - Distributed Generation units: probabilistic energy generation affiliated to a geographic area pattern [6], its prime mover and its energy converter. There is a special interest in understanding the impact of wind turbines and centralized heat and power (CHP) plants on the distribution power system, because they are widely spread out in Denmark [6].

    - Load: probabilistic energy consumption shape affiliated to both geographic area and time frame pattern, in order to ensure the balance between generation and demand, like in [6]. Load model may be clustered in three types: urban, rural, and industrial. And in order to derive a probabilistic model of loads using a normal distribution, each cluster will be considered to split up the year in season time frames, and within each season, one will distinguish a model for weekdays and another model for weekend. And then, within each of these models, a normal distribution for each hour will be derived.

The results provided by this probabilistic analysis let to the DNO control and operate the system in a suitable way. First, the impacts of DG in power quality and availability will be identified. Then, new strategies and methodologies will be developed to assure the appropriate operation and control of distribution systems with high level integration of renewable generation units.

Next steps

The work described here is a short state of art and shows new methodology approach to deal with new power systems issues regarding to distributed generation. The work will continue with the modelling of DG units. The first one will be wind generators as they have widely been introduced. It will be developed based on the previous works conducted at the IET, AAU, and will be developed based on both the previous deterministic modelling and simulation work conducted at the IET, AAU, and the existing literature. The data from a local distribution system operator will help to verify the models.

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