PLANNING THE DEVELOPMENT OF HIGHLY DISTRIBUTED POWER SYSTEMS

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ABSTRACT

In this paper the particular aspects of Highly Distributed Power Systems (HDPS) are described and the HDPS planning problem is discussed. The requirements for a flexible HDPS planning framework are outlined. Some initial results that illustrate the adequacy of the proposed approach are presented. Finally, the next steps towards a fully functional planning framework are discussed.

INTRODUCTION

In recent years, power systems have experienced a gradual shift towards a more distributed configuration. This change is caused mainly by environmental concerns, technological innovation and new government policies. As a result of this trend towards distributed power systems, it is expected that some future power systems will include large penetrations of small scale generators and storage devices [1]. A Highly Distributed Power System (HDPS) will be comprised of several different generation technologies and diverse energy sources in a geographically dispersed power grid. The variability of loading will be increased because of this dispersed configuration. Moreover, the interaction of these loads with energy sources with limited predictability will result in complex behaviour within the HDPS.

The distinctive features of HDPS make planning them a very complicated task that needs to be analyzed. Even if HPDS planning is not a centralized task, and as a result a proper investment plan will never be carried out, research into HDPS planning will expand the knowledge relating to the complex behaviour of HDPS. This will provide a better understanding of the interaction of diverse energy sources and generation technologies in a distributed system. Also, a HDPS plan will provide useful information to the key parties involved in the research and development of HDPS like councils, utilities, energy developers and academics.

The focus of this research is the identification and development of appropriate planning techniques for HDPS. These techniques should take into account not only the particular characteristics of HDPS, but also requirements that today's electric power industry poses. In this paper, a brief definition of HDPS is discussed. Next, the requirements for a flexible HDPS planning framework are outlined. Some results showing the proposed approach are presented. Finally, the next steps required for a fully functional planning framework are outlined.

HIGHLY DISTRIBUTED POWER SYSTEMS

Li et al. [2] define a HDPS as an integrated power system with diverse generation technologies, varied energy sources, and geographically dispersed loads and generators. Management and control is considered to be decentralised. Additionally, because of the dispersion of loads and the characteristic availability of the energy sources, energy profiles within the HDPS are expected to be highly variable. A set of criterion to characterize HDPS is also proposed in [2]. These criteria define the distinct characteristics of HDPS and will be a starting point to define HDPS case studies (Table 1).

The concept of HDPS is very close to the one of distributed generation (DG) and Microgrids. However, while the definition of DG is focused in the size and location of the generators [3], the particularity of HDPS lies in the variety of technologies and energy sources considered. A HDPS is a power system that includes a high number of small scale distributed generators (DG) from different technologies. Moreover, diverse energy sources with highly variable energy profiles are expected to interact within the HDPS. These particularities are the reason why most DG planning techniques are not applicable to HDPS planning [4].

Table 1. Criterion for the classification and characterization of HDPS [2]

Aspect of distribution	Criterion
Technology	More than 4 generation technologies including storage and DSM.
Geographical	Local generation capacity can supply one third of total load and 100% of high value load.
Variability of energy profiles	Higher uncertainty in the energy profiles, increase of forecast error by 10%.
System management and control	The system is divided into sub-systems which are managed and controlled locally.
Diversification of energy sources	More than 2 types of energy sources are used for the generation of electrical power.

As noted, a HDPS can be very similar to a Microgrid. Both include small scale generators that supply energy to local loads from diverse energy sources. However, in some cases the generation within the Microgrid is expected to match all the local demand [5]. In contrast, in the case of HDPS generation is not expected to match the total of the local demand. On the contrary, it is expected that a HDPS will interact with other HDPSs and with the main grid, creating in this way a market for selling and buying energy. The interaction of the HDPS with the main grid must be considered in the planning procedure, as it might have great effect in some of the objectives considered.

HDPS PLANNING – REQUIREMENTS

Neimane [6] analysed in depth the distribution system planning problem. Based on this work and taking into account the particular characteristics of HDPS and the challenges that today's electricity industry poses [1] the requirements for a good HDPS planning technique were identified [4]. A good HDPS planning technique should:

- Consider multiple and conflicting objectives
- Consider the dynamic nature of the power system
- Consider the dynamic nature of the planning problem
- Provide flexibility in terms of the attributes, objectives and constraints considered
- Be able to handle uncertain information

Ideally all of these requirements should be met. However, a HDPS should also be simple enough to be used in diverse environments. Previous studies have identified a gap between 'the theory and practice of distribution system planning' [7]. As a result, these requirements should be analyzed, and if it is necessary a compromise between simplicity and the requirements should be met.

Multiple and Conflicting Objectives

Normally, a planning objective consists in the maximisation or minimisation of an attribute. For the most part, traditional planning techniques include only a single objective in the planning procedure, commonly minimisation of cost or minimisation of line losses. However, a technique that considers only one objective will be solving just one part of the problem. In contrast, including multiple objectives in the planning procedure has many advantages [4, 8]. Also, a multi-objective technique illustrates the trade-offs between different objectives, resulting in more informed decisions.

The HDPS planning problem is a multi objective optimisation problem. The planning objectives are related mainly with economical (i.e. cost, revenue), technical (i.e. voltage profile, line losses, energy generated, reliability) and environmental attributes (i.e. carbon emissions, reduction of emissions).

A common practice in planning is to convert these attributes to cost, and then to minimise the aggregated cost. However, some of the attributes (and the related objectives) can not be converted to cost in an accurate way, since they are not naturally cost variables [8, 9]. As a result of this conversion, accuracy is lost and uncertainty increased. Therefore, a key aspect of a multi objective approach is to decide which attributes are converted to monetary terms, and which attributes will remain in their original units.

Dynamic Nature of the Power System

The benefits and drawbacks of DG depend not only in the location and size of the generators, but also in the complex relationship of generation and demand over time [10, 11]. Load varies constantly. Similarly, generation from renewable or non-dispatchable energy sources is highly variable (i.e. wind, solar, combined heat and power). HDPS are dynamic in essence and it is unlikely that a single snapshot of the power system will adequately reflect the benefits and drawbacks of this complex interaction. Thus, the HDPS planning process must consider effectively the whole load and generation profiles.

Dynamic Nature of the Planning Problem

Planning is focused on finding the best scheduling of investments in order to serve future demands and achieve the planning objectives. Although most literature recognises planning as a dynamic task, few of the techniques proposed are dynamic or pseudo dynamic. The reason for this is that 'a dynamic problem formulation results in dramatic increase of computational efforts' [6]. However, suboptimal plans are caused not only by the wrong size or location of equipment, but also by poor timing of investments [7]. Therefore, a good HDPS planning technique must consider not only load growth and time value of money, but also the possibility that investments can occur at different points in time. Clearly the number of stages considered should be determined according to the processing capacity available.

Flexibility

Today's electricity industry requires planning tools that are flexible and adaptable [12]. When planning is no longer a centralised task, different planners will approach the planning problem with diverse perspectives. Even for the same planner, the approach taken for each project depends on the specific conditions of the environment and the constraints and objectives of the project. Therefore, the planner should be able to choose the attributes, objectives and constraints to consider [1], and also the importance of one objective in relation to others. It can be expected that including different objectives will produce different optimal plans; this can be very useful when the planning environment is as dynamic as today's electricity industry.

Uncertainty

Traditional planning techniques are often deterministic and static. Information is assumed to be certain, known and unchanging. However, this is not always the case. Uncertainty is present in measured and forecasted data. Neimane [6] recognizes that a high degree of uncertainty will result in low quality decisions. Thus, a good HDPS planning technique must be able to cope with uncertainty. While including all the uncertainties in the planning procedure would be impossible, the most important sources of uncertainty must be dealt with. In the case of HDPS the main sources of uncertainty will be related to load growth, the level of penetration of the different DG technologies, the future availability of generation technologies and the availability of energy resources. In some cases a scenario approach can be used (e.g. load growth) and in others appropriate modelling techniques should be used (i.e. Monte Carlo simulation for the energy sources and load).

ADDRESING THE REQUIRMENTS OF HDPS PLANNING TECHNIQUES– INITIAL RESULTS

In order to illustrate some of the requirements of the proposed approach a 19 node 0.4 kV radial feeder was analysed using a multi attribute approach. The feeder supplies energy to 68 properties via 4 sub-feeders. Thermal load is assumed to be provided by gas boilers, which is the most common case in the UK. A backward/forwards sweep AC power flow algorithm underpinned the simulation of seven attributes used for the multi attribute analysis: energy imported from the grid, energy exported to the grid, line losses, DG energy generated, total CO_2 emissions, maximum voltage raise and maximum voltage drop.

With the intention of adequately representing the variability of the demand in the analysis, half hourly load profiles were synthesised for each node. These profiles were based on UK generic distribution system (UKGDS) profiles [13]. The nodal peak demand was calculated with a coincidence factor to account for the number of houses connected to each node. Also, an exponential probability distribution within a Monte Carlo simulation was used to emulate the variability of the load in each node. The load variation took into account the characteristics of domestic demand in the UK. Demand profiles for four typical days were produced.

Similarly, four typical days for two types of generation profiles were synthesised: micro-combined heat and power (micro CHP) and solar photovoltaic (PV). The profiles were based on [10] and [13] and were adjusted to represent a realistic capacity factor for the UK. In this case the variability of the energy sources was not modelled (constant profiles were assumed). It was assumed that the energy not consumed within the feeder was exported to the grid (no storage). A detailed description of all the assumptions made and the models used can be found in [4].

To illustrate clearly the advantage of a multi attribute analysis and explore the effect of considering different load profiles a high penetration of micro generators was assumed. It was supposed that each property owns a micro generator. Generator capacities were increased from 0 kW up to $4kW_p$ for PV and 1.5 kW_e for micro CHP. Figure 1 shows the trade off between annual line losses and CO_2 emissions for the scenario described. Three different UKGDS load profiles were used to create the node loads: Domestic Economy (DE), Domestic Unrestricted (DU) and Commercial (C).

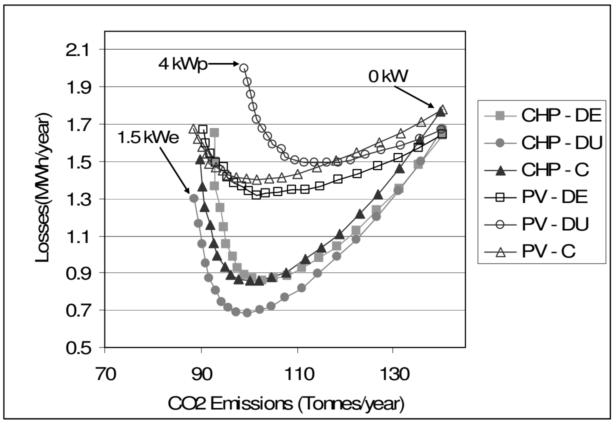

Figure 1 CO2 emissions vs. Line Losses

The generation profile of the micro CHP units is more coincident in time with the load than the PV profile. As a result, line losses are lower with micro CHP units. If the only objective of the planner or policy maker was to minimise line losses, micro CHP units would have a clear advantage. However, more CO_2 emissions can be saved by increasing PV penetration (the slope of the PV curves is less pronounced). As a result, the planner or policy maker faces a trade-off between these two attributes that depend on their specific objectives. Clearly a planning problem is multi dimensional and it will include more than two attributes. The point of the two attribute analysis shown in Figure 1 is only to illustrate the multi attribute approach proposed.

Figure 1 also shows that load profiles and generation type do have an effect on the trade-off curves. Minimum points are shifted, and in some cases the slope of the curve is more pronounced, creating different trade-offs between losses and CO_2 emissions. This proves the importance of considering adequate load and generation profiles when planning HDPS.

The multi attribute analysis facilitates to perform a "what if" analysis of different scenarios. However, in order to develop plans it is necessary to implement a multi objective programming technique. The multi objective technique will allow obtaining a set of optimal solutions from a search space defined by the objectives, constraints and preferences of the planner or policy maker.

CONCLUSIONS

Because of the use of different technologies, the diversity of energy sources and the variability of energy profiles, HDPS require an appropriate planning technique for their development. This technique must be able to include the particular characteristics of HDPS and also handle the requirements of today's electricity industry. In this paper the requirements for a HDPS planning technique have been identified and described.

The development of HDPS is a multi-objective problem, where a flexible approach is required. Different planners with diverse approaches must be able to choose the objectives and constraints to include in the problem. The dynamic nature of HDPS must be included in the analysis and the availability of variable energy sources should be adequately modelled. Similarly, the dynamic nature of the planning task must be considered. The HDPS planning technique must be able to handle the main uncertainties of the problem. Initial results that show the adequacy and flexibility of the proposed approach are shown in this paper.

Further work will include the implementation of a multi-objective programming technique. Uncertainty will be included using a scenario approach and modelling the energy sources in order to reflect their characteristic availability. As well, the use of a dynamic or pseudo dynamic approach for the planning technique will be analyzed and if it is feasible it will be implemented. The flexible approach proposed in this paper will be maintained and more objectives and attributes will be included.

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