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Evaluating the feasibility of operation and planning practices for mutual benefits of DNOs and power developers

A.M. Abd-el-Motalab[a,*], Lázaro Alvarado Barrios[b]

[a] Department of Electrical Engineering, University of Warwick, Coventry CV4 7AL, United Kingdom
[b] Department of Electrical Engineering, University of Loyola Andalucía, Campus Sevilla 41014, Spain

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ABSTRACT

In the UK, the power sector is moving away from the traditional centrally controlled power system to a decentralized power system, where a greater number of generation plants are connected to the distribution networks. However, incorporating distributed generators (DGs) into distribution networks faces several challenges because the allowable hosting capacity is restricted due to network constraints. In contrast to the most recent researches which investigated the feasibility of active network management practices for the benefits of either distribution network operators (DNOs) or power developers. This study focuses on investigating the feasibility of different operation and planning practices for the mutual benefits of both DNOs and developers. A representative UK 11 kV distribution network is modelled for comparative analyses and, the feasibility of each operation and planning practice is assessed over a 10-year period in terms of the additional DG capacity accommodated, the reduced network losses and network reinforcement costs. The main contributions of the research are therefore: (1) Quantifying the benefits of voltage control schemes using passive/active network management and power factor control of the DGs; (2) Quantifying the benefits of switchgear reinforcement at the primary distribution busbar; and (3) Proposing a competent hybrid optimization toolbox based on particle swarm optimization and pattern search to solve the operational-planning problem. It is concluded that operating the network under coordinated voltage control, dispatching DGs power factor and upgrading the switchgears at the primary distribution busbar enhance the mutual benefits of the power developers and DNOs. Moreover, the competency of the proposed hybrid solver is clarified in terms of the results quality and computational time. The results provide the decision makers with the flexibility to apply different options to increase the profit.

1. Introduction

Deploying distributed generators in power networks is being promoted as one of the solutions to reduce the reliance on fossil fuels. It also has direct effects of reducing network losses and deferring the investment for network upgrading. However, connecting DGs to power networks has given rise to a range of challenges including fault level increase and power quality issues which limit the level of DG penetration.

Researchers and engineers have investigated different planning techniques to maximize the DG penetration with respect to the networks constraints. Recent studies [1,2] showed that the issues to be addressed should include: (1) modelling the uncertainties of renewable energy sources, fuel prices, load demand and electricity market, (2) representing the incentives of both the distribution network operator (DNO) and DG developer, (3) enabling the active operation of the distribution network involving communication and control, and (4) developing more efficient computational algorithms for high-dimensional space problems.

In [3], a probabilistic load flow model for DG placement to minimize the losses was presented. The net present value analysis of the planning was carried out for biomass, wind, solar-photovoltaic, and diesel-engine DGs to show the viability in bilateral and competitive market scenarios. Refs. [4,5] provided a risk-based optimization approach to model a multistage distribution expansion planning problem that takes DG into account as a flexible option to temporarily defer large network investments. In [6], an optimal generation placement plan was provided considering the network and electricity market uncertainties. In [7], a planning model and an active network management scheme for increasing the DG capacity and minimizing the power curtailment were proposed. In [8], an economical model was applied only during on-peak and off-peak load periods to determine the location/size and offered prices of DGs to profit both the DNOs and power developers. Ref. [9] proposed a multi-period AC optimal power flow

* Corresponding author.
E-mail address: ahmad.ali.edifera@outlook.com (A.M. Abd-el-Motalab).

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Nomenclature

C_L	loss incentive (£/MWh)
C_{CHP}^{fl}	CHP unit fuel cost (£/Therm)
C_{DG}	generation feed-in tariff payment (£/MWh)
D_{DNO}	benefit from deferral of network upgrades (£)
$DPBP$	discounted payback period (years)
E_{DG}	DG generated energy (MWh)
K_{in},K_{out}	cash inflows/outflows (£)
K_{inv}	total investment cost (£)
N_P	planning period (years)
N_s	number of system states
OM	operational & maintenance cost (£/MWh)
P_{DG}	DG active power (MW)
P_{DG}^{cur}	curtailed DG power (MW)
P_L	load active power demand (MW)
P_U	active power of the utility interconnecting with the distribution network (MW)
Q_{DG}	DG reactive power (MVAr)
Q_L	load reactive power demand (MVAr)
Q_U	reactive power from the utility interconnecting with the distribution network (MVAr)
r	discount rate
S_l	distribution line thermal capacity (MVA)
S_{rDG}	DG rated capacity (MVA)
SCL	short circuit level (MVA)
ϕ_{DG}	phase angle between voltage and current
	time duration of a system state

algorithm to determine the optimal accommodation of DGs to minimize energy losses. A voltage control scheme along with DG power factor dispatch is embedded in the optimal power flow formulation to explore the effects on loss reduction.

The feasibility of adapting DG power factor and applying coordinated voltage control for the optimal operation of the network was recently investigated in [10,11]. Researchers in [12] proposed a DG expansion planning strategy, and the reactive capability limits of different renewable DG systems covering wind, photovoltaic, and biomass generation units were included in the planning model. In [13], the authors proposed a dynamic planning of distributed generation units considering active network management. The authors investigated the effect of active management on reducing the network losses and purchased electricity from the grid. In [14,15], the authors investigated the impact of dispatching the photovoltaic generators reactive power on increasing the penetration level of distributed generators. Also, in [16], a multi-configuration multi-period optimal power flow-based technique was proposed to assess the maximum distributed generation capacity under different active network management schemes.

The shortcomings of the previous researches mentioned within the literature include some of the following: (1) investigating DG expansion planning benefits for either the DNO or power developer but not both; (2) excluding economic indices which quantify the feasibility of the investment decisions over a specified planning period, i.e., discounted payback period or net present value; (3) excluding the impact of the active network management and dispatching DG power factor control in DG expansion planning and quantifying the effects on the planning decisions; (4) direct dependency on heuristic optimization techniques which may fail in complex problems where the search space is large. In addition, the impact of the fault level headroom (the difference between the switchgear fault level capacity and the actual fault level at the primary substation buses) on the mutual benefits of developers and operators has not been discussed. With considering the previous shortcomings, the indicated researches in the literature could lead to wrong and unjustified planning decisions.

In some countries, such as the UK, DG developers and network operators are separate parties. The benefits of both parties must be coordinated. The common practice is to connect the DGs operating at unity power factor; such a practice could frequently cause the voltage limits to be breached, limiting the penetration level. On the other hand, the typical switchgear rating at 11 kV primary buses is 250 MVA for the breaking capacity [17], which may also limit the allowable connection capacity due to inadequate fault level headroom. In this paper, a 10-year planning period is modelled for a representative 11 kV distribution system and two case studies are performed to investigate the consequences of the current operation and planning practices on the benefits provided to the DNO and DG developers. The benefits for the DNO are assessed in terms of minimizing the network losses and the upgrading costs, whilst the profits for the developer are ensured by the discounted payback period (DPBP). System uncertainties and reactive power capability limits of the DGs, particularly (PV) systems and gas fired (CHP) units, are considered.

In the first case study of this research, the fault constraint is alleviated by increasing the fault level headroom with switchgear breaking fault level increased to 266MVA. This allows to examine the current voltage control schemes in the market: (1) DGs operating at unity power factor within a passive network, representing a voltage-constrained network (Case 1, current practice in the UK market), (2) DGs power factor adaptation within a passive network (Case 2), and (3) DG power factor adaptation with the active network management assuming that the measurement and communication infrastructure is in place (Case 3). In the second case study of this research, the scenario of the fault-constrained network is analyzed with switchgear rating of 250 MVA for the breaking capacity at the primary distribution buses, reflecting a fault-constrained network (typical practice in the UK market) and the feasibility of such a typical rating is investigated. The modelled uncertainties include solar irradiance and load demand growth. A hybrid solver with particle swarm optimization (PSO) and pattern search (PS) is adopted for each of the operation and planning scenarios. Therefore, the optimization solver is characterized by the global and local search capabilities to speed up the convergence and to avoid falling into local optimum.

The intended contributions of this study are therefore (1) to develop an operational planning framework for optimizing the DG location and size and ensuring the mutual benefits of the DNO and power developer; (2) to quantify the effects of voltage control schemes, along with upgrading the switchgear at the primary distribution busbar on the DG expansion planning decisions and (3) to propose a competent hybrid optimization toolbox based on particle swarm optimization and pattern search to solve the operational-planning problem.

The rest of the paper is organized as follows. Section 2 introduces the modelling of system uncertainties. Section 3 describes the restrictions on DG penetration in distribution networks, and illustrates the concept of the active network management along with DG power factor control to increase the network hosting capacity. The planning model is presented in Section 4 with all the necessary constraints and the proposed optimization solver is discussed in Section 5. The case study results and the conclusions are provided in Sections 6 and 7, respectively.

2. Modelling the uncertainties

Historical data are used for load demand prediction over the planning period. Similarly, the solar irradiance data were obtained for the area in concern. In this paper, the modelling of the uncertainties includes two stages [12].