Electrical Power and Energy Systems 33 (2011) 1243–1250

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Effect of load models on assessment of energy losses in distributed generation planning

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ARTICLE INFO

Article history:
Received 2 June 2010
Received in revised form 21 December 2010
Accepted 12 April 2011
Available online 18 May 2011

Keywords:
Distributed generation
Load model
Energy losses
Voltage profile
Load forecasting

ABSTRACT

Distributed Generation (DG) is gaining in significance due to the keen public awareness of the environmental impacts of electric power generation and significant advances in several generation technologies which are much more environmentally friendly (wind power generation, micro-turbines, fuel cells, and photovoltaic) than conventional coal, oil and gas-fired plants. Accurate assessment of energy losses when DG is connected is gaining in significance due to the developments in the electricity market place, such as increasing competition, real time pricing and spot pricing. However, inappropriate modelling can give rise to misleading results. This paper presents an investigation into the effect of load models on the predicted energy losses in DG planning. Following a brief introduction the paper proposes a detailed voltage dependent load model, for DG planning use, which considers three categories of loads: residential, industrial and commercial. The paper proposes a methodology to study the effect of load models on the assessment of energy losses based on time series simulations to take into account both the variations of renewable generation and load demand. A comparative study of energy losses between the use of a traditional constant load model and the voltage dependent load model and at various load levels is carried out using a 38-node example power system. Simulations presented in the paper indicate that the load model to be adopted can significantly affect the results of DG planning.

1. Introduction

The load in a distribution system generally consists of three main types, i.e., residential, commercial and industrial load, with their proportion in the total load demand varying with time, e.g., hourly, daily and seasonally. The nature of these three types of loads is such that their active and reactive power components respond differently to variations in the voltage and frequency of the system [1,2]. System planners need to understand the exact nature of load sensitivity of voltage in order to precisely quantify the economic benefits of installing DG. Korunović et al. [3] studied the static load characteristics of a medium-voltage distribution network by conducting field measurements and concluded that steady-state distribution load can be modelled as exponential voltage-dependent model in a relatively wide voltage range, from 0.96 to 1.1 of the nominal voltage with errors less than 5%.

The variation in the actual power demand with voltage has become more prominent in recent years as increasing penetration of renewable DGs, such as intermittent wind, has made voltage profiles on the distribution feeders more dynamic. The connection of DG to distribution networks near load centre could change magnitude and direction of network power flows. This would impact on network operation and planning practices of distribution companies with both technical and economic implications. Investigations have therefore been carried out into DG planning in distribution systems in recent years [4–13], among which power system losses reduction due to the introduction of DG in distribution systems attracts much attention [10–13]. Most of these investigations focused on assessing the power loss reductions brought about by DG and utilised a constant load model in the power flow analysis, that is, the load power was considered to be independent of variations in feeder voltage. In general, the regulator sets a loss target for each of the UK distribution network operator (DNO). DNOs are rewarded if their real losses are lower than the loss target. Otherwise, the DNOs are economically penalised. Although at present the economic incentives to reduce losses are on the DNOs, it is possible that DNOs will pass part of the reward to DG owners for assisting reducing network losses in the future [12]. However, an accurate quantification of energy losses associated with DG largely depends on the load models employed in the power flow algorithms. Therefore, the load models will have a direct consequence on DNO's profit.

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doi:10.1016/j.ijepes.2011.04.003

Frantz et al. [14] highlighted that the load model can significantly affect the predicted system performance. A detailed voltage-dependent load model was adopted in an optimal capacitor installation/switching study by Rizy et al. [15] in a distribution system where the authors demonstrated that the detailed load model accurately predicted that the active power injection increased with the voltage increase whilst the constant load model failed to do so. Singh and Misra [16] performed a comparative study of real and reactive power loss, real and reactive power intake at the main substation and MVA support provided by installing DG resources for different type of load models. The authors in [16] highlighted that load models can significantly affect the optimal location and sizing of DG resources in distribution system and they also integrated the detailed load models in DG planning using multi-objective optimisation [17]. Qian et al. [18] carried out a study of the effect of load models on the assessment of power losses when a high penetration level of DGs is integrated in LV distribution systems. These studies successfully accounted for load models in DG planning, however, only catered for a single load level and failed to take into account the variations in renewable DG power output and making them impossible to determine the actual impact of variable forms of renewable DGs. As renewable DG is highly variable power source. At any instant in time its export will alter the existing power flows and bus voltages in the direct path from the connected bus to the substation. Subsequently, the voltage and voltage-dependent load at all buses will change at each time instant. Therefore, with a high penetration level of renewable energy generation, a single power flow solution can no longer describe the possible system states in a representative way.

The focus of the present paper is to evaluate the significance of load models on assessment of energy losses in a distribution system with high penetration level of DG, using a 38-bus example power system as a vehicle. In order to capture the effects that the variability of both demand and renewable DGs has on the performance of distribution systems, this paper proposes a methodology based on time series simulations to assess the energy losses of distribution systems with high penetration level of renewable DGs.

2. System modelling and simulation

2.1. The example system

The example system shown in Fig. 1 [19] will be used for the study. The voltage rating of the radial system is 11 kV. DGs are to be connected to the system as embedded generations, instead of being connected directly to the Grid Supply Point (GSP, defined as the point of supply from the national transmission system to the local system of the distribution network operator or non-embedded customers [20]). Details of the system can be found in Table A1 in Appendix A.

Simulations are carried out for a calendar year to analyse the impact of load models on distribution losses under different scenarios. The computation of energy losses is on a half-hourly basis

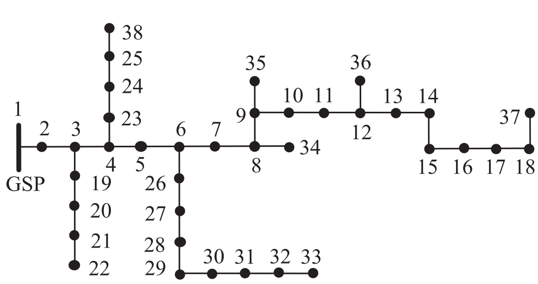

Fig. 1. 38-node radial distribution system [19].

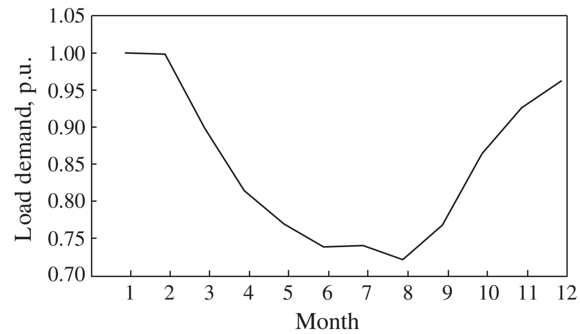

Fig. 2. Monthly load level of the studied system.

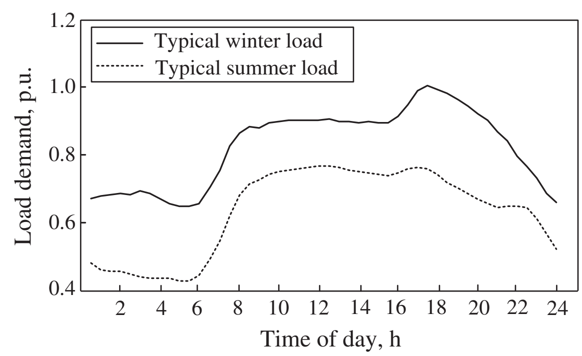

Fig. 3. Normalised load profiles in winter and summer of the studied system.

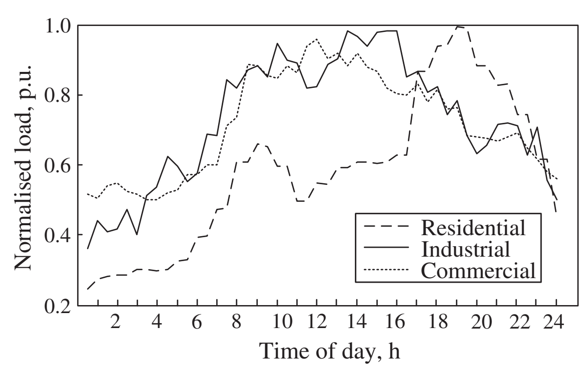

Fig. 4. Normalised load patterns for the three load classes [22].

which requires half-hourly demand data; however, the 38-node sample system does not provide half hourly load data. As a result, the data given in Table A1 is assumed to be the peak load and loads for the rest of time are obtained by assuming the same load variation as real historical data in Figs. 2 and 3. The power demand at each of the 38 nodes arising from each of the residential, industrial and commercial sectors are assumed to follow the pattern shown in Fig. 4, with detailed figures in Table A2. Power system simulation was carried out using the 'Interactive Power Systems Analysis' (IPSA) software [21].

2.2. Components of load power demand

Fig. 2 shows the typical annual load profile in the UK. The daily demand profile varies over the seasons of a year as given in Fig. 3 where the peak demand occurred on 23rd January 2008, and the minimum demand occurred on 22nd June 2008 [22]. Fig. 4