Available online at www.sciencedirect.com

ScienceDirect

Journal of Electrical Systems and Information Technology 3 (2016) 94–107

www.elsevier.com/locate/jesit

Impact of distributed generators on the power loss and voltage profile of sub-transmission network

A.S.O. Ogunjuyigbe, T.R. Ayodele *, O.O. Akinola

Power Energy Machine and Drives (PEMD) Research Group, Electrical and Electronic Engineering Department, Faculty of Technology, University of Ibadan, Nigeria

Received 20 May 2015; received in revised form 4 November 2015; accepted 5 November 2015
Available online 17 March 2016

Abstract

This paper presents the impact of distributed generator (DG) on the power loss and voltage profile of sub-transmission network at different penetration levels (PLs). The various DG technologies are modeled based on their electrical output characteristics. Voltage profile index which allows a single value to represent how well the voltage matches the ideal value is developed. The index allows a fair comparison of the voltage profile obtained from different scenarios. The extent to which DGs affect power losses and voltage profile depend on the type of DG technology, PL and the location in which the DG is connected to the grid. The integration of DGs reduces power losses on the network, however, as the PL increases, the power losses begin to increase. A PL of 50–75% is achieved on 69 kV voltage level and 25–50% penetration on 13.8 kV voltage level without an increase in the power loss. Also more DG can be integrated into the network at point of common connection of higher voltage level compared to the low voltage level.

Keywords: Renewable distributed generation; Sub-transmission network; Power loss; Voltage profile; IEEE 14-bus system

1. Introduction

In recent years, there have been increasing interests in distributed generation. This is as a result of market deregulation, technological advancement, governmental incentives, and environment impact concerns (Freitas et al., 2006). The traditional way of generating electrical power is the vertical approach where electricity is fed to the load centers through long transmission and distribution network (Davda et al., 2011). However, the environmental and technical problems associated with the traditional method have made the horizontal approach where DGs are part of the power system a better alternative. According to Attia et al. (2010), distributed generation (DG) refers to a small-scale generation, which

* Corresponding author.
E-mail addresses: a.ogunjuyigbe@ui.edu.ng (A.S.O. Ogunjuyigbe), tr.ayodele@ui.edu.ng, tayodele2001@yahoo.com (T.R. Ayodele), oakinola611@stu.ui.edu.ng (O.O. Akinola).
Peer review under the responsibility of Electronics Research Institute (ERI).

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jesit.2015.11.010

is not directly connected to the bulk transmission system and is not centrally dispatched. It can be of great advantage in isolated locations where central generation is impracticable or where grid extension is difficult (Borges and Falcao, 2003) and it can be fed back into the grid in an integrated way. The available size of DG per module can be as little as 1 kW to as high as 250 MW depending on the technology (Ackermann et al., 2001). Based on size, DGs may be classified into micro (1 W to 5 kW), small (5 kW to 5 MW), medium (5–50 MW) and large (50–300 MW)(Ackermann et al., 2001). The power ratings of medium and large DGs make it practically infeasible to utilize such generators in distribution networks.

Authors have proposed different approaches and indices in an attempt to understand the possible impact of DG on the grid: global performance index that makes use of weighting methods has been proposed by Attia et al. (2010) to study the distributed generation impacts on distribution networks. It was reported that the proposed performance index is flexible which makes it suitable as a tool for finding the most beneficial places where DGs may be located. The effect of distributed generators on line losses and network resonances on North American distribution feeder has been studied by Rangarajan et al. (2014). The network resonance study was performed using PSCAD/EMTDC simulation software while the line loss and voltage profile was determined using Distribution Engineering Simulation Software (DESS). It was concluded that DGs are beneficial to the network in term of voltage profile improvement and line loss reduction. El-Khattam and Salama (2002) focused on introducing a new approach to generate power in the distribution network and in addition enhance the distribution system's voltage profile and reduce the electric system losses by installing DG in the distribution system. It was revealed that DG has a great positive impact on improving the voltage profile and reducing the total electric power losses through the entire distribution network. Bawan (2012) investigated the usage of DGs to reduce the power losses and to improve the voltage profile based on location of DG and size of injection. The study was implemented using application program ETAP 6.0 and the Manokwari electricity distribution system as case study, the results shows that at certain location, the power injection of DG has resulted in reduction in power loss from 240.15 kW to 99.39 kW and it was found to be more economic than without DG installation.

In all the aforementioned studies, DGs are integrated into the distribution network. This makes the generators to be closer to the load centers with its attendant advantages as a result of the proximity to the load centers. However, most distribution networks are weak and radial in nature with low short-circuit capacity. Therefore, there is limit in which power can be injected into the distribution network without compromising the power quality and the system stability. To overcome this challenge, there is possibility of installing DG at the sub-transmission level. Sub transmission networks are at a higher voltage level with higher short circuit capacity compared to distribution networks and they are meshed. This allows more power injection into the power system transmission network with higher reliability. However, there is need to understand the possible impact of DG on this network. This paper seeks to investigate this by connecting DG technologies to a sub transmission network at increasing penetration level and observing the impact they have on the losses and voltage profile of the sub-transmission network.

2. Sub-transmission network

A sub-transmission network is employed in this study; it is a circuit that supplies power to distribution networks from transmission networks. It has a voltage between the transmission and distribution level. They are mesh networks which can be active. In other words, sub transmission networks might have active or reactive power generators in one or more nodes (Shahariar et al., 2014a,b). The IEEE 14 bus test network as depicted in Fig. 1 is popularly utilized for modeling sub transmission network (Shahariar et al., 2013) and it is adopted in this study. The data for the network was obtained from (Milano, 2010). It has its buses at three voltage levels – 13.8, 18 and 69 kV.

3. Modeling of distributed generators

The types of technologies employed in Distributed Generators can be classified into three based on their electrical output characteristics (Mozina, 2010). These classes are shown in Table 1 with the DG technologies categorized under them.

Synchronous generator technologies (SGTs) has the ability to maintain their terminal voltage by varying the amount of reactive power they generate. Thus, they are able to operate at varying power factors. In the case of induction generator technologies (IGTs), reactive power is needed to magnetize their rotors and this can be supplied either by the grid or capacitor banks. The asynchronous generator based technologies (AGTs) use power electronic devices as interface to