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Evaluation of maximum allowable capacity of distributed generations connected to a distribution grid by dual genetic algorithm

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ABSTRACT

This paper proposes a dual genetic algorithm based approach to evaluate the maximum allowable capacity of distributed generations (DGs) connected to a distribution grid. The uncertainties in the existing deterministic approaches for evaluating the steady-state voltage deviation due to distributed generation are discussed as well. Nowadays, deterministic approaches are widely adopted by those who propose the interconnection of DGs. However, the existing deterministic approaches overlook some operation conditions that may give rise to an incorrect result and lead to a wrong decision in practical applications. In this paper, various factors affecting steady-state voltage deviation are discussed first. Then, a maximum allowable DG capacity evaluation approach based on the dual genetic algorithm is proposed. Finally, the uncertainties of the existing deterministic approaches are discussed. It is intended as reference for utility engineers processing DG interconnection applications.

1. Introduction

The Kyoto Protocol went into effect on February 16, 2005. The need to reduce greenhouse gases has led to growing worldwide interest in renewable energy generation, especially wind power. Due to the desire for more renewable energy, many small power sources have been hooked up to distribution systems. The penetration of distributed generation (DG) is fast increasing in distribution grids throughout the world, especially in Europe. The major part of the increasing DGs should be covered by wind power. Wind energy is a type of clean energy, produces no air pollution, and therefore has rapidly become the most competitive energy resource among the renewable energy resources. As outlined in GWEC's Global Wind 2008 Report [1,2], global wind energy capacity could reach more than 1000 GW by the end of 2020. Wind power could produce about 2600 TWh of electricity per year, which is to supply 10–12% of global electricity demand by 2020. The CO_2 emission factor for the conventional energy sources is about 600 g CO_2/kWh. Wind power would reduce as much as 1500 million tons of CO_2 every year.

The 2009 United Nations Climate Change Conference, commonly known as the Copenhagen Summit, was held at the Bella Center in Copenhagen, Denmark, between 7 December and 18 December. The conference included the 15th Conference of the Parties (COP 15) to the UNFCCC and the 5th Meeting of the Parties (COP/MOP 5) to the Kyoto Protocol. According to the Bali Road Map, a framework for climate change mitigation beyond 2012 was to be agreed. The conference was preceded by the climate change: Global Risks, Challenges and Decisions scientific conference, which took place in March 2009 and was also held at the Bella Center.

The Copenhagen Accord was drafted by the US, China, India, Brazil and South Africa on December 18. The document recognized that climate change is one of the greatest challenges of the present day and that actions should be taken to keep any temperature increases to below 2 °C. The document is not legally binding and does not contain any legally binding commitments for reducing CO_2 emissions. Many countries and non-governmental organizations were opposed to this agreement, but 138 countries have signed the agreement on January 4, 2010.

IEC 61400 series standards are an important basis providing reliable certification processes and acceptance criteria for standards related to the design of wind turbines in Europe. In addition, rules for measurement and assessment of power quality characteristics of grid connected wind turbines are included in IEC 61400-21 [3]. IEEE-1547 is the standard for interconnecting distributed resources (DRs) with electric power systems, nationwide in the United States of America [4]. IEEE-1547 offers a way to more efficiently manage distributed energy resources, and ensure the reliability of the power system.

The reduction of distribution network power loss, release of transmission capacity, and enhancements of system continuity

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and reliability are some of the advantages of DG applications. Therefore, the use of DGs, such as small wind turbines, photovoltaic (PV), gas engine and fuel cell systems, is fast increasing in residential buildings throughout the world. Many studies on the economic and environmental evaluation of energy utilization in residential distribution systems have been presented. In [5], the energy utilization efficiency of the Turkish residential–commercial sector in 2001 by using energy and exergy analyses were evaluated. In [6], the installation, technical characteristics, operation and economic evaluation of a grid-connected building-integrated photovoltaic system installed in Northern Greece were proposed. By using a computerized renewable energy technologies assessment tool, the technical and economical factors are examined. To assess the financial payback of building-integrated photovoltaic systems, a number of different economic and financial feasibility indices are evaluated for different financing scenarios. In [7], the analysis of financial payback periods and carbon savings under various scenarios applicable to micro-wind devices and the urban environment has been presented. From the environmental point of view, a multi-criteria evaluation of residential energy supply systems was proposed in [8]. In [9], the effective load carrying capacity (ELCC) methodology is used to strategically site these distributed generators integrated to the building envelope. In this case, PV generators integrated to building facades and rooftops in urban areas at limited penetration levels can be modeled as negative loads. In [10], the analysis of simple economic payback of wind turbine was investigated. To predict the payback period of the solar concrete collector, a simple economic analysis was conducted in [11].

In [12], a methodology was presented to evaluate size and cost of PV power system components. The cost of PV system components was determined based on the size of PV system components. The life cycle cost analysis for the PV system was presented for estimation of unit cost of electricity generated from the stand-alone PV and building integrated PV systems. In [13], two typical micro combined heat and power (CHP) technologies, namely, gas engine and fuel cell for residential buildings, were analyzed. By using a plan and evaluation model for residential micro CHP systems, two different operating modes including minimum-cost operation and minimum-emission operation are taken into consideration. That is, the economical and environmental potentials of the micro CHP systems are taken into account. In [14], the determination of the energy, environmental and economic efficiency of the most common building materials and thermal insulation solutions were proposed. The above-mentioned studies mostly focus on the economic and environmental evaluation of DG systems.

Besides the advantages of DG applications, the parallel operations of DG with the power grid alter the traditional operating rules of the latter and pose new issues regarding power quality, e.g. voltage deviations, flicker, harmonic, etc. In [15], several system issues which may be encountered as DRs penetrate into distribution systems were pointed out. The voltage issues covered are the DR impact on the system voltage, interaction of DR and capacitor operations, interaction of DR and voltage regulator, and impact on the operation of line drop compensators (LDCs). Protection issues include fuse coordination, feeding faults after utility protection opens, impact of DR on interrupting rating of devices, faults on adjacent feeders, fault detection, single phase interruption on three phase line, recloser coordination and conductor burndown. And, loss of power grid and system restoration issues were also discussed in [15].

However, the most critical impact of DG on the distribution grid is the steady-state voltage deviation (or slow voltage variation). Hence, a simply applicable deterministic approach to steady-state voltage deviations becomes imperative. For that reason, some evaluation methods of steady-state voltage deviations have been proposed [16–19]. In [16,17], some concepts of deterministic approaches were presented. Slow and fast voltage deviations, flicker and harmonic emissions evaluation methodologies were considered in [18,19].

Distinct from the above-mentioned approaches for determining the maximum allowable capacity of DGs connected to a distribution grid, the proposed dual genetic algorithm (DGA) is designed to improve the efficiency of the current initial review process. That is, the proposed approach is not designed to evaluate a specific DGs interconnection case with given system topologies and operation conditions. On the contrary, the proposed approach is designed to predetermine the range of the solution sets of possible installed DG capacities and to consider the feasible ranges of the system parameters and operation conditions for the entire or portions of distribution systems of a power utility. The solution sets obtained by the proposed DGA approach can be applied to deal with the initial review process to speed up the screening process for most of DGs interconnection cases without the time-consuming power flow-based system impact evaluations.

In recent years, genetic algorithm (GA) has been extensively employed in numerous fields due to its flexibility and efficiency. There are many successful applications, such as phase arrangement [20], economic dispatch [21], network reconfiguration [22,23], capacitor placement [24], and others. After multiple comparisons of performances of the testing optimal solution techniques, the GA is adopted here to solve the problems of the maximum allowable DG capacity.

The paper is organized as follows: Section 2 presents the existing deterministic approaches steady-state voltage deviation due to DGs interconnection; Section 3 introduces the major factors affecting steady-state voltage deviations due to DGs interconnection; Section 4 presents the proposed algorithm for finding the range of solution sets of maximum allowable DGs capacities; Section 5 presents test cases and results to build the relation between the maximum allowable DGs and the short-circuit capacity at the connection point of the DG. Finally, a conclusion will be drawn in Section 6.

2. Existing deterministic approaches to steady-state voltage deviation

For most parts, (1) and (2) are usually used to assess steady-state voltage deviations due to DGs interconnection with the distribution network [16–19].

$$d\% = \frac{RP_\phi + XQ_\phi}{\left|V_{\mathrm{DG(w/o)}}\right|^2} \times 100 \tag{1}$$

where $d\%$ denotes the steady-state voltage deviation as a percentage of the nominal voltage; $V_{\mathrm{DG(w/o)}}$ is the nominal line-to-line voltage (in kV) without DG output; R and X represent the equivalent resistance and inductive reactance at the DG-connected point respectively (in Ω); and P_ϕ and Q_ϕ stand for the maximum active and reactive power produced by DG (in MW and Mvar) respectively.

$$d\% = \frac{S_{\mathrm{DG}}}{S_{\mathrm{S.C.}}} \cos(\phi + \theta) \times 100 \tag{2}$$

where $d\%$ denotes the steady-state voltage deviation as a percentage of the nominal voltage; $S_{\mathrm{S.C.}}$ is the network short circuit capacity at the point of DG interconnection; S_{DG} stands for the rated apparent power of DG at 1-min time interval; and ϕ and θ represent the phase angle of the grid driving-point impedance and the phase angle between the output voltage and current of DG, respectively. Network short-circuit capacity and grid driving-point impedance angle are the parameters that describe the strength and characteristic of the grid at the point of DG interconnection.