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Anti-islanding selection for grid-connected solar photovoltaic system applications: A MCDM based distance approach

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Abstract

The main objectives of this paper are to identify the major challenges of islanding-detection and suggest an appropriate islanding-detection method (IDM) for grid-connected solar photovoltaic system (GCSPVS) application using multi-criteria decision-making (MCDM) analysis. Related articles appearing in the field of islanding-detections for GCSPVS as well as other types of distributed generators are studied and analyzed so that the following questions can be answered: Which factors dominate the selection of IDM? Which evaluating factors are the crucial ones? Which evaluating criteria are paid more attention to for a particular application? In this research, the preferences of the criteria with their correlations have been evaluated by the analytic network process (ANP). And, these criteria preferences are made involved in the decision matrix of the technique for order preference by similarity to ideal solution (TOPSIS) which is a distance based optimization technique. Unlike hierarchy based approach, the proposed approach takes into account the interdependence relationships among all the constraint of IDM selection and the sensitivity analysis of the model indicates the robustness of the selection.

Keywords: Analytic network process; TOPSIS; Islanding-detection method; Grid-connected solar photovoltaic application

1. Introduction

A new paradigm of electrical network is with the significant penetration of distributed generations (DGs). A numerous problems are to be tackled when DG units are connected to the electrical networks. Islanding-detection is one of the primary concerns in the interconnected DGs. Islanding is defined as the continued operation of a DG unit or a group of DG units energizing a portion of network at the time of loss of utility grid. The islanding situation jeopardizes public security or endangers maintenance workers. Several researches on unintentional islanding-detection have been accomplished to ensure the system operation as per the requirements of the different standards.

A grid-connected solar photovoltaic system (GCSPVS) basically consists of a photovoltaic generator (set of arrays) and a power conversion stage (inverter) (Yu et al., 2010). The basic of a GCSPVS is depicted in Fig. 1. A DC smoothing capacitor optionally with the components for a boost or buck–boost type DC/DC converter is used as DC interface between the SPV array and DC/AC converter. The DC/AC converter stage involves switching devices (e.g., IGBTs, MOSFETs) in a push–pull or bridge-type fashion which converts the DC power into

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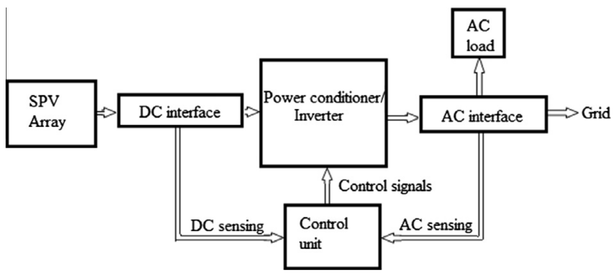

Fig. 1. Basic block diagram of a GCSPVS.

the AC power (Ahmad et al., 2013). Typically, the AC interface unit consists of a low-pass filter, a line-frequency transformer or inductor and protective devices. The main control and monitoring algorithm with the proper gate driving logics of semiconductor switches is incorporated in the control unit (Trujillo et al., 2010).

As islanding impacts on operation and power quality of the system, personnel and equipment safety, etc., GCSPVSs should be equipped to anticipate it (Llaria et al., 2010; Ye et al., 2004). Recently, several control and monitoring schemes for DGs have been devised to effectively detect the islanding condition and quickly disconnect DG from the network (Mahat et al., 2008; Teoh and Tan, 2011; Yu et al., 2010). Standards-making bodies and solar inverter manufacturers are used to give a lot of efforts in deciding an appropriate anti-islanding scheme for a GCSPVS application. It is impeded due to many reasons. Several technologically established islanding-detection methods (IDMs) are available posing both merits and demerits. Also, a number of criteria as well as their preference order by the decision-maker influence an effective IDM selection. Therefore, there should be an appropriate method to analyze different types of IDMs for evaluating suitability in present GCSPVSs and forecasting for future applications. A suitable MCDM analysis should be applied in this situation for considering all constraints directly and indirectly influencing the anti-islanding selection (Datta et al., 2011; Germano and Roulet, 2006).

MCDM is applied in decision-making problems deriving a way to come in a transparent process when faced with numerous and conflicting evaluations (Luna-Rubio et al., 2012). Different MCDM methods such as preference ranking organization method for enrichments evaluations (PROMETHEE) (Alsayed et al., 2014; Chatzimouratidis and Pilavachi, 2012), evacuation management decision support system (EMDSS) (Lin et al., 2010), elimination and choice expressing reality (ELECTRE) (Beccali et al., 1998; Chatzimouratidis and Pilavachi, 2012), technique for order preference by similarity to ideal solution (TOPSIS) (Lai et al., 1994), analytic hierarchy process (AHP) (Germano and Roulet, 2006; Saaty, 2006), analytic network process (ANP) (Saaty, 1996), and fuzzy sets (Yu and Dexter, 2010), among others, are already reported in different decision-making problems.

This paper has analyzed and evaluated the operation of the various widely used IDMs, namely, *rate of change of output frequency (RCF), phase-jump detection (PJD), harmonic detection (HD), impedance measurement (IM), slip-mode frequency shift (SMS), and Sandia frequency shift (SFS)*. Comprehensive analysis of the main functional characteristics of IDMs like suitability for inverter based DGs (SIDG), non-detection zone (NDZ), implementation cost (IC), suitability for multiple DG units system (SMDGS), operating time (OT), degradation of power quality (DPQ) and reliability (R), yields evaluation of IDM for an application.

It is desirable to have an appropriate method for evaluating the anti-islanding methods in order to get the proper selection for an application. AHP is a hierarchy method transforming qualitative to quantitative analysis of criteria in order to generate a set of priorities for alternatives (Saaty, 1996). The analytic network process (ANP) is a generalization of the AHP for considering mutually influential factors in the hierarchy (Luna-Rubio et al., 2012). TOPSIS is a potential optimization method to identify solution from a finite set of choices. Alone TOPSIS does not take care of interdependence relationships among the elements. Nevertheless, the interdependencies may occur among the elements in the same cluster or in the different clusters in a complex decision-making model. Therefore, in this research, an ANP integrated TOPSIS technique for finding out the best anti-islanding technique GCSPVS application has been devised out.

The following section discuses the literature survey on anti-islanding detections. Section 3 explains on the performance analysis of different IDMs. Section 4 highlights the ANP and TOPSIS methodology. The proposed methodology has been discussed in Section 5. Sections 6 and 7 present validation of the proposed model and sensitivity analysis, respectively. Finally, discussion and conclusion are included in Section 8.

2. Review of IDMs

Over the years, various techniques have been developed to detect islanding in different types of DG system. Islanding-detection methods, which have been proposed, are generally classified into following four categories: passive methods, active methods, hybrid methods and communication-based methods.

The passive detection methods monitor quantities such as voltage, phase angle, frequency, and harmonic distortion, at the output of the DG to judge whether there is an islanding operation. A GCSPVS equipped with an overvoltage relay (OVR), an undervoltage relay (UVR), an overfrequency relay (OFR), and an underfrequency relay (UFR) has the preliminary islanding-detection capability (Ahmad et al., 2013; Chowdhury et al., 2009; Hung et al., 2003). However, if output and load consumption of a DG unit approach a balance, the changes in voltage and frequency of the system are not enough for enabling islanding-detection by these relays. PJD method searches the rapid changes of the phase difference between the