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Evaluation of digital metering methods used in protection and reactive power compensation of micro-grids

Haidar Samet

School of Electrical and Computer Engineering, Shiraz University, Shiraz, Iran

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ABSTRACT

Stand-alone micro-grids (MGs) and grid-connected MGs with high penetration level of Distributed Generation (DG) are growing at a fast rate. In these grids, the power quality disturbances such as harmonics, inter-harmonics and deviation from the fundamental frequency are widespread. The influence of these disturbances on two categories of digital metering algorithms is evaluated in this paper. The first category is related to the measurement of the fundamental frequency component of current and voltage signals, which are used as inputs of the digital protection algorithms. Most of the relays only use fundamental frequency component of their input voltage and current signals to fulfill the desired protective functions. The accuracy of the protective relays highly depends on the performance of the applied algorithms for extracting the fundamental components. The second evaluated category is related to the reactive power calculation algorithms, which are used in the static VAr compensator (SVC) control system. Utilizing SVC is growing due to the DGs such as wind turbines magnify voltage fluctuations called flicker. Since the SVC compensates only the reactive power related to the fundamental frequency component, the reactive power signal should not be sensitive to the harmonics. In addition, the reactive power calculation should be fast enough that SVC can follow the abrupt changes to mitigate the flicker, efficiently. In this paper, frequency deviation, harmonic, and inter-harmonic phenomena are considered as the most causes for power quality problems. Their influence in digital metering algorithms is evaluated. It is confirmed that defining new indices is mandatory to fully reflect algorithms' accuracy and efficiency. Furthermore, the field measurements of instantaneous voltage and current of a wind farm and electric arc furnaces are used for the evaluation.

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E-mail address: samet@shirazu.ac.ir

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1. Introduction

In recent years, using renewable energies for electric power generation has experienced a very fast development in the whole world. In many countries, Distributed Generations (DGs) which typically use renewable energy sources are being used at a growing rate due to economic, environmental, and political considerations [1–5]. Several new technologies have been developed and marketed for DGs, which have the capacity of a few kilowatts to 100 MW [6]. However with the increase of the renewable energy sources in the distribution network, the system power quality becomes an important issue [7–11]. The integration of renewable energy sources such as wind plants and solar photovoltaic into the power system may cause power quality problems [12–14]. Voltage flicker and harmonics are the most common power quality issues which are raised by the high penetration of renewable energy sources [15,16].

Micro grids (MGs) operate both in grid-connected and stand-alone conditions. Previously, standards have not allowed any kind of intentional or unintentional islanding (IEEE-925-1998), but nowadays, only unintentional islanding is not permitted (IEEE-1547-2003) [17,18]. Therefore, stand-alone operated MGs and intentional islanding are more common where the MG does not have any connection to the main grid. The main difference between isolated and grid-connected systems is the means, by which the voltage and frequency are controlled [19]. On the grid-connected MGs, frequency is controlled by the very large generators in the main grid. In an isolated MG or intentional islanding, the DG must control both frequency and voltage. In many isolated MGs, frequency deviation of several Hertz is common. For example, Hawaii's electric utilities require inverters to tolerate frequency deviations from 57.0 Hz to 60.5 Hz [20]. On the other hand, inverter is utilized in the most DGs. The output voltage is not a pure sinusoidal and it includes harmonics [21,22]. So, isolated MGs and intentional islanded systems may suffer from low power quality [23–25].

The mentioned power quality issues; harmonics and frequency deviation may affect the performance of the metering devices which are used in the monitoring [26], control, and protection of MGs. It may cause errors in the measurement of electrical quantities, undesirable performance of the control systems, and maloperation of the protection systems.

The influence of harmonics and frequency deviation on digital metering algorithms is evaluated in this paper. Two categories of measurement methods are considered:

1) Methods for calculation of the fundamental frequency component of current and voltage signals which are used as inputs of the digital protection algorithms.
2) Methods for calculation of the reactive power, which are used in the control system of Static VAr Compensator (SVC) for flicker mitigation of time varying loads and DGs such as wind turbines.

Digital protective relays play vital roles in modern power systems and with their efficient operation; safety and security for the system are guaranteed [27–29]. Digital protection relays receive current or voltage waveforms as their input signals. For performing various protective functions, extraction of the desired components of the input signals are carried out using the digital algorithms. The conventional measurement algorithms should extract the fundamental component of the input signals, while non-fundamental components are filtered. The effectiveness of the protective relay for performing protective functions such as, fault detection, estimating, and location is highly dependent on the performance of digital algorithms. However, their performance can be affected by power quality problems. Two cases of the most problematic disturbances which have the worst effect on performance of the digital relays are frequency deviation and waveform distortions such as harmonics and inter-harmonics.

For algorithms based on fixed pre-set sampling intervals, frequency deviation can be the main problem. There are many studies on frequency detection and estimation. A class of fundamental frequency estimation algorithms for unbalanced three-phase power systems is proposed in [30]. In [31], a synchronized frequency estimation algorithm suitable for measurement at the distribution level is proposed and tested under noise and harmonic conditions. A general approach to harmonic decoupling is presented in [32], which is suitable for three-phase grid-connected inverters. In [33], a DFT-based frequency estimation algorithm is proposed to reduce the estimate error due to noise and the leakage effect. A single-phase grid voltage fundamental frequency estimation technique for smart meters is introduced in [34].

Waveform distortion is another topic of interest, which can have negative effects on the performance of digital metering algorithms. The term "waveform distortion" in this study is considered as the interweaving of fundamental components of a relay's input signals with harmonics or inter-harmonics. Some studies propose a methodology of harmonic detection based on a wavelet neural network [35], which can be used in active power filters. For other types of harmonic detection methods, a method of designing an adaptive detector based on adaptive control theory is presented in [36]. A new estimation method based on the concepts of anti-conjugate harmonic decomposition and cascaded delayed signal cancellation is established in [37]. In case of inter-harmonic detection, there are fewer studies. A simple method of inter-harmonic estimation known as estimation of signal parameters via rotational invariance techniques is presented in [38]. In [39] the authors consider the latest IEC standards and introduce new improvements to eliminate the problems due to synchronization errors of the analyzed waveforms. Phase-locked-loop (PLL) algorithm is another method of inter-harmonic estimation presented in [40]. This method, compared to the previous ones, improves accuracy and convergence time while reducing the computational burden.