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Wavelet optimized EWMA for fault detection and application to photovoltaic systems

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ABSTRACT

Electrical power generation using photovoltaic (PV) became an active and continuous growing area for academic and industrial research. The complexity of PV systems and the increase in reliability requirement become a very important issue in automation. Grid-connected PV systems are among the top power technologies with the highest rate of development. Therefore, their proper operation and safe handling is a top priority. To respond for this exigency, we develop a novel technique for PV power systems monitoring. Various key variables can be monitored in PV systems, which include the voltage and frequency of the grid, the voltage and the current of the AC and DC converters, as well as climate data, such as the temperature and irradiance. Tight monitoring of these variables will provide more effective and less interrupted energy supplies. The developed monitoring method is applied and validated using simulated data of PV systems. The developed technique combines the advantages of Exponentially Weighted Moving Average (EWMA), multi-objective optimization (MOO) and Wavelet representation. The MOO is used here to solve the problem of choosing an optimal solution of the following two objective functions: (i) missed detection rate (MDR) and (ii) false alarm rate (FAR) where both of them are simultaneously minimized. Additionally, the use of wavelet representation improves the monitoring performances by reducing the MDR and FAR. The wavelet representation is applied to obtain precise deterministic characteristics besides decorrelation of autocorrelated measurements. The new proposed technique, called Wavelet Optimized EWMA (WOEWMA), is compared with the classical EWMA and Shewhart charts where they are used for detecting single and multiple faults (for example, Bypass, Mismatch, Mix and Shading faults). The performances of the monitoring scheme are evaluated using MDR and FAR indicators.

1. Introduction

The rapid technological development worldwide imposes a continuous demand of energy that can't be secured using the fossil energy sources. As well, energy generation using this method produces harmful gases that impacts negatively the environment, climate and health. Therefore, it is crucial to seek other energy sources. At this stage, renewable energy represents a promising alternative for a clean and sustainable future which includes: bioresources, sunlight, geothermal, hydropower, wind and ocean (wave and tide), can be progressively adopted toward a sustainable environment. Some researchers are targeting young generations to create awareness about renewable energy sources to address the concerns regarding running out of resources as well as environmental and atmospheric pollution (Altuntaş and Turan, 2018). Power generation using solar energy outperforms other methods due to the it's growing in term of research and production. Moreover, there is a time matching of highest production with highest demand. Governmental incentives in growing number of countries, the property of modularity, scalability and location flexibility are significant factors that foster solar energy. Consequently, electrical power generation using photovoltaic (PV) became a dynamic and constant growing field for academic and industrial research. The International Renewable Energy Agency (IRENA) indicates that Solar PV energy deployment has risen steadily for nearly two decades, from inferior to 9 gigawatts (GW) connected capability in 2007 to over 290 GW in 2016 (Timilsina et al., 2012). Despite these advantages, PV systems faces several practical

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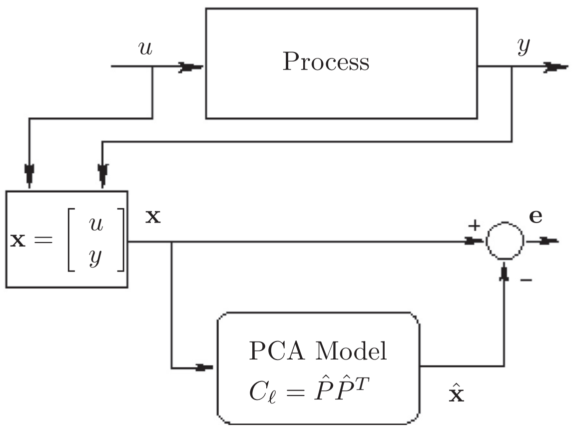

Fig. 1. PCA based residual generation.

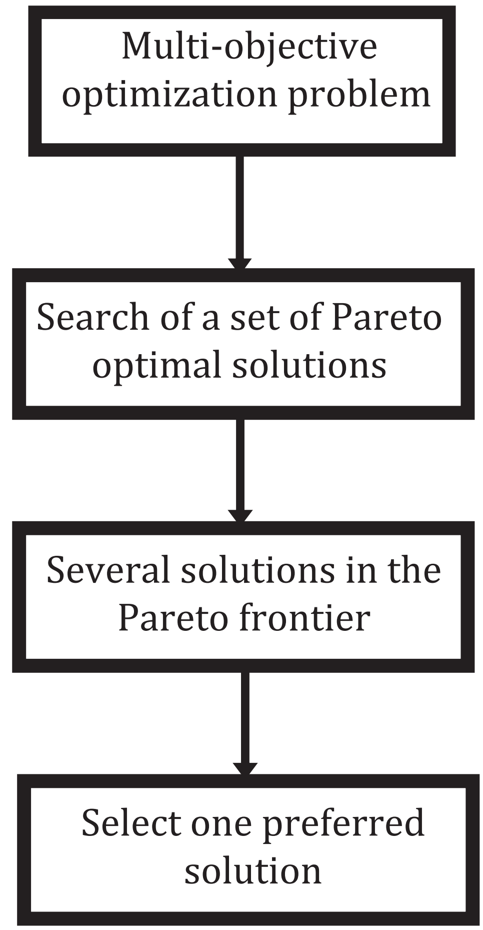

Fig. 2. Flow-chart of multiobjective optimization scheme.

barriers that affect its performance by decreasing its efficiency. For instance, a faulty PV network may be running for several days or weeks before being detected and repaired. As a result, this will reduce systems reliability and profitability.

Several fault detection and monitoring methods have been presented in the literature to cope with the complex nature of industrial and manufacturing tasks. Multivariate statistical approaches like principal component analysis (PCA) (Harkat et al., 2006; Schmitt et al., 2016; George et al., 2009) and partial least squares (PLS) (Muradore and Fiorini, 2012; Kruger et al., 2001) were considered for industrial supervision. PCA is the most applied method due to simplicity in theory and operation. It converts the original input variables into independent variables in a low dimensional subspace.

In the field of process monitoring and for different applications, PCA is the most used among multivariate data driven methods (Jackson and Mudholkar, 1979; Kresta et al., 1991; MacGregor and Kourti, 1995; Kourti and MacGregor, 1995; Braatz, 2000; Jackson, 2005; Harkat et al., 2018).

In Hu et al. (2013), fault diagnosis is realized using parameter based PV model obtained by combining energy balance equation and electrical model. The crucial model parameters are computed from two working points of the PV module and corresponding temperature. In Garoudja et al. (2017), EWMA chart is used for performance monitoring of the of PV systems. The method is based on the residuals obtained from a one-diode mode. The technique is approved empirically in monitoring of the DC side of PV systems as well as partial shading detection. The researchers in Ji et al. (2017), proposed an automatic technique for detecting PV failures. Depending on the collected monitoring, different failures will affect differently the PV system. In fact, they proposed an approach capable of reconfiguring, in a systematic and iterative way, the PV array until the failures are localized depending upon the current-voltage (I-V) curve of the (sub-)array. Other methods have the capacity to identify numerous key failures such as open-circuit failures, mismatch failures and short circuit failures. In Tsanakas et al. (2015), the authors used thermal image processing and the Canny edge detection operator to detect module-related failures that imply hot-spot heating consequences. The approach was used successfully for faulty PV modules. The artificial intelligent based techniques were used also in this context. For instance, artificial Neural Networks (ANN) is adopted in the literature were two various algorithms are then established in order to identify and isolate eight different types of failures (Chine et al., 2016). The wavelet transform was also proposed for fault detection using standard deviations of the wavelet coefficient of the grid voltage (Kim, 2016). The fault detection scheme developed in Yi and Etemadi (2017) is adopting the pattern recognition method with a multiresolution signal decomposition method for extracting the required characteristics. Depending on that, a fuzzy logic system decides fault occurrence.

In Hu et al. (2014), a thermography-based temperature distribution analysis was proposed to examine various fault groups. The suggested approach has been confirmed via numerical simulation as well as experimentally. This approach provided numerous improvements with respect to earlier works. The authors in Hu et al. (2015) have suggested an inexpensive PV array fault detection method through optimizing the locations of electrical sensors. Therefore, the productivity will be increased while reducing the capital and maintenance costs. The authors in Platon et al. (2015) have developed a practical online fault detection system capable of handling inaccurate measurements and abnormal values. The algorithm compares the measurements with predicted values in AC generator. The approach was validated using measurements from a 120-kW PV plant situated in Toronto. In Silvestre et al. (2016), the researchers presented a tool for distant monitoring and control of grid connected PV systems where the evolution of main PV system parameters is acquired from empirical model. The parameters RMSE between real monitored data and results obtained from the modeling of the PV array is used for evaluation purposes. An autonomous PC-