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Microgrid protection under wind speed intermittency using extreme learning machine☆

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ABSTRACT

Operation of wind turbine-based microgrids is characterized by increased intermittency due to the uncertainty in wind speed, which significantly affects the voltage-current profile. Conventional overcurrent relays based on prespecified threshold setting quite often are not able to detect faults under sporadic behavior of wind generators. With the aim of developing a protection scheme which is immune to the stochastic variation in wind speed under both grid-connected and islanding mode, a technique based on Discrete wavelet transform (DWT) and Extreme learning machine (ELM) has been proposed for mode detection, fault detection/classification and section identification. Uncertainty in wind speed has been modeled using Weibull distribution function and further incorporated in the protection modules. The proposed scheme has been validated using different statistical indices and compared with reported techniques for varying fault scenarios. Further, the effectiveness of the proposed scheme has also been validated for practical field applications by performing real-time simulations.

1. Introduction

With the aim of decreasing burden on the transmission system, reduction in harmful gas emission and meeting the consumer's demand with enhanced reliability, the conventional power infrastructure has undergone a vast transition in the last few decades from centralized generation to onsite generation [1]. With the rapid advancements in renewable-based distributed energy resources (DER) such as solar and wind systems, the requirement of resilient power network at distribution level is achieved by a new concept of active distribution grid, commonly referred to as microgrid. Among the commonly used renewable DERs in a microgrid, doubly fed induction generator (DFIG) based wind energy system has received considerable attention in recent times because of the advancements in wind turbine technology and minimal land requirement [2]. The rapidly increasing penetration of wind energy based DERs poses several challenges in providing suitable protection of microgrid due to their inherent dynamic behavior resulting from varying weather conditions. The variable wind speed profile significantly impacts the voltage-current characteristics of the wind turbine-based microgrids. The conventional overcurrent relays based on prespecified threshold settings may not be sensitive enough to detect the fault occurring under varying wind speed. In spite of the ease of selecting threshold values for different cases, multiple threshold setting based relays are highly sensitive to sensor noise and operating conditions [3]. Also, the dependency of fault current on the mode of operation (grid-connected and islanded) and type of interfacing (Inverter and Synchronous based) demand variable protection

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Nomenclature

w_s	Wind speed (m/s)
a	Scale parameter of weibull distribution function
b	Shape parameter of weibull distribution function
N	Number of samples
m	Number of classes
w_i, b_i	Weights and biases of ith hidden neuron
g	Kernel function
x_j	Input matrix
o_j	Output of network
t_j	Target vector
H	Hidden layer output matrix
β	Output weight vector
β_i	Connecting weight
T	Target vector
$H^{\dagger}$	Moore-penrose generalized pseudo-inverse of H
λ	Regularization parameter
$\mathrm{R_f}$	Fault resistance (Ω)
θ_{f}	Fault inception angle (°)
$\mathrm{L_f}$	Fault location (km)

settings of the conventional overcurrent relays [4–5]. In the absence of an adaptive setting, the various factors contributing to relay maloperation include sudden load variation, variation in DER penetration level, unintentional DER disconnection and harmonics in the distribution system due to nonlinear loading. As compared to grid-connected mode, developing a proper protection strategy for islanding mode is more challenging due to the relatively low magnitude of fault [3]. The sporadic nature of wind based DERs and their effect on the fault current further complicates the protection task.

Several protection techniques have been reported in the literature with regard to the protection of wind-based microgrids. Few of the significant techniques include, data-mining based differential scheme [6], time-frequency transform based technique [7], superimposed reactive energy based scheme [8], fast recursive discrete fourier transform with fuzzy based module [9], superimposed sequence current based technique [10], differential current based protection strategy [11], positive sequence component based scheme [12], differential spectral energy calculation technique [13], Hilbert–huang transform and machine learning based scheme [14], a coordinated distance protection scheme for microgrid [15]. However, none of the existing techniques have incorporated the effect of wind speed uncertainty in the development of a protection scheme for performing the task of fault detection/classification and section identification. The wide variation in the voltage-current profile due to intermittency in wind-based generation may often lead to maloperation (underreach or overreach) of threshold setting based overcurrent relays. The techniques adopted for extracting features for microgrid protection include Discrete Fourier Transform (DFT) [6], Stockwell-transform (ST) [7], Discrete Wavelet Transform (DWT) [16–17] and Hilbert transform (HT) [8]. For classification, the notable schemes include Artificial Neural Network (ANN), Support Vector Machine (SVM) [6], Decision Tree (DT) [16] and an ensemble of k-nearest neighbor (kNN) [17]. However, the reported classification techniques for classifying the fault and identifying the corresponding zone suffer from the drawback of poor generalizability and relatively slow execution time for complex datasets.

In this regard, to meet the challenges mentioned above, the present work aims at the development of a novel protection scheme for wind energy based microgrid without multiple relay settings, which is immune to the intermittency in wind speed and is also insensitive to the mode of operation. This is achieved by modeling the random wind speed intermittency profile through Weibull distribution function and incorporating the same in the protection module. The overall scheme is composed of two stages, extraction of discriminative information (features) from the raw voltage and current signals, followed by using the information for accurate mode detection, fault detection/classification and section identification. In the present work, a scheme based on the combined framework of DWT and extreme learning machine (ELM) has been proposed for microgrid protection. Due to the increased scalability and lower computational complexity, ELM allows faster learning and better generalization of complex datasets [18]. Further, ELM is not influenced by the common drawbacks associated with other classification techniques i.e. slow convergence, local minima issues and iterative tuning. Existing application of ELM in power system includes power quality recognition [19] and islanding detection for grid-connected distribution system [18].

The post-fault current-voltage information recorded at relaying buses are processed to generate the features in terms of the standard deviation of approximate discrete wavelet coefficients, which are fed as input to the ELM based classifier to perform fault detection, classification and section identification. The reliability of the proposed fault detector/classifier and zone identifier has been assessed for different scenarios through statistical indices i.e. dependability and security. The performance of the proposed scheme has also been compared with ANN and SVM based techniques, in addition to examining