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Optimization of neural network parameters by Stochastic Fractal Search for dynamic state estimation under communication failure

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ABSTRACT

A powerful metaheuristic technique is proposed that uses a mathematical concept called Stochastic Fractal Search (SFS) to ensure fast convergence along with accuracy. This paper intends to determine the optimal set of multilayer perceptron neural network (MLP) parameters (weights and thresholds) to improve the performance of MLP by using the SFS technique. The SFS is used because of its effective search in finding the global minima and therefore, it avoids the MLP neural network trapped in local minima. The hybrid approach (MLP-SFS) is applied to solve the dynamic state estimation (DSE) problem at the filtering stage. DSE amalgamates forecasting procedure with measurement data to precisely assess the system state. The approach classifies the process into three stages. In the first stage, a short term hourly load forecasting is applied using support vector machine (STLF-SVM) for time series to forecast the unavailable load data due to communication failure from the previous hourly historical data load. The second stage constitutes an optimal power flow (OPF) that is used to determine the minimum cost generation dispatch to serve the given load and convert the obtained loads, and generations into measurement data. The third stage has a filtering process, which uses SFS technique to optimize the MLP neural network parameters (weights and thresholds) to estimate the system state. The hybrid MLP-SFS is used to find the optimal connection weights and thresholds for the MLP neural network. Following this, a simple backpropagation neural network (BPN) will adjust the final parameters. The approach is tested on IEEE 14-and 118-bus systems using realistic load patterns from the New York Independent System Operator (NYISO) under several scenarios of measurement error and communication failure. The mean absolute percentage error index of the system state (phase and magnitude voltage) is used to determine the accuracy of the approach (MLP-SFS). Results of the proposed approach (MLP-SFS) are compared with non-optimized MLP (random weights and thresholds) and other methods, such as, optimized MLP based on genetic algorithm (MLP-GA) and Particle Swarm Optimization (MLP-PSO) individually. The results indicate that the hybrid (MLP-SFS) increases the precision by about 20%–50% and reduces the computational time around by 30%–50%, which is good for real-time applications, such as, security assessment and contingency evaluation. Details of the models of generation and distribution level are not part of the state estimation in the high voltage transmission problems.

1. Introduction

Power flow pattern has been less anticipated due to the expansion in electric power grid throughout the recent ten years. The expansion is exhibited in the entrance of renewable energy sources and deregulation of the power system. The power system grid must be observed and controlled proficiently by control centers to be operated in a secure and reliable manner. Modern energy management (EMSs) and control systems could assist in maximizing energy savings and minimizing the cost of energy. However, they are intricately connected to accomplish the desired objective. Different proposals to EMSs with distinctive optimization techniques and different grid structures have already been presented in literature [1–10]. SE is the main part of the EMS system, which utilizes a redundant set of data to determine precise and dependable states of the power system. The system states (voltage phasors) are further used in real-time applications including security investigation, economic operation dispatch and load flow [11].

Conventional WLS state estimation has been widely used due to its high precision and easier implementation. The accuracy of WLS estimator is based on the availability of instantaneous measurement to assess the system state. For instance, the system state

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can be assessed at time, step t when the measurement at only step t is utilized. At the point when the system encounters some sort of communication failures, such as, delayed or lost measurement data, the execution of the WLS estimator breaks down. Therefore, specific parts of the electric power grid will be unobservable and control centers will have no information about these parts. Another drawback of the WLS state estimation is that, it cannot measure the system state for the next time, step $t+1$ [12]. Moreover, several DC power flow SE studies have been represented to overcome the AC state estimation problems [13]. In the aforementioned referenced study, the author built a DC power flow model (DCPF) to improve the accuracy of power flow estimation by introducing the measurement noise detection approach.

Conventional SCADA system suffers from low updating rate and inaccuracy. These limitations can restrict the reliability of SE. PMU devices play an important role in improving the precision of power system.

PMUs can increase the sampling rate of measurements from several seconds per measurement (conventional SCADA) to over 30 measurements per second. This is vital for improving monitoring and analysis of the dynamic conduct of power systems. PMUs give synchronous measurements (via global synchronous time stamps), which can synchronize measurements from far off areas to provide a continuous picture of the entire power system. Both the voltage and current phasors of a given bus can be measured directly from where it is installed on power network [14]. However, it is difficult to introduce a PMU on each node of the power grid due to the expensive cost of PMU devices in addition to the constrained communication channel bandwidth. Therefore, past reviews state estimations that concentrate on PMUs and optimal meters placement. There are various earlier techniques that deal with PMUs and meter placement in the distribution system. In Ref. [15], the authors proposed circuit representation model of SE error to demonstrate the relationship between estimations and SE errors. A logarithmic articulation of the circuit representation model is implemented where the optimal meter placement problem is effectively changed into an optimal network expansion problem. The model has proven superiority for enhancing SE in distribution network. Ref. [16] provides literature review on Phasor Measurement Units and Optimal Meters Placement for State Estimation Studies.

Generally, Kalman Filter (KF) is utilized to find solutions for the DSE problem because of its easier implementation, ability to forecast the system states and efficiency. Therefore, KF has been utilized extensively in many DSE applications. In Ref. [17], two-level DSE is presented using EKF that combines both SCADA and PMU data. Parallel DSE is improved on a graphic processing unit (GPU), which is particularly intended for preparing large data sets. The approach is proposed to improve the computational time in the DSE for large-scale grids. A two-stage Kalman filtering technique is introduced in Ref. [18] to assess the static conditions of voltage phasors, the dynamic conditions of rotor angles and speeds of the generator. In the first stage, it takes the raw PMU data into the Adaptive Kalman Filter with Inflatable Noise Variances. The output is then taken into the second stage, which utilizes an Extended Kalman filter to estimate the true dynamic states.

It concluded that EKF can provide an accurate solution to the DSE problem under normal operating conditions but under sudden load changing conditions and drastic generation variation, there can be a challenge due to a higher degree of non-linearity in the measurement function [19]. Approach [20] has implemented optimal KF instead of EKF to obtain the unknown complex bus voltages in addition to finding the linear relationship between complex element voltage and complex bus voltage. KF gives a more precise and quicker estimation. Hybrid technique combines unscented transformation with KF, which has been proposed in Ref. [21] to enhance the accuracy and to conquer the drawbacks of EKF technique. Decentralized DSE of power systems using unscented Kalman filter based on consensus algorithm has been discussed in Ref. [22].

The objective function turns out to be exceptionally non-linear, discontinuous and undifferentiable due to the presence of non-linear devices, such as, var compensators, distributed generators and transformers with on-load tap changers in the power system. This further reduces the solution of conventional optimization methods [23]. To overcome the limitations of classical optimization methods, artificial intelligence techniques, evolutionary algorithms, fuzzy and neural networks have been used as a prospect to add new scopes to the area of DSE [24]. Recently, a method based on fuzzy control theory improved with a sliding surface in Ref. [25] to explore the dynamic state estimation where the sudden load variation happened. This method can cleverly direct the solution to a close ideal trajectory to reduce the computational time. The technique combined the error and the rate of error as an incorporated input variable. Another approach based on ANN has been discussed in Ref. [26]. In Ref. [26], ANN was based on bus load prediction (DLP) for dynamic state estimation. The method classifies the process into two stages: short-term load forecasting and rectangular coordinate formulation for filtering. It concluded that ANN based on DLP gave a precise prediction, an accurate estimation and less computational time.

The principle objective of evolutionary techniques is to determine the optimum solution in the favorable region already identified. However, for dynamic optimization environment, this sort of approach may encounter a convergence issue due to exist dynamic landscape changes in one region and if there are no particles of the algorithm in this region, the algorithm will not be able to react to the change proficiently, and might not succeed in tracking the changing global optimum [27]. Recently, metaheuristic techniques have been employed to find the solution of difficult problems, which require investigating a larger space. Normally, metaheuristics depend on four primary purposes: investigating the space effectively with being insensitive to the magnitude of the search space, reducing the computational time, solving large and complex problems, and obtaining robustness. Additionally, there is simplicity of design and implementation [28]. Natural phenomena behaviors are the inspiration of metaheuristic techniques. Genetic Algorithm (GA) presented in Ref. [29] mimics the behavior of natural evolution processes. Particle Swarm Optimization (PSO) is proposed in Ref. [30] to simulate the behavior of flocks of birds in searching their food. Both Artificial Bee Colony (ABC) and Ant Colony (AC) are represented in Refs. [31,32] to simulate the foraging behavior of bee swarm and ant colonies respectively. These algorithms are utilized to tackle complex computational optimization problems, however, fast convergence along with accuracy is not ensured. Therefore, another powerful metaheuristic technique is proposed that uses a mathematical concept called fractal to overcome the above disadvantages. The proposed method shows superiority compared to other metaheuristic algorithms in case of finding the global minima, avoiding being stuck in local minima and for reducing the computational time.

This paper presents a newly improved hybrid optimization technique for multilayer perceptron neural network (MLP) parameters (weights and thresholds) based on Stochastic Fractal Search technique (MLP-SFS) to solve the dynamic state estimation under communication failure problem. The effectiveness of MLP (random weights and thresholds) and optimized MLP based SFS technique (optimized weights and thresholds) have been examined on IEEE 14-and 118-bus test systems using realistic load patterns from the New York Independent System Operator (NYISO) under different communication failure and measurement error. The hybrid