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Static transmission expansion planning for realistic networks in Egypt

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ABSTRACT

Transmission network planning (TEP) is very important task in electric power systems. It begins with the establishment of power demand growth scenarios, in accordance with forecasts along the time and to obtain the optimal expansion plan, while fulfilling power systems constraints. This paper proposes a two-stage TEP procedure for two realistic transmission Egyptian networks, Western Delta Network (WDN) and 500 kV of Extra High Voltage Network (EHVN). In the first stage, the Adaptive Neuro-Fuzzy Inference System (ANFIS) is employed to obtain the predicted long-term load forecasting (LTLF) up to 2030. In the second one, the Integer Based Particle Swarm Optimization (IBPSO) technique is developed for solving the static TEP problem. The proposed TEP aims at finding the optimal transmission routes, at least capital investment costs, to meet the forecasted load. The TEP problem is formulated as non-linear, large scale, mixed-integer and non-convex optimization problem. The static TEP problem is employed using DC power flow model. The proposed TEP methodology is tested on standard Garver 6-bus test systems. The load forecasting methodology is dependent on the historical (Actual) peak load data for the UEN from 1993 to 2015. The location and capacity of new site of generation station are selected to meet the demand required. Also, the AC load flow method is emerged with the TEP solution employed by IBPSO for Garver and EHVN to assess the voltage, reactive power and security constraints. Numerical results show the capability of the proposed procedure to solve TEP problem at acceptable economical and technical benefits.

1. Introduction

The outstanding feature of electric power systems is the steady growth of consumption at annual averaging rate of 7–10% which means that the power demand will be doubled every 10 years. The required expansion of main parts for the power systems generation, transmission and distribution are so lies that much capacity must be added to reinforce the power system at regular or sequential intervals.

Electrical load forecasting is an important tool to ensure the energy supplied by utilities meets the load plus the energy lost in the system [1]. Load forecasting is always defined as basically the science or art of predicting the future load on a given system, for a specified period of time ahead. Load forecasting is very importance for efficient planning, operation and control of modern power systems [2]. Long term load forecasting is illustrating the first phase for expansion planning of different parts of power systems [3]. The authors in Ref. [4] classified load forecasting into three categories based on forecasting time range. Long-Term Load Forecasting (LTLF) is concerned with power consumption forecasting in time period of more than one year. Medium-Term Load Forecasting (MTLF) is considered for a period more than one week up to few months. Short-Term Load Forecasting (STLF) is related to the range from one hour to one week.

Ref. [5] illustrated the load classifications normally used as well as some important characteristics of various types of load profile. The previous forecasting methods are dependent on natural and characteristic of load sectors in Ref. [6]. In the latter part of the twentieth century, it has become the traditional methods of load forecasting [7–9] inaccurate in addition to the error rate which be large. The accuracy of the LTLF has significant effect on developing future generation and distribution planning. Expensive overestimations of predicted load demands will result in large construction investments of excess power facilities, while consumer discontentment will be direct result of underestimations process. Unfortunately, it was difficult to forecast load demand accurately over a planning period of several years. This fact is due to the uncertain nature of the forecasting process [3]. Therefore, the new trend

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is to investigate artificial intelligence methods for load forecasting process in Refs. [10–14]. In Ref. [10], the cooperative ant colony optimization-genetic algorithm approach was employed for construction of energy demand forecasting knowledge-based expert systems. The long-term/mid-term electric load forecasting based on short-term correlation and annual growth was presented in Ref. [11]. The neural networks (NNs) were presented for short term load forecasting [12] and for day-ahead electricity price forecasting [13] while the dynamic NN was presented in Ref. [14] for medium term system load forecasting.

Transmission network planning (TEP) is very important task in modern electric power systems. It begins with the establishment of power demand growth scenarios, in accordance with forecasts along the time and to obtain the optimal expansion plan [15–17]. The main aim of TEP is to minimize the investment costs of the additional transmission lines that meet the power system requirements for future demand and future generation configuration without violating any operational constraints [18,19]. The solution of the TEP involves determining the new circuits must be installed in an electric system in order to meet the forecast demand at the lowest cost, while at the same time satisfying prescribed technical, financial and reliability criteria [17,20,21]. Transmission system planning can be generally classified into three categories based on planning time range [22] as:

- Long Term Horizon Planning (LTHP): which are characterized by a high degree of uncertainty as the planning horizon may be more than ten years.
- Medium Term Horizon Planning (MTHP): where the uncertainties are reduced as the planning horizon may be up to ten years.
- Short Term Horizon Planning (STHP): where the uncertainties are even more reduced as the planning horizon may be up to five years.

Transmission expansion planning problem of power networks has been generally modeled using two approaches, static planning problem and dynamic planning problem. In this work, the aim is to solve the static long term horizon planning problem for realistic networks. During the last few decades, it was observed the quickly continuous progress in the area of optimization. Various theoretical, algorithmic and computational methods have been integrated to solve engineering and management problems. Particle swarm optimization (PSO) technique is one of the heuristic global optimization methods put forward originally by Kennedy and Eberhart in 1995 [23]. A review on the application of PSO for various power system applications was reported in Ref. [24]. Several variants of PSO algorithm were developed for photovoltaic/hydrogen system [25], reactive power and voltage control considering voltage security assessment [26], power system stability [27], power system stabilizer design [28–30], optimal power flow [31] and for optimized generation costs [32]. Several authors are comprising a snapshot review of particle swarming perspective, including variations in the algorithm, current and ongoing research, applications and open problems [33–39]. Recently, PSO has become a candidate for many optimization applications due to its high-performance and flexibility.

This paper proposes a multi-stage long term horizon planning of TEP problem. In the first stage, ANFIS is employed to obtain the predicted loads in the future which are dependent on LTLF. In the second stage, this paper develops the IBPSO technique for solving the static TEP problem. The TEP objectives are to minimize the total capital investment cost of the transmission system and to determine the optimal transmission routes to satisfy the requirements of loads in the future. The location and capacity of new site of generation station are selected to meet the demand required. The proposed IBPSO is applied to obtain the optimal planning for two realistic transmission networks in Egyptian networks. These networks are the 66-kV of Western Delta Network (WDN) and 500-kV of Extra High Voltage Network (EHVN).

The salient contributions of the current paper can be summarized as follows:

- This paper proposes a bi-level transmission expansion problem. The first level forecasts the long term load demand up to 2030 for two realistic networks in Egypt. While in the second level the transmission routes are optimized.
- The load forecasting is carried out using ANFIS.
- The standard Garver network is used to prove the capability of the proposed IBPSO method.
- Statistical tests are employed to prove the efficiency of forecasting process
- Assessing the load forecasting method compared with conventional methods.
- Investigation of the IBPSO as an optimization algorithm.
- DC load flow is merged to the IBPSO method for efficient TEP solution.
- To assess the voltage, reactive power and security constraints, an AC power flow is carried out on the TEP solution.
- Numerical results show the capability of the proposed procedure to solve TEP problem at acceptable economical and technical benefits.

This paper is organized as: Section 2 states the main steps of ANFIS for load forecasting, Section 3 describes the problem formulation of TEP, Section 4 presents the proposed IBPSO technique to solve TEP problem, Section 5 Implementation and results are discussed, Section 6 summarizes the conclusions in this paper.

2. Load forecasting using ANFIS technique

ANFIS combines the flexibility and partisanship of fuzzy system as well as quick response and adaptability nature of artificial neural network (ANN) [40]. in this paper, the proposed ANFIS technique is presented to predict the LTLF of peak load demand. LTLF is critical issue to plan and carry on future load demand and investment such as size of energy plant and location. The usage of artificial intelligence methods is widely extended for engineering problems due to its merit of finding valid solutions compared with conventional methods. The ANFIS method combines the merits of fuzzy logic and artificial neural networks. Although Neural Network (NN) has powerful learning ability, fuzzy structure has strong inference system. In contrary, ANFIS merges these two desired features in the same topology [41–43]. The ANFIS is investigated to obtain long term forecasting results and the obtained results are compared to conventional mathematical methods to show validity and error levels. To show error levels, mean absolute error and mean absolute percentage error are used [43]. The basic steps of ANFIS structure are presented in Fig. 1 as:

Step 1: Identifying the input data of model. These inputs have historical years and actual peak load data.

Step 2: Collecting all available data set from previous periods and normalizing all data scale.

Step 3: Dividing data into training and test data sets. The training data acts 70%–90% of available data.

Step 4: Running and estimating all of the reasonable ANFIS, determine the type of membership function and number of linguistic variables.

Step 5: Selecting the best ANFIS model through MAPE criteria.

Step 6: Future projection of input variables using autoregressive model in defined future years.

Step 7: Total peak loads prediction using selected ANFIS