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A mixed integer linear programming model for transmission expansion planning with generation location selection

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Abstract

This paper presents a mixed integer linear programming model for single stage least cost transmission expansion planning that considers generation plant location selection. The model includes DC load flow equations and $(N-1)$ security constraints. The non-linearity of the load flow equations is avoided by using a new state enumeration method that reduces the size of the model formulation. Methods are developed for identification of the critical contingencies of a network and formulation of security constraints of the identified critical contingencies by using line outage distribution factors. The number of variables and constraints in a transmission planning model would be reduced considerably by using these methods. Such a reduction would help to handle relatively large transmission planning problems and incorporate more technical considerations. A case study of the Sri Lankan power system is conducted in order to illustrate the potential of the new approach.

Keywords: Transmission expansion planning; Security constraint; Generation location selection

1. Introduction

Transmission network expansion planning is a complicated non-linear optimization problem in which the power flow and the transmission network security analyses are the two major modelling issues. The problem has been solved through heuristic methods [1,2] as well as traditional mathematical optimization techniques [3–8]. However, heuristic methods are not rigorous from the mathematical viewpoint. The traditional mathematical optimization techniques find it difficult to solve the transmission planning problem due to non-linearity and size (i.e. number of constraints and variables) of the problem. A state enumeration method was devised by Gilles [4], Farrag and El-Metwally [3] and Seifu et al. [7] to avoid non-linearity of the power flow equations. A branch is defined as a set of identical circuits connecting two nodes of the network. The branches, which are feasible options for capacity additions during the planning horizon, are considered as candidate branches. The states of a candidate branch are the possible number of its circuits. The new state enumeration method in this paper reduces numbers of variables and constraints of the proposed transmission planning model. This would facilitate handling relatively large transmission expansion planning problems.

The size of the problem formulation is mainly affected by its security constraints. The transmission security criterion of the proposed model is the single circuit outage $(N-1)$ criterion, which is commonly used in existing models [7,8]. Hereafter a single circuit outage of a branch is called a ‘contingency’. A contingency is said to be critical if it can affect the capacity of a branch of the network. The proposed model considers two methods: (i) the identification of the critical contingencies of the network before model formulation; and (ii) the formulation of security constraints to the identified critical contingencies using line outage distribution factors (LODFs) [9]. LODFs are used to calculate power flows under contingency conditions directly. In contrast, DC load flow analysis solves a set of equations to determine power flows in various branches of a network. Unlike existing methods, the proposed method does not need any additional variable in formulating the security constraints. As a result, there is a substantial reduction in the number of variables used in the formulation. Furthermore, the proposed method to identify critical contingencies reduces the number of constraints of the formulation considerably. As a result, the computational problem associated with the transmission planning accounting generation location selection becomes relatively simple. Since the method

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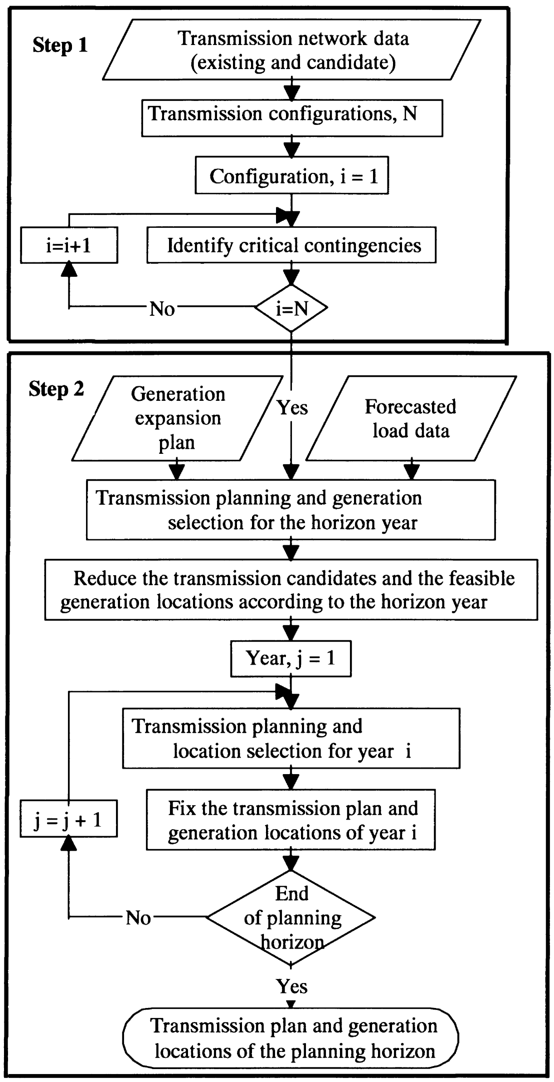

Fig. 1. Structure of the planning procedure.

of identifying critical contingencies does not involve any assumption, it maintains the accuracy of the transmission planning exercise.

A common practice in transmission expansion planning is to minimize the cost of transmission capacity and losses within the operational and security constraints of the power system. However, the cost of transmission depends on capacity and location of the existing and the new generation plants as well as time of commissioning of new generating plants. Horne et al. [10] studied the impact of power plant locations on transmission plans. In this study, generation plant location and transmission capacity additions are identified sequentially using a simplified linear programming model. The mixed integer linear programming model proposed in this paper considers both location selection of planned generating units and transmission expansion planning simultaneously. Here costs of transmission capacity and losses as well as costs of generation operation and capacity are included in the objective function of the model. Since generation expansion planning is to be done prior to the transmission planning, costs of generation of new units at their feasible locations are calculated according to the expected energy generation of the units in generation planning studies.

Section 2 discusses the overall transmission-planning framework followed by a description of the procedure to identify the critical contingencies. The single stage transmission planning model is presented in Section 4 in which the proposed state enumeration method and the transmission security constraints are described in detail. The model proposed here is applied in the case of the Sri Lankan power system for long-term transmission expansion planning using horizon year planning criterion. Section 5 outlines the case study. Section 6 summarizes the major conclusions of the study.

2. Transmission planning framework

The structure of the long-term transmission planning framework is given in Fig. 1. The first step of the planning framework involves the analysis of all possible configurations of the network including all candidate branches in order to identify critical contingencies. The next step involves the use of critical contingencies in the formulation of the single stage planning models for each time interval of the planning horizon. This model formulation ensures that an optimal transmission network will have sufficient capacity to meet all possible contingencies. The horizon year planning approach [11] is used for the long-term planning studies.

3. Identification of critical contingencies

The proposed method for identifying critical contingencies of branches involves the use of LODFs, which show the approximate changes in line flows for changes in the network configuration. By definition, the LODF is expressed as [9]:

$$d_{l,k} = \Delta f_l / f_k^0 \tag{1}$$

where $d_{l,k}$ = LODF when monitoring line l after an outage on line k; Δf_l = change in power flow on line l after the outage and f_k^0 = original power flow on line k before the outage.

The above definition is given in a general form in which a line could represent an individual circuit or a branch (i.e. a set of identical circuits connecting two nodes). Since the security criteria used in the proposed model is a single circuit outage, LODFs are calculated to monitor a branch (i.e. monitoring branch) under a single circuit outage of the same branch or another branch (i.e. contingency branch). If a single circuit outage occurs in the monitoring branch, such a condition is defined as an own contingency condition of that monitoring branch. In general, security of branches