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'Transmission expansion planning under different uncertainties'

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Abstract

This study aimed to determine the transmission expansion plan by considering the uncertainties in the electricity energy market. In the modelling and solution phase, the concept of cross-docking used in logistics and storage will be used, and the electrical conduction model will be created in the cross-docking logic light. With the help of the literature data, the problem will be solved with meta-heuristic method and transmission expansion plan will be established. Our work is aimed to be the interesting modelling work in the field of industrial engineering, addressing many uncertainties in the electricity market.

Keywords: 'Transmission expansion planning, genetic algorithm, uncertainties, electricity, simulation'.

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1. Introduction

Transmission expansion planning (TEP), the problem of deciding that the new transmission lines should be added to an existing transmission network in order to satisfy system objectives efficiently, is one of the main strategic decisions in power systems and has a deep, long-lasting impact on the operation of the system (Lumbreras & Ramos, 2016) In other words, in the electric industry, the transmission expansion plan is aimed at improving the existing system or finding the most appropriate expansion solution in the process of establishing new transmission lines.

Taking into consideration the load increases and expected demand in the electric power networks, preparing the transmission expansion plan has been a subject for over 10 years. The generation expansion planning, the distribution expansion planning and the TEP generally decide when, where and how much new production, new lines and new distribution networks will be made (Alqurashi, Etemadi & Khodaei, 2016). While making these decisions, our goal is to balance the total supply and demand taking into account the technical, economic and political constraints. According to the report of the American Society of Civil Engineers, $ 27.5 billion was spent for electricity transmission and distribution investments in the United States in 2011, and total expenditure of $ 331 billion by 2040 is estimated (U.S. Department of Energy, 2015).

While the difficulty of establishing a supply and demand balance in the electricity market is predicated on the idea that this market is governed by a single decision maker, there are some difficulties in managing in the long run by competition from a one-sided (governmental) approach in terms of security, cost and manageability. In line with today's global world, the electricity market is dominated by private sector production and distribution models under the control of the law. The key actors in the electricity market are listed: Flexible generators with energy and reserve (e.g. combined cycle gas turbines); inelastic producers with only energy-providing units, such as nuclear power units that do not have the flexibility to adjust production to real-time operating conditions (e.g. wind energy units); consumers who may or may not be able to comply with energy-efficient and real-time operating conditions such as a large aluminum plant; retailers whose buy for sale to their customers for profit and an independent system operator (ISO) who manage the market and use a market clearing procedure appropriate to determine reserve levels, production and consumption quantities and market prices (Conejo, Baringo, Kazempour & Siddiqui, 2016).

For the investments to be made in the electricity transmission and production facilities, the view of the long-term system players should be taken. The uncertainties should be determined in a comprehensive and careful manner and the problem should be considered as a large-scale optimisation problem. The investment in electricity energy systems is usually a very gradual process. That is, expansion and reinforcement interventions are sequentially performed in different points over time. However, placing such a dynamic framework in a decision-making tool makes it difficult to calculate. For this reason, when a dynamic framework is considered, some simplifying assumptions are needed in the description of the system in general.

In this study, the problem of TEP will be considered, taking into account the uncertainties in the electric energy systems. In particular, uncertainties will be addressed by considering the characteristics of different regions, future demand forecasting and the availability of production facilities.

2. Literature review

Electricity can be regarded as a product that cannot be stored as stock. Many uncertainties arise in the field of production, transmission and consumption in the electricity transmission system. In production area, the integration of an increasing number of renewable energy sources, such as wind power plants, into electricity transmission networks is a major source of uncertainty. The intermittent and stochastic nature of renewable energy sources is a source of concern for the safety and reliability of the electricity network and plays an important role in the planning, operation and evaluation of the grid (Wen et al., 2015). Other uncertainties in the field of production: The future development in the investment costs of different production technologies (especially renewable power) is considered as investment alternatives which will be the future development in the operating costs of different production technologies (in particular, the fuel costs) as well as future investment decisions made by the producers other than the market representatives. The main source of uncertainty in consumption is hourly, daily and annual demand. This can be summarised as a change in the future consumption of freight points along the transmission network, annual demand growth/decline and distribution of geographical demand. In addition, no market representative has any definite knowledge of the bidding behaviour of other market representatives, both in terms of quantity and price. Such uncertainties should be carefully considered when identifying the problem. In such problems, the aim is to determine the most appropriate production schedule at the lowest operation cost, taking into account the system operation constraints such as hourly load balance and environmental constraints (Reza, Hooshmand & Khodabakhsian, 2013).

Today, there are many studies on TEP. The TEP has been searched for different viewpoints, different methods, different constraints and different purpose functions. Hemmati and other evaluated the convergence expansion problem according to different methods such as solution methods, reliability, distributed generation, electricity market, uncertainties, network structures and reactive power planning (Hemmati, Hooshmand & Khodabakhshian, 2013). The TEP problem can be defined in a number of different ways as appropriate. These objectives can be summarised as: competition among market shareholders, provision of a competitive and non-discriminatory environment for all players, reduction of transmission bottlenecks, minimisation of production costs, minimisation of risks, improvement of reliability and safety, consideration of scattered production, minimisation of environmental damages (Ruiz & Conejo, 2015). In the work done by Pineda and others, the proposed mathematical model minimises the total installation and operation cost, while at the same time it involves the use of renewable energy in a certain area (Pineda, Morales & Boomsma, 2014). The public organisation, which is the energy manager of many countries, has also done a lot of work on this area. One of the most important of these is the ENTSO-E-A (2014) and ENTSO-E-B (2014) study, which includes the European transmission expansion plan.

In recent years, robust modelling has gained momentum due to these superior features including uncertainty in modelling. The basic idea of robust linear optimisation is to find the most optimal and robust solution when the uncertainties are within a certain range. This approach is an easy-to-implement method to obtain a solution without the need to create a large number of uncertainty scenarios (Wen et al., 2015). In the Ruiz study, the problem of the TEP plan under uncertainty in the electric energy system is addressed. Different sources of uncertainty have been taken into account, including different types of production opportunities for future demand growth and different regions within the electricity energy system. A robust optimisation model is used to generate investment decisions that reduces the total cost of the system to the worst, by forcing the uncertain parameters in the uncertainty set to be in the worst case. The proposed formulation occurs on a three-level optimisation problem where the mixed integer, which can be replaced by the lower-level problem KKT optimality conditions. The resulting mixed integer bi-level model is solved efficiently by decomposition using a cutting plane algorithm (Ruiz & Conejo, 2015). Lorena and others research (Lorena, Narciso & Beasley) that produce a solution using genetic algorithm (GA) for the generalised assignment problem. Charlin and others (Charlin, Rudnick & Araneda, 2015) research in this area is a research that produces a solution using GA

The layout of the remaining of this paper is as follows: in our next section, we will give the problem notation and mathematical formulation. Some data which use to solve the problem are also given. The result and discussion part of the problem will be explained in Section 4. The final section will be talked about the conclusion and future work.

3. Problem statement

The objectives in the TEP problem often coincide. So, it is not possible to improve all at the same time. In this case, it turns the problem into a multi-objective optimisation problem. In general, the solution methods can be classified as mathematical optimisation model and meta-heuristic methods. Linear programming, nonlinear Programming, mixed-integer programming, Benders decomposition algorithm, branch boundary algorithm, game theory, dynamic programming are the mathematical modelling methods that can be used in this area. Among the meta-heuristic methods, ant colony, artificial immune system, artificial neural networks, fuzzy systems, genetic algorithm and annealing simulation are among the methods used to solve the problem. Basic mathematical formulations used in conduction expansion studies: transport models, hybrid models, DC power flow models and decomposition models (Romero, Monticelli, Garcia & Haffner, 2002).

The formulation of the mathematical model to be used in this area is as follows:

c_{ij} : The cost of the line to be made to the i-j line

s_{ij} : Susceptance of line i-j

n_{ij} : Number of lines to be added to line i-j

n_{ij}^{0} : Number of lines existing on i-j line

f_{ij} : Flow between i and j

f_{ij}^{max} : Capacity of i-j line

S: Incidence Matrices

f: vector included f_{ij} and θ_j for node

g: production vector for all nodes

d: demand vector for all nodes

g^{max} : Maximum generation capacity

n_{ij}^{max} : Maximum line capacity

γ : A cluster of all possible lines

$$Min \sum_{(i,j)\grave{o}\,\gamma} c_{ij} n_{ij} \tag{1}$$

s.t

$$S f + g = d \tag{2}$$

$$f_{ij} - s_{ij} (n_{ij}^{0} + n_{ij}) (\theta_i - \theta_j) = 0 \tag{3}$$

$$| f_{ij} | \leq (n_{ij}^{0} + n_{ij}) f_{ij}^{max} \tag{4}$$

$$0 \leq g \leq g^{max} \tag{5}$$

$$0 \leq n_{ij} \leq n_{ij}^{max} \tag{6}$$

$$n_{ij} \quad \text{integer; } \theta_j \text{ unbounded} \tag{7}$$

$$(i, j)\grave{o}\,\gamma \tag{8}$$

This model is a mixed-integer nonlinear model. Demand is considered as fixed. The second constraint is derived from the Kirchhoff's current rule for the conservation of the limiting load. The third constraint is derived from the Ohm's linear current law. 4, 5 and 6 are capacity constraints for flow, production and line number, respectively. Demand in this model is deterministic.

$$Min \sum_{(i,j)\grave{o}\gamma} c_{ij} n_{ij} + \sigma \sum ls_i - \lambda z \tag{9}$$

s.t

$$S f + g = ls - z d^m \tag{10}$$

$$f_{ij} - s_{ij} (n_{ij}^0 + n_{ij}) (\theta_i - \theta_j) = 0 \tag{11}$$

$$| f_{ij} | \leq (n_{ij}^0 + n_{ij}) f_{ij}^{max} \tag{12}$$

$$0 \leq g \leq g^{max} \tag{13}$$

$$0 \leq n_{ij} \leq n_{ij}^{max} \tag{14}$$

$$0 \leq ls \leq d^{max} \tag{15}$$

$$\frac{D_T^{min}}{D_T^m} \leq z \leq \frac{D_T^{max}}{D_T^m} \tag{16}$$

$$n_{ij} \text{ integer; } \theta_j \text{ unbounded} \tag{17}$$

$$(i,j) \grave{o} \gamma \tag{18}$$

In the above model, the situation in which the total demand is unclear is considered. *ls*, *σ*, *λ*, are load shedding for node, penalty and award respectively. d^m , d^{max} , d^{min} are average, maximum and minimum demand per node respectively. The highest value for total demand is D_T^{max} and the lowest value is D_T^{min}. Total demand is in the meantime. For the total demand, the demand in the station is also determined by $z d^m$ depending on the variable *z*.

The σ value is the penalty coefficient for the immeasurable electricity and has taken its place in the objective function. This value is often between $ 500,000 and $ 1,000,000/MW in the literature. This implies that an investment of approximately 500,000–1,000,000 for each MW deduction is required. Furthermore, depending on the value of z, i.e., the coefficient λ is used as a reward in the objective function, depending on the requested claim rate.

If both production and demand are uncertain, the problem becomes even more complex. In the next section, the problem will be solved by meta-heuristic method considering uncertainties in poduction and consumption.

4. Result and discussion

In this section, the schematic part of the Garver 6-bus problem is used (Garver, 1970), which is one of the basic example problems created by Garver and used in this area. This problem was created for the addition of a 6th new station to a 5-bus transmission line. Garver's initial 6-bus system is shown in Figure 1 and the distances between buses are given in Table 1. In Table 1, the distances for candidate lines are shown in red.

Table 1. Garver's 6-bus distances matrix

	1	2	3	4	5	6
1	-	40	38	60	20	68
2	40	-	20	40	31	30
3	38	20	-	59	20	48
4	60	40	59	-	63	30
5	20	31	20	63	-	61
6	68	30	48	30	61	-

Production and consumption levels of Garver are considered fixed. For example, production at station 1 is shown as 50MW, consumption as 80MW.

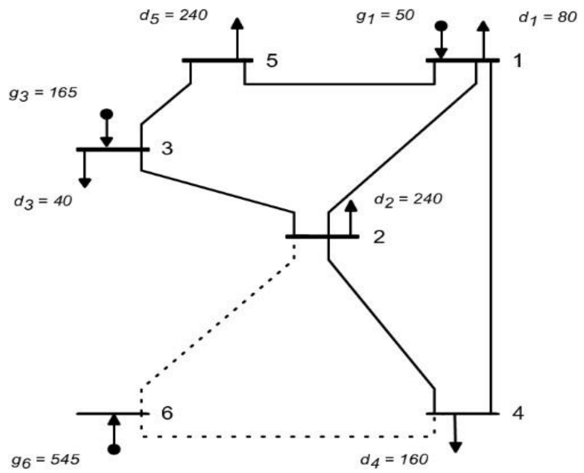

Figure 1. Initial configuration of Garver's network (Garver, 1970)

The Garver 6-bus example has been reconstructed for situations where production and consumption are stochastic and is shown in Figure 2. Other data, such as line capacity, line construction cost, susceptance and reactance are considered to be identical to the Garver 6-bus example. Node 1 generation is assumed stochastic as normal with mean 50MW and standard deviation 10. Also, demand is normally distributed with mean 100MW and standard deviation 20. Node 2 generation assumed as fixed with 200MW. Node 6 is main production station which is uniformly distributed between 570 and 700.

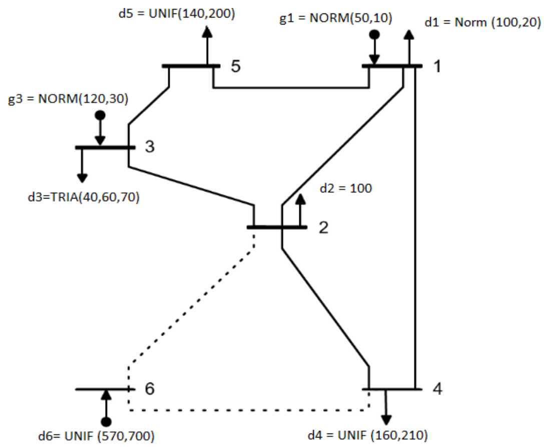

Figure 2. Modified configuration of Garver's network

This problem is solved by simulation model and GA. Our objective function contains: operation cost, line installation cost and the penalty cost for unmet demand. Taking into consideration the social problems that the electricity interruption will cause, the cost of the penalty is included in the objective function. First, GA code was created using MATLAB 7.0 programme. The proposed GA has the following basic features: 1) It uses a fitness function that takes into account the values of the inappropriate individuals tested. 2) It differs from GA which is recommended by Holland, because in each iteration only one person's location changes; and 3) apply an effective local remediation strategy for each individual tested. Then, the solution obtained by the GA was used as the initial solution for the Arena 14 programme and the optimisation was made using the OptQuest programme. The solution obtained is given in Table 2.

Table 2. Solution for modified Garver's 6-bus

	Number of added circuit					
	1	2	3	4	5	6
1	-	2	-	2	1	-
2		-	1	-	-	3
3			-	-	2	1
4				-	-	3
5					-	-
6						-

In the solution proposed for the problem developed under uncertainty, three new lines with capacities of 100MW each between 2 and 6, three new lines with capacities of 100 MW each between 4 and 6, one line between 3 and 6 are required. In addition, new lines should be established to increase the capacity next to the old lines due to the increase in demand.

5. Conclusion and further studies

In this study, a TEP has been developed for the cases where production and consumption are uncertain considering the current electricity transmission characteristics. Since the mathematical model is a nonlinear mixed-integer model, the problem is solved by using a combination of the GA and the simulation model. The proposed method is evolving due to its flexible structure. Other uncertainties in the field of electricity transmission will be included in the model. The proposed solution is a decision support system for decision makers when the speed and flexibility of access are taken into consideration.

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