TRANSMISSION EXPANSION PLANNING UNDER DIFFERENT UNCERTAINTIES: CASE OF KCETAS

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ABSTRACT

This study aimed to determine the transmission expansion plan by considering the uncertainties in the electricity energy market. The uncertainties are addressed by taking into consideration recent developments such as the characteristics of different regions, future demand forecasting, availability of production facilities and electricity systems integration in renewable energy in electrical systems. Since the mathematical model is a nonlinear mixed integer model, with the help of literature data, the problem will be solved with genetic algorithm method and Transmission Expansion plan will be established.The solution method was tested using Kayseri and Civarı Elektrik Türk A.Ş. (KCETAŞ) data. Our work is aimed to be the interesting modelling work in the field of industrial engineering, addressing many uncertainties in the electricity market. The proposed method is evolving due to its flexible structure. Other uncertainties in the field of electricity transmission will be included in the model.

1. INTRODUCTION

Electric energy, which is an indispensable part of our daily life, is one of the most important problems of power systems. Electricity is indispensable for many basic operations of the government and private sector. The sustainability of electrical energy is indispensable for many sectors, such as security, education, transport, industry and households. Electricity is a very important asset both socially and economically. Without adequate sources of power, businesses and the community cannot operate at full capacity and this is an obstacle to economic growth. Socially, the lack of sufficient power source, ie the absence of electricity, is a negative factor that directly affects the prosperity of society. Electric energyis the result of many different systems working together. Electricity energy systems consist of many decision makers. These decision makers decide at different times to achieve different goals. This makes it difficult to tackle this area of problems. Electric networks are interconnected regional systems. An event in one location affects other locations. The system must always be in balance to ensure reliable operation. Electricity becomes available when four basic operations are realized. These operations are electricity generation, electricity transmission, electricity distribution and electricity consumption.

Within these four basic operations, many uncertainties are dominant. The uncertainties in the production area have become extremely complex with the integration of renewable energy generation facilities such as wind power plants and solar energy plants. The electricity production inherent to these production sources is in a lustrous structure. The uncertainties in transmission and distribution can be summarized as leakage, loss and failure. Consumption is already uncertain because it is related to demand.

Because electricity is a product that cannot be held as stock in high quantities, production and consumption must take place simultaneously. This idea led to the whole of electricity operations being carried out by the public authority until the beginning of the 21st century. Thanks to the development of intelligent technologies and computer systems, the public in many countries now

regulates and controls only electricity operations.
Investment in electrical energy systems is usually a very gradual process. That is, expansion and reinforcement interventions are performed sequentially in different points over time. However, placing such a dynamic frame in a decision making tool may force calculation. Therefore, when a dynamic framework is considered, some simplifying assumptions are needed in explaining the system in general [1].
Safety and reliability of electricity transmission is extremely important as it provides the operation between production and consumption. At this point, long term transmission expansion strategies should be developed taking into account the future electricity generation projection and consumption forecast. It is important that this plan is done correctly because the investments for the transmission are long term investments from 1 year, and it is possible to make a sudden change of decision in today's extremely long term. Transmission expansion plans are generally prepared for periods of 5 years or 10 years.
Transmission Expansion Planning (TEP), the problem of identifying new transmission lines that need to be added to an existing transmission network to effectively fulfil system objectives, is one of the main strategic decisions in power systems and the impact on system operation is profound and long-lived[2]. The expansion plan, the improvement of the existing system, or the establishment of new transmission lines in order to find the most appropriate expansion solution [3]. Generation Expansion Planning (GEP), Distribution Expansion Planning (DEP) and Transmission Expansion planning (TEP) generally decide when, where and how much new production, new lines and new distribution networks will be made [4]. When making these decisions, our goal is to balance the total supply and demand taking into account the technical, economic and political constraints. In production area; the integration of an increasing number of renewable energy sources such as wind farms 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 grid and plays an important role in planning, operating and evaluating the grid [5].
The solution to this problem by taking uncertainties is quite complicated due to the nature of the problem. The goal is to arrive at the lowest cost solutions by using forecasting and production data on a daily or hourly basis. Different targets are emerging in the long run and more important issues are coming to the forefront. A model that will be created taking into account the punctual values will cause electricity interruptions and social distress. there is also a very high cost in a model that will be constructed considering the possible situation [6].
The layout of the remainder of the paper is as follows: in our next section, we will give the problem basic features notation and mathematical formulation. Proposed genetic algorithm structure and Kayseri and Civarı Elektrik Türk A.Ş. (KCETAŞ) data is given in section 3. 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.

2. PROBLEM STATEMENT

The problem is generally classified as one-stage, multi-stage; AC and DC model,; objective function differences and solution method type. Although researches are mostly focused on the static TEP problem, research has gained momentum for the dynamic multi-stage problem in recent years. In terms of model type, DC model researches are in the foreground according to AC model researches. Effective operations in this area include solving the problem without considering reactive power with the DC model and then testing the problem by taking into consideration AC power flow and reactive power. Despite the fact that many different kinds of conditions are taken into account as objective function, the most commonly used objective function parameters are the cost of investment, the cost of operation and the cost of penalty for non-compliant electricity.

The objectives of the TEP problem often coincide. For this reason, it is not possible to recover at the same time. In this case, the problem becomes a multi-objective optimization problem. In general, solution methods can be classified as mathematical optimization model and meta-heuristic methods. Linear Programming, Nonlinear Programming, Mixed Integer Programming, Bender Decomposition Algorithm, Branch Boundary Algorithm, Game Theory, Dynamic Programming, mathematical modelling methods that can be used in this area. Meta-heuristic methods include Ant Colony Algorithm, Artificial Immune System, Artificial Neural Networks, Fuzzy Systems, Genetic Algorithm, Annealing Simulation. Fundamental mathematical formulations used in transmission expansion studies: transport models, hybrid models, DC power flow models and decomposition models [7].

In this study, a solution was developed by using genetic algorithm for single-stage DC model. The well-known classic model is as follows [8]:

$$Min \sum_{(i,j)\epsilon\gamma} c_{ij} n_{ij} \quad (1)$$

s.t

$$S\ f + g = d \quad (2)$$

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

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

$$0 \leq g \leq g^{max} \quad (5)$$

$$0 \leq n_{ij} \leq n_{ij}^{max} \quad (6)$$

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

$$(i,j)\ \epsilon\gamma \quad (8)$$

This model is a mixed integer nonlinear model. Demand is considered fixed. 2 is derived from the Kirchhoff's Current Rule for the conservation of the limiting load. The third constraint is the Ohm linear current law. The constraints 4, 5 and 6 are capacity constraint for flow, capacity constraint for production and capacity constraint for line number, respectively. Demand in this model is deterministic.

3. GA STRUCTURE & TEST DATA

A genetic algorithm has been developed to solve the problem. The genetic algorithm consists of 0 1 variables. First, a matrix was created in which existing lines were represented (A1). This matrix is 1 for existing lines and represents 0 for candidate lines. Thanks to this binary coding, there is no compatibility problem when genetic algorithm operators are used. Examples are based on the Garver 6 bus problem [9].

Lines	1-2	1-3	1-4	1-5	1-6	2-3	2-4	2-5	2-6	3-4	3-5	3-6	4-5	4-6	5-6
A1	1	0	1	1	0	1	1	0	0	0	1	0	0	0	0

Fig. 1.Structure of A1

In order to increase the number of operations and the efficiency of the algorithm, a matrix of A2 was created without considering the calculations for the existing lines. The A2 matrix presented below contains the possible solution. This A2 solution matrix only suggests adding a new line between 2-6 and 4-6 as a solution.

Lines	1-3	1-6	2-5	2-6	3-4	3-6	4-5	4-6	5-6
A2	0	0	0	**1**	0	0	0	**1**	0

Fig. 2.Structure of A2

The genetic algorithm operators will be performed on the relevant A2 matrix, and the solution obtained is then made by the matrix A3, which is a combination of the load flow and the suitability of A1 matrix A2.

Lines	1-2	1-3	1-4	1-5	1-6	2-3	2-4	2-5	2-6	3-4	3-5	3-6	4-5	4-6	5-6
A3	1	0	1	1	0	1	1	0	**1**	0	1	0	0	**1**	0

Fig. 3.Structure of A3

The one-point crossover operator is used as the crossover operator. According to this operator, 2 individuals are randomly selected from the population. Then a random crossover point selection is made. When the new individual is created, the genes up to the crossover point are generated from the second parent after the first crossover point.Single point mutation operator was chosen. This operator selects a random gene and changes the value of this gene to 0 if it is 1, 1 if it is 0.

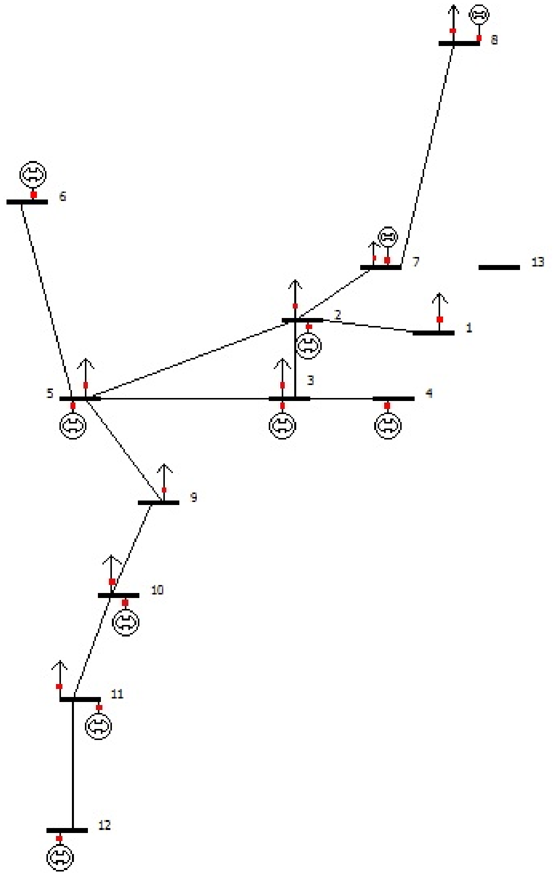

Fig. 4.Transmission network scheme(KCETAS 13 Bus)

Kayseri and Civari Elektrik A.Ş. (KCETAŞ) has 12 stations in the field of activity. The transmission network for these substations is shown in Figure 4. In Talas, the central district of Kayseri, electricity consumption has increased rapidly due to population growth. Depending on the development of the district, it was decided to establish 13 stations in this area. Demand and production on bus stations are different. Consumption characteristics 1, 2, 3 and 13 are realized in stations near the city centre. Production is carried out with natural gas in station 4, with hydroelectric power station in bus 6. In the power plant with 10,11 and 12, renewable energy especially solar systems are provided. Renewable energy is inherently stochastic and contains uncertainty. Of course, Kayseri alone does not have the independent transmission network in Turkey. 7 and 11 stations with very high voltage transmission lines (380kV) is connected to the other in Turkey. Because of the proximity of our work to the need for consumption, the 7th station was chosen as a slack bus and the unavailable request was assumed to come from this source throughout sources.

Table 1. Transmission system data (Kayseri)

Line	Resistance (per unit)	Reactance (Per unit)	Invest. Cost 100000$	Capacity MW	Lenght (km)
Line 1 - 2	0,06	0,24	36	100	12
Line 1 - 4	0,07	0,26	52	100	13
Line 1- 13	0,06	0,24	12	100	12
Line 2 - 3	0,05	0,2	10	100	10
Line 2 - 5	0,14	0,54	27	80	27
Line 2 - 6	0,17	0,66	33	70	33
Line 2 - 7	0,04	0,16	24	100	8
Line 3 - 4	0,04	0,14	7	100	7
Line 3 - 5	0,1	0,4	20	100	20
Line 3 - 9	0,12	0,46	23	100	23
Line 4 - 9	0,15	0,58	29	75	29
Line 5 - 6	0,15	0,58	29	75	29
Line 5 - 9	0,09	0,36	18	100	18
Line 6 - 7	0,19	0,74	37	70	37
Line 7 - 8	0,24	0,96	48	60	48
Line 7 - 13	0,06	0,22	22	100	11
Line 8 - 13	0,23	0,94	47	60	47
Line 9 - 10	0,09	0,36	18	100	18
Line 10 - 11	0,09	0,36	18	100	18
Line 11 - 12	0,11	0,44	22	90	22

The features, lengths and costs of existing and candidate lines are shown in Table 1. The darker colored lines show the candidate lines. Table 2 shows the load amounts for which the production and consumption are considered constant.

Table 2. Static station load & generation data (Kayseri)

	Generation MW	Load MW	Net MW
Station 1	0	90	-90
Station 2	0	150	-150
Station 3	15	190	-175
Station 4	190	0	190
Station 5	30	70	-40
Station 6	100	0	100
Station7	370	140	230
Station8	30	25	5
Station9	0	30	-30
Station10	75	50	25
Station11	80	70	10
Station12	85	0	85
Station13	0	160	-160

First, the nonlinear static model is transformed into linear by the DC Model assumption.

Using the data in Table 1 and Table 2, the model was solved mathematically with LINGO 17.0 program. As the best solution, one new line with capacity of 100MW between 3 and 4, one new line with capacity of 75 MW between 5 and 6, two new lines with capacities of 100 MW each between 7 and 13, one line between 9 and 10 are required. Objective function value is found 9800000$. Then the solution for the static problem was compared with the developed genetic algorithm and it was observed that the algorithm found the best solution at approximately 30 iterations for this problem.
The KCETAS 13-bus example has been reconstructed for situations where production and consumption are stochastic and is shown in Table 3. Other data, such as line capacity, line construction cost, susceptance and reactance are considered to be identical to the KCETAS-bus example. For example, Node 1 demand is assumed stochastic as normal with mean 90 MW and standard deviation 10. Node 3 demand is is uniformly distributed between 190 and 210. Node 4 generation assumed normal with mean 200 MW and standard deviation 30. Station 7 is selected as slack in order to ensure the reliability of the system. The other data are shown in table 3.

Table 3. Modified station load & generation data

	Generation MW	Load MW
Station 1	0	NORM (90,10)
Station 2	0	150
Station 3	15	UNIF (190,210)
Station 4	NORM (200,30)	0
Station 5	30	70
Station 6	100	0
Station7	Slack	Slack
Station8	30	25
Station9	0	30
Station10	UNIF (75,100)	50
Station11	UNIF (80,110)	70
Station12	UNIF (80,100)	0
Station13	0	UNIF (160,300)

This problem is solved by 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. GA code was created using MATLAB 7.0 programme.

In the solution proposed for the problem developed under uncertainty, one new line with capacity of 100MW between 3 and 4, one new line with capacity of 75 MW between 5 and 6, three new lines with capacities of 100 MW each between 7 and 13, two line between 9 and 10 are required.

4. RESULT & DISCUSSION.

In this study, a transmission expansion plan will be developed where production and consumption are unclear when considering the current electricity transmission characteristics [10]. Since the mathematical model is a nonlinear mixed integer model, the problem is solved by using a genetic algorithm. The proposed method is developed due to its flexible structure. Other uncertainties in the field of electric conduction will be included in the model. When uncertainty is included in the model, it is aimed to take uncertainty into consideration through scenarios. Scenario analysis can be used if probable examples of an ambiguous variable are known in the future, but there is no indication of their probabilities. It can be used to examine the effect of outcomes on "scenario uncertainty" or "non-random" uncertainties. Generally, decision makers examine a limited number of scenarios that can consist of various indefinite variables to explore the various possible futures. Sometimes the probabilities can also be added to the scenario. In a sense, scenario analysis can be a broader sensitivity analysis, although its objectives are different. The results obtained by the scenario analysis, min-max regret, expected cost, etc., before the decision makers are presented to the decision makers. and the like.
In the future, the system will be re-solved for the extraordinary circumstances and the system's stability will be tested for N-1 state (all elements in the system are individually

unloaded from the system respectively, and the system is loaded).

The realistic example of the voltages in the real power system is that the perfect voltage profile assumption is the most critical voltage and that the voltage profile is the greatest source of the active power prediction error. The real power system is very sensitive to deviations and should be careful when interpreting the results. The perfect, straight stress profile seems to be the most critical of all the assumptions. This assumption will be tested with more real-world applications and hypothetical error rates will be examined.

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Nomenclature

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 j 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

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