EEE 577 Project Report

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I. Introduction

The transmission network is one of the most complex feats of engineering ever created. Thousands of different apparatus, equipment and personnel, spread over a large area combine together to operate this marvel of human invention. Managing and operating such huge networks is already a daunting task, but when it comes to improving and adding to the already complex network, the problem increases manifold. That is why Transmission Expansion Planning (TEP) is a very detailed study of the transmission system that seeks to improve areas which could be overburdened due to increasing load and the corresponding increase in generation capacity. This paper takes a very simple transmission expansion problem and seeks to model and solve it using the programming package AMPL.

II. Tools Used

A. Modelling

The transmission network was modelled using the programming language AMPL as a Mixed Integer Problem (MIP) and was solved using the Gurobi solver. The coding was done using AMPL's own IDE.

B. Dataset

The dataset utilized for modelling this power system was the IEEE Reliability Test System (RTS) 1979 and 1996. The dataset contains a total of 73 buses, 120 transmission lines and 99 generators. While formulating this problem the load on each bus was assumed to have increased threefold, i.e. the load on each bus was multiplied by 3. To cater for the increase in load, the number of generators on each bus were also tripled. The generator tripling was done by assuming each generating making two copies of itself on each bus. This would obviously lead to transmission line congestion and subsequent need for Transmission Expansion Planning.

III. Nomenclature

A. Sets

G: Sets of generators, $g \in G$
g(n): Set of units connected to bus n.
K: Sets of transmission elements, $k \in K$
N: Sets of buses, $n \in N$

B. Parameters

C_g*: Operational cost of gen g*
$C_k^{Newlinw}$*: Cost of adding a new line k*
d_n*: Demand at bus n*
P_g^{max}*: Maximum generation capacity of generator g*
F_k*: Thermal rating of transmission line k*
B_k *: Susceptance of line k*

C. Variables

P_g *: Real power dispatch for unit g.*
w_k*: Binary variable to decide whether to install new line*
${\delta_n}^r$*: Voltage angle of bus n the branch is connecting to*
${\delta_n}^s$*: Voltage angle of bus n the branch is connecting from*
P_k*: Flow on branch k*

IV. Objective Function And Constrants

$$Minimize: \sum_{\forall g} P_g C_g + \sum_{\forall k} C_k^{newlinw} w_k \qquad (1)$$

$$P_g \leq P_g^{max} \qquad \forall g \; (2)$$

$$-F_k \leq P_k \qquad \forall k \in ExistingLineSet \; (3)$$

$$P_k = B_k[\delta_n^r - \delta_n^s] \qquad \forall k \in ExistingLineSet \; (4)$$

$$-F_k w_k \leq P_k \leq F_k w_k \qquad \forall k \in NewLineSet \; (5)$$

$$-(1-w_k)M \leq P_k - B_k[\delta_n^r - \delta_n^s] \leq (1-w_k)M \qquad \forall k \in NewLineSet \; (6)$$

$$\sum_{k=n^s} P_k - \sum_{k=n^R} P_k = \sum_{g=n} P_g - d_n \qquad \forall n \; (7)$$

Note: This is Part A of the project

Eq (1) is the objective function. We aim to minimize the operating cost of running the generators (given by the product of the generators' output and the operational cost of the generators for all generators) plus the cost of addition of new lines (given by the product of the cost of installing new lines and the decision variable whether the line has to be installed or not). The decision variable w_k is 1 if a line is to be installed and is 0 if the line does not need to be installed.

Eq (2) is the first condition. It specifies that the output of each generator in the system has to be less than the maximum output capacity of the generator. This condition is necessary for the normal operation of the system because operating generators above their max power rating could severely damage them.

Eq (3) limits the flow of power on an existing line k and ensure that it does not exceed the thermal ratings of the line. This is needed because power flow through the lines increases their temperature. Beyond a certain temperature the lines could become damaged.

Eq (4) specifies that the power flow on a line k, given by the B-Theta formulation of AC power flow. The B_k is the susceptance of line k and the theta are the bus angles for buses at either end of the line. Take note that the lines specified in this constraint are all from the existing line set.

Eq (5) limits the flow of the line on the newly installed line below F_k, the maximum line thermal rating. The decision variable w_k is there to ensure that the condition is only applied if a line is to be installed.

Eq (6) uses the big-M method to ensure that there are no non-linear terms while formulating the power flow on newly installed lines using the B-Theta method, if they are to be installed. If the decision variable w_k is 1, the Eq (6) becomes and equality constraint similar to Eq (4). If w_k is 0, i.e. the line is not going to be installed, then the large value of M ensures that the constraint is not binding [1].

Eq (7) is the node balance constraint. It states that for each bus n, the net injection on that bus (the generation minus the load) should be equal to the difference of power flowing into and out of the bus.

V. Solving The Optimization

The method used in this paper to solve the optimization is modelling the system and constraint as a Mixed Integer Problem (MIP). The problem can be modelled as such because it consists of variables, some of which are binary or integers. The method employed here to solved the MIP is called the Branch and Cut algorithm. Simplex method is used to evaluate each instance of the problem and for each non-integer solution a cutting plane is used to further find constraints which may be satisfied by the feasible points. Then the branch and bound technique is used to divide the problems into multiple subproblems. The newly generated linear problems are then solved, seeking integer solutions and at minimum cost. The process is repeated until the allocated time runs out or a solution is found within the optimality gap. Lower and Upper bounds are constantly being defined during the algorithm and they are used to get rid of unfeasible or expensive solutions [1].

This is a widely popular method for solving optimization problems because it provides quick solutions within the specified time. Other than its quickness, the algorithm provides and optimality gap. This gives you a measure of how accurate the solution is.

The strategy used to solve the problem involved first sorting and selecting relevant data from the IEEE RTS dataset. The generator data, the transmission line data and the bus data were all simplified to the parameters which are needed. Since our primary aim in expansion of the transmission system by adding new lines, a new set of transmission lines was made in addition to the original set having the same parameters as the original set. This means that each new line, if it is to be installed, would be installed parallel to the already existing lines. Then, since we were given two types of lines with different costs per mile, the information regarding their installation cost was added to the data. We were given the choice of two types of transmission lines. To model these in the new set we generated twice the amount of lines originally present half of these with the first specification of the transmission lines and the other half with the second specification, each with its own binary decision variable.

The model and the equations are then programmed using AMPL and the resulting model is solved using the Gurobi solver with an optimality gap of 0.001. The Gurobi solver has a pre-solve algorithm which gives rid of the infeasible solutions before starting with the branch and cut algorithms.

VI. Results

The simulation results indicate that the total number of transmission lines to be installed is 18, 8 lines of type 1 and 10 lines of type 2.

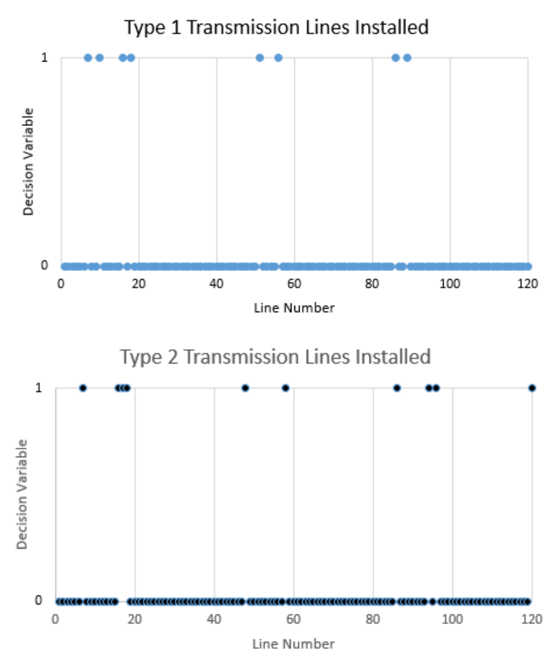

Figure 1. New transmission lines installed

Figure 1 illustrates parallel to the new lines of both types which are going to be installed. It can be inferred from the chart that in many instances both the type 1 and type 2 lines are being proposed. This means that there is large overload on the lines parallel to which the new lines have to be installed.

This is to be expected since in addition to tripling the load on each bus we also tripled the number of generators on each bus. Since not all buses had generators, this resulted in a large number of generators on some buses. Therefore, there were large power flows on lines connected to those buses, specifically on lines connecting such buses with a large number of generators.

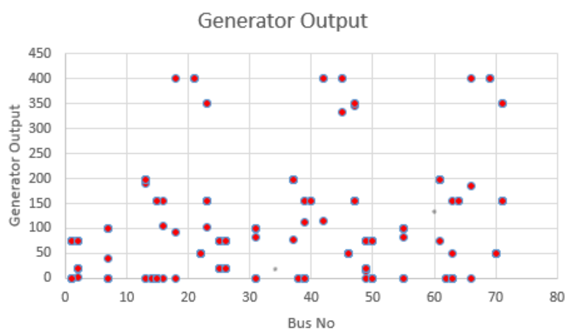

Figure 2. Generator outputs on each bus

This is better illustrated when we compare it with the final generator outputs on each bus. Some buses have generators with comparatively higher output than others. These are the buses which put large amount of stress on their connected transmission lines. Especially when we consider that cheap generators with large max power output were modelled to be three times their number on the same bus, the pattern makes sense.

The total cost incurred in dollars was $2190568.671. This also includes cost of running the generators.

VII. Conclusion

A very simple instance of a very complex problem like Transmission Expansion Planning was successfully solved using AMPL and Gurobi and the minimization of cost of operation and installation of new lines was observed. The number of lines required to be installed was kept minimum to save capital and an optimal solution was found.

References

[1] Hui Zhang, “Transmission Expansion Planning for Large Power Systems”, page 40 https://repository.asu.edu/attachments/114555/content/Zhang_asu_0010E_13288.pdf