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Micro Genetic Algorithm based Overload minimization approach for Transmission Expansion Planning

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Abstract—*Broadly two solution approaches are used in solving the Transmission Expansion Planning (TEP) problem namely, Load curtailment minimization approach and Overload minimization approach. Overload minimization approach involves lesser computational efforts but has problem of non convergence of load flow in presence of isolated nodes. In literature, isolated nodes are dealt with modeling system Z-bus with fictitious lines of high impedance from reference to new nodes. This paper incorporates this technique in Micro Genetic Algorithms (MGA) and Genetic Algorithms (GA)to solve TEP problem. The fitness function is defined as inversely proportional to sum of weighted investment cost and overloads on the lines. The plans with high fitness and zero overloads are chosen, which are then tested for their utility by a Utilization Index (UI). The congestion costs for all chosen plans are also estimated. Multiple plans are analyzed across different attributes by trade off approach to help the decision maker. The complete algorithm implementation is described. The results for a practical Brazilian 87-bus test case are obtained and compared with results in literature.*

Index Terms*—Power Deregulation, Gauss Seidel, Micro Genetic algorithm, Transmission expansion planning and System overload.*

I INTRODUCTION

The basic principle of TEP is to minimize the network construction and operational costs while satisfying the requirement of delivering electric power safely and reliably to load centers along the planning horizon [1]. The expansion of a transmission network may include the construction of new overhead lines or underground cable in new corridors, and the upgrading of existing lines or cables in corridors already in use by increasing the number or the capacity of lines or cables, increasing the rated voltage, the improvement on the capacity and control equipment (FACTS, Capacitor banks etc.). In a more broad sense, one may also consider the introduction of generators in appropriate places to allow a better balance between generation and loads, and better use of the network, increasing the transmission capacity of the network

From the stake-holders point of view, transmission expansion should attend the following targets [2].

- Encourage and facilitate competition among market participants;
- Provide non-discriminatory access to cheap generation for all consumers;
- Alleviate transmission congestion;
- Minimize the investment, the risk of investments and operation costs;
- Increase the reliability of the network;
- Increase the flexibility of system operation while reducing the network charges;
- Minimize the environmental impacts;
- Allow better voltage level regulation.

Even though the principles are quite simple, the complexity of the problem and the impact on society due to the heavy investments that have to be made, together with the costs incurred due to failures, make TEP on as a challenging issue. The following are some of the factors that distinguish TEP as a challenging field in power system analysis [2].

- Complexity of the problem; TEP is a complex problem because it has a mixed integer nonlinear programming nature. It is also a complex mathematical problem as it involves, typically, a large number of variables.
- Usually, heavy investments must be made. This kind of investments goes a long way to strain the economy of the country or region undergoing such expansion plans.

Transmission expansion planning addresses the problem of strengthening an existing transmission network to optimally serve a growing electricity market while satisfying a set of economic and technical constraints. Various techniques, including simulated annealing, tabu search, evolution strategies, greedy randomized adaptive search procedure (GRASP), probabilistic reliability criteria (PRC), and probabilistic load flow (PLF), have been used to study the problem [3] – [7]. It is difficult to obtain the optimal solution of a composite power considering the generators and transmission lines simultaneously in an actual system, and therefore, transmission expansion planning is usually performed after generation expansion planning.

This paper presents a method for determining the optimal number of transmission circuits required in each network corridor using genetic algorithm (GA). Gauss – siedel power flow algorithm was used to determine the line flows and voltage magnitudes in each network corridor and network bus respectively. The static transmission expansion planning (STEP) problem was formulated using a DC power flow model [8], [9].

II. MICRO GENETIC ALGORITHM(MGA)

Genetic algorithms are simple, robust, flexible, and able to find the global optimal solution. They are especially useful in finding solution to problems for which other optimization techniques encounter difficulties [8]. A basic genetic algorithm is constituted by a random creation of an initial population and a cycle of three stages, namely: • evaluation of each chromosome; • chromosomes selection for reproduction; • genetic manipulation to create a new population, which includes crossover and mutation. Each time, this cycle is completed, it is said that a generation has occurred. A.Standard Micro genetic algorithm The disadvantage of GAs is the high processing time associated. That is due to their evolutionary concept, based on random processes that make the algorithm quite slow. However, different methods for reducing processing time have already been proposed, such as more appropriate choice of solution coding and reduction of search space using the specialist knowledge. One alternative method known as micro genetic algorithms, whose processing time is considerably smaller, is shown in [11] .

Most GAs produce poor results when populations are small, because insufficient information is processed about the problem and, as a consequence, premature convergence to a local optimum occurs. Population size generally varies from 30 to 300 individuals. In contrast, MGAs explore the possibility to work with small populations (from five to 20 individuals usually) in order to reduce the processing time. From a genetic point of view, it is known that frequent reproductions inside a small population may disseminate hereditary diseases rarely found in large populations. On the other hand, small populations can act as natural laboratories where desirable genetic characteristics quickly can emerge. In MGAs, mutations are unnecessary because after a certain number of generations, the best chromosome is maintained and the rest are substituted by randomly generated ones. On the other hand, it requires adoption of some preventive strategy against loss of diversity in population. The MGA implemented in the present work is reported in the following algorithm:

1) Select a population of n randomly generated individuals. Alternatively, n-1 individuals may be generated randomly together with one good individual obtained from previous search

2) Evaluate fitness and determine the best individual which is always transferred to the next generation. This “elitist” strategy guarantees against the loss of good information embedded in the best individual produced thus far

3) Select individuals for reproduction with the tournament selection strategy (for example with k=2)

4) Apply crossover with probability equal to 1 to favor exchange of genetic information among the population

5) Check for convergence by measuring the amount of diversity left in the population (by counting the total number of bits which are unlike those possessed by the best individual). If population diversity has fallen under a preselected threshold, go to Step 1; otherwise, go to Step 2.

III.GENETIC ALGORITHM (GA)

The use of Genetic Algorithm for problem solving is not new. The pioneering work of J.H. Holland in the 1970’s proved to be a significant contribution for scientific and engineering applications. GA is inspired by the mechanism of natural selection, a biological process in which the stronger individuals are likely to be the winners in the competing environment. Here, GA uses the direct analogy of such natural evolution. It presumes that the potential solution of a problem is an individual and can be represented by a set of parameters. Standard genetic algorithm is a random search method that can be used to solve non-linear system of equations and optimize complex problems. The base of this algorithm is the selection of individuals. It doesn’t need a good initial estimation for sake of problem solution, In other words, the solution of a complex problem can be started with weak initial estimations and then be corrected in evolutionary process of fitness [10]. GA also combines various operators namely; selection, crossover, and mutation operators with the goal of finding the best solution to a problem. GA searches for this optimal solution until a specified termination criterion is met. A proto-typical GA consists of the following steps.

- Generate initial generation
- Measure fitness
- Select a mating pool
- Mutate randomly selected member of the mating pool
- Pair the members of the mating pool.
- Perform crossover to obtain the new generation
- Iteration continues until some stopping condition is satisfied.

The Mutation operator selects one of existed integer numbers from the mating pool and then changes its value randomly. Reproduction operator, similar to standard form, reproduces each individual proportional to the value of its objective function. Therefore, the individuals which have better objective functions will be selected more probable than other chromosomes for the next population [15].

The selection operator selects the individual in the population for reproduction. The more fit the individual, the higher its probability of being selected for reproduction. The crossover operator involves theswapping of genetic material (bit-values) between the two parent strings. Based on predefined probability, known as crossover probability, an even number of individuals are chosen randomly. Each individuals (children) resulting from each crossover operation will now be subjected to the mutation operator in the final step to forming the new generation. The mutation operator enhances the ability of the GA to find a near optimal solution to a given problem by maintaining a sufficient level of genetic variety in the population, which is needed to make sure that the entire solution space is used in the search for the best solution.

In the context of TEP, the alternative expansion plans are referred to as the individuals. These individuals are what make up the mating pool as stated above. The power flows in the network together with other line flow constraints are all modeled mathematically and constitute part of the Algorithm [10], [11].

IV. MATHEMATICAL MODELLING

In this section, the mathematical models as proposed in [8], [12] and [13] are outlined. It consists of a Power flow model and a static transmission expansion planning (STEP) model.

A.Power flow model:

This provides a model of the nonlinear relationships among bus power injections, power demands, bus voltages and angles with the network constants providing the circuit parameters.

The power flow model provides information on the electrical performance of the lines with actual power flows in such lines. They also provide information about the line and transformer loads as well as losses throughout the system and voltages at different points in the system [12].

In developing power flow equations, a 3 – phase balanced system operation is assumed; hence per – phase analysis is utlized to obtain the necessary equations.

$$S_i \triangleq S_{Gi} - S_{Di} \quad (1)$$

$$I_i = I_{Gi} - I_{Di} \quad (2)$$

$$I_i = \sum_{k=1}^{n} Y_{ik} V_k \quad (3)$$

$$S_i = V_i I_i^* = V_i \sum_{k=1}^{n} Y_{ik}^* V_k^* \quad (4)$$

$$V_i \triangleq |V_i| e^{\angle V_i} = |V_i| e^{j\theta_{ik}} \quad (5)$$

$$\theta_{ik} = \theta_i - \theta_k \quad (6)$$

$$Y_{ik} \triangleq G_{ik} + jB_{ik} \quad (7)$$

$$S_i = \sum_{k=1}^{n} |V_i||V_k|(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}) \quad (8)$$

Resolving real and imaginary ports we otain

$$P_i = \sum_{k=1}^{n} |V_i||V_k|(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}) \quad (9)$$

$$Q_i = \sum_{k=1}^{n} |V_i||V_k|(G_{ik}\sin\theta_{ik} - B_{ik}\sin\theta_{ik}) \quad (10)$$

Gauss – Siedel power flow modification was also adopted as highlighted in this section. Recall from equation 4 that:

$$P_i - jQ_i = V_i^* I_i = V_i^* \sum_{k=1}^{n} Y_{ik} V_k$$

$$= |V_i|(\cos\delta_i - j\sin\delta_i)\sum_{k=1}^{n} |Y_{ik}V_k|(\cos\theta_{ik} + j\sin\theta_{ik})(\cos\delta_k + j\sin\delta_k) \text{........}11$$

$$= \sum_{k=1}^{n} |Y_{ik}V_iV_k|(\cos\delta_i - j\sin\delta_i)(\cos\theta_{ik} + j\sin\theta_{ik})(\cos\delta_k + j\sin\delta_k) \text{........}12$$

Where Pi and Qi are the net real and reactive powers expressed in per-unit. Thus, for buses where real and reactive power are injected into the bus, such as generator buses, and have positive values. For Load buses where real and reactive powers are flowing away from the bus, Pi and Qi have negative values.

$$P_i = \sum_{k=1}^{n} |Y_{ik}V_iV_k| \cos(\theta_{ik} + \delta_k - \delta_i) \text{.......}13$$

$$Q_i = -\sum_{k=1}^{n} |Y_{ik}V_iV_k| \sin(\theta_{ik} + \delta_k - \delta_i) \text{.......}14$$

For the voltage controlled buses, the bus voltage must be equal to the specified voltage. Also, the maximum and minimum reactive powers at these buses are also specified and the value of Qi(for i=1,2,3,….n)must lie between these limits. [23], [24].

1. $|V_i| = |V_i|_{spec} \ for \ i = 2,3, \ldots \ldots .n$
2. $Q_{i\,min} < Q_i < Q_{i\,max} \ for \ i = 2,3, \ldots \ldots .n$

If during any of the iterations, we find out that Qi is outside the limits specified, Qi is fixed at the minimum or the maximum value as the case may be and then the bus is treated as a PQ bus (load bus).

B. Static transmission expansion planning model

Generally, transmission expansion planning could be classified as static or dynamic. Static expansion determines where and how many new transmission lines should be added to the network up to the planning horizon [8]. Implicitly, we could infer the major goal of Static TEP is finding an appropriate number of new circuits that should be added to the transmission network.

The Static transmission expansion planning problem was formulated as follows using a DC power flow model [8], [9].

$$TC = \sum_{i,j\in\Omega}^{n} C_{IJ}\, Xn_{IJ} \quad .....15$$

TC: Construction cost of lines along the planning horizon C_{IJ} : Construction cost of each line in corridor.

Equation 17 represents the construction cost of new lines which should be added to the network for delivering safe and reliable electric power to load centers over the planning horizon. Several constraints are also modeled in a mathematical representation to ensure that the mathematical solutions are in line with planning requirements. These constraints are stated in the following sections [8].

$$P_i = \sum_{J}^{NB} P_{ij} + d_i \text{ (I=1,2,....NB) } (i,\ j \in \Omega) ....16$$

Where, NB = total number of buses in the network

P_i & d_i : Generation and demand on bus i

P_{ij} : Power flow of each branch i-j

Equation is known as the Dc power flow node balance constraint. Also,

$$P_{ij} = \gamma_{ij} X(n^{0}_{ij} + n_{ij}) X(\theta_i - \theta_j) ......17$$

Where

γ_{ij} : Total Susceptance of circuits in corridor

$(\theta_i - \theta_j)$: Voltage phase angles of buses respectively

IV. IMPLEMENTATION

The Gauss – Siedel power flow model was implemented using MATLAB. The flowchart used in implementing the Gauss – Siedel Power flow model is shown in Figure 1 and that of the Genetic algorithm is shown in Figure *2*.The output of the Gauss –Siedel load flow algorithm constitutes the input of the Micro Genetic Algorithm and Genetic algorithm flowchart. The various blocks in the Micro Genetic Algorithm and Genetic Algorithm flowchart are described in section.

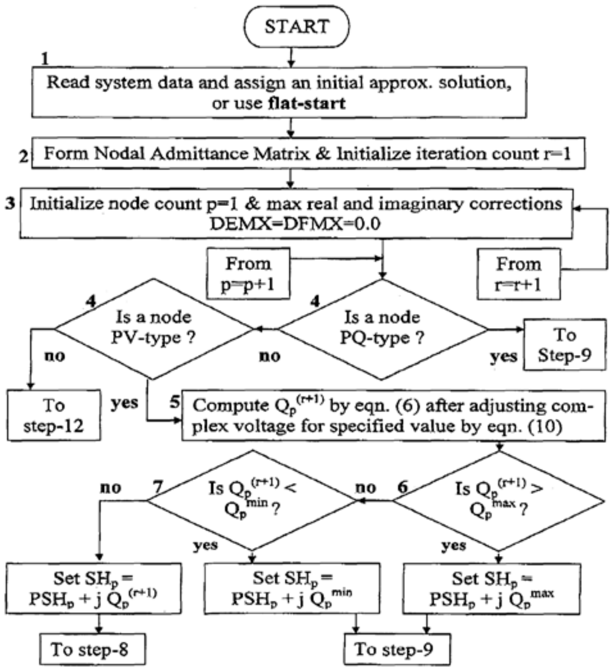

Fig:1 **Prior Art: Flow-chart of Gauss-Seidel Loadflow (GSL) Method**

Fig 1 Gauss – Siedel (GS) Power Flowchart

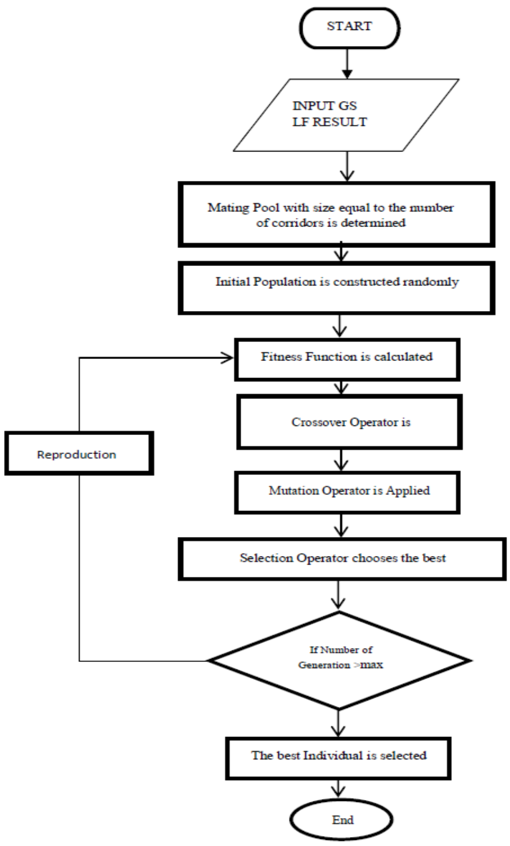

Fig. 2 Genetic Algorithm Flowchart

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V. RESULTS AND DISCUSSION

IEEE 14 – bus network was used as a test system to demonstrate the effectiveness of the chosen method. The network data for the IEEE 14 – bus test network was gotten from [14].The voltage magnitude, voltage angle and line flow of the IEEE 14 – bus network as calculated are shown in tables I and II. Also, the optimal number of extra lines required in each network corridor as calculated is tabulated in Table III.

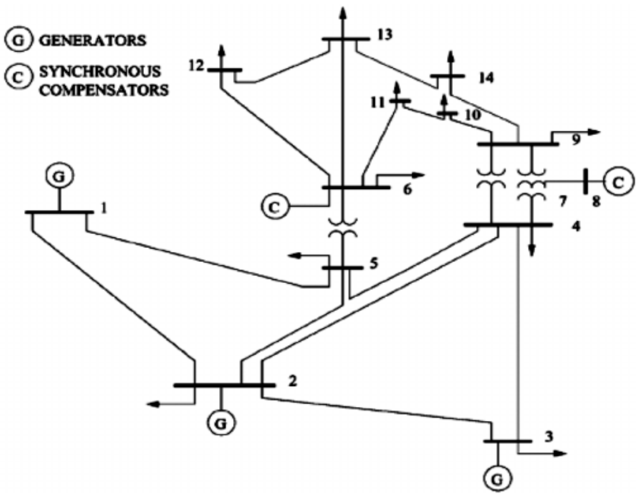

Fig:3 IEEE 14 – bus test network

Table I: Voltage Magnitude And Voltage Angle

Bus Number	**Voltage Magnitude(p.u.)**	**Voltage Angle**
1.	1.0600	0
2.	1.0186	-4.6495
3.	1.0047	-13.0577
4.	0.9940	-10.2633
5.	0.9998	-8.7037
6.	0.9721	-15.0821
7.	0.9828	-13.8216
8.	1.0131	-13.8216
9.	0.9596	-15.7607
10.	0.9537	-15.9883
11.	0.9590	-15.6947
12.	0.9559	-16.1048
13.	0.9509	-16.1923
14.	0.9359	-17.1686

Table II: Line Flows

From Bus	**To Bus**	**Line Flow (p.u.)**
1	2	2.0220
1	5	2.8506
2	3	0
2	4	0
2	5	0.3277
3	4	0
4	5	0
4	7	0
4	9	0
5	6	0
6	11	0
6	12	0
6	13	0
7	8	0
7	9	0.6353
9	10	0.2140
9	14	0.1568
10	11	0.0373
12	13	0.0274
13	14	0

Table III: Number of New Circuits and Network Adequacy

S/NO	**BRANCH**	**NEW CIRCUITS**	**NETWORK ADEQUACY (YEARS)**
1.	1 – 2	4	6
2.	1 – 5	5	1
3.	2 – 5	0	5
4.	9 – 10	0	5

Table I and Table II show us the status of the network during the expansion year. A load growth coefficient of 1.07 was used to ascertain how the network would fare with yearly increase in demand. The transmission network adequacy is a measure of the length of time within which the transmission expansion plan would still be viable. The following can be inferred from the results so obtained:

□□ Line flow in branch –1 2 already exceeds the transmission capacity of the Line, thus the TEP proposes that 4 extra lines of the same capacity be constructed to relieve the already existing line in the branch. It also stipulates that the extra lines would become inadequate 6 years after expansion.

□ Line flow of the line in corridor 1 – 5 also exceeds the transmission capacity of the line, much more than that of the line in corridor 1 – 2. Thus the TEP proposes that extra 5 lines of same capacity be constructed to relieve the already the congested line. However, the network adequacy of this plan is just 1 year. Improving the network adequacy would require an increase in the generation capacity, possibly in bus 2.

□Lines in corridors 2 – 5 and 9 – 10 both do not require extra lines; however the network adequacy of both lines is set at 5 years.

VI. CONCLUSION

This work addresses transmission system expansion planning using genetic algorithm. The number of transmission lines to decongest the branches and the corresponding network adequacy were both determined using this method. This work also provides a practical approach that could serve as a useful guide for the decision maker in selecting a reasonable expansion plan in the face of the prevalent circumstances.The model was also tested on IEEE 14 – bus network in order to ascertain the viability of the chosen methodology on diverse network models. They also suggest that transmission congestion occurs when actual or scheduled flows of electricity on a transmission lines are restricted below the level that grid users desire or when actual or scheduled flows exceeds the transmission capacity of the line.

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