



**STATIC TRANSMISSION EXPANSION PLANNING TO
ENHANCE RELIABILITY OF POWER SYSTEM USING
CONSTRAINED GENETIC ALGORITHM**

By

Eng. Ahmed Ibrahim Seddik Mohamed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

in

Electrical Power and Machines Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Title of Thesis:

Static Transmission Expansion Planning to Enhance Reliability of Power System Using Constrained Genetic Algorithm

Key Words:

Transmission expansion planning, Static planning, Expected energy not served, Genetic algorithm, Optimization, AC load flow, Gauss-Seidel, Graver 6-bus test system

Summary:

An exact and effective model of long-range static transmission expansion planning which is created in thesis applies genetic algorithm optimization technique to minimize the cost objective function that comprises both fixed and variable costs for all planned facilities, in addition to transmission energy losses cost and expected energy not served cost due to generation contingency.

The cost objective function is subject to system stability constraints in terms of upper and lower limits on the voltage magnitude and swing angle at system buses, and system security constraints in terms of power flow limitation, thermal capacity limitation, and the permissible number of parallel lines to be installed in each right-of-way.

The model applies AC load flow using Gauss-Seidel to allow the inclusion of system stability and security constraints into the model. The model provides accurate assessment for system stability and study the effect of the reliability index on the planned facilities. Garver 6-bus test system is utilized to test and justify the appropriateness of the created model.

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Dedication

Dedicated to my Mother and Father whom dedicated all their lives, love and care for me and my brothers

Dedicated to my great bothers Mohamed and Mostafa, for the continuous encouragement and support

Also, dedicated to everyone tried to help me, all my teachers, professors, my friends, ...

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Nomenclature

| | |
|----------------|---|
| b_{ij} | : j^{th} Binary digit of the i^{th} string |
| B_{ij} | : Susceptance or Imaginary part of i^{th}, j^{th} of Nodal Admittance Matrix |
| B | : Susceptance matrix of the existing and added line in the network |
| B_{mk} | : Susceptance of element (m, k) |
| c_{ij} | : Cost of candidate circuit for additional to the branch $i-j$ |
| c_{ij}^t | : Cost of candidate circuit for additional to the branch $i-j$ at stage t |
| C_A | : Available Generation Capacity |
| C_j | : Remaining Generation Capacity |
| $C_{j,k}$ | : Installation cost worth value of line k in right-of-way j |
| $C(x)$ | : Value of the transmission expansion planning |
| C_l | : Largest Generating Unit |
| D | : Real load demands vector in all network nodes |
| D_j | : Load curtailment duration as result of contingency j |
| E | : Total Energy Demand During the Period of Study |
| E_1 | : Power losses cost worth value per unit power |
| E_2 | : Expected energy not served worth value per unit energy |
| $EENS_k$ | : Expected Energy not Served k due to Capacity Outage O_k |
| $EENS_T$ | : Total expected energy not served due to generation contingency |
| f_{ij} | : Total branch power flow in branch $i-j$ |
| f_{ij}^{max} | : Maximum branch power flow in branch $i-j$ |
| f_j | : Portion of F_j which corresponds to not going through the boundary wall between the loss-of-load state set and the no-loss-of-load state set. |
| f_{Oj} | : Outage event j frequency of occurrence |
| F^{min} | : Solution of the highest ranking chromosome |
| $F_i(x)$ | : Solution corresponding to i^{th} chromosome |
| F_j | : Frequency of Departing System state j |
| G | : Real power generation vector in existing power plants |
| g_i | : Real power generation at node i |
| g_i^{min} | : Lower real power generated at node i |
| g_i^{max} | : Upper real power generated at node i |
| G_i | : Power generated by generator i |
| G_{ij} | : Conductance or Real part of i^{th}, j^{th} of Nodal Admittance Matrix |

| | |
|------------------|--|
| G_{mk} | : Conductance of element (m, k) |
| I | : Annual rate |
| K | : Scaling Factor |
| L | : Length of the string |
| L | : Expected Load |
| L_d | : Load at bus d |
| L_{kj} | : Amount of load curtailment at bus k as result of contingency j |
| LC | : All contingencies leading to load curtailment |
| n_{ij}^0 | : Number of circuits in original base system |
| n_{ij} | : Number of circuits added to the branch $i-j$ |
| n_{ij}^{max} | : Maximum number of allowable parallel lines to be installed in right-of-way between bus i and j |
| N_b | : Number of buses in the system |
| N_{gd} | : Set of generation connected to bus d |
| N_l | : Number of right-of-ways available in the system |
| N_{ld} | : Set of transmission lines connected to bus d |
| N_p^j | : Permissible number of parallel lines in right-of-way j |
| P_0 | : Total annual transmission power loss |
| P_{Gi} | : Active power generated at bus i |
| P_j | : Probability of Capacity Outage |
| P_k | : Active power flowing in a transmission line |
| P_{Li} | : Active power load drawn at bus i |
| P_m | : Net injected active power at bus m during planning horizon |
| P_{mk} | : Active power flow from bus m to bus k during planning horizon |
| $P_{mk,max}$ | : Right-of-way connecting bus m to k active power capacity limit |
| P_{Oj} | : Probability of failure of outage event j |
| P_{loss}_k | : Power loss at transmission line k |
| P_{loss}_{i-k} | : Power loss in line segment $i-k$ |
| Q_{Gi} | : Reactive power generated at bus i |
| Q_k | : Reactive power flowing in a transmission line |
| Q_{Li} | : Reactive power load drawn at bus i |
| Q_m | : Net injected reactive power at bus m during planning horizon |
| r_{ij} | : Resistance of transmission line connecting bus i and j |
| $R_{j,k}$ | : Variable cost worth value of line k in right-of-way j |
| t_0 | : Base year |
| t_j | : Percentage of time when the load exceeds C_j |

| | |
|---------------------|---|
| T | : Time horizon |
| V | : Transmission investment cost |
| V_i | : Voltage magnitude at bus i |
| V_j | : Voltage magnitude at bus j |
| V_{ki} | : Imaginary part of bus k voltage |
| V_{kr} | : Real part of bus k voltage |
| V_{mi} | : Imaginary part of bus m voltage |
| V_{mr} | : Real part of bus m voltage |
| w_{mk} | : Weighting factor for the capacity of active power of right-of-way connecting bus m to k |
| x_{ij} | : Reactance of transmission line connecting bus i and j |
| θ | : Bus voltage phase angle vector |
| θ_i | : Voltage angle at bus i |
| θ_j | : Voltage angle at bus j |
| θ_{ij}^{cal} | : Calculated phase angle |
| θ_{ij}^{max} | : Predefined maximum phase angle |
| δ_{inv}^t | : Discount factor to find the present value of an investment at stage t |
| $\delta_{k,min}$ | : Minimum limit on bus k swing angle |
| $\delta_{k,max}$ | : Maximum limit on bus k swing angle |
| $\alpha_{j,k}$ | : Integer equal (1) in case that line k of right-of-way j is utilized within planning horizon, and (0) otherwise |
| $\beta_{j,k}$ | : Integer equal (1) in case that line k in right-of-way j is installed within planning horizon, and (0) otherwise |
| Ω | : Set of all candidate branches for expansion |

Abbreviations

| | |
|-------|---|
| AC | : Alternating Current |
| ACLF | : AC Load Flow |
| ACS | : Ant Colony Search |
| AI | : Artificial Intelligent |
| ANN | : Artificial Neural Network |
| CHA | : Constructive Heuristic Algorithm |
| CRM | : Capacity Reserve Margin |
| DC | : Direct Current |
| DCLF | : DC Load Flow |
| DDO | : Discrete Dynamic Optimization |
| EENS | : Expected Energy Not Served |
| FACTS | : Flexible AC Transmission System |
| FAD | : Frequency and Duration |
| FDLF | : Fast Decoupled Load Flow |
| FERC | : Federal Energy Regulatory Commission |
| GA's | : Genetic Algorithms |
| GDP | : Gross Domestic Product |
| GEP | : Generation Expansion Planning |
| HL | : Hierarchy Level |
| IEEE | : Institute of Electrical and Electronics Engineers |
| IGA | : Improved Genetic Algorithm |
| ILP | : Integer Linear Programming |
| KCL | : Kirchhoff's Current Law |
| kV | : Kilovolt |
| KVL | : Kirchhoff's Voltage Law |
| LLU | : Loss of Largest Unit |
| LOEE | : Loss of Energy Expectation |
| LOLD | : Loss of Load Duration |
| LOLE | : Loss of Load Expectation |
| LOLF | : Loss of Load Frequency |
| LOLP | : Loss of Load Probability |
| LP | : Linear Programming |
| MCS | : Monte Carlo Simulation |