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 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*
$Ploss_k$	:	Power loss at transmission line *k*
$Ploss_{i\text{-}k}$	:	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
$\delta_{inv}^{\ t}$	:	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