Electrical Power and Energy Systems 61 (2014) 90–100

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Hybrid expansion planning considering security and emission by augmented epsilon-constraint method

Hani Mavalizadeh, Abdollah Ahmadi *

Department of Electrical Engineering, Iran University of Science and Technology, Tehran, Iran

ARTICLE INFO

Article history:
Received 1 June 2013
Received in revised form 14 February 2014
Accepted 7 March 2014

Keywords:
Multi-objective optimization
GEP
TEP
Emission
ELNS
AHP

ABSTRACT

In this paper a new approach on hybrid generation and transmission expansion planning in power systems is introduced. The proposed approach presents a multi-objective planning method which simultaneously minimizes total cost of planning (including non-uniform fuel cost and investment cost of new generation units and transmission lines), total $\boldsymbol{NO_x}$ and $\boldsymbol{SO_2}$ emission and a security index called ELNS (Expected Load Not Served). The DC power flow is used to model the transmission flow constraint. Furthermore, fuel supply limitation has been included for thermal units. More than one candidate line with different reactances and capacities in each corridor has been used which makes the model more practical in transmission expansion sector. This work is an effort to implement the augmented epsilon-constraint method for generating the Pareto optimal solutions in the hybrid expansion problem. In order to select the best solution among Pareto solutions, Analytic Hierarchy Process (AHP) method has been used. To prove the efficiency of the proposed method, numerical simulation results on the modified Garver's 6-bus system and 24-bus IEEE reliability test system are presented. The results show good performance of the proposed method.

Introduction

The demand for electricity is growing rapidly. Fig. 1 [1] is an electricity demand forecast between 1990 and 2030 for various regions all over the world. It shows rapid growth in demand, so it is essential for a power system to expand in response to growing load. Another reason for system expansion is unit retirement. As time goes by, useful life of some existing generating units comes to an end so their retirement should be compensated by installing new generation units on the system. As the investment cost for an expansion plan in power systems is very high, even a slight reduction in the investment cost in terms of percent, means saving a considerable amount of money. Hence, it is very important for a system planner to find the most economical possible plan.

A good expansion plan should select the units which must be built, specify their type and capacity, and determine where and when to build them [2]. A comprehensive model should investigate all of the mentioned issues. There are a lot of approaches available for solving planning problems in scientific literature, but just a few of them have considered all of the above issues. For example, WASP-IV [3] is a powerful tool which uses a dynamic programming approach to find generation unit capacities needed to be installed on the system considering a security index, such as LOLP (Loss of Load Probability) but this software does not indicate where to build new generation units. In WASP-IV, fuel cost is assumed to be uniform all over the system which is an incorrect assumption in most cases, since fuel cost is proportional to the distance between fuel sources and generation units. Another invalid assumption in WASP-IV is that the entire load is assumed to be in one node. That is, the geographical distribution of the load is not considered which is obviously an invalid assumption. When the amount of generation capacity needed to be built is known, but the location of new units is unknown, the problem of designing he least cost plan becomes very complicated, particularly when considering the fuel cost to be non-uniform [4].

Generally, the expansion problem is considered to be a nonlinear, non-convex optimization problem [5]. There has been much effort on solving it using meta-heuristic algorithms such as genetic algorithm, simulated annealing, and Tabu search, which are usually intended to solve GEP (Generation Expansion Planning) and TEP (Transmission Expansion Planning) problems, separately.

In Refs. [4, 6] security constrained models of transmission system planning are presented. When solving TEP problems, some parameters, such as the topology of the network in the base year, generation and demand for the specified planning horizon and candidate circuits are considered to be known by the planner.

* Corresponding author. Tel.: +98 917 168 8909; fax: +98 0761 3333272.
E-mail address: ahmadi.abdollah.janah@gmail.com (A. Ahmadi).

http://dx.doi.org/10.1016/j.ijepes.2014.03.004
0142-0615/

Nomenclature

f	index for fuel sources
i	index for buses
s	index for scenarios
M	index for technologies
cap	index for capacity of each line
type	index for reactance of each type
q	index for capacity of each generating unit
k	index for credible contingencies
C_{GEP} (i, m, s)	the investment cost to build new generation unit in bus i with technology m, in scenario s
C_{TEP} $(i, j, cap, type, s)$	the investment cost to build new transmission line between bus i and j with specified capacity and type in scenario s
TF (f, i, s)	the amount of transported fuel between fuel source f and generation unit in bus i in scenario s
PF (f)	the fixed price of the fuel in the fuel source
TP (f, i)	the price of transporting fuel from fuel source f to the generation center in bus i per kilometer
d (f, i)	the distance between fuel source f and generating unit located at bus i
π (s)	the probability of scenario s
$P^{available}_{m,q}$	table that shows for technology m, what generation capacities are available
$P^{available}_{cap}$	table that shows for capacity cap, what transmission capacities are available
P_G (i, m, s)	generated power at bus i from technology m in scenario s
P_D (i, s)	load at bus i in scenario s
B (i, j)	susceptance between bus i and j
θ (i, s)	voltage angle at bus i in scenario s
PG_{final}	post-expansion generated power
PG_{start}	pre-expansion generated power
B_{final}	network susceptance matrix in post-expansion condition
B_{start}	network susceptance matrix in pre-expansion condition
$P_{D_{\text{final}}}$	load demand in post-expansion condition
$P_{D_{\text{start}}}$	load demand in pre-expansion condition
θ_{final}	voltage angles array in post-expansion condition
θ_{start}	voltage angles array in pre-expansion condition
ΔPG	the amount of added power generation capacity during the planning horizon
ΔP_D	the amount of increase in electrical power demand during the planning horizon
ΔB	changes in transmission line susceptance matrix
$\Delta\theta$ (i, s)	change in voltage angles of bus i in scenario s
V (i, m, q, s)	binary decision variable that equals 1 when a new generation unit of type m is planned to be built at bus i with capacity q in scenario s by the optimization problem
W $(i, j, cap, type, s)$	binary decision variable that equals 1 when a new transmission line between bus i and bus j with capacity cap and reactance type is planned to be built by the optimization problem in scenario s
Z (i, j, s)	extra variable used to eliminate the nonlinearity in the model
Y	a large enough scalar
$B^{available}_{cap,type}$	table that shows the construction cost of each line with specific capacity and type
ΔPT (i, j, s)	change in transmission capacity between bus i and bus j in scenario s
$P_{\max}$ (i, j)	maximum allowed power flow between bus i and bus j
η (m)	contribution factor of generation technology m
$hour$ (m)	shows the maximum operation hours of technology m
E (i, m, s)	energy generated at bus i by technology m in scenario s
CF (s)	total consumed fuel in the planning period in scenario s
α (m)	fuel consumption coefficient for technology m
FL	maximum fuel available in that period
$heat$ (f)	heat rate of each type of fuel
MT (f, i)	maximum fuel transportation capacity between fuel source f and bus i
β (m)	SO_2 production multiplier for technology m in ton per MW h
γ (m)	NO_x production multiplier for technology m in ton per MW h
E_{SO2} (s)	total SO_2 produced in scenario s in ton
E_{NOx} (s)	total NO_x produced in scenario s in ton
$prob$ (k)	probability of each contingency
P_{shed} (i, k, s)	the amount of load shedding at bus i for contingency k in scenario s
dir (i)	is equal to 1, the ith objective function is maximized and is -1, when the ith objective function is minimized
s_i	surplus variable for the constraints in the ith objective function
r_i	range of the ith objective function
q_i	weighting factor for the ith objective function
CI	consistency index
CR	consistency ratio
RI	consistency index dependent on number of items being compared
$\lambda_{\max}$	principal eigenvalue of comparison matrix
n	number of competing Pareto solutions in AHP method

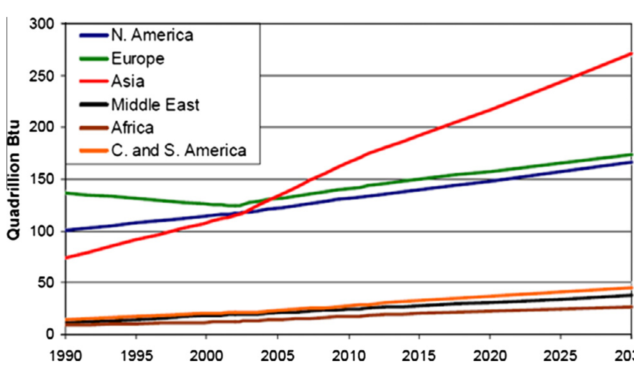

Fig. 1. Global energy demand.

For a long time, researchers have considered GEP and TEP separately to reduce the complexity of the problem [7]. The main reason justifying this decomposition is that, most of the expansion cost relates to GEP; therefore, one can first solve the GEP problem. After solving the GEP problem, the generation units needed to be built are selected. Then, the new system including new generation units can be considered as the primary system for solving the TEP problem. It is proven that with this decomposition, there will not be a big diversion from the optimal point [2]. It should be noted that the power system constraints, such as line flow limits, load demands, and security requirements are still responsible for a correlation between the two planning problems [8].

In Ref. [7] TEP problem is solved based on the meta-heuristic Ant Colony Optimization (ACO). LOLC (Loss of Load Cost) is used