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Composite generation and transmission expansion planning considering distributed generation

Ahmad Rouhani [a,*], Seyyed Hadi Hosseini [b], Mahdi Raoofat [c]

[a] Young Researchers and Elite Club, Beyza Branch, Islamic Azad University, Beyza, Iran
[b] Department of Electrical Engineering, Zanjan University, Zanjan, Iran
[c] Department of Power and Control Engineering, School of Electrical and Computer Engineering, Shiraz University, Shiraz, Iran

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ABSTRACT

This paper presents a model for use in the problem of composite generation and transmission expansion planning considering distributed generation. Generation expansion planning is defined as the problem of determining what capacity, which, and when new generating units should be constructed over a long range planning horizon, to satisfy the expected energy demand using single nodal generation planning model. Then, the place of every planned generating units and distributed generation is determined simultaneous with transmission expansion planning considering nonuniform geographical fuel supply cost and potential of distributed generation technology. The problem is formulated as a Mixed-Integer Linear Programming. By allocating the overall generation capacity among the grid nodes and determining the new transmission element additions along the planning horizon, the overall cost of the system is minimized. To assess the capabilities of the proposed approach, the Iranian Power Grid as a large scale system is considered. The effectiveness of the proposed modifications is illustrated in detail.

Introduction

Rapid growth in consumer demand, along with other technical and economical reasons may cause inadequacy in the available electric network. So, electric utilities face the challenge to serve electricity demand for the coming years with acceptable reliability, safety and quality through the expansion in generation, transmission and distribution systems [1]. Therefore planning for the electric power sector encompasses generation, transmission and distribution systems [2]. Generation expansion planning (GEP) is considered one of major parts of power system planning issues. The aim of GEP is to seek the most economical generation expansion scheme achieving an acceptable reliability level according to the forecast of demand increase in a certain period of time. (Long-term planning can cover more than 30 years) [2].

The feasibility of the generation structure, the cost of primary energy resources and fuel for the scheme, and the reliability indices of electricity supply, make generation planning a very complicated optimization mathematically [3]. Some of these restrictions have been applied in GEP in the recent literature [4–7]. But applying transmission line restrictions is not simply possible without transmission expansion planning (TEP). On the other hand, not applying this constraint may led to non-optimal response.

WASP-IV is powerful software developed by International Atomic Energy Agency (IAEA) in which a dynamic programming approach is employed to find an overall optimal required generation capacity for the network so that an index, such as LOLP, is minimized [8]. In using WASP-IV, it is assumed that the fuel cost throughout the geographical distribution of the network is uniform. This assumption is invalid in real life, as allocation of a power plant far from a fuel resource supply center results in high fuel transmission costs. Moreover, in using WASP-IV, a single-node load center is assumed which is not obviously a valid assumption [8]. In other words, while WASP-IV is capable of predicting the overall generation capacity requirements for the grid, it is unable to geographic-ally distribute and allocate the capacities among the areas [9].

As mentioned before, the investment in a power plant is greatly influenced by the environment in which the power plant is situated, e.g. water supply, dissipation conditions, and the cost of the land. In addition the geographical locality also has a bearing on the entire system investment and operational cost. For example there will be additional transmission investment cost if the power plant is far away from the load centers and the fuel cost will be greater if the power plant is far from a fuel source [2]. However, the locations of generating units and costs of transmission lines

* Corresponding author. Tel.: +98 7127623257.
E-mail address: rouhani@biau.ac.ir (A. Rouhani).

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Nomenclature

Acronyms and abbreviation

DP	dynamic programming
LDC	load duration curve
LINGO	linear interactive and general optimizer
LOLP	Loss of Load Probability
MATLAB	matrix laboratory
WASP	wien automatic system planning

Indices and sets

T	number of years in a planning horizon
t	year index along the planning horizon
d	load duration curve level index
i	existing or candidate thermal plants index
j	existing or candidate DG technologies index
si	existing and candidate plants index
h	existing or candidate hydroelectric plants index
c	hydrological conditions index
b	bus index
l	existing and candidate transmission line index
le	existing transmission line index
lc	candidate transmission line index
lb	existing and candidate transmission lines index connected to bus b
m	transmission lines type index
f	fuel type index for thermal plants
e	emission type index of generating units

Variables

$LOLP_{ct}$	LOLP index of critical period in year t
ε	standard level of LOLP index
γ	spinning reserve ratio
β_{jb}	geographical potential of DG technology j in bus b
α	allowed penetration of DG in network
a_t	lower bound of reserve margin in year t
b_t	upper bound of reserve margin in year t
t_d	duration of subperiod d
I_{tsib}	present value for investment cost of generating unit si in year t in bus b
F_{tsib}	present value for fuel cost of generating unit si in year t in bus b
M_{tsib}	present value for maintenance cost of generating in bus b unit si in year t.
O_{tsib}	present value for operating cost of generating in bus b unit si in year t
S_{tsib}	salvage value for investment cost of generating unit si in year t in bus b
CDG_{jb}	investment cost of DG technology j in bus b
CT_{lcm}	investment cost of a circuit of candidate transmission line lc of type m
CG_{ib}	Investment cost of generating unit i in bus b
CF_{db}	cost of fuel consumed in subperiod d in bus b
D_{ct}	forecast peak demand in the critical period of year t
D_{db}	total demand in bus b in subperiod d
D_b	total demand in bus b
PG_{ct}	installed generation capacity in the critical period of year t
PG_{hc}	installed generation capacity of hydroelectric plant h in hydrological condition c
PG_{db}	total installed generation capacity in bus b in subperiod d
PG_b	total installed generation capacity in bus b
PDG_{djb}	total installed generation capacity of DG type j in bus b in subperiod d
P_{dl}	Power flow capacity in existing or candidate transmission line l in subperiod d
P_{dle}	power flow capacity in existing transmission line le in subperiod d
$P_{le}^{\max}$	maximum power flow capacity of a circuit in existing transmission line le
P_{dlcm}	power flow capacity of a circuit in candidate transmission line lc of type m in subperiod d
$P_{lcm}^{\max}$	maximum power flow capacity of a circuit in candidate transmission line lc of type m
P_{blbl}	power flow capacity from bus b to lb in transmission line l
$P_{blbl}^{\max}$	maximum power flow capacity in transmission line l
$W_{hcdt}^{\max}$	maximum energy enhanced from hydroelectric plant h in hydrological condition c in subperiod d in year t
F_{id}	fuel consumption of thermal unit i in subperiod d
F_{ifd}	fuel consumption type f of thermal unit i in subperiod d
$W_{fd}^{\max}$	maximum fuel type f available in subperiod d
E_{iedt}	total emission type e of generating unit i in subperiod d in year t
$E_{edt}^{\max}$	maximum emission type e in subperiod d in year t
NG_{it}	number of new generating unit i constructed in year t
$NG_{it}^{\max}$	maximum number of allowed generating unit i constructed in year t
$NG_i^{\max}$	number of determined generating unit i by WASP
$NDG_j^{\max}$	number of determined DG technology j by WASP
NDG_{jb}	number of installed DG technology j in bus b.
$NDG_{jb}^{\max}$	maximum number of allowed DG technology j in bus b
NG_{ib}	number of installed generating unit i in bus b
$NG_{ib}^{\max}$	maximum number of allowed generating unit i in bus b
NT_{lcm}	Number of candidate transmission line lc of type m
NT_{lc}	number of constructed circuit of candidate transmission line lc
$NT_{lc}^{\max}$	maximum number of constructed circuit of candidate transmission line lc
n_{island}	number of island detection
S	feasible solution domain of GEP
Z	objective function of the expansion plan

are usually neglected. It is customary to assume that there are adequate transmission lines to achieve any generation expansion plans. To solve separately the TEP problem, different methodologies have been presented [10–16]. Actually the practical situations are often different from above premise, especially in some developing countries where transmission networks are very large and weak. So, TEP and GEP have considerable effects on each other. Therefore, considering GEP & TEP as two separate optimization problems, results in reducing the genuine optimization point [2]. Therefore generation and transmission expansion planning is a key factor in a long term power system operation [17].

After 1990, the locations of generating units and costs of transmission lines are receiving more attention [18,19]. An algorithm is proposed in [20] for generating unit location optimization. The transmission congestion and competition on power generation expansion was studied in [20]. The market-based coordination of transmission and generation capacity planning is proposed in [21].

On the other hand, distributed generation (DG) is one new option being promoted for solving distribution system capacity problems [22–24]. DG is a feasible alternative for developing new capacity, especially in competitive electricity networks, from an economic, technical and environmental point of view [25–29]. Power system