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Security constrained unit commitment with flexibility in natural gas transmission delivery

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A B S T R A C T

This paper presents a formulation of fuzzy optimization for uncertainties in natural gas in fuel constraints for hourly individual unit and total unit fuel consumptions. Security Constrained Unit Commitment (SCUC) is usually a mixed integer programming and gas load flow has a non-linear equation a genetic algorithm is proposed to solve natural gas transmission network. A fuzzy mixed integer programming optimization is briefly discussed and adapted to deal with security constrained unit commitment schedule. Finally, two case studies are investigated (IEEE 6-bus system with 7-node natural gas transmission grid and the IEEE 118-bus power system linked with 14-node gas transmission test system) and the SCUC results are discussed and compared for the both cases of fuzzy constraints and crisp model.

1. Introduction

Day-ahead market is usually cleared by an independent system operator (ISO) with the aim of committing units to achieve minimum operating cost. In this procedure, named security constrained unit commitment (SCUC), two kinds of constraints should be considered namely system constraint and unit constraints. System constraints include load balance, system spinning reserve, fuel constraint, bus voltage being within permissible limits, limitation on line flow, etc. In addition, unit constraints relate to generation units such as ramp rate limit, minimum on/off time, etc. SCUC is introduced in detail in Shahidehpour et al. (2002).

Further, A model for fast SCUC solving of large scale systems is presented in Fu et al. (2013). In this model, the number of integer variables is reduced by fixing unit states and changing fixed states into "committable" when the solution is infeasible. A Markov-based stochastic unit commitment considering wind power forecasts is developed in Yu and Litvinov (2013) and the uncertainties in wind power forecasts are modeled in Markov modeling framework so as to improve the modeling accuracy.

Natural gas transmission network can directly affect the economic of power systems and plays a very important role in defining the maximum limits of natural gas power generation units. Under some weather conditions, e.g. cold winter days, the peak of electricity and natural gas demands could occur simultaneously. In this situation, congestion of gas pipeline may lead to reduction of generating capacity or forced outage of gas fired units. The pipeline gas flow transient equations are non-linear and successive linear programming can be used to iteratively solution of the problem (Liu et al., 2011). In Liu et al. (2009), constraints of gas transmission in SCUC problem is presented and Benders decomposition algorithm is used to separate the gas transmission feasibility and check subproblems emerged from the master SCUC problem. In Liu et al. (2010), augmented Lagrangian relaxation is implemented to create a coordination between scheduling of power plants and natural gas systems. In Li et al. (2008), natural gas transmission network is incorporated in SCUC by imposing various fuel constraints. From the point of view of power system reliability, a model for natural gas transmission system is presented in Munoz et al. (2003).

SCUC problem is engaged with various uncertain parameters such as uncertainty in day-ahead forecasted demand, outage of transmission lines and generation units, uncertainty in fuel constraint, etc. Therefore, solving SCUC problem without a consideration of the effects of uncertainties (deterministic approach) would result in a risky operation of power system and decrease the reliability level of system. For aims of modeling the uncertain parameters of SCUC problem, probabilistic, stochastic

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Nomenclature

T	Number of hours for the scheduling period.
i	Index of generation unit.
N	Number of generation units.
w	Index of compressor.
t	Index of time.
s	Supplier index in natural gas system.
u	Load index in natural gas system.
g	Index of natural gas power plants.
m	Index of power transmission line.
k, n	Index of node in natural gas transmission network.
r, q	Index of bus in power transmission network.
b_i	Linear cost coefficient of unit i.
c_i	Constant cost coefficient of unit i [$/h].
e	Number of hours when unit is ON.
o	Number of hours when unit is OFF.
$y_{i,t}$	Startup binary indicator.
$z_{i,t}$	Shutdown binary indicator.
v_i^1, v_i^2, v_i^3	Binary variables of activation.
γ	Phase shifter angel.
α	Fuzzy objective function.
θ_r	Voltage angle of bus r.
$\mu_f(k)$	Fuel membership degree for state k.
Pf_b	Power flow of line b [MW].
Pf_m^{max}	Limit of Power flow in line b [MW].
f_{kn}	Gas flow through node *k* to *n* [kcf/hr].
π_k	Pressure of node k [psig].
π_0	Standard pressure [psig].
GL	Natural gas load.
SP	Natural gas supply.
Di	Internal diameter of pipe between nodes [inch].
T_0, Ta	Standard, Average gas temperature [°R].
Z_a	Compressibility of gas.
H_w	Horsepower of compressor w.
F_r	Pipeline friction factor.
L	Pipeline length [miles].
G	Gas specific gravity (gas = 0.6).
λ_i	Contracted fuel price of ith generation units [$/MBtu].
$P_{i,t}$	Scheduled generation of unit i at time t [MW].
$P_{D,t}$	Forecasted load at time t [MW].
P_{LS}	Interruption of electricity load [MW].
R_t	System spinning reserve at time t [MW].
$I_{i,t}$	Binary variable represents ON/OFF status of unit i at time t.
F_w	Fuel consumption of compressor.
χ_w,β_w,α_w	Parameters of fuel consumption function of compressor *w*.
$P_{i,min}$, $P_{i,max}$	Minimum/maximum generating capacity of unit i [MW].
DR_i, UR_i	Ramping up/down limit of unit I [MW/h].
$SD_{i,t}$	Shutdown cost of unit i at time t [$].
$ST_{i,t}$	Startup cost of unit i at time t [$].
ρ	Load shedding price [S/MWh].
T_i^{off}, T_i^{on}	Minimum OFF/ON time of unit i.
δ_i	Error between actual and calculated values of ith fuzzy constraint.
x_{rq}	Reactance of power line between bus r and q.
F^{totmax}	Maximum total fuel consumption [kcf].
F_i^{max}	Maximum fuel consumption of unit i [kcf].
N	Number of generating units.
NG	Number of natural gas power plants.
NN	Number of gas transmission nodes.
NC	Number of compressors.
NGL	Number of gas loads.
NGS	Number of gas supplies.

and fuzzy methods are implemented in Miranda and Hang (2005); Kim and Singh (2002); El-Saadawi et al. (2004); Saber et al. (2007); El-Hawary (1998); Victoire and Jeyakumar (2006). A two-stage adaptive robust optimization model for the security constrained unit commitment (SCUC) problem is modeled in Bertsimas et al. (2013) in which units are committed in the first stage and the dispatch problem has full adaptability to the uncertainty of solar and wind energy. The errors in the forecasted hourly load, wind speed, available water, and solar radiation are taken into account using fuzzy sets in Liang and Liao (2007).

In this paper, a linear model for SCUC is presented in which natural gas transmission network is considered. In order to solve the nonlinear equations of gas transmission network, genetic algorithm (GA) has been implemented here. Additionally, the uncertainty of fuel constraint is considered and modeled through fuzzy method. The proposed model in this paper is a bi-level model in which the first level obtains the optimum dispatches for natural gas network provided that all gas fired generation units are ON. Genetic algorithm is implemented in this level to solve non-linear natural gas network equations. Natural gas delivered to the power plants is not crisp because of the forecasting error of other gas loads such as commercial and residential. The uncertainties in hourly gas constraint are modeled with Fuzzy optimization to solve SCUC with maximum degree of flexibility. The second level solves the SCUC problem, implementing maximum amount of gas obtained in the first level. In this way, the second level optimization is a fuzzy mixed integer linear programming. Therefore, the novelties of this paper could be itemized as follows:

- Linking SCUC of power systems with natural gas transmission networks.
- Proposing a fast method that solves the gas network's equations precise enough to be capable of using in SCUC problem.
- The hourly uncertainties in natural gas transmission are modeled by fuzzy logic.
- Proposing a linear model for fuzzy decision making in SCUC considering the natural gas transmission system.

The paper is organized as follows: the SCUC formulation is presented in section 2. In section 3, natural gas transmission network equations are presented. In section 4, fuzzy optimization for uncertain constraint in daily natural gas constraint and hourly natural gas constraint of each unit are discussed. The solution method is formulated in 6. The two illustrative examples are shown in section 6 and, finally, conclusions can be seen in section 7.

2. SCUC formulation

As mentioned before, in SCUC, the aim is to commit and dispatch generation units in a reliable and economical way. Therefore, the objective function of (1) could be considered for SCUC problem while, in deregulated power systems, the objective function would be about the social welfare. The total cost would be formulated as follows: