Applied Thermal Engineering 70 (2014) 1294–1305

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Power grid simulation model for long term operation planning

Jan Zábojník*, Michal Dvořák

Czech Technical University in Prague, Faculty of Electrical Engineering, Department of Control Engineering, Karlovo náměstí 13, 12135 Praha 2, Czech Republic

HIGHLIGHTS

- Comprehensive mixed-integer power grid simulation model is developed.
- Proposed solution strategy aims to lower computational times of large power grids.
- Efficient formulation of power unit outage scheduling algorithm is presented.
- Proposed approaches are demonstrated on an annual simulation of Czech power grid.
- Influence of hydrothermal decomposition on the solution quality is analysed.

ARTICLE INFO

Article history:
Received 4 January 2014
Received in revised form
5 May 2014
Accepted 7 May 2014
Available online 2 June 2014

Keywords:
Transmission network model
Large scale simulation
Hydrothermal decomposition
Mixed-integer linear programming
Operations planning

ABSTRACT

In this paper a comprehensive mixed-integer linear programming (MILP) model of transmission network and power plants is presented. The model is capable of forced and regular outage simulation with respect to the spinning reserve requirements. The model formulation includes thermal, pumped-storage and conventional hydro plants as well as renewable resources. Fast and efficient outage scheduling algorithm suitable for prospective studies is presented. We also show how the overall price minimisation can lead to unrealistic pumped-storage plants dispatch and how can this behaviour be corrected using hydrothermal decomposition. To overcome this issue a dedicated MILP water planning model is proposed and its results are compared to the real day production profiles of pumped-storage and conventional hydro plants. The simulation times and results of models with and without hydrothermal decomposition are compared on an annual simulation of Czech transmission network (61 power plants, 110 units and 31 nodes connected by 53 lines). Simulations produced by the model presented in this paper exhibit realistic transmission system behaviour, which was confirmed by the Czech TSO. The annual simulation times stay below reasonable values allowing multiple scenario prospective studies.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Transmission networks are highly complex systems. Many companies across different fields of interests utilise computer simulations of those networks in attempt to predict their future behaviour. One type of these companies are transmission system operators (TSOs). TSOs are companies entrusted with transporting energy on a national or regional level, using fixed infrastructure. Many TSOs are currently dealing with more complex conditions in their networks mainly due to massive increase of installed wind and solar sources with intermittent power production. A comprehensive simulation software is often necessary to predict power resources commitment under various network states for the network development planning. In this paper an optimisation model developed in collaboration with Czech TSO is presented.

1.1. Literature survey

Long term operation planning of complex transmission networks is a difficult and challenging task. The dimension of this problem significantly grows with the number of connected power sources and the modelled level of detail. This problem generally consists of two subproblems dependent on each other – the unit commitment (UC) and the corresponding network power flow problem. The power flow computation is in general a non-linear task which in a combination with NP-hard unit commitment problem makes the task so difficult.

A comprehensive bibliographic survey of the unit commitment (UC) problem formulations and various solution techniques can be found in Ref. [1]. The listed methods include deterministic

* Corresponding author. Tel.: +420 224357343.
E-mail addresses: jan.zabojnik@fel.cvut.cz, zabojjan@fel.cvut.cz (J. Zábojník).

http://dx.doi.org/10.1016/j.applthermaleng.2014.05.064
1359-4311/© 2014 Elsevier Ltd. All rights reserved.

methods, such as mathematical programming, dynamic programming, Lagrangian relaxation and Benders' decomposition. Also, benefits and disadvantages of many heuristics and metaheuristics have been evaluated, e.g. priority lists, evolutionary programming, Tabu search and expert systems. From the listed methods, formulations based on mathematical programming are very frequent in transmission systems modelling as is it straightforward to consider power flow equations while solving the UC problem. Also, powerful general-purpose solvers exist for various classes of mathematical programming problems, especially for mixed-integer linear programming problems (MILP). Another advantage of a MILP formulation is that it is possible to obtain a certificate of optimality and that an estimation on the proximity of the current solution to the optimal one is known. The recent progress in the unit commitment modelling using MILP formulation is summarised by Ref. [2].

The main disadvantage of a MILP formulation is the necessity of a linear model. The linearised version of a generally non-linear power flow model is called DC load flow and is often used among optimisation models. In Ref. [3] the network model with DC load flow constraints was used to schedule power generation in a Belgian power grid. This method was also used in the Sri Lanka transmission expansion planning problem [4] to model power flows in sparsely interconnected transmission network. Recently the development of solvers for mixed-integer non-linear programming problem (MINLP) has rapidly advanced. However, MINLP solvers are most efficient in the case of convex optimisation problems, which is not the case of a full non-linear load flow model. Also, the dimension of the problem tackled in this paper is so large that it is challenging task even for MILP solvers in its linearised version. Hence, a MINLP formulation of a unit commitment problem with non-linear power flow equations remains impractical.

Even for state-of-the-art MILP solvers the long-term unit commitment optimisation models are generally intractable without further decomposition. Often, the decomposition is based on the receding horizon optimisation, in which the adjacent time intervals are solved sequentially. In Ref. [5] the effect of different receding horizon lengths was tested on an annual simulation of Greek energy market. The solution quality was slightly improved using a longer horizon, however the necessary computational time increased exponentially. Another solution approach presented in Ref. [6] is based on the problem decomposition of optimal power flow (OPF) problem and an iterative unit commitment optimisation. The simulation model was used to solve a transmission expansion planning problem, however from all the types of production units only the model of thermal plant was presented.

Additional functionality of the simulator, such as regular and forced outages simulation, increase model complexity and thus simulation times. Hence, very efficient techniques for incorporating these features into the simulation model have to be used. In Ref. [3] a forced outage simulation methodology based on the receding horizon optimisation is used. A solution obtained without considering (previously randomly scheduled) forced outages is retained up to the hour of the first forced outage. Then a new optimisation starting at the time of this particular forced outage (taking into account only this one) is performed and only the result values up to the next forced outage are retained. The computation then proceeds in this manner. In each segment of computation (i.e. between two outages), off-line units are not permitted to start-up instantly but have to respect their start-up time (usually several hours). In Ref. [3] only the state of units in the first hour are considered and the states in the hours after the forced outage are neglected. Hence, in the case there is a set of units which were about to start-up right after the forced outage occurrence (e.g. to meet the demand increase at the time) an unrealistic schedule would be produced as these units would be forced to remain in off-line state and a possible more expensive units will be committed instead of them.

Apart from forced outages also planned outages need to be considered. The power market consists of a group of independent generation companies (GENCOS). Each GENCO optimises the outage schedule of all its production units in order to maximise its profit neglecting the transmission network constraints. In Ref. [7] a complex stochastic risk-based maintenance outage scheduling model of a GENCO was presented. Version enhanced by the network constraints suitable for TSOs transmission outage planning is presented in Ref. [8]. Similar work in Ref. [9] proposed coordinated generation and transmission maintenance scheduling with coupling constraints in order to find optimal GENCO and TSO schedules at once. In Ref. [10] the heuristic iterative outage scheduling approach was presented. Scheduling problem with network reliability maximisation is solved, outage schedules from GENCOs are compared to this plan and if the network reliability constraints are not met restrictions are imposed to the GENCOs outage plans and a new iteration is performed. In Ref. [11] a similar problem was solved using particle swarm optimisation with the loss of load probability as the reliability index. The proposed iterative optimisation ended when the generation adequacy level was sufficient.

For the prospective studies the TSO can estimate the schedule in a similar way as in Ref. [10] or [11], however, such a large scale optimisation is computationally too expensive comparing to the prospective study simulation times and the maintenance costs related to the GENCOs subproblems may be unknown. Moreover, the schedule is not required to be optimal considering the level of uncertainty in prospective studies. Hence, a deterministic outage scheduling algorithm similar to the initial reliability maximisation problem of a complex outage scheduling methodology in Ref. [11] or the first phase of Ref. [10] that estimates the outage positions from the unit parameters and expected power demand is sufficient. (As the scheduling problem difficulty grows almost exponentially with the number of possible outage positions, as compact formulation as possible should be used.)

The realistic cooperation of hydro and thermal plants represents another issue. Performing the overall optimisation of the thermal dominated systems the peak-shaving dispatch effect of hydro plants can be suppressed when the power price difference between the day and the night is small. This can be prevented using the hydrothermal decomposition that schedules production of hydro plants ahead of production of thermal plants. In reality most the thermal plants usually hold as steady power output as possible while letting the flexible hydro plants cover peaks in load. This approach is well known and many modifications were developed. In Ref. [12] a hydrothermal decomposition problem with no network constraints was solved by Benders decomposition approach. The same method but with network constraints and a power imbalance penalisation that prevents non-feasible solutions in the optimisation approach is used in Ref. [13]. In Ref. [14] an optimisation model suitable for long-term cooperation problems with transmission network and losses is presented. Iterative optimisation with low computational times is enabled by pure linear problem formulation that neglects lower power production limits of power units. In Ref. [15] a hybrid genetic algorithm is applied to short term generation scheduling. Efficient use of hydro plant reservoir as a genetic variable allowed search iteratively for optimal thermal generation with the hydro subproblem remained fixed. In Ref. [16] a simplified model of thermal plant units with only generation and spinning reserve constraints was used to compute optimal utilisation of reservoirs of hydro plants in power grid with high penetration of Wind power plants. The overview of another optimisation methods that can be applied to solve the short-term

Download English Version:

https://daneshyari.com/en/article/646169

Download Persian Version:

https://daneshyari.com/article/646169

Daneshyari.com