Engineering Applications of Artificial Intelligence 37 (2015) 236–249

Contents lists available at ScienceDirect

Engineering Applications of Artificial Intelligence

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

Multi-objective unit commitment with introduction of a methodology for probabilistic assessment of generating capacities availability

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ARTICLE INFO

Article history:
Received 19 April 2014
Received in revised form
6 July 2014
Accepted 18 September 2014
Available online 11 October 2014

Keywords:
Unit commitment
Generation dispatch
Power system
Unavailability
Genetic algorithm
Multi-objective optimization

ABSTRACT

The goal of the short-term unit commitment is the minimization of the total operation cost while satisfying all unit and system constraints. One of the main issues while solving the unit commitment optimization problem is the planning of the capacity reserves of the power system. In order to address this issue, a dynamic method for probabilistic assessment of generation unavailability is proposed within this paper. The main highlight feature of this method is that it has the capacity to account for the unavailability implications of the generating unit states, being committed or decommitted as well as their start-up characteristics. This allows more comprehensive hour-to-hour scheduling analyses from the aspect of probabilistic unavailability assessment. The generating capacities unavailability is designated as the relevant unavailability measure regarding the power supply to loads. The unit commitment problem is developed as a multi-objective optimization problem. Two objective functions are considered: the total operating cost of the generating capacities as one and generating capacities unavailability as the other objective function. An improved hybrid genetic algorithm is applied for solving the problem. A test power system is used as a case study. The obtained results indicate the need and benefits of more detailed modelling of the power generation availability.

1. Introduction

The general idea behind the short-term unit commitment (UC) is meeting the forecasted load on a short-term basis (one day or up to one week) by accordingly scheduling the on or off line status of the generating capacities (Cheng et al., 2002). The objective of the short-term UC is the minimization of the total operation cost while satisfying all unit and system constraints. The UC problem is highly constrained, non-linear, mixed integer optimization problem. The exact solution of the problem can be obtained by complete enumeration, a process which is not computationally feasible for realistic power systems (Orero and Irving, 1997; Wood and Wollenberg, 1996).

Modern meta-heuristic algorithm based techniques have been extensively employed for solving generation scheduling problems. One of the first applications of genetic algorithm (GA) on the generation (economic) dispatch optimization problem is shown in Ref. Walters and Sheble (1993). Approximately in the same period the simulated annealing (SA) algorithm was also applied for the optimal generation dispatching (Wong and Fung, 1993). Since then various modern techniques have been used for the single objective and multi-objective generation dispatch problem. In Ref. Elsayed et al. (2014) a new GA has been proposed for solving engineering problems including optimal generation dispatching. A modified particle swarm optimization has been used on the static generation dispatch problem considering valve point-effects and prohibited operating zones (Neyestani et al., 2010). Ref. Lu et al. (2011) introduces three novel chaotic differential evolution techniques for solving the dynamic generation dispatch problem.

UC problem is another part of the generation scheduling that was solved with modern meta-heuristic algorithms. Since beginning of the 1990s, when the GAs were first employed in power system optimization, they have become very popular tool for solving the UC problem. In Ref. Dasgupta and McGregor (1994) the application of a binary coded GA has been discussed for solving the UC problem. Similar study was presented in Ref. Kazarlis et al. (1996) where Kazarlis et al. applied a binary coded GA on a 10-unit test system. The results in this study are compared with classical techniques such as dynamic programming (DP) and Lagrange relaxation (LR). Later on, the application of a real coded GA for the UC problem was discussed (Damousis et al., 2004). It was shown that real coded GA can produce better results than the LR method that was used as a benchmark in the paper, also the execution time of the algorithm was reduced compared to the binary coded GA. Other modern meta-heuristic techniques have

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http://dx.doi.org/10.1016/j.engappai.2014.09.014
0952-1976/

been extensively used for the UC problem as well, such as: evolutionary programming (Juste et al., 1999), neural networks (Ouyang and Shahidehpour, 1992), simulated annealing (Mantawy et al., 1998), particle swarm optimization (Ting et al., 2006), ant colony (Simon et al., 2006) and artificial bee colony algorithm (Chandrasekaran et al., 2012).

A careful planning of the reserves is required in the short-term UC schedule in order to ensure an adequate reliability level. Even though most of the above-mentioned techniques offer an acceptable solution for the UC problem, they are using old and most commonly used methods for reserve planning, i.e. low margin as a percentage from the real system load at each time interval and the reserve equal to the power output of one or more of the largest units. These methods can lead to overscheduling which means more reliable and uneconomic unit commitment as well as underscheduling which means more economic and less reliable unit commitment. However, some studies, where probabilistic reserve evaluation is used, have been performed. Dillon et al. presented a probabilistic method for proper representation of the reserves associated with different unavailability levels (Dillon et al., 1978). The developed model is integrated within the short-term UC as constraint that has to be satisfied. This model ensures that a given reliability level is achieved. Similar approach is used in Ref. Shi et al. (2004) where a stochastic mechanism is developed for the short-term UC with probabilistic determination for spinning reserve constraint. In Ref. Lee and Chen (2007) a method for solving the short-term UC problem with probabilistic reserves is discussed. In Ref. Simopoulos et al. (2006) evaluation of the required spinning reserve capacity is performed by applying reliability constraints based on loss of load probability (LOLP) and expected energy not supplied (EENS) indices. Similar approach is presented in Ref. Jalilzadeh et al. (2009) where a dynamic penalty constraint is applied for the EENS constraint. A two-level, two-objective optimization scheme based on evolutionary algorithms for solving UC problem by considering stochastic power demand variations is proposed in Ref. Georgopoulou and Giannakoglou (2009). The total operating cost is used as one objective while the risk of not fulfilling possible demand variations is used as the second objective to be minimized. In other words the paper investigates the trade-off between total cost and the risk due to load uncertainties. In Ref. Lei et al. (2008) the loss of load expectation (LOLE) is included as a constraint in the long-term UC for calculating the cost of supplying the reserve. In Ref. Bouffard and Galiana (2004) an algorithm is developed that includes the scheduling of spinning reserve according to a hybrid deterministic/probabilistic reliability criterion. This hybrid criterion behaves consistently with purely probabilistic criteria such as LOLP. In most of these methods an optimal reserve planning is achieved when a probabilistically determined generating reserve is used as controlled criteria/constraint, instead of an independent objective function. Additionally, most of these techniques do not account for the implications for unavailability of the commitment of a specific unit at given time interval and the time needed for these units (rapid-starting, slow-starting) to be online and start generating. These are the main motivations for the work done in this study.

The increased reliability of power supply corresponds to increased costs (Billinton and Allan, 1988). The same rationale is valid for the short-term unit commitment. This research is focused on the interdependence between the total cost of power production, the capacity outage unavailability and generation reserves in the short-term UC. The main objective of this study is to develop a dynamic method for power system probabilistic unavailability evaluation. The generating capacities unavailability is the relevant unavailability measure. As such, the LOLP is used as an unavailability index herein. This approach has the capacity to account for the time inertia related to different generating units to be online and start generating. The second objective of the paper is performing trade-off analysis between the total production costs and the capacity outage unavailability. Therefore, the UC is presented as a multi-objective optimization problem. For comparative purposes a deterministic model is introduced as well. This deterministic model is defined as a function of the spinning reserve.

For solving the short-term UC optimization problem an improved hybrid GA is constructed. The algorithm uses classical method, i.e. priority list in order to create the initial population. An improvement of the classical hybrid GA (Orero and Irving, 1997) is proposed by employing hybrid solutions additionally within the initial population. The algorithm employs repairing mechanisms and penalization technique to deal with the constraint violations. The UC problem is solved in three separate formulations. Firstly, the problem is solved as a single objective, once considering the total production cost objective function and secondly, considering the generation unavailability function. At the end, the problem is solved as a bi-objective, considering both of the objective functions. Two scenarios are analysed: considering and not considering the spinning reserve constraint. The obtained results show that compromise between cost and unavailability is achieved. Additionally, improvements on the used test power system are proposed and the system as such is solved using the same model. For verification purposes, the used algorithm has been applied on a 10, 20, 40, 60, 80 and 100 unit systems and the obtained results were compared with others available in the literature.

2. Power system reliability

The primary objectives of the modern power systems are to provide a reliable and economic supply of electric energy to their customers. The main issue in the planning and also in the operating phases has always been the adequate reserves of generating capacity. Consequently, the level of redundancy and the associated cost are designated as the prime question. By definition, the reserve capacities that are spinning, synchronized and ready to take up load are known as spinning reserve. Some power system operators include only the spinning reserve in the assessment of system adequacy, while others include also the rapid start units such as gas turbines and hydropower plants or assistance from the interconnected systems. These additional factors added to the spinning reserve are all together known as operating reserve (Billinton and Allan, 1996). The operating capacity domain, i.e. the short-term unit commitment is of interest in this research paper.

In general, each power system operation is associated with prediction of the expected load, i.e. short-term load forecasting, and consequently providing for and scheduling of sufficient generation capacity. The time needed for a specific generating unit to produce an output ranges from few minutes in the case of gas turbines and hydropower plants to several hours in the case of thermal generating power plants. This is especially important for the intermediate load units which are mostly coal-fired units that have considerable starting inertia (several hours). If an unexpected change occurs in the power system and additional generation is required immediately, the intermediate load units cannot be counted for at this point of time if they are not committed and spinning. Therefore, within the probabilistic unit commitment evaluation these units should be considered as unavailable in the time interval when they are decommitted.

Various design, planning and operating criteria and techniques have been developed over many decades in an attempt to resolve and satisfy the dilemma between the economic and reliability constraints (Billinton and Allan, 1996). Most of these criteria and