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A Heuristic algorithm to solve the unit commitment problem for real-life large-scale power systems

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ABSTRACT

One of the main needs that power system operators around the world have is to solve complex Unit Commitment models for large-scale power systems in an acceptable computation time. This Paper presents an alternative Heuristic algorithm that successfully addresses this need. The Heuristic algorithm makes use of various optimization techniques such as Mixed Integer Linear Programming (MILP), Quadratic Programming (QP), Quadratically Constrained Programming (QCP), and Dynamic Programming (DP). CPLEX 12.2 is used as the main optimization engine for MILP, QP, and QCP. DP is an in-house algorithm used to obtain the commitment of Combined Cycle Plants (CCPs) when represented with the component-based model. This Heuristic algorithm combines the global optimality capabilities of MI (L) P formulations with the highly detailed models available for CCPs using LR–DP formulations. The Heuristic algorithm introduced in this Paper is capable of solving up to 1-week scenarios with a 1-hour time window for the complex Mexican Power System.

1. Introduction

The Unit Commitment (UC) problem is one of the most widely studied problems in Electrical Engineering. Over the last four decades, a number of different techniques have been proposed to solve it.

Mixed Integer Programming (MIP) was first used to solve the unit commitment (UC) problem in [1]. The formulation is based on the definition of three sets of binary variables to model the start-up, shut-down, and on/off states of every generator for every time period. In [2], an alternative Mixed Integer Linear Programming (MILP) formulation is presented. Even though it only requires a single set of binary variables, one per unit per period, more constraints are formed. An alternative way to linearize the problem has been presented in [3]. Another linear formulation is presented in [4]. A basic idea for combining Lagrangian Relaxation (LR) and MIP techniques is presented in [5], where, in order to solve the problem faster, a lower bound for the UC problem is obtained by means of LR and then this lower bound is used when solving the UC problem with the IBM CPLEX optimizer [6]. Other techniques used are dynamic programming [7], pure LR methods [8–11], unit de-commitment, advanced priority listing [12], and Benders Decomposition [13].

Population-based techniques have also been used to solve the UC problem [14,15]. In evolutionary programming (EP) techniques, populations of contending solutions are evolved through random changes, competition, and selection to obtain a final solution. In [16], an algorithm is proposed in which an overall UC schedule is coded as a string of symbols and viewed as a candidate for reproduction. Initial populations of such candidates are randomly produced to form the basis of subsequent generations. In [17], an evolutionary algorithm (EA) with problem specific heuristics and genetic operators has been employed to solve the UC problem. The initial random population is seeded with good solutions using a priority list method in order to increase the speed of convergence and improve the efficiency of the algorithm. In [14], a two-level, two-objective optimization scheme based on EAs is proposed for solving the UC problem. At the low level, a coarsened UC problem is defined and solved using EAs to locate promising solutions at low cost. Promising solutions migrate upwards to be injected into the high level EA population for further refinement. In addition, at the high level, the scheduling horizon is partitioned in a small number of subperiods of time which are optimized iteratively using EAs. Genetic algorithms (GAs) are a general purpose optimization technique that is based on the principle of natural selection and natural genetics. Reference [18] introduces an application of a combined LR and GA method for the UC problem. The proposed

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LR–GA incorporates GA into the LR method in order to update the Lagrangian multipliers and improve its performance. Ref. [19] introduces a new genetic operator, based on unit characteristic classification, along with intelligent techniques that generate initial populations.

Several heuristic methods have also been proposed in the literature. For instance, [20] presents and adaptation of the extended priority list method. This heuristic algorithm consists of two basic steps: in the first step, an initial UC solution is obtained by the priority list method disregarding the operational constraints. In the second step the UC obtained is modified using some heuristics in order to fulfill the operational constraints. Reference [21] proposes an algorithm that uses priority list based heuristics in the form of inference rules to find a suboptimal, and later on an optimal, schedule for a given load pattern. In [22] a Lagrangian relaxation approach for the solution of the short-term unit commitment problem in hydrothermal power-generation systems is presented. The proposed approach is based on a disaggregated Bundle method for the solution of the dual problem. The disaggregated Bundle method provides information that can be used for generating a feasible solution of the primal problem and for obtaining an optimal hydro scheduling. Reference [23] proposes an enhanced adaptive Lagrangian relaxation for the UC problem; it consists of adaptive LR and heuristic search. After the adaptive LR best feasible solution is obtained, the heuristic search consisting of unit substitution and unit de-commitment is used to fine tune the solution.

Power System Operators around the world have the need to solve detailed UC models for large scale Power Systems within a computation time that is acceptable for operation practices. Several operational, technical, and economical constraints must be considered in these detailed models. Although LR-based approaches are highly regarded in the academia as some of the most effective and suitable ways to solve large-scale UC problems, their ability to find primal feasible solutions decreases as the number and complexity of relaxed constraints increases. Recent reports show the ability of commercial optimization software to solve real-life UC problems based on MIP, MILP, and MIQCP formulations [24]. In fact, the tendency amongst power system operators around the world is to move from LR formulations to MI (L) P-based formulations, *i.e.*, PJM, California ISO, ISO New England, MISO, NYISO (near future), and the Southwest Power Pool (SPP) in the USA; and Terna in Italy.

Of particular interest for power system operators is the accurate modeling of Combined Cycle Plants (CCPs). To this date, there are no detailed CCP models for MI (L) P that compare to the one introduced by the authors in [25]. The model introduced there is a component-based model that accurately represents start-up sequences, different stopping modes, and transitions between configurations and states. The approach in [25] is an LR–DP approach. The implementation of detailed component-based models for CCPs and Hybrid CCPs (HCCPs) with MI (L) P is no trivial matter and, for large-scale power systems, computation time and memory requirements are expected to be a problem.

Based on the above, the authors introduce a fast-solving Heuristic algorithm capable of handling UC problems for large-scale power systems. This Heuristic algorithm combines the global optimality capabilities of MI (L) P formulations with the highly detailed available models for (H) CCPs using LR–DP formulations. To achieve this, the Heuristic algorithm successfully combines MILP, QP, QCP and DP.

The remaining sections of this Paper are as follows: Section 2 briefly comments on the MIQCP model for the UC problem, and on the LR–DP approach for (H) CCPs used by the Heuristic algorithm. A detailed presentation of the Heuristic algorithm is made in Section 3. In Section 4, the solution approach taken by the Heuristic algorithm is compared to two other approaches based on MIQ (C) P in order to validate its solution quality. Afterwards, the Heuristic model is used to solve the Mexican Power System for 1-week planning horizons. Finally, Section 5 closes the Paper with relevant conclusions.

2. An MIQCP model for the UC Problem and an LR–DP component-based model for (H) CCPs

This section briefly comments on the MIQCP model used to represent the UC problem and on the LR–DP component-based model used to represent (H) CCPs. Both models have been previously introduced by the authors in [24,25], respectively. For the sake of continuity, the model introduced [24] is reproduced next without any further comments. The notation used in the model is described in Appendix (A).

2.1. MIQCP model for the UC problem

- **Objective Function**: Minimizes the variable generating costs, fixed start-up costs from either a cold stop or a hot stop of generating units, the cost of purchasing energy from Independent Power Producers, the cost of curtailing load from interruptible loads, the cost of shedding load, and the cost from violating the transmission limits in regional tie-lines and groups of tie-lines.

  Two simplifications made in the MIQCP model are worth mentioning: The one is that (H) CCPs are represented using the aggregated model, and the other is that the start-up costs for both Thermal Conventional Units (TCUs) and (H) CCPs are considered fixed.

$$\sum_{i\in\mathcal{I}}\Bigg\{\sum_{u\in\mathcal{Z}'}\Big[a_{u,i}g_{u,i}^2+b_{u,i}g_{u,i}+c_{u,i}\beta_{u,i}+AF_{u,i}\tau_{u,i}+AC_{u,i}\xi_{u,i}\Big] + \sum_{u\in\mathcal{PI}}CP_{u,i}g_{u,i}+\sum_{l\in\mathcal{CI}}CI_{l,i}L_{l,i}+CC_iX_i+\sum_{m\in\mathcal{M}}P_m\left(f_{m,i}^{+}+f_{m,i}^{-}\right) + \sum_{n\in\mathcal{N}}P_n\left(f_{n,i}^{+}+f_{n,i}^{-}\right)\Bigg\}. \tag{1}$$

- **Constraints**:
  - Power balance

$$\sum_{u\in\mathcal{U}}g_{u,i}+\sum_{l\in\mathcal{CI}}L_{l,i}+X_i=d_i,\ \forall\ i\in\mathcal{I}. \tag{2}$$

  - Spinning reserve

$$\sum_{u\in\mathcal{Z}_r}(\hat{\hat{g}}_{u,i}\beta_{u,i}-g_{u,i}) + \sum_{ch\in\mathcal{CH}_r}\sum_{vh\in\mathcal{VH}_r}\left(\beta_{vh,i}\hat{\hat{g}}_{vh,i}-\sum_{u\in\mathcal{GH}_{ch_r}}\beta_{u,i}\hat{\hat{g}}_{u,i}\frac{\sigma_{u,i}}{1+\sigma_{u,i}}-g_{vh,i}\right) \geqslant l_{r,i},\forall\ r\in\mathcal{R},\ i\in\mathcal{I}. \tag{3}$$

  - Active power flow on regional tie-lines and groups of regional tie-lines

$$\sum_{u\in\mathcal{U}}sfe_{m,u,i}g_{u,i}+ce_{m,i}-f_{m,i}^{+}\leqslant\overline{fp}_{m,i},\forall\ m\in\mathcal{M},\ i\in\mathcal{I}, \tag{4}$$

$$\sum_{u\in\mathcal{U}}sfe_{m,u,i}g_{u,i}+ce_{m,i}+f_{m,i}^{-}\geqslant-\overline{fn}_{m,i},\forall\ m\in\mathcal{M},\ i\in\mathcal{I}, \tag{5}$$

$$\sum_{u\in\mathcal{U}}sfg_{n,u,i}g_{u,i}+cg_{n,i}-f_{n,i}^{+}\leqslant\overline{fp}_{n,i},\forall\ n\in\mathcal{N},\ i\in\mathcal{I}, \tag{6}$$

$$\sum_{u\in\mathcal{U}}sfg_{n,u,i}g_{u,i}+cg_{n,i}+f_{n,i}^{-}\geqslant-\overline{fn}_{n,i},\forall\ n\in\mathcal{N},\ i\in\mathcal{I}. \tag{7}$$