Chapter 2
Operation Management on Autonomous Power System

E.S. Karapidakis

Abstract The running developments in the field of power systems have, as a result, the maximization of complexity and their marginal operation with regard to their dynamic security. This becomes more perceptible in autonomous power systems. Consequently, in the modern energy environment, the use of enhanced operation management and monitoring programs is judged necessary. The results that are arrived at in the present chapter were developed via a concretization of algorithms, which were incorporated in an implemented operation and planning management system. The presented algorithms have as object to improve the level of combination between unit commitment, economic dispatch and dynamic security assessment (DSA).

2.1 Introduction

Energy Management System (EMS) is one of the main control center's programs. The high processing power, which is provided by modern computers, creates the requirement for significant fast and reliable energy management programs in power system's control centers [13]. An EMS also includes dynamic security assessment algorithms for real-time performance [4], which considered as critical support factor for rational planning and power system operation. Specifically, any EMS is separated into two basic categories, depending on their implementation time:

- The real-time planning and operation programs, where the load and corresponding wind power production forecasting (when such possibility exists), supply the necessary data entry for economic dispatch (ED) and unit commitment (UC) algorithm integration. Then, DSA algorithms provide the safety level of a given profile under pre-selected contingencies, in order for a final and optimal operation decision to be retrieved.

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- The short-term planning and system operation programs, where, off-line, the system administrator analyzes and estimates the next most optimal possible operation system profiles via different scripts.

The results that are arrived at in the present chapter were developed via the concretization of algorithms, which were incorporated in an implemented operation and planning management system. The presented algorithms have as object to improve the level of combination between unit commitment, economic dispatch and dynamic security assessment.

2.2 Algorithm Implementation

The main modules of the implemented program are related either to real-time operation management, or to short-term power system planning, as is shown in Fig. 2.1. Specifically, the following sub-algorithms were integrated and examined.

2.2.1 Load and wind power forecasting

The mathematic methods for load demand forecasting, and in certain cases, for wind power generation forecasting, are divided into three basic categories:

- Time series methods, where load demand curves follow given seasonal, monthly, weekly and daily periodicity, [2].
- Regression based methods, where load demand forecasting is calculated by the linear combination of previous hours, [9].

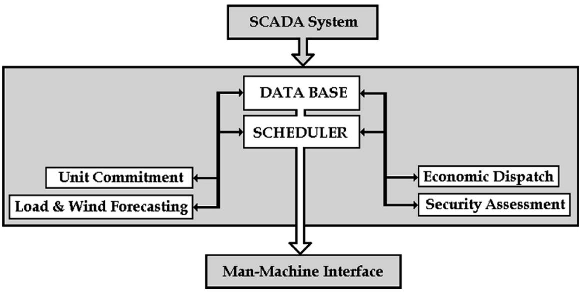

Fig. 2.1 EMS functions & procedures

- Computational intelligence based methods, through supervised learning, where large number of historical data are used for artificial intelligence architectures training [19, 18, 12, 15].

2.2.2 Unit Commitment

Electrical power generation Units Commitment (UC) problem is a complex optimization problem with many restrictions [10, 1, 16]. Specifically, the mathematic expression is given as:

$$\min \sum_{t=0}^{T-1} \sum_{i=1}^{N} u_i^t C_i(g_i^t) + (1 - u_i^{t-1}) u_i^t s_i \tag{2.1}$$

with the following restrictions, as load demand on the examined time horizon (2.2), the required spinning reserve (2.3) and the technical minimum and maximum limits of units generation (2.4).

$$\sum_{i=1}^{N} g_i^t = D^t \tag{2.2}$$

$$\sum_{i=1}^{N} r(g_i^t) \geq R^t \tag{2.3}$$

$$g_i^{\min} \leq g_i^t \leq g_i^{\max} \tag{2.4}$$

The previous equations represent the problem of economically optimal power units generation profile in power systems. In Table 2.1 below, all the parameters are individually described.

Table 2.1 Parameter description

Symbol	Description
N	Total number of power units
T	Time
D^t	Load demand
R^t	Required spinning reserve
g^t	Power generation
g^{min}	Minimum power generation
g^{max}	Maximum power generation
u^t	Decision of unit i operation
$C_i(g_i)$	Fuel cost function of unit i
$r(g_i)$	Spinning reserve function of unit i
s_i	Start-up cost of unit i
r_{max}	Maximum spinning reserve

2.2.3 Economic Dispatch

Economic analysis of each of the conventional generation units is based on the following general economic parameters:

- Hourly Fuel Consumption (Kcal/h): the hourly fuel consumption is given as a function of generating power P of the corresponding unit.
- Hourly Fuel Cost (Euro/h): the hourly fuel cost results from the hourly fuel consumption and the corresponding cost, according to the relation:

$$F = \frac{\text{kcal}}{h} \cdot \frac{\text{Euro}}{\text{kcal}} = \frac{\text{Euro}}{h} \tag{2.5}$$

- Differential Hourly Fuel Consumption d(Kcal/h)/d(MW)): the differential hourly fuel consumption represents the difference of hourly consumption fuel (d(Kcal/h)), which results from produced power change (d(MW)), as it appears in:

$$\mathrm{d(kcal/h)/d(MW)} \tag{2.6}$$

- Differential Production Cost (Euro/MWh): the differential production cost results from the differential hourly consumption and the corresponding cost, according to the relation:

$$\frac{\mathrm{d(kcal/h)}}{\mathrm{d(MW)}} \cdot \frac{\text{Euro} \cdot 10^6}{10^6 \cdot \text{kcal}} = \frac{\text{Euro}}{\text{MWh}} \tag{2.7}$$

An energy system, which allocates a significant number of power generation units, with different technical and economical characteristics, the total production cost varies sensibly, according to production combinations of the available generators. Accordingly, economic dispatch of power generation units is a classic optimization problem with restrictions [8, 3]. The mathematic expression of the previous optimization problem is:

$$\min\left(\sum_{t=1}^{N} C_i(P_i)\right) \tag{2.8}$$

with the following restrictions, as load demand on the examined time horizon (2.9), the required spinning reserve (2.10) and the technical minimum and maximum limits of units generation (2.11).

$$\sum_{i=1}^{N} P_i = D + L \tag{2.9}$$

Table 2.2 Parameter description

Symbol	Description
N	Total number of power units
D	Load demand
R	Required spinning reserve
P_i	Power generation of unit i
P^{min}	Minimum power generation
P^{max}	Maximum power generation
$C(P_i)$	Fuel cost function of unit i
R_i	Spinning reserve of unit i

$$\sum_{i=1}^{N} P_i \geq P \tag{2.10}$$

$$P_i^{\min} \leq P_i \leq P_i^{\max} \tag{2.11}$$

The previous equations (2.8), (2.9), (2.10) and (2.11) represent the optimal economic dispatch problem of power generation for the running load demand. In Table 2.2, all the corresponding parameters are individually described.

The fuel consumption curve of each unit is given in the majority of cases from a second degree polynomial function:

$$C(P_i) = a \cdot P^2 + b \cdot P + c \tag{2.12}$$

Previous relation is used in the proposed algorithm, while it is considered as analytically significant and representative of the real production cost of the corresponding units.

2.2.4 Dynamic Security Assessment

A reliable dynamic secure operation monitoring requires the analysis of tens or even hundreds of possible operating profiles (steady and transient), in desirable and practically feasible computational time, [17].

The mathematic methods for dynamic security assessment of a power system under pre-selected disturbances (as short-circuits and unit's trip) are divided into two categories:

- Conventional Mathematic Methods, where the results are given via analytic recurrent mathematic functions or corresponding mathematic models, which describe in detail the examined system. However, the analytic mathematic solution of this complex problem requires the availability of a prohibitorily long period of time, taking into account the modern EMS real-time operation [6].

- Expert systems and computational intelligence based methods, where the previous experience of operators, combined with a considerably large number of historical data, is used for AI architectures training [20, 11], in order for satisfactorily fast and precise DSA results to be achieved.

2.3 Operation Management

A short-term generation planning and power system operation program was developed, taking into account the technical restrictions and the economic characteristics of each generation unit. Initially, the program determines an available unit commitment for a given load demand curve, while the selected generators' set points are recalculated via individual economic dispatch algorithms. Then, the dynamic safety level of the proposed operation profile is estimated under various pre-selected transient disturbances, in order for an acceptance or a redefinition of new security margins to be retrieved. More precisely, the main program processes are:

1. Twenty-four hours' Economic Unit Commitment.
2. Dynamic Security Assessment of the previous Unit Commitment.
3. New Unit Commitment with new Dynamic Security Criteria.
4. Final Dynamic Security Level Verification.

The software package (algorithms and interface) has been implemented with Visual Basic (version 6) in multi-document interface, while UC and DSA modules have been developed independently, as dynamic link libraries (dlls), in order to provide an easy replacement. The database is a relational database (RDBMS) via dynamic access object (DAO 3.6).

2.3.1 Data Entry

In Fig. 2.2 below, a data entry sample of load demand curve and wind power generation is depicted.

2.3.2 Unit Commitment

Under the selected load demand curve and the corresponding wind power production, the UC algorithm provides the most optimal calculated system generation profile.

The technical characteristics (min/max), cost curves, start-up costs and fuel consumptions, as well as the response type of each conventional generation unit, contribute to corresponding unit set points determination.

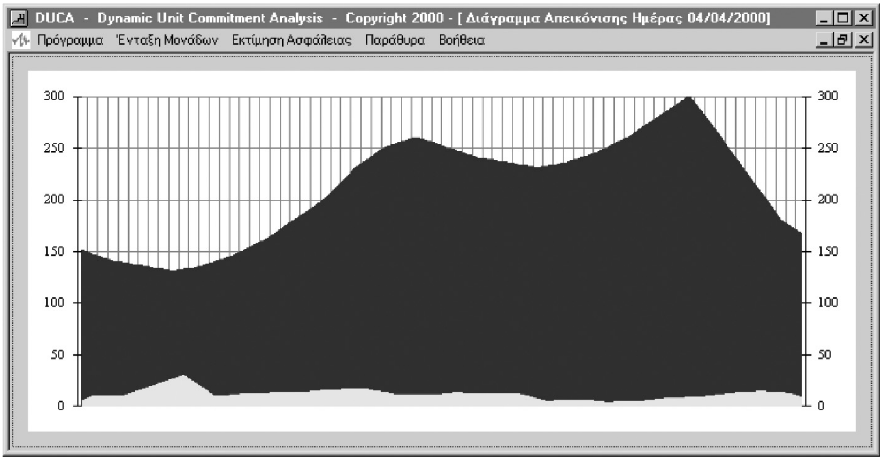

Fig. 2.2 Load and wind power data entry

One more algorithm parameter that influences considerably the generation dispatch profile is the desirable spinning reserve. In Fig. 2.3, UC results for the examined time horizon (24 hours), is presented, taking into account all the previous data.

According to the previous Fig. 2.3, load demand is mainly covered by the “base” power units, as six steam units (green) and the combined cycle unit (orange). Continuously, high loads are covered by the four “fast” diesel units (mauve), while the main daily peaks are served by the available gas units (red).

Part of total load, as was already reported, covers the selected wind power production (yellow) for the examined time period, while the spinning reserve

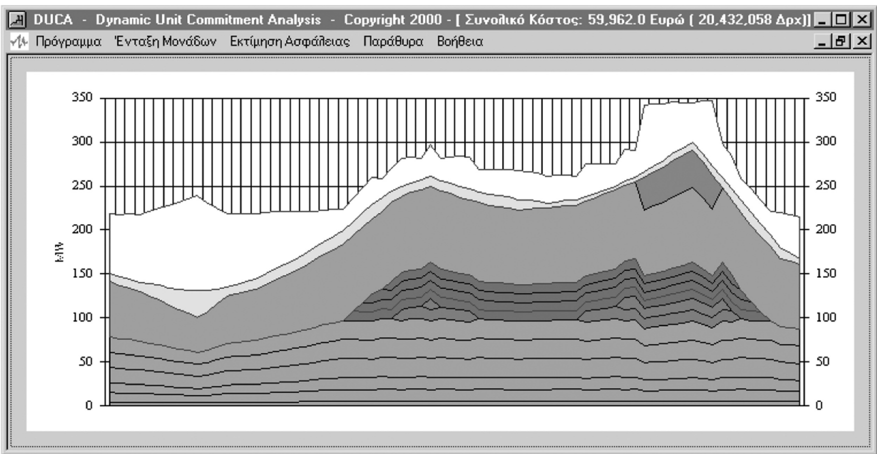

Fig. 2.3 Unit commitment monitoring

(white) is calculated according to the proposed operation profile. The total cost of the proposed dispatch, with 10% spinning reserve limit, is calculated in 59,962.

2.3.3 Dynamic Security Assessment

The previous UC results provide the data entry of dynamic security level estimation algorithm under pre-selected disturbances of the examined 24-hour schedule. In Fig. 2.4, the level of dynamic safety, in parallel with load demand and wind power production, is presented.

Algorithms results are combined in one total indicator line (grey), which is presented as the percentage (%) of absolute security level, giving a picture of power system safety level in case of several contingences. More concretely, the current indicator results as medium term from the classification of examined functional points (zero unsafe and one safe) via five decision trees of pre-selected common disturbances.

2.3.4 Preventive Security Assessment

Unit commitment module is executed once again, receiving as additional entry the dynamic security restrictions, which were exported by the DSA algorithm [14]. In the following Fig. 2.5, final preventive security assessment results are plotted, where all the corresponding diagrams of the examined power system for short-term planning and operation are in one screen.

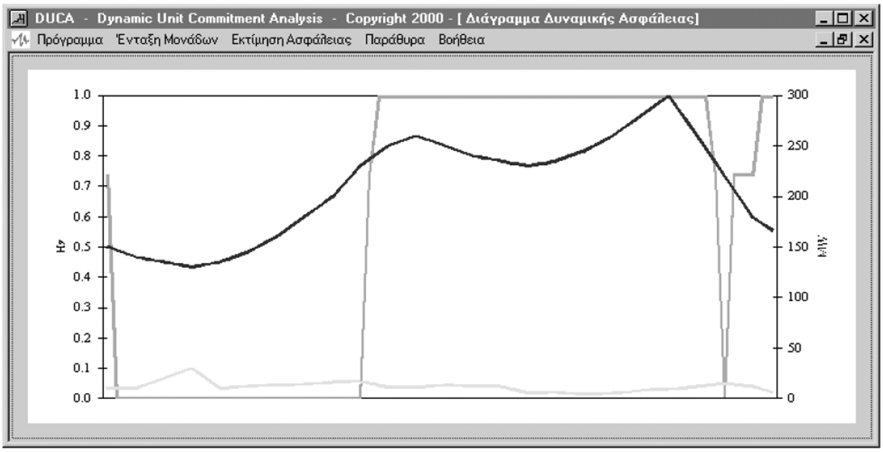

Fig. 2.4 Dynamic security level monitoring

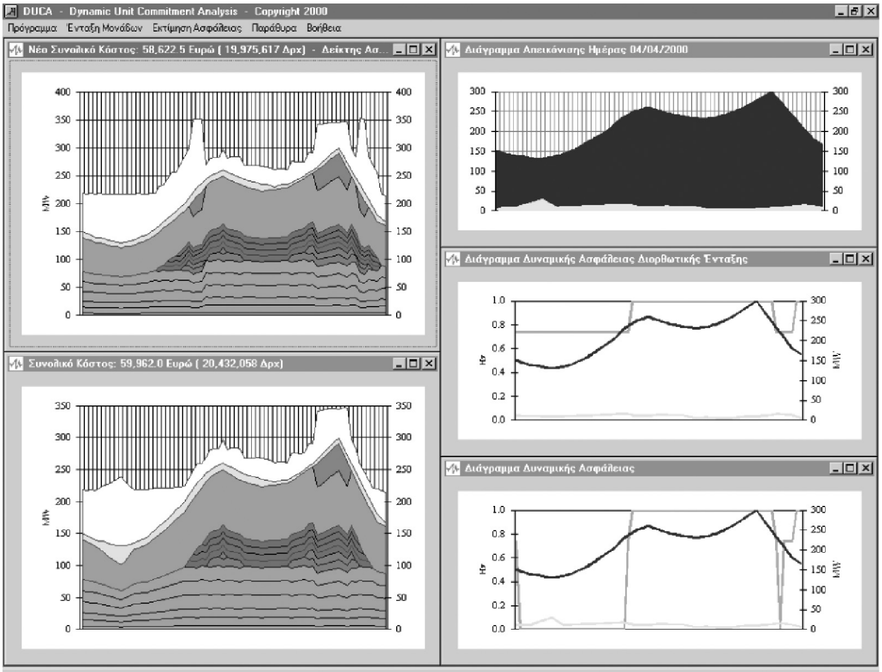

Fig. 2.5 Final results screen

The improvement of dynamic security level is confirmed by safety index. As is shown in Fig. 2.5, the difference between the previous security level without restrictions and the final proposed profile easily becomes obvious.

2.4 Conclusion

From the start of electrical energy systems, human operators (system dispatcher) had the whole responsibility of power generation and distribution control. During the 1980 s, Nathan Cohn (IEEE Computer Application in Power, January 1988) described a precocious energy management application of power generation and distribution control. Since then, the programs that are used in power systems control centers present significant improvement, based on the modern computer's increasing processing power [5, 7].

The present chapter presents a real-time energy management program for short-term operation planning, which was initially applied in Crete's autonomous power system. The efficiency of the program's calculations are judged to be sufficiently satisfactory, taking into account the evaluations results in real operation conditions.

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