Generation Maintenance Scheduling Considering Short-term Operational Constraints

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Abstract— **Generation units' maintenance scheduling in power system implemented to maintain the system reliability. Because this planning implemented by the system operator in an integrated way, it is necessary to take into account the operational constraints. One of the problems in mid-term planning which includes maintenance scheduling is the coordination between different maintenance teams and also operation technical constraints. The competition issue and liberalization in the electricity industry and conferment maintenance scheduling and coordinating these tasks with other procedures are the most significant issues which system operator and experts encounter with them. In this paper, generation maintenance scheduling problem is taking into account and formulated in mathematical optimization representation. In order to illustrate the feasibility and robustness of the presented approach we address the Iran's power generation maintenance scheduling considering both energy and short-term reserve margin.**

Keywords— Maintenance Scheduling, Probabilistic Simulation and Reliability

I. INTRODUCTION

Power system planning separated into long-term planning, mid-term planning, short-term planning and real-time system planning. The main purpose of long-term planning is to expand the electric energy generation and transmission with the least cost and the highest reliability level. In mid-term maintenance planning, dedicating fuel to the generation units and the optimal operation of water resources issue considered. Optimal planning of generation units and determining the generation optimal commitment considered in the short-term planning. Finally, some actions made to balance the generation and consumption momentary amount using SCADA/EMS when the system is in the real-time operating mode. In each time horizon, the main purpose of planning is to supply loads with the least cost and the highest reliability level. Thus, all planning implemented to reduce the operation risk and ensure the real-time operation conditions. The mid-term planning is a joining ring between short-term and long-term planning. The main purpose in such planning is to supply the gas and combined cycle power plants and also the optimal generation scheduling of hydro-electric units. In addition, it includes coordination and maintenance scheduling of generation units and transmission system equipment.

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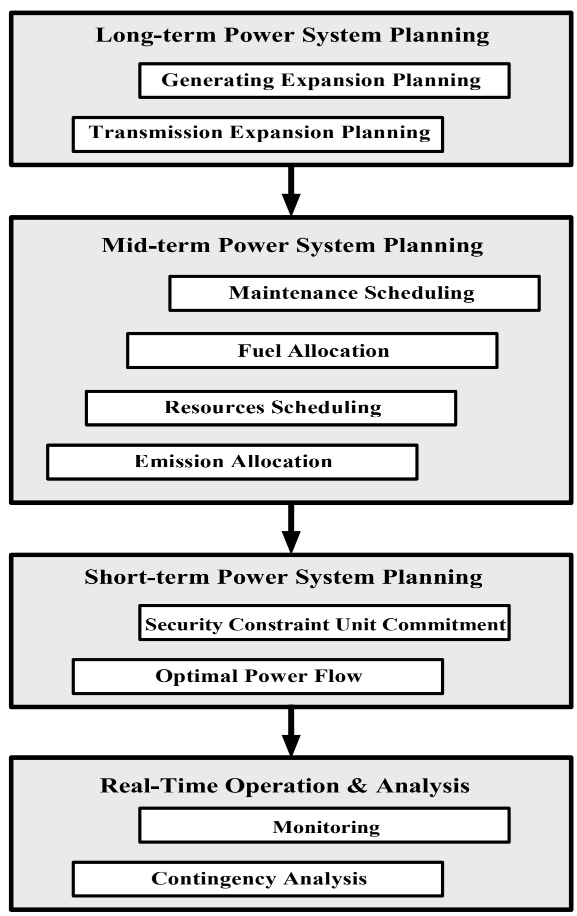

Fig. 1. Power system planning hierarchy

The purpose in such planning is to reduce the forced outage of these equipment when they are servicing or in operation state, generally including periodic, annual an overhauling of existing equipment and sometimes replacing existing equipment with reserve ones and preventing equipment forced outage because of exhaustion. The scheduling issue managed and implemented in unified way before power system liberalization. In the other words, electricity energy supply trustee implemented the maintenance planning annually. In such a case, the maintenance team including experienced crew start working with a pre-determined schedule regardless of economic issues corresponding to maintenance scheduling and energy price of that time interval [2].

By starting reconfiguration and separating generation, transmission and distribution in the power system, the maintenance scheduling comes into conflict with economic activities of different generation companies (GENCO) and transmission companies (TRANSCO). However, each mentioned one itself is responsible for their units and equipment operation. In this situation, the independent system operator (ISO) performs as a supervisor for system secure operation and maintaining system reliability [3].

Another independent institute in the modern power system is market operator (MO) having a duty different from ISO who is responsible for electricity market operation and market surveillance. MO duty is to implement market and determine the ancillary service pricing mechanism toward supplying energy. In the modern power systems, ISO supervises the operation issue [4].

After determining the energy supply units in planning horizon which is normally day-ahead market, generation companies undertakes supplying the determined loads. In such situation, if a unit has a forced outage, ISO reacts to the loss of generation and MO declares the load supply momentary cost and the generation units now has to buy energy from the power market. This issue leads to consider this problem in bidding price by GENCOs [5].

In such conditions, assessing and managing risk can be robust instrument to get rid of drawbacks caused by this problem. [6]. In this paper, the optimal maintenance scheduling of generation units implemented by considering the operation short-term conditions and the techno-economical issues and also considering Iran power system necessary secure reserve margin.

II. OPTIMAL MAINTENANCE SCHEDULING

Making the best decision to implement the maintenance scheduling for an entire network leads to solve a very complicated complex optimization problem with binary variables. The techno-economical constraints domain on the optimal maintenance scheduling turns this problem into a two or multi-level optimization problem. In the first step, some constraints and the length and the type of maintenance must be added to the model. After this step, that energy generation short-term constraints and reserve and the reliability criteria will be assessed. In a closed-loop program, if any constraints not verified, the problem can be revised in the first loop by causing some cuts. As mentioned above, cost and reliability issues are two ones conflict with each other that each one executed in one level and the answers will be assessed in the next level. If any optimal answers of past levels assign cuts, answers had to be revised. The main purpose of power system from the reliability viewpoint is continuously supply loads with high quality. These criteria are very significant from industrial and ordinary consumers' viewpoint. The generation unit outage directly affects this issue and its criteria. From economic viewpoint, the cost dedicated to annual maintenance by generation units is remarkable. Maintenance costs include constant costs and variable ones. Constant cost is independent of whether a unit is working or under maintenance conditions and variable cost is proportional to the generation unit working and its exhaustion conditions and also its long-term operation. In addition to these cost, some other type of cost can be potentially added to the system cost. For instance, when a unit is out of service, it loses the chance to benefit from the power market. In such situation, for units having high efficiency, the system operator has to select units with lower efficiency and generally with lower reliability and high cost of energy generation to supply energy and providing the necessary reserve. Thus, both from the independent system operator and the generation unit operator viewpoints, these two criteria, means reliability and the economic issue of supplying energy are very significant. Therefore, the maintenance issue of generation units is a multi-objective optimization program with complicated and various constraints which its implementation becomes more complicated by enlarging the system size. So, it is essential to have a regular method to analyze it. The mathematical objective function of the optimal maintenance planning problem is minimizing system cost including maintenance cost and in-circuit units operation cost presented as (1). In this equation, the major cost corresponds to fuel cost of in-circu units. Units' overhaul planning implemented as time intervals with weekly window. Note that the study period is 52 weeks or in other words, it is perform annually [7].

$$Min \sum_{i=1}^{52} \sum_{t=1}^{N} C_{it}(1 - x_{it}) + \sum_{t=1}^{52} \omega_t \quad (1)$$

Where, x_i is the *i*-th generation unit state in *t*-th week and "0" corresponds to the time interval in which the unit is out of service because of maintenance. C_{it} is the *i*-th generation unit maintenance cost in *t*-th week and ω_t is the energy generation cost in *t*-th week.

$$x_{it} = 1 \quad t < e_{it} \quad or \quad t > l_{it} + d_{it} \quad (2)$$

$$x_{it} = 0 \quad S_i \le t \le S + d_{it} \quad (3)$$

$$x_{it} = 0 \;\; or \;\; 1 \quad e_{it} \le t \le l_{it} \quad (4)$$

$$\sum_t x_{it} = l_{it} - e_{it} - d_{it} \quad e_{it} \le t \le l_{it} \quad (5)$$

$$\sum_t \sum_i r_{ij}(1-x_{ij}) \leq \alpha_{jt} \qquad (6)$$

$$EENS_r \leq \varepsilon \qquad (7)$$

The maintenance planning constraints categorized to two sections, first one corresponds to the technical constraints and the unit maintenance and the second one corresponds to reliability constraints including load supply constraints and the system necessary reserve, which e_{it} and l_{it}, respectively point to the first and the last maintenance interval and d_{it} shows the i-th unit maintenance interval; S_{it} means the maintenance starts from s-th hour; r_{ij} is the total necessary resources for the i-th unit; α_{jt} corresponds to the total existing resources in t-th interval; y_{it} is the i-th unit operation level in t-th interval and k_i shows the i-th generation unit capacity; ε is the system acceptable level of expected energy not served (EENS). Equations 1 to 4 correspond to the system overhaul time window request and its continuity. Equations 5 and 6 correspond to the system reliability constraint and its reserve margin [7].

III. SHORT-TERM GENERATION PLANNING

Security-constrained unit commitment (SCUC) program is one of the most important issues which ISO takes into accounts in short-term planning of power system both in regulated and deregulated power market. In the mentioned planning, accessible generation units compete with each other to supply load in a specified time interval, generally day-ahead or week-ahead market. In the modern power system's electricity market, independent system operator (ISO) asks generation units to bid a price. According to the market rules, generation units are able to bid their price in a rising step-wise mode, maximum steps are 10 steps in Iran electricity market [8].

Iran electricity market mechanism is based on pay as bid (PAB) mechanism and for each producer if it is in the generation planning, there would be an account according to their offered price. In such planning the on-line units are able to benefit from selling energy in comparison to those which are out of service. Another important issue is the regular implementation of the unit maintenance scheduling according to devices and the generation system equipment catalogs. If any unit has a forced outage in the pre-determined program set by the system operator, the unit's owner must buy the accepted energy from the spot market and does its commitment that this action is the ISO duty as its representative. Depending on market conditions the system load, price is 10 to 15 times more than the maximum price of that hour or year. So, it is obvious that postponing the maintenance scheduling to benefit more increases the unit outage risk and after that large drawback because of the unit forced outage. Ahead problem in short-term planning is to minimize the energy generation and reserve by the system operator in the day-ahead market.

Thus, the short-term market can be modeled as an optimization problem with (8) objective function and some constraints must be considered in the short-term and mid-term planning.

$$Min \sum_{k=1}^{Nk} \sum_{t=1}^{m} aP_g^2(k,t) + bP_g(k,t) + c(k,t) \qquad (8)$$

The mentioned problem constraints are as follows:

- **The system real power and the necessary reserve equilibrium:**

$$\sum_{k=1}^{Nk} P_g(k,t) * I(k,t) \geq PD_t \qquad (9)$$

$$\sum_{k=1}^{Nk} R_g(k,t) * I(k,t) \geq SP_t \qquad (10)$$

where:

PD_t : the forecasted load in period t

SR_t : the forecasted reserve in period t

These unequally constraints show that the total generation by the generation system must be more than or equals to the system forecasted load. This issue is true for the reserve too.

- **Generation units acceptable range**

In order to operate with high efficiency in long-term, the generation amounts of units must be between the minimum and the maximum limit. It means that the system total generation and reserve must be in this range.

$$P_{\min}(k) \leq P_g(k,t) + R_g(k,t) \leq P_{\max}(k) \qquad (11)$$

- **Reliability criteria evaluation**

The power system reliability is the most important problem in the power system planning both in modern and traditional power systems. It is so important that the operation considering reliability constraints is prior to the generation program with economic constraints. There are so many criteria presented to assess power system reliability such as loss of load probability (LOLP), EENS, etc.

LOLP shows the probability of not supplying the forecasted loads by the generation system and EENS declares the amount of the expected not supplied load by the power system [10].

In this paper, in each time interval, the criteria LOLP and EENS calculated for each state and if they are in the permitted range, the final optimal maintenance planning has been got. Otherwise, the deviation from the mentioned criteria is considered in the objective function as a surcharge coefficient.

$$RIV(t) = \begin{cases} (EENS_{tot}(t) - EENS_{\max})^2, & if \;\; EENS_{tot}(t) > EENS_{\max} \\ 0 & , \; Otherwise \end{cases} \qquad (12)$$

The new objective function can be written as follows:

$$Min\sum_{i=1}^{52}\sum_{t=1}^{N}C_{it}(1-x_{it})+\sum_{t=1}^{52}\omega_t+\sum_{t=1}^{52}P_tRIV_t \qquad (13)$$

Where, P_t is the surcharge coefficient of violation from reliability criteria and calculated for each hour having a price several times more than the price of that hour and RIV_t is the violation value from the EENS constraint in that week. As mentioned above, the purpose of generation units maintenance planning is to reduce the force outage risk of generation units in the planning horizon. One of the most important criteria of measuring a unit outage rate got by analyzing the generation unit operation records and determining the forced outage rate (FOR) parameter. This engineering system's vital parameter shows the probability of the system undesirable outage and depends on the engineering system type conditions. This parameter also used to calculate other qualitative and quantitative criteria of reliability.

One of the most important reliability criteria which must have been calculated in the planning study is LOLE criterion that is mathematical expected value of not supplied load that is in number of days or number of hours versus the study time interval.

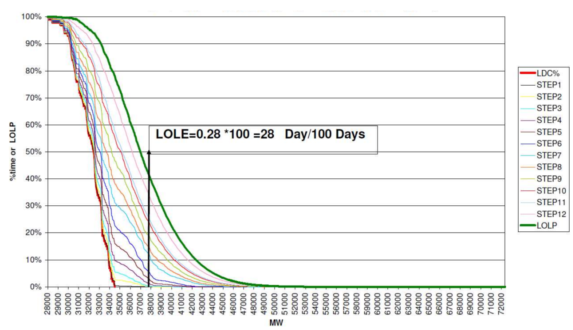

Fig. 2. Simulation results of generation equivalent on the load continuity curve for summer 100-day interval

Fig. 2 shows these criterion calculations by the generation equivalent simulation method using system inverse load continuity curve for Iran power system in summer [11].

IV. SIMULATION STUDIES

To analyze the presented maintenance planning method, Iran system has been studied. According to the generation system significance, only generation system maintenance scheduling considered and the transmission system maintenance totally ignored. However, it is possible to plan the maintenance both transmission and generation system simultaneously using stochastic programming [12] of generation and transmission systems. Nevertheless, in this situation, calculations become more complicated rather than the generation system alone. In this case, 211 generating units are considered in maintenance scheduling program assessment.

It also should be noticed that the overhaul and periodic maintenance scheduling, excitation change, combustion room checking, hot path, renovation, reconstruction, annual surveys,

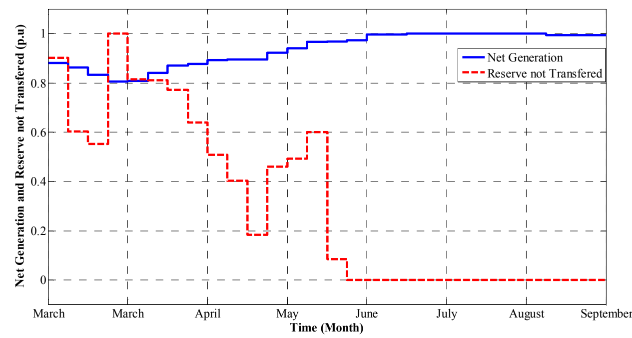

Fig. 3. Unit net product results and the system non-transferable reserve for the mentioned interval

8000-hour, 4000-hour are all considered. Some of these programs are pre-determined and some are decision variables.

Fig. 3 shows the maintenance scheduling of the first 6-month for Iran power system which the system net product for this time interval (February last week to September 3rd week). This curve normalized according to the annual load peak. It can be seen with continuous line. The dotted-line curve corresponds to non-transferable reserve in the power system. Results show that by approaching to the warm season and the annual consumption peak, the system uses its reserve in the best way. In practice, the non-transferable reserve minimized.

REFERENCES

[1] M. Shahidehpour, *et al.*, *Market Operations in Electric Power Systems*. New York: John Wiley & Sons, 2002.
[2] PJM Training Materials-LMP 101, PJM
[3] NYISO Transmission & Dispatch Operations Manual,NYISO,1999
[4] FERC electric rate schedule, ISO-New England, 2001.
[5] F. Li and R. Bo, "DCOPF-Based LMP Simulation: Algorithm, Comparison With ACOPF, and Sensitivity," *IEEE Trans. Power Syst.*, vol. 22, pp. 1475-1485, Nov. 2007.
[6] S. Stoft, *Power System Economics-Designing Markets For Electricity*. New York: IEEE/Wiley, 2002.
[7] M. Davari, *et al.*, "Determination of Mean and Variance of LMP Using Probabilistic DCOPF and T-PEM," presented at the PECon08, 2008.
[8] C. L. Su, "Probabilistic load-flow computation using point estimate method," *IEEE Trans. Power Syst.*, vol. 20, pp. 1843-1851, 2005.
[9] L. Liu and A. Zobian, "The importance of marginal loss pricing in an RTO environment," *Electricity J.*, vol. 15, pp. 40-45, Oct. 2002.
[10] E. Litvinov, *et al.*, "Marginal loss modeling in LMP calculation," *IEEE Trans. Power Syst.*, vol. 19, pp. 880-884, May 2004.
[11] J. Zhu, *et al.*, "Real time loss sensitivity calculation in power systems operation," *Electric Power Systems Research*, vol. 73, pp. 53-60, Jan. 2005.
[12] J. L. M. Ramos, *et al.*, "On the use of loss penalty factors for generation scheduling," in *in Proc.IEEE Power Eng. Soc. Annu. Meeting* 2003, pp. 926-931.
[13] F. Li, *et al.*, "Marginal loss calculation in competitive spot market," in *IEEE Int. Conf. Deregulation, Restructuring Power Technol. (DRPT)*, 2004, pp. 205-209.
[14] A. J. Wood and B. F. Wollenberg, *Power Generation, Operation and Control*. New York: John Wiley & Sons, 1996.