# An Evolutionary Generation Scheduling in an Open Electricity Market

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**Abstract- The classical generation scheduling problem defines on/off decisions (commitment) and dispatch level of all available generators in a power system for each scheduling period. In recent years researchers have focused on developing new approaches to solve non-classical generation scheduling problems in the newly deregulated and decentralized electricity market place. In this paper a GA based approach has been developed for a system operator to schedule generation in a market akin to that operating in England and Wales. A generation scheduling problem has been formulated and solved using available trading information at the time of dispatch. The solution is updated after new information is obtained in a rolling fashion. The approach is tested for two IEEE network based problems, and achieves comparable results with a Branch and Bound technique in reasonable CPU time.**

## 1 INTRODUCTION

### *1.1 Problem domain*

The solution of the classical generation scheduling problems involves the determination of the unit commitment and economic dispatch for each generator in a power system at each time interval in the scheduling period [1, 2]. Unit commitment is a discrete problem which decides which of the generators are on or off in each time interval of the scheduling horizon. Economic dispatch determines the allocation of the power output (system load) to the online generators. Traditionally, the electricity generation, transmission and distribution industries were fully regulated with a centrally controlled structure. Thus, the generation scheduling problem was solved centrally to minimize the total cost of power generation in a power system over the scheduling period [1]. The power system operator had a full control as well as the technical and costing information of each generating units.

In the last decade many countries have gone through privatization of their electricity industries [3-6]. In many instances this has seen a move towards competition with market forces left to determine price. In many situations generators (who produce electricity), suppliers (who supply the electricity to the end customers), and other traders can freely trade electricity in an open market. The changes to market structure are not only associated with electricity market participation but also affect the optimal operation of power systems; requiring a whole range of new issues to be addressed. Now all market participants who wish to trade energy have to compete through one or many free markets, such as bilateral, power exchanges and balancing markets [5, 6]. The power system is operated by an independent system operator (ISO) to balance supply and demand of electricity in the real time [5]. Generally the ISO does not own any generators but has the responsibility for managing the balancing mechanism to maintain security and reliability of power systems. The ISO does this by scheduling the generation level of participating generators in balancing market. The generation scheduling has changed drastically as the industry is deregulated. Cost minimization is only a goal for generation companies and the main priority may be to meet their contractual commitments. The ISO, on the other hand, is only aware of the trading prices (not the actual costs) but can use these to optimally match the generation and load [7]. Consequently, existing methods need to be adapted to accommodate the market effects. This paper focuses on the formulation solution of this ISO generation scheduling problem to satisfy the total balancing market load at the minimum balancing cost subject to the operational constraints of power system and participating generators.

### *1.2 Solution techniques*

A variety of different techniques have been employed to solve the generation scheduling problems of the electricity industries with the centrally controlled structure [8, 9]. The solution requires the simultaneous consideration of unit commitment and economic dispatch. In general, generation dispatch problems are highly constrained and combinatorial in nature, and continue to present a challenge for efficient solution techniques [1,8,9].

Systematic procedures based on a variety of mathematical programming algorithms have been proposed and tested for the generation scheduling problems. The main drawback of the mathematical programming techniques is that the number of combinations of states that must be searched increases exponentially with the size of problem and becomes computationally prohibitive [1,9]. Heuristic rule based approaches have long been used by industry with varying degrees of success. Solution approaches of these types are based on specialized techniques that work particularly well for a given problem but are often only of limited applicability to other problems [1]. Recently, evolutionary based approaches have been tested to solve scheduling problem of electricity industries. A review on the applications of evolutionary-based techniques to power systems and generation scheduling is given in [9]. An evolutionary programming approach with a number of special mutation operators is used in [10]. GAs capable of dealing with the commitment and dispatch variables coupled by dynamic constraints for each time interval in the scheduling period have been developed using an extra special mutation operator [11], and with an adaptive evaluation (fitness) function and four specific crossover/mutation like operators [12].

Previous work by the authors presented GA-based approaches for the generation scheduling problems in centralized electricity industries have shown promising results [2, 13, 14]. However, the techniques used in the centralized system operation are not ideal for addressing the new market environments. Market driven dispatch can be more volatile than traditional situations given that prices are inherently more variable than costs. Furthermore, the ISO has limited information of the market participants and the planning/information horizon is short.

This paper proposes a GA based approach to solve an ISO dispatch problem for a market similar to the New Electricity Trading Arrangement (NETA) market currently operated in England and Wales. This approach can easily be adapted to handle dispatch problems in other market structures. Two test cases based on IEEE networks are tested through simulation. The results obtained are compared with that of a Branch and Bound technique.

The paper is organized as follows. Section 2 introduces the NETA market structure and formulates the ISO generation dispatch problem. Section 3 discusses the proposed GA approaches, their implementation. Section 4 presents two test case studies and the results obtained. The conclusions are noted in Section 5.

# 2 PROBLEM DESCRIPTION

## *2.1 NETA Market Structure*

The NETA market structure, currently operating in England and Wales, is represented by three main market segments: a contracts market, a balancing market, and an imbalance and settlement process [3]. Using bilateral contracts sellers and buyers enter into transactions where the quantities traded and the prices are freely negotiated. These transactions are then brought to the ISO with a request that transmission be provided. If there is no congestion in the transmission network the ISO simply dispatches all requested transactions. The remaining power is traded through the balancing market. The balancing market provides a mechanism where generators and suppliers submit bids and offers to deviate away from contracted positions. Bids are specified when generator/supplier wishes to decrease its production/supply of electricity, subject to a payment to the ISO. Offers are specified when generator/supplier wishes to increase its production/supply of electricity, in which case payment is made to the generator/supplier. The ISO utilizes available bids and offers to firstly ensure that supply meets demand and secondly to alleviate any network problems which may occur.

Participants within NETA must pass details of trades to the ISO prior to one hour before physical delivery in a particular half-hour [3]. This cut-off time is referred to as gate-closure. Between gate-closure and physical delivery the balancing market is in operation. Fig. 1 shows a simple schematic of the temporal aspects of the NETA operation. The study market in this paper follows these rules and temporal aspects.

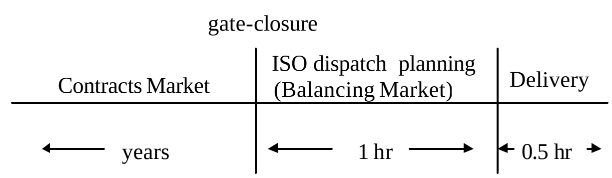


Fig. 1: Time line for NETA operation.

## *2.2 ISO dispatch problem*

The ISO dispatch problem in the NETA-like market is to decide commitment and generation level of units participating in the balancing market (balancing market units). This is done at a minimum balancing cost using submitted bids and offers subject to secure and balanced operation of the power system. The ISO solves the dispatch problem in stages: operations planning and real-time operations. In the operations planning horizon, generation is scheduled with the security criteria for adequate reserve to withstand generator outages. Transmission security for operations planning is usually ensured by simulating the worst case scenarios according to some standard procedures [15]. In real time operations, generation is automatically dispatched to meet load. If adequate reserves are available, load should always be met provided that the transmission capacity is there. Here the continuous adjustment of the generation must be performed to exactly match the total load that is varying, and the adequate reserves must always be available that can respond to the changing load as well as a loss of a generation unit [16].

In this paper the solution of an operations planning dispatch for the balancing market operation similar to NETA is considered. The total balancing cost of the power system depends on the available bids and offers submitted by participants and on the system demand. The bilateral transactions do not impact on the total balancing cost, hence, are not considered in this paper. In order to minimize the uncertainty of fluctuating demand and availability of balancing market units a shortest ISO dispatch planning period (see Fig. 1) is suggested. A short optimization period, however, can localize the results of the optimization procedure. This paper proposes an approach which utilizes any information available for a period longer than the ISO dispatch planning period in a rolling fashion, as described in section 3, to make dispatch decision for the period immediately after the gate-closure.

### 2.3 Mathematical formulation

This section presents the ISO generation scheduling problem as a mixed integer programming (MIP) problem extending the MIP model of the centralized system presented in [13]. A complete list of the notation used is given below:

| | |
|---|---|
| $N$ | number of units |
| $T$ | number of time intervals |
| $a_i^t$ | commitment (binary) |
| $b_i^t$ | start-up indicator (binary) |
| $g_i^t$ | shutdown indicator (binary) |
| $p_i^t$ | generation of unit *i* at time *t* |
| $p_i^{\min}$ | minimum generation |
| $p_i^{\max}$ | maximum generation |
| $r_i$ | ramp rate |
| $t_i^{\text{on}}$ | minimum on time |
| $t_i^{\text{off}}$ | minimum shutdown time |
| $p_{i,t}^f$ | contractual position of unit *i* at time *t* |
| $p_{j,t}^o$ | volume accepted of offer *j* at time *t* |
| $p_{k,t}^b$ | volume accepted of bid *k* at time *t* |
| $c_{j,t}^o$ | cost rate of offer *j* at time *t* |
| $c_{k,t}^b$ | cost rate of bid *k* at time *t* |
| $F$ | total balancing costs |
| $D^t$ | demand of balancing market at time *t* |
| $l^t$ | transmission constraint limit |
| $R$ | reserve level |

Start-up and shutdown indicators are defined by

$$b_i^t = \begin{cases} 1 & \text{if } a_i^{t-1} = 0, a_i^t = 1, \\ 0 & \text{otherwise,} \end{cases} \tag{1}$$

$$g_i^t = \begin{cases} 1 & \text{if } a_i^{t-1} = 1, a_i^t = 0, \\ 0 & \text{otherwise.} \end{cases} \tag{2}$$

A commitment and dispatch schedule is given by the arrays $\{a_i^t\}$ and $\{p_i^t\}$. These are the variables of the optimization problem. The power generation of unit *i* at time *t* can be defined as,

$$p_i^t = \begin{cases} p_{i,t}^f + \sum_{j\in i} p_{j,t}^o - \sum_{k\in i} p_{k,t}^b & \text{if } a_i^t = 1 \\ 0 & \text{otherwise} \end{cases}. \tag{3}$$

The objective of the ISO dispatch problem is to minimize the total balancing cost. The total balancing cost depends on the available bids and offers submitted to the ISO to balance the system demand. When offers of a generator (i.e. increases in electricity generation) are accepted the generator is paid for the increased electricity production. When bids (i.e. decrease in electricity generation) are accepted the generator has to pay for the decreased production of electricity from its contractual position. The ISO utilizes available bids and offers to firstly ensure that supply meets demand and secondly to alleviate any network problems which may occur.

Mathematically this objective function for the balancing market is given by,

$$\min F = \min_{a_i^t, p_{j,t}^o, p_{k,t}^b} \sum_{i=1}^{N} \sum_{t=1}^{T} a_i^t \left( \sum_{j\in i} c_{j,t}^o p_{j,t}^o - \sum_{k\in i} c_{k,t}^b p_{k,t}^b \right). \tag{4}$$

This is subject to a variety of operational constraints of balancing market units and the power system:

Generation limits: Each generator is constrained by a minimum and maximum generation.

$$a_i^t p_i^{\min} \le p_i^t \le a_i^t p_i^{\max} \quad \text{for } i = 1,\ldots,N,\ t = 1,\ldots,T. \tag{5}$$

Ramp rates: Each generator is generally constrained by ramp rates which limit the rate of change of the generation.

$$\left.\begin{array}{r}\text{if } a_i^{t-1} = a_i^t = 1 \text{ then } -r_i \le p_i^t - p_i^{t-1} \le r_i, \\ \text{if } b_i^t = 1 \text{ then } p_i^t = p_i^{\min},\end{array}\right\} \text{for } i = 1,...N,\ t = 1,...,T. \quad (6)$$

Minimum on times: For each generator the time between a consecutive start-up and shutdown must be greater than the specified minimum on time.

$$b_i^t + \sum_{t'=t+1}^{\min(t+t_i^{on}-1,T)} g_i^t \le 1 \text{ for } i = 1,\ldots,N,\ t = 1,\ldots,T-1. \quad (7)$$

Minimum shutdown times: Once a generator has shut down, the minimum shutdown time must elapse before it can be started up.

$$g_i^t + \sum_{t'=t+1}^{\min(t+t_i^{\text{off}}-1,T)} b_i^t \le 1 \text{ for } i \in I_{MST}, t = 1,..., T-1. \quad (8)$$

Demand: The predicted power demand from the balancing mechanism must be met by the sum of the generation of all the balancing market units.

$$\sum_{i=1}^{N} p_i^t = D^t \text{ for } t = 1,\ldots,T. \quad (9)$$

Reserve: The on-line generators must together maintain a specified reserve capacity.

$$\sum_{i=1}^{N} a_i^t p_i^{\max} \ge D^t + R \text{ for } t = 1,\ldots,T. \quad (10)$$

Transmission: There may be specified bounds on the total generation of local groups of generators.

$$\sum_{i \in I_{TC}} p_i^t < l^t \text{ for } t \in T_{TC}. \quad (11)$$

Initial conditions: The state and the generation level of generators at the beginning of the scheduling period must be considered.

$$a_i^0,\ p_i^0 \text{ given for } i = 1,...,\ N. \quad (12)$$

In the above $I_{MST}$ and $I_{TC}$ denote particular subsets of units associated with the constraints, and $T_{TC}$ is a subset of times. Equations (1) - (12) define a mixed integer linear programming (MIP) model for the balancing market dispatch problem. The optimization process for any time period is conducted over a 'window' period as discussed in the following section.

# 3 PROPOSED SOLUTION APPROACH

## *3.1 Rolling window approach*

At any time the ISO will have full information of bids and offers for the next two half-hourly periods as a result of the gate-closure. However, many units submit bids and offers in blocks for many half-hourly time periods [6]. The ISO, therefore, usually has partial information of bids and offers for some time periods beyond the one-hour balancing period. This partial information can be utilized for optimizing the operations planning for a period longer than the ISO dispatch planning period. It is assumed in this paper that the ISO has full information of bids and offers for the next two half-hourly periods and partial information of for other subsequent five half-hourly periods due to the block bids and offers. The proposed optimization procedure formulates a dispatch problem over this seven half-hourly period, which is referred to here as a 'window' as illustrated in Fig. 2.

A rolling window approach is proposed for solving the ISO generation scheduling problem as shown in Fig. 2. The formulated problem over a window is optimized. The dispatch results for the first time period after the gate-closure is accepted as an 'optimized' solution for that time period. As the gate-closure moves forward to the next time period, recent information of offers and bids is obtained for the next seven half-hourly periods. A new dispatch problem over the redefined window, including a new period, is solved and the solution of the first time period of the window is accepted. In this way, the proposed algorithm updates dispatch results in the 'rolling window' fashion in every half-hour using up to date bids and offers.

## *3.2 GA search approach*

The optimization search process of the proposed dispatch procedure is based on a GA method [17,18]. A GA mimics the natural evolutionary adaptation and works with a 'population' of possible solutions. It creates successive 'generations' of the population by several simple 'genetic' operators. The objective function is absorbed into an evaluation function, which may take account of constraint violations via penalty terms. In each generation, solutions are selected stochastically according to their fitness in order to contribute to the next generation. Relatively 'fit' solutions survive; 'unfit' solutions tend to be discarded. A new generation is created by stochastic operators - typically 'crossover', which swaps parts of encoded solution strings, and 'mutation', which introduces a small random change in the strings. Successive generations yield fitter solutions which approach the optimal solution to the problem.

As an attempt to encode both the commitments and dispatch between committed units within a single GA, a problem representation has been designed using a string of binary and real numbers [13]. A sub-string containing one binary variable and one real number has been used to represent a generating unit at a particular time period as shown in Figure 3. The binary bit represents commitment and the real number indicates the dispatch variable of the unit for that time period.

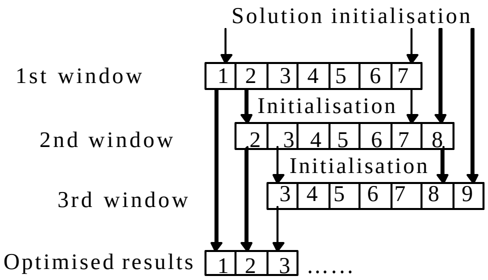


Fig. 2: Rolling window approach.

$$\left| a_1^1 \ \mathrm{p}_1^1 \right| \ldots \left| a_i^1 \ \mathrm{p}_i^1 \right| \ldots \left| a_N^1 \ \mathrm{p}_N^1 \right| \ldots \left| a_i^t \ \mathrm{p}_i^t \right| \ldots \left| a_1^7 \ \mathrm{p}_1^7 \right| \ldots \left| a_i^7 \ \mathrm{p}_i^7 \right| \ldots \left| a_N^7 \ \mathrm{p}_N^7 \right|$$

Time period 1 Time period 7

Fig. 3: The GA solution encoding.

A penalty function approach has been employed to take account of the constraints for the test problem [17]. The penalty value for each constraint violation is proportional to the amount by which the constraint is violated. The evaluation function, $E_v$, is the weighted sum of penalty values for each constraint violation and the objective function itself as described by equation,

$$E_v = F + \sum_k w_k P_k \ , \tag{13}$$

where $F$ is the objective value as described in (4); $P_k$ is penalty value for breaking the $k$th constraint of the problem; and $w_k$ is preference weighting for the $k$th constraint. The weighting coefficients are chosen in such a way that in general the penalty value for the constraint violations dominates over the objective function.

The GA approach requires an initial population of candidate solutions for each of rolling windows to start the search process, which can be created randomly or by using some other means [2]. The proposed approach creates the initial population for the very first window (time periods 1 to 7) sampling the search space randomly (see Fig. 2). The approach accepts the best solution for the first time period (time period 1) from the final population after the search process for the 'optimized' solution for this window is completed. The final solutions for the remaining time periods (time periods 2 to 7) are then used to initialize the starting population for the next window (time period 2 to 8), with randomly created solution for the last time period (time period 8) and so on. In this way the search time, hence the convergence of the population, for the windows other than the very first one, can be improved. Two-point crossover and random mutation operations are employed in this application.

The particular GA parameters (population size, number of generations, crossover probability and mutation probability) that give the best performance for each of the proposed approaches have been identified empirically. The general approach adopted during the tests of each of the GA designs was to conduct ten runs until the stopping criterion (a given CPU time) is reached.

## 4 CASE STUDIES AND RESULTS

### *4.1 Test problems description*

Two case studies derived from the IEEE test networks have been tested with the proposed dispatch procedure. The first test system, which will be referring to IEEE9 in this paper, is loosely derived from the IEEE 9-busbars test network [19]. This is a small size test problem with 3 generating units which provides a simple benchmark. The generation limits, ramp rates for increasing and decreasing of generation levels, minimum on time and minimum off time of the generators are given in Table 1.

Table 1: Relevant data of the generating units.

| Unit | Min gen. (MW) | Max gen. (MW) | Ramp rate MW/period | Min on time (periods) | Min off time (periods) |
|---|---|---|---|---|---|
| 1 | 50 | 200 | 10 | 2 | 3 |
| 2 | 37.5 | 125 | 10 | 2 | 3 |
| 3 | 25 | 75 | 10 | 2 | 3 |

Each generator submits three bid/offer prices and volumes of electricity to the balancing market for each half-hour delivery period at the gate-closure. For clarity of the discussion the offers and bids both are referred here to ‘offers’ (a bid can be represented by a negative offer). The bilateral contracts are ignored as they do not impact on the total balancing costs. As an example the offer patterns of generator 1 over 48 half-hour period is depicted in Figure 4. The predicted demand pattern for the ISO balancing market of the test problem is shown in Figure 5.

The second test system is of bigger size, which has 7 generator units. The data for the problem are derived from the IEEE 57-busbars test network [19], and are not presented here. This problem is referred to IEEE57 in this paper. Each of these 7 generators submits five bid/offer prices and volumes for each half-hour delivery period at the gate-closure. There are limits on the upper and lower power output of groups of balancing market units which should be respected in order to satisfy the transmission restrictions of the network.

In the both test cases described above the solution is to decide commitment and dispatch level of the participating balancing market units at a minimum balancing cost over a period of 24 hours (48 half-hour periods) with a rolling window of 3.5 hours. The predicted demand must be met by the sum of the generation of all the units; in addition the on-line units must together maintain a specified reserve capacity. Individual generating units are characterized by constraints including the minimum and maximum generation levels, ramp rate limits on the increase and decrease in generation, and the minimum on and off times.

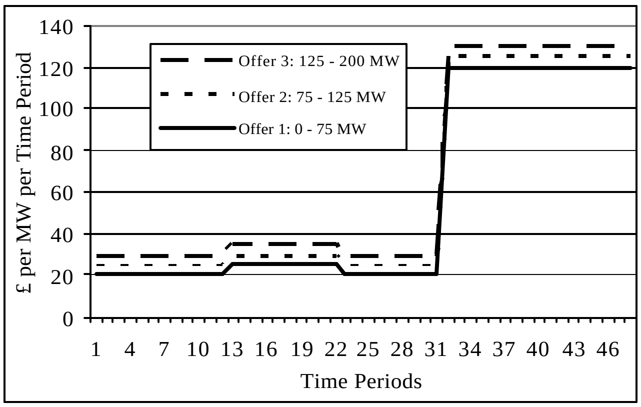


Fig 4: The biding pattern of generating unit 1for IEEE9 test problem.

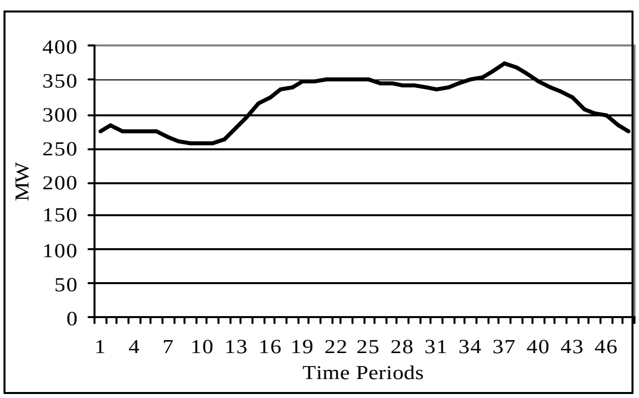


Fig 5: The predicted power demand in the balancing market of IEEE9 test problem.

### *4.2 Test results comparison and discussion*

As discussed above the objective represented by equation (4) with constraints represented by (1)-(3) and (5)-(12) form a linear MIP problem, where $a$, $b$ and $g$ are binary variables and $p^t_i$ are continuous variables. This linear MIP can then be solved using the branch and bound (BaB) technique. For comparative purposes as well as applying the GA based technique, the Branch and Bound (BaB) method has been employed to solve the dispatch problems using a similar rolling window fashion.

The optimum solution of the problems found by the BaB technique for test problem IEEE9 is depicted in Figure 6. The figure shows the generation dispatch over 48 half-hour scheduling periods for the participating three generators. Note that none of these three generators is off during the scheduling periods.

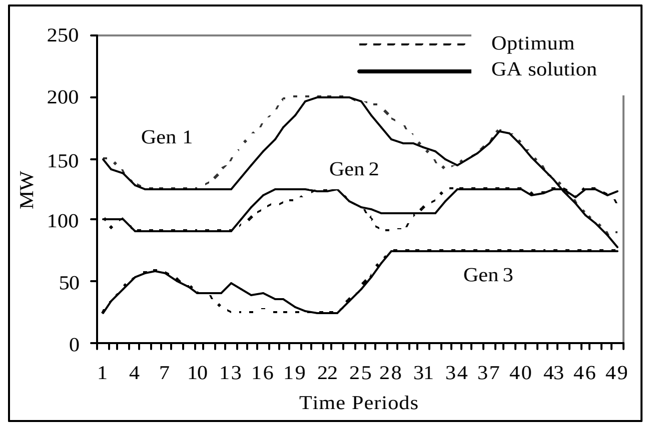


Fig 6: Generation schedules obtained using the BaB and GA approaches for IEEE9 test problem.

The profile of balancing costs over the scheduling periods given by the optimum solution for the IEEE9 test problem is drawn in Figure 7. The summary details (total balancing costs for 48 half-hour periods and the computational time) of the optimum solutions for the both IEEE9 and IEEE57 test problems are presented in Table 2.

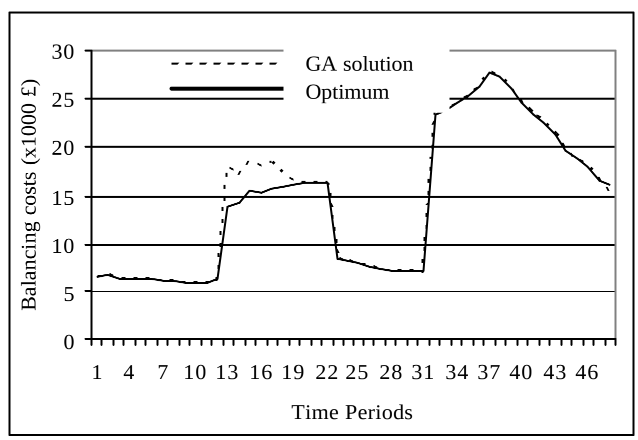


Fig 7: Balancing costs over the scheduling periods obtained using BaB and GA approach for IEEE9 test problem.

Ten runs were conducted using the proposed GA approach for the test problems with the GA parameters identified empirically. All the experiments were conducted in a personal computer with Pentium III processor and 64 MB RAM.

For IEEE9 test problem the best generation dispatch and the balancing cost profile given by the GA approach are plotted in Figure 6 and Figure 7 respectively. As it can be seen from these figures that the GA solution gives the allocation of generation close to the optimum solution in the most of time periods, except the time periods between 13 and 22, and between 26 and 33. The balancing costs were not affected much by the GA solution in the time periods 26-33, but there is slight increase in the costs for periods 13-22. In fact generator 3 significantly increased the price of electricity requiring drastic changes in the generation schedule, and the GA could not finely tune the dispatch variable in the given computational time.

Similar experiments were conducted for the IEEE57 test problem. Although the generation dispatch given by the GA differs slightly in many of the time periods, the profile of the balancing costs are very close that given by the optimum solution.

Table 2 summarizes the test results obtained for the both test problems. The cost of the optimum solutions, the averaged costs of the best solutions found over the ten GA runs are shown for the both test problems. The best solution obtained over the ten runs and computational time for one run are also recorded in Table 2.

Table 2: Results obtained from the dispatch procedures.

| | | | |
|---|---|---|---|
| IEEE9 | BaB | Cost [£] | 683,424 |
| | | CPU time [s] | 219 |
| | GA | Cost averaged over ten runs [£] | 699,812 |
| | | Best cost over ten runs [£] | 684,109 |
| | | CPU time for one run [s] | 219 |
| IEEE57 | BaB | Cost [£] | 2,633,622 |
| | | CPU time [s] | 461 |
| | GA | Cost averaged over ten runs [£] | 2,680,356 |
| | | Best cost over ten runs [£] | 2,634,140 |
| | | CPU time for one run [s] | 377 |

Table 2 shows for the IEEE9 problem the BaB approach performs better than the proposed GA-based approach. The averaged best result obtained over ten GA runs is 2.4% higher than the optimum solution obtained using BaB method for the same CPU time. The best result found among ten GA runs differs from the optimum solution by less than 0.1%.

For IEEE57 problem the BaB approach took 461s CPU time to find the optimum solution. The performance of the GA-based approach compares well with that of the BaB approach for this size problem. The averaged best result obtained over ten GA runs is 1.8% higher than the optimum solution. The best solution found over ten GA runs is very much comparable with the optimum solution. The GA approach did not improve the best solution after 377s.

It can be seen that the CPU time taken by the BaB approach increased significantly for the 7-unit test system compared with that for the 3-unit test system. The rate of increase of the CPU time is, however, less for the GA-based approach compared with that for the BaB approach. It should also be noted here that the test problems considered have been specifically designed to fit to the BaB technique. The mathematical programming based BaB works well for the small-size problem, however this is not applicable to large-scale problems as the computational time increases prohibitively with the problem size [2]. Furthermore, it cannot readily be applied to problems with nonlinear objectives and constraints.

## 5 CONCLUSIONS

This paper has explored a new approach to solve the unit commitment and dispatch problem for a system operator in an open electricity market environment. An optimization procedure is formulated in a rolling window fashion and a GA based search approach has been employed to solve the problem. Although the ISO has the responsibility for the smooth operation of the power system, it does not possess complete technical, market and trading information beyond the gate-closure. The proposed rolling window procedure utilizes the information available at the time and updates the solutions after new biding information is obtained. The GA encodes both unit commitment and economic dispatch problems in the solution string. The evaluation function to be minimized is the weighted sum of the total balancing costs and penalty values for violations of any constraint.

Two IEEE network based problems have been tested for the NETA-like market structure which has currently been operating in England and Wales. The results obtained show that the GA-based approach offers not-inconsiderable advantages over these alternative formulations. Although it is computationally slower than a classical branch-and-bond solution for the small test system described, results have shown that it does not suffer the same rate of slow-down as the problem grows - it is therefore more suited to realistic problems.

The GA approach implemented in this paper may be further improved by using domain knowledge to generate meaningful initial solutions and repair the candidate solutions during the search process, and by hybridizing it with other approaches for refining the candidate solutions before and/or after the GA process. This could reduce further reduce the computational time of GA. Further research is in progress to investigate all these and other issues.

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