

A NEW METHODOLOGY TO SOLVE JOINT ENERGY AND PRIMARY RESERVE SCHEDULING

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Received February 2012, Revised May 2012, Accepted June 2012

Abstract

The unit commitment problem has been broadly studied in recent years in many researches. However, this is not all of the important tasks for independent system operator. One of the most important tasks is the optimal provision of primary frequency regulation reserve with the lowest cost that should be considered in the unit commitment problem. Frequency control in power system, as an ancillary service, has closed dependence to hourly scheduling of energy. In this paper, a novel approach is proposed to solve simultaneous scheduling of energy and primary reserve using genetic algorithm. The proposed methodology is fast and simple against conventional methods. In addition, applicability of scheduled primary reserve has been considered in optimization process. Finally, simulation results for a 17 unit case study are presented in comparison with a related work. The simulation results using Matlab 2009a are presented which verify the effectiveness and robustness of the proposed method.

Keywords: droop characteristic, frequency deviation, genetic algorithm, primary reserve, ramp up limit, simultaneous, scheduling

Nomenclature

g_{it}	Scheduled generation of unit i in the pre contingency state during time period t
r^{pr-max}_i	Ramp up limit of unit i under primary regulation
R_i	Slop of governor droop for unit i
Δf_{bi}	Break Frequency deviation of unit i
Δf_{cr}	Critical frequency deviation allowed
n	Number of units
m	Order of contingency
$g_i^{\min}$	Minimum possible generation output of unit i
$g_i^{\max}$	Maximum possible generation output of unit i
Δg_i^j	Generation deviation in output of unit i after contingency due to outage of unit j
S^v	Set of lost generating units due to contingency
d_t	System demand during time period t

y_{it}	Equals 1 if unit i turns on during time period t and equals zero if it does not.
z_{it}	Equals 1 if unit i turns off during time period t and equals zero if it does not
u_{it}	A variable defining the operation status of generator i during time period t (equals 1 if the unit is on and zero if it is off)
r_{it}	Scheduled primary reserve of generating unit i during time period t
r_{it}^{se}	Scheduled secondary reserve of generating unit i during time period t
r_{it}^{tr}	Scheduled tertiary reserve of generating unit i during time period t
c_{su}	Start up cost of generating unit i
c_{sd}	Shut down cost of generating unit i
c_i	Unit i fixed generation cost
a_i	Unit i quadratic generation cost parameter
b_i	Unit i linear generation cost parameter
q_i	Primary reserve price for unit i
q_{it}^{se}	Secondary reserve price during time period t
q_{it}^{tr}	Tertiary reserve price during time period t
v_i	A variable defining the operation status of governor of generating unit i (equals 1 if the governor is in active mode and zero if not)
C_{it}^{pr}	Unit i primary reserve cost during time period t
C_{it}^{se}	Unit i secondary reserve cost during time period t
C_{it}^{tr}	Unit i tertiary reserve cost during time period t

1. Introduction

Fast growing load in power systems associated with a large gap between heavy load and light load periods, generation scheduling and unit commitment (UC, hereinafter) has become a crucial issue in operation time horizon and UC problem has

always been an important research challenge in power systems and especially under restructured environment. On the other hand, sudden variations or unwanted changes in system demand may cause a frequency deviation in power systems. Frequency control is one of the most important tasks of independent system operator (ISO, hereinafter). In restructured electricity industry. In power systems, frequency control can be considered as an ancillary service that will be provided using the eligible resources made available by market participants which make UC problem more complicated. Usually, generation reserve capability is called as "frequency control reserve", which is classified as primary, secondary and tertiary reserve depends on their response time and how they are deployed [1, 2]. Primary reserve is provided by generating units through their local droop characteristic in response to system frequency deviation from nominal, a closed-loop process denoted here as primary frequency regulation. This is the fastest of the three reserve control strategies with a response time of the order of seconds. The secondary reserve, which has a response time of the order of minutes, known as automatic generation control (AGC) and more specifically Load Frequency Control (LFC), is applied to regulate the area control-error (ACE) [3]. ACE regulating is compensated via tertiary reserve. It should be noted that, for regulating ACE, all operational constraints must be satisfied [4]. The tertiary reserve, with a response time of the order of minutes, can be used for congestion management, improvement of lost reserves and compensation of the incomplete tasks that has not done by AGC. In this paper, primary reserve scheduling is emphasized while secondary and tertiary reserve has not been considered.

In addition, provision of primary frequency services is functional to hourly scheduling of energy [5, 6]. The used value for primary reserve of each unit depends on the frequency deviation occurred due to the lost generating units. Furthermore, scheduling of energy and ancillary services (AS) are developed using simultaneously or sequentially methods in different countries. From market point of view, energy and ancillary services are transacted simultaneously while technically ancillary services will be produced after preparation of energy in sequential scheduling. AS must be sorted qualitatively in sequential scheduling second method, in other words the primary reserves are scheduled firstly while the secondary & tertiary reserves will be scheduled hierarchically. In ancillary service market the reserve with lower quality can be replaced by the reserve with higher quality. It means that the primary reserve can be used for secondary reserve, if it is necessary. Using sequential scheduling method, it is possible that "price reversal" be occurred, where this event has been experienced in California and Newengland [9]. Simultaneous scheduling is more complex in comparison with sequential scheduling but the global optimal solution is accessible in Simultaneous method. In fact, in sequential scheduling, the outputs of generating units are input data as some constant parameters which are obtained from UC. So this method cannot warrant the achievement of globally optimal solutions. In addition, it is possible, the final solution of sequential method be not practical. However, as scheduling of energy and reserves are strongly coupled, scheduling them simultaneously will be more advantageous [5, 6] ending with a higher social welfare [6].

The work reported in [7] is one of the most important researches about scheduling of energy and primary reserves which has used an iterative economic dispatch. The values of generation and reserve of each unit are modified successively in aforementioned paper. In [8], operational and stability constraints have been considered in scheduling problem using

decision tree solution method. However, in both of the above mentioned approaches, generation is scheduled a priori and then the reserve is scheduled, in the other words this is the sane sequentially scheduling. Restrepo et al proposed an approach in formulation of unit commitment considering primary and tertiary reserve constraints simultaneously in [5]; they have used GAMS software to solve the simultaneous scheduling as a mixed integer linear problem using linearization of quadratic cost function. The paper published by Galiana and colleagues indicates that simultaneous method increases social welfare [6]. In [9], Rajabi mashhadi et al have published a paper about impacts of capabilities and constraints of generating units on simultaneous scheduling of energy and primary reserve but all of the proposed constraints in [10] is not considered in this paper. [11], [12], [13] are other papers which are associable to provision of frequency reserves.

In the work reported by Ebrahimi and Mozafari, optimal load frequency control in a two-area interconnected power system based on genetic algorithm is presented [14].

This seems that the scheduling of energy and primary reserve is studied in several researches using simultaneous and sequential methods. However, the mathematical configuration of simultaneous scheduling of energy and reserve has not been attended by authors, in the other words they have focused on final solution instead of solution method.

This paper is focused on simultaneous scheduling of energy and primary reserve. The reserve should suffice for compensating large and sudden outages, in the form of loss of one or more generating units, in an isolated power system.

In this paper, the proposed method breaks the original simultaneous scheduling problem in two optimization problem including an inner and an outer loop. But this is not a sequential technique.

To obtain the globally optimal scheduling of energy and reserve, a heuristic iterative method based on genetic algorithm will be used in outer loop and quadratic programming technique is used to solve the non linear quadratic problem in inner loop. All operational and general constraints for scheduling of energy and reserve presented in previous works are considered in proposed formulation. The simulation results verify the accuracy and rapidity of the proposed methodology in comparison with previous methods. In addition, the final solution is applicable and the method needs low computational time.

2. Problem formulation

In this section, problem formulation of simultaneous scheduling of energy and primary reserve for an isolated power system are presented. It should be noted that loads respond to frequency deviation inherently, denoted as load damping effect, however it is neglected in following problem formulation. The power market in this paper is assumed as *pay as bid* and the contingency has been considered as $N-m$ though the contingency is considered in the form of $N-1$ in simulation results.

According to previous researches the objective function to minimize can be expressed as Eq(1), where the objective function includes operation cost as first part and primary reserve cost as second part.

It should be noted that primary reserve scheduling costs consist of two terms, 1) Preparation costs and 2) deployment costs. In continue, the second part is neglect in problem formulation and just the first part of these costs is considered and just primary reserve is discussed in problem formulation. Full considering for primary, secondary and tertiary reserve is given at appendix.

$$\begin{aligned} \text{Min} : & \sum_i \sum_t [y_{it} C_{it}^{su} + z_{it} C_{it}^{sd} + C_{it}(g_{it}, u_{it}) \\ & + C_{it}^{pr}(r_{it}^{pr})] \end{aligned} \quad (1)$$

Operation costs include start-up, shut-down and running costs. It is assumed that running costs of generating units are defined by a quadratic polynomial as equation (2) and primary reserve is assumed as a simple linear equation as Eq(3), [5],[9],[10].

$$C_{it}(g_{it}, u_{it}) = u_{it} \cdot c_i + b_i \cdot g_{it} + a_i \cdot g_{it}^2 \quad (2)$$

$$C_{it}^{pr}(r_{it}^{pr}) = q_{it}^{pr} \cdot r_{it}^{pr} \cdot v_{it} \quad (3)$$

In continue, the general constraints of simultaneous scheduling are presented.

I) Pre-contingency system power balances, here the system loss has been neglected.

In condition of considering power losses, total generating output must be equal to demand plus loss during each hour.

$$\sum_i g_{it} = d_t \quad (4)$$

II) Specified limits of generating units as below.

$$u_{it} \cdot g_i^{\min} \leq g_{it} \leq u_{it} \cdot g_i^{\max} \quad (5)$$

III) Upper limit of primary reserve, in this paper, contingencies defined by loss of pre-specified combinations of generating units. This implies that following each contingency, only negative frequency deviations will occur. Figure 1 illustrates the relation between primary reserve and frequency deviation for an arbitrary unit i . the upper generation bound, $\bar{g}_{it}$, used in Eq(6) is the maximum output of unit i under primary frequency regulation, defined by either the unit frequency-regulation ramp limit, $r_i^{pr-\max}$, or by unit generating capacity limit, $g_i^{\max}$, whichever is smaller. Unit frequency-regulation ramp limit is the maximum reserve that a unit can produce within 10 seconds following a contingency.

$$r_{it}^{pr} = \begin{cases} -\frac{1}{R} \Delta f_i^b, & \text{if } \Delta f_i^b \geq \Delta f \geq 0 \\ \min(g_i^{\max} - g_{it}, r_i^{pr-\max}) = \bar{g}_{it} - g_{it}, & \text{if } \Delta f \geq \Delta f_i^b \end{cases} \quad (6)$$

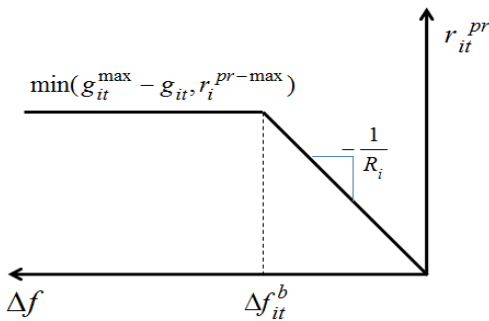


Fig.1: Primary reserve characteristics of unit i

On the other hand, the relation between primary reserve and frequency deviation is linear according to droop of unit before the vertical line, $\Delta f = \Delta f_i^b$, and for frequency deviation more than Δf_i^b , it is restricted to unit generating capacity limit or ramp up limit.

IV) summation of scheduled primary reserves of participating units must be greater than or equal to total lost generation, Since generation and demand must balance under each of the order of contingency, the remaining healthy generating units must provide enough reserve to make up for the lost generation

under any contingency, occurring during any time interval t of the scheduling horizon. These requirements for primary reserve are as below:

$$\sum_{i=1, i \neq j}^n u_{it} \cdot v_{it} \cdot r_{it}^{pr} \geq \sum_{j \in s^k} u_{it} \cdot g_{jt} \quad (7)$$

The above inequality restricts the values of primary reserves to a lower limit.

V) Critical system frequency deviation allowed, to avoid load shedding by under-frequency relays, the frequency deviations must be limited as follows: [5]

$$|\Delta f| \leq |\Delta f_{cr}| \quad (8)$$

Where, Δf_{cr} is the minimum allowed negative frequency deviation. This constraint represents that the employment of primary reserve should not be entailed to an inordinate decline in nominal frequency. Athwart the aspect of relation (8) seems to be a nonlinear constraint but it is a linear constraint unlike what it seems to be. so it is possible that the above relation be rewritten as below:

$$r_{it}^{pr} \leq \frac{\Delta f_{cr}}{R_i} \quad (9)$$

It should be mentioned that both of Δf_{cr} and R_i are per unit parameters. Since we defined two upper restrictions in addition to Eq(9) heretofore so a general relation is able to be written as follows:

$$r_{it}^{pr} \leq \min(g_i^{\max} - g_{it}, r_i^{pr-\max}, \frac{\Delta f_{cr}}{R_i}) \quad (10)$$

VI) The scheduled primary regulation reserve for unit i , r_i^{pr} , must be greater than or equal to the maximum generation deviation relative to the pre- contingency level over all contingencies [10].

$$\Delta g_{it}^j \leq r_{it}^{pr} \quad (11)$$

The final solution of scheduling problem will not be applicable if the above constraint is not satisfied. This important matter is not considered in [9] during optimization process and explained in [10] perfectly. This is the single nonlinear constraint of simultaneous scheduling of energy and primary reserve which is considered in solution method using a novel approach in this paper.

Other conventional constraints for short time scheduling of unit commitment such as minimum up time, minimum down time, start up cost and shut down cost of units can be considered in optimization process. However, in this paper, only start up cost constraint has been considered.

3. Proposed solution method

The type of simultaneous scheduling of energy and primary reserve is a Mixed Integer Non Linear Programming (MINLP) problem [5]. Where the binary variables are the representation of on/off status and continual variables represent the values of generation and reserves. In solving this problem two important challenges arise: 1) the fact that primary reserve of unit i must lie on the piece-wise curve imposed by Eq(6), particularly considering that the elbow of this curve is described by two decision variables, one is the saturation level, $\bar{g}_{it} - g_{it}$, and the corresponding frequency deviation is another. 2) The fact according to Eq (12), the variable, $\bar{g}_{it}$, is defined as the minimum of two variables [5].

$$\bar{g}_{it} = g_{it} + \min(g_i^{\max} - g_{it}, r_i^{pr-\max}) \quad (12)$$

The performance of genetic algorithm does not depend on derivable or convexity of the objective function and here the optimization problem is a MILNP problem. The genetic algorithm which is one of most popular heuristic methods is capable to converge to global optimal solution [15]. More about Genetic Algorithm are expressed at the appendix. Genetic algorithm has been commonly applied to solve similar optimization problems [16], [17]. In this method, the ineligible statuses of units have been sieved in optimization process using some algebraic analysis on the mathematical structure of simultaneous scheduling problem. Although the proposed method can be used in a multi period scheduling but the method only is implemented on a single period scheduling for simplicity. The primary process of solution method has been extracted from [9] but considering all of the proposed constraints in [10] for simultaneous scheduling problem. In continue it is assumed the AGC is not installed on the system and tertiary reserve will be prepared subsequently so the secondary and tertiary reserves are not considered.

3.1 Encoding binary variables

In this paper, it is assumed that each unit can lie in three modes which are: 1) unit is shut down, 2) unit is turn on but does not participate in frequency control, 3) unit is turn on and has participated in frequency control as shown in table 1

Table 1. Possible status binary variables

u	v
0	0
1	0
1	1

According to the above table, the status of each unit can be defined by two bits with a decimal upper limit restricted to three [15]. Figure 2 illustrates a schematic representation of an individual chromosome typically.

1	0	1	1	1	0		1	0	0	1
unit 1		unit 2						unit n		

Fig.2: Arbitrary chromosome schematic

3.2 Determination of solution feasibility

In [9], several beneficial relations are presented to identify and eliminate the infeasible chromosomes from candidate solutions in genetic algorithm. Some of them are the same preconditions of unit commitment problem and some are extracted based on specified limitations including ram up limit and generation limits.

In order to express the proposed method we recast the Eq (10) as below:

$$Eq(10) : \begin{cases} u_{it} \cdot r_{it}^{pr} \leq g_i^{\max} - g_{it} \\ u_{it} \cdot r_{it}^{pr} \leq r_i^{pr-\max} \\ u_{it} \cdot r_{it}^{pr} \leq \frac{\Delta f_{cr}}{R_i} \end{cases} \quad (13)$$

The expression of Eq (15) is indicated in Figure 3.

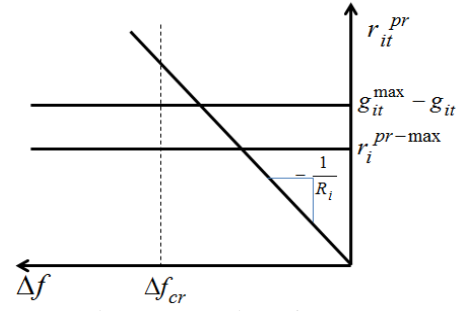


Fig.3: Expression of Eq (13)

Figure 3 illustrates that three bounds are defined for primary reserve. There are twins on the vertical axis due to spinning capacity limit and ramp up limit and one on the horizontal axis due to critical frequency deviation allowed.

Now assume a contingency of the order of $N-1$ has occurred, in the other words, system operator has lost one of generating units and system frequency is fallen at a final value in steady state. Draw a virtual vertical line at $\Delta f = \Delta f^k$, where Δf^k is the steady state frequency deviation. Obviously the virtual line hits the horizontal bounds and slopping line. So we have three reserves for each participating unit but the minimum value is correct according to (10). It is clearly that the system frequency reaches steady-state at a value that causes the sum of the on-line generators output to be equal to the system load so the sum of the reached primary reserves must be equal to lost generation in steady state formed as equation (14).

$$\sum_{i=1, i \neq j}^n \min(g_i^{\max} - g_i, r_i^{pr-\max}, \frac{\Delta f^k}{R_i}) = g_j \quad (14)$$

Since Δf^k , is less than Δf_{cr} , so at $\Delta f = \Delta f_{cr}$ the relation (14) can be recast as (15).

$$\sum_{i=1, i \neq j}^n \min(g_i^{\max} - g_i, r_i^{pr-\max}, \frac{\Delta f_{cr}}{R_i}) \geq g_j \quad (15)$$

The left part of the above relation is a sum of minimum values of several terms so it can be rewritten as below from mathematical point of view.

$$\sum_{i=1, i \neq j}^n g_i^{\max} - g_i \geq g_j \quad (16)$$

$$\sum_{i=1, i \neq j}^n r_i^{pr-\max} \geq g_j \quad (17)$$

$$\sum_{i=1, i \neq j}^n \frac{\Delta f_{cr}}{R_i} \geq g_j \quad (18)$$

Notice that many relations in addition to the above equations can be written; for the same reason the above relations are some necessary conditions and not enough conditions. If we write the Eq (16) for all sets of lost generating units ($j=1, 2, \dots, n$) and then sum them to each other, with attention to equation (4), we have:

$$\sum_{i=1}^n (g_i^{\max}) \geq \frac{\sum_{i=1}^n u_i}{\sum_{i=1}^n u_i - 1} d \quad (19)$$

similarly, if the above computation be implemented on the relation (17) and (18), new preconditions will be obtained as follows:

$$\sum_{i=1}^n (r_i^{pr-max}) \geq \frac{d}{\sum u_i - 1} \quad (20)$$

$$\sum_{i=1}^n \left(\frac{\Delta f_{cr}}{R_i} \right) \geq \frac{d}{\sum u_i - 1} \quad (21)$$

Relations (19- 21) are valid against contingency of the order of $N-1$. For condition of contingency with order of $N-m$ the relations (22-25) can be used to eliminate the impossible status of units.

These preconditions assure that binary genetic algorithm works with feasible chromosomes.

$$\sum_{i \in S^v} (g_i^{max}) - \sum_{i \in S^v} (g_i^{min}) \geq \max(\sum_{i \in S^k} g_i^{min}) \quad (22)$$

$$\sum_{i \in S^v} (u_i \cdot r_i^{pr-max}) \geq \frac{m}{\sum u_i - m} d \quad (23)$$

$$\sum_{i \in S^v} (u_i \cdot \frac{\Delta f_{cr}}{R_i}) \geq \frac{m}{\sum u_i - m} d \quad (24)$$

$$\sum_{i=1}^n (u_i \cdot g_i^{max}) \geq \frac{\sum u_i}{\sum u_i - m} d \quad (25)$$

Figure 4 Shows the flowchart of the proposed solution method based on application of defined preconditions. The flowchart shows the general flow for the various stages of our method. While initial population, in the method, is randomly generated, binary variables are encoded especially. In each step, population is checked for the solution feasibility and infeasible strings are eliminated. Therefore, new random populations are generated. This would ensure that only feasible strings are considered for solving the problem of simultaneous scheduling of energy and primary reserve. Major steps in flowchart are explained as below:

In first stage, the problem data are collected. In the second step, a set of initial values is generated randomly for binary variables. Third step according to proposed preconditions determines the feasibility of binary population. In fourth step, the values of primary reserves and generation outputs, for feasible binary variables, will be obtained solving the linear constrained quadratic program. In this step also the fitness function for feasible subset of binary population will be computed. The fitness function will be penalized for infeasible subset of binary population. In fifth step the values of fitness function with binary population are sent to genetic algorithm. New population generated by genetic algorithm is replaced by old population and this process, steps 1 to 5, will be continued until the stopping criterion is satisfied. In sixth step, the optimal solution will be applied to a modificative algorithm.

In the flowchart, Blok 4 and 18 are not embedded in previous work reported in [9]. Here, Blok 4 prevents ineligible strings and Blok 18 reduces computational time because it is done outside of optimization process. Blok 18 tasks to justify the constraint defined by Eq (11). In the other words, in Blok 17 optimal generations and primary reserves are defined but it is possible that the post contingency generation deviation of healthy generating units be greater than scheduled primary reserves for some generating units [10]. So the scheduled primary reserves must be modified finally, this important is the task of Blok 18.

Figure 5 illustrates the modificative algorithm for a typical 4 unit case study.

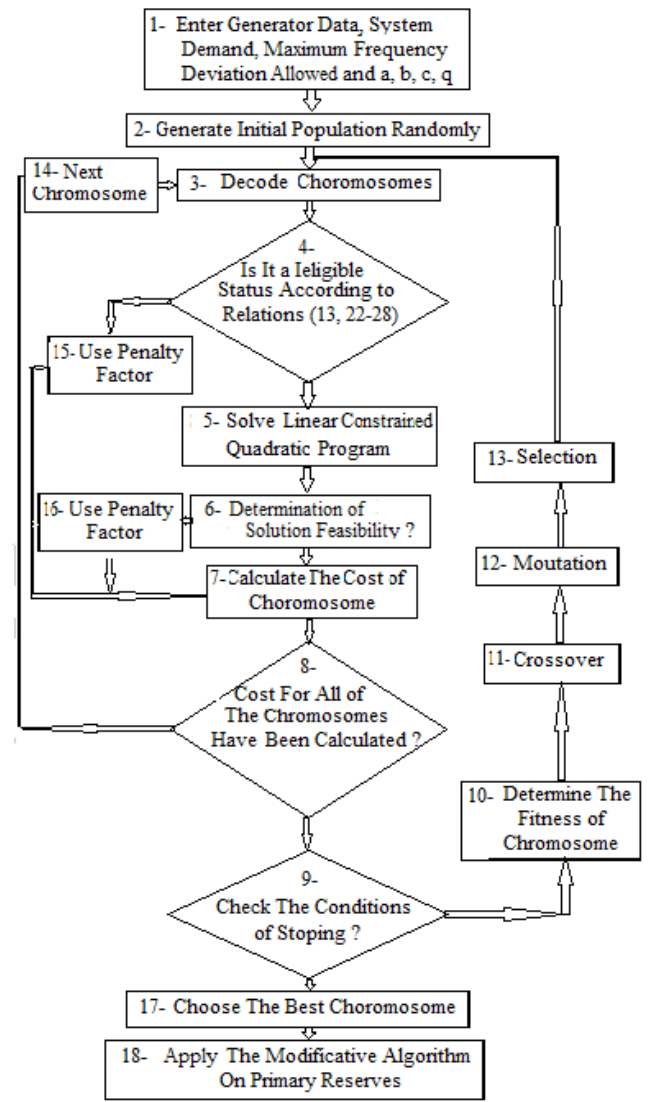


Fig.4: The flowchart of proposed method

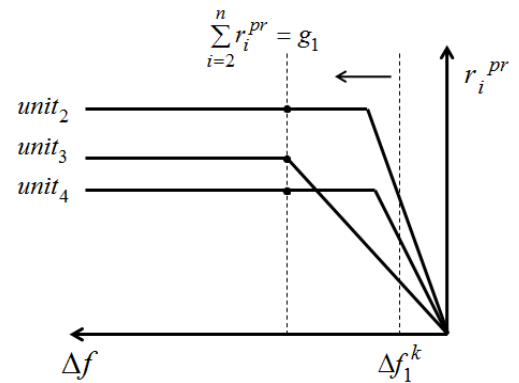


Fig.5: Modificative algorithm of Blok 18

After determination of generations and reserves, Figure 5 can be depicted and then the vertical line, $\Delta f_1^k = 0$, can be drawn while one(or more) of units has been lost. This line hit the steady state speed characteristic (droop) of participating units. Then Δf_1^k will be increased continually while total sum of reserves to be equal to lost generation. This method is employed for other units successively and table 2 will be obtained finally.

Amounts needed for primary reserves are the maximum values of any column of table 2 for each participating unit.

Although in this paper the regulated primary reserves are being reappraised but this is different in comparison with sequential scheduling and not be mistaken with sequential method because

in sequential method the generating units output (g_i) are obtained from unit commitment and economic dispatch.

Table 2: Modification of primary reserves

lost unit	r_1	r_2	r_3	r_4
Unit 1	0	r_{12}	r_{13}	r_{14}
Unit 2	r_{21}	0	r_{23}	r_{24}
Unit 3	r_{31}	r_{32}	0	r_{34}
Unit 4	r_{41}	r_{42}	r_{43}	0

4. Case study and simulation results

In this section the proposed method to solve simultaneous scheduling of energy and primary reserve is tested on an isolated power system including 17-generating units. This system is scheduled over a 1-h horizon, using generator data from an existing study [7]. System frequency and maximum allowed frequency deviation have been assumed to be 50 Hz and -500mhz, respectively. The demand of the system has been to be 1500MW. The droops of all units is assumed to be 5%. In this case, loss of one generating unit (N-1) at a time has been considered as the security criterion [18],[19]. The initial population, in the method, is randomly generated; population size and the maximum generation of GA are 20 and 200, respectively. Crossover and mutation probabilities are considered to be 0.8 and 0.01, respectively.

Table 3 presents the number of infeasible status in comparison with all of possible status of units which are identified using proposed preconditions in (19-25). The feasible search space of optimization problem is around 15% of the initial search space. Initial search space includes ineligible and eligible status. Whereas it was around 87% of initial search space if the proposed preconditions be not used. So there is a vast search space reduction for a highly constrained mixed integer optimization problem.

Furthermore, the feasible search space is able to be reduced more using rather extractable relations, but inordinate reduction in feasible search space hazards the genetic algorithm convergence because we are generating initial population randomly. In other words, there is a tradeoff between convergence time and initial feasibility.

In Table 4, generation output and primary reserve using proposed method are presented in comparison with results in [5],[10] for the same case study.

Table 3: status in case study

Total number of ineligible and eligible status	Number of identified strings by method in [9]	Number of identified strings using proposed relations
129140163	17063424	92078278

The results express that the operation costs are declined 7% compared to [10]. Furthermore the computational time improvement is the additional advantage of this methodology.

Figure 6 illustrate the primary reserve levels and break frequency for each participating unit. This is a graphical expression of table 4.

Relation (8) presents the allowed frequency deviation limit. According to the first assumpsit the frequency deviation must be less than or equal to 500 mhz following loss of any

generating unit. If we shut down an individual generating unit due to a virtual contingency in the form of loss of one generating unit, Δf^k and desired primary reserve values will be obtained for all generating units as shown in Table 5 and Table 6, respectively. Table5 indicates that the maximum frequency deviation is equal to 324.4 MHz against outage of A, B, E, F, J. frequency deviation will be at minimum value following loss of unit P because generation output for this unit is smallest output value (Table4). Whereas, the relation (11) is considered in problem formulation, so the desired primary reserves (Table 6) , altogether, are less than scheduled primary reserves unlike the previous works such as [9].

Table 4: Simulation results in comparison with [10]

<i>unit</i>	<i>g</i> MW	<i>r</i> MW	Δf_b mhz	<i>g</i> MW	<i>r</i> MW	Δf_b mhz
A	166	26	197.0	166	26	197.0
B	167	25	209.7	167	25	209.7
C	134	20	324.7	134	20	324.7
D	108	15	304.9	108	15	304.9
E	176	16	170.9	176	16	170.9
F	177	15	152.4	177	15	152.4
G	—	—	—	86	5	137.4
H	—	—	—	—	—	—
I	123	21	191.6	70	21	191.6
J	173	19	172.1	173	19	172.1
K	—	—	—	—	—	—
L	—	—	—	—	—	—
M	104	10	219.3	104	10	219.3
N	111	15	297.6	111	15	297.6
O	—	—	—	—	—	—
P	61	10	211.9	—	—	—
Q	—	—	—	28	5	201.6
cost	55675.6£			58412£		
	proposed method			method in [10]		

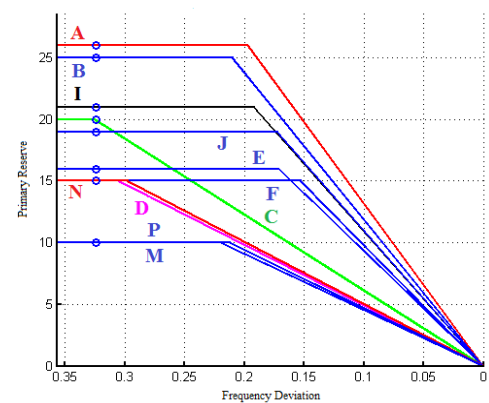


Fig.6: Primary reserve levels and break frequencies

It should be mentioned that maximum Δf^k_i is less than or equal to maximum break frequency deviation (Δf^i_b). Here, it is satisfied as $324.4 < 324.7$.

Some of frequency deviations in Table 6 are equal to zero because some of units don't participate in frequency control.

Presented numbers in Table 4 as scheduled primary reserves are the maximum values of the respective column of Table 6.

Figure 7 shows the convergence trend of the genetic algorithm during 200 generations. Since the ineligible chromosomes are

penalizing, hence they have much expense and been appeared just in first generations.

Table 5: The values of steady state frequency deviation following loss of any generating unit

Lost Generating Unit	Δf^k (mhz)
A	324.4
B	324.4
C	157.1
D	124.4
E	324.4
F	324.4
G	0
H	0
I	152.8
J	324.4
K	0
L	0
M	119.3
N	128
O	0
P	69.7
Q	0

Table6: Desired primary reserves against loss of any generating unit

		Loss of unit ...										
		A	B	C	D	E	F	I	J	M	N	P
Desired primary reserve of unit ...	A	0	25	20	15	16	15	21	19	10	15	10
	B	26	0	20	15	16	15	21	19	10	15	10
	C	21	19	0	7.7	15	15	17	17	7.2	7.9	7.4
	D	16	15	7.7	0	12	12	14	14	5.7	6.3	5.9
	E	26	25	20	15	0	15	21	19	10	15	10
	F	26	25	20	15	16	0	21	19	10	15	10
	I	20	18	9.4	7.5	14	15	0	17	7	7.7	7.2
	J	26	25	20	15	16	15	21	0	10	15	10
	M	16	14	7.3	5.9	11	12	13	13	0	6	5.6
	N	17	15	7.9	6.3	12	13	14	14	5.8	0	6
	P	9.2	8.3	4.3	3.4	6.5	6.9	7.6	7.7	3.2	3.5	0

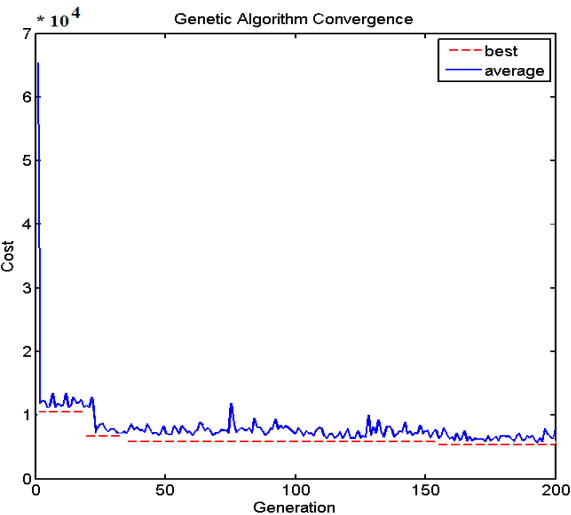


Fig.7: Genetic algorithm convergence

5. Conclusion

A 1-hour unit commitment problem subject to primary regulation reserve constraints is formulated in this paper. This problem has not received as much attention in the previous works. It is considered that some participating generating units are allowed to do not participate in primary frequency control due to defining binary variable v_i in problem formulation. Since the type of simultaneous Scheduling problem is MINLP, so a novel method based on binary genetic algorithm is proposed. In this research, only credible contingencies, negative frequency deviation following each contingency have been considered. In this novel method, statuses of generating units are expressed as binary variables. In addition, some preconditions are presented to identify the ineligible chromosomes in each population which have not also received enough attention too. These preconditions very seriously will cause a significant reduction in the computational time. Finally, the proposed approach has been implemented on an isolated power system and the simulation results are presented in comparison with a previous work. Results indicate that the final solution is practical and more optimal. The proposed method is easy to implement with low computational time and numeric results show that our method has the following merits: efficient searching ability, robustness in result.

ACKNOWLEDGMENT

Many thanks go in particular to Mr.Ghasemnejad for his contributions during the preparation of this paper.

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A. APPENDIX

A.1 Genetic Algorithm

Heredity or Genetic algorithms are practical, robust optimization and search techniques. Genetic algorithms were invented by Holland to mimic some of the processes of natural evolution and selection. These algorithms are different from most of the conventional optimization methods and these algorithms need design space to be converted into genetic space. A more striking difference between genetic algorithms and most of the traditional optimization methods is that GA uses a population of points at one time, in contrast to the single point approach by traditional optimization methods. The most interesting aspect of GA is that they do not require any prior knowledge of the function to be optimized and they exhibit very good performance on the majority of the problems applied.

The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population evolves towards an optimal solution. The genetic algorithms can be used to solve a variety of optimization problems that are not well suited for standard optimization algorithms. The basic structure of the genetic algorithm is given below:

A.1.1: Initial population. The GA operates on a population of consisting of a number of chromosomes simultaneously. The

initial population of binary numbered vectors (in BGA) is created randomly. Each of these vectors represents one possible solution to the search problem. Based on the size of search space the population size needs to be selected.

A.1.2: Fitness evaluation. Fitness evaluation is a procedure to determine the fitness of each string in the population. The fitness value is the only information available to the GA and the performance of the algorithm is highly sensitive to the fitness values. As the algorithm proceeds, we would expect to increase the individual fitness of the best chromosome as well as the total fitness of the population as a whole.

A.1.3: Stopping criterion. After the calculation of fitness values of each chromosome the next step is to check the termination criterion. Termination criterion of the GA decides whether to continue searching or stop the search.

A.1.4: Reproduction. During the reproductive phase of the GA, good chromosomes (parents) in pairs are selected from the current generation's population for producing offspring and placing them in the next generation's population. Parents are selected randomly from the population using a scheme which favors the more fit individuals. Good individuals will probably be selected several times in a generation; poor ones may not be at all. This can be achieved by many different schemes, but the most common method is the roulette wheel selection. Roulette wheel with a pointer is shown in Figure 8.

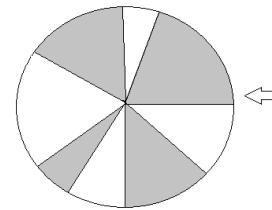


Fig.8: Roulette wheel with a pointer

A.1.5: Crossover. The crossover operator is the main search tool. It mates chromosomes in the mating pool by pairs and generates candidate offspring by crossing over the mated pairs with probability P_c as shown in Figure 9. There are many types of crossover techniques available in the literature.

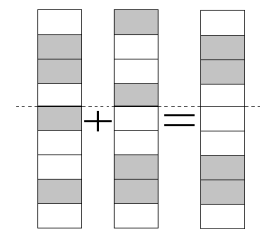


Fig.9: Crossover

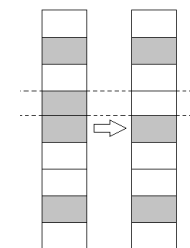


Fig.10: Mutation

A.1.6: Mutation. After crossover, some of the genes in the candidate offspring are modified with a small mutation probability P_m as shown in Figure 10. The mutation operator is included to prevent premature convergence by ensuring the population diversity.

The flowchart of the Genetic Algorithm is shown in Figure 11.

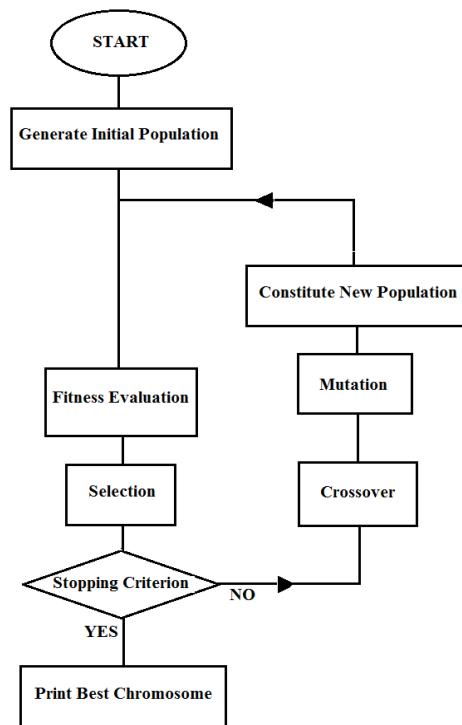


Fig.11: The Flowchart of genetic algorithm