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Power Flow Tracing Based Reactive Power Ancillary Service (AS) in Restructured Power Market

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***Abstract*—**Ancillary services are support services which are essential for humanizing and enhancing the reliability and security of the electric power system. Reactive power ancillary service is one of the important ancillary services in a restructured electricity market which determines the cost of supplying ancillary services and finding of how this cost would change with respect to operating decisions. This paper presents a new formation that can be used to minimize the Independent System Operator (ISO)'s total payment for reactive power ancillary service. The modified power flow tracing algorithm estimates the availability of reserve reactive power for ancillary service. In order to find optimum reactive power dispatch, Biogeography based optimization method (BPO) is proposed. Market Reactive Clearing Price (MRCP) is then estimated and it encourages generator companies (GENCOs) to participate in an ancillary service. Finally, optimal weighting factor and real time utilization factor of reactive power give the minimum ISO's total payment. The effectiveness of proposed design is verified using IEEE 30 bus system.

***Keywords*—**Biogeography based optimization method, Power flow tracing method, Reactive generation capability curve and Reactive power ancillary service.

I. INTRODUCTION

IN a competitive electricity market, sufficient freedom is provided to the market participants to interact among themselves. Here, both the buyers and sellers try to buy and sell electric power so as to maximize their profit. In such a situation, to meet the desired transactions, power flow in the transmission network violates some of the physical limit of the transmission system. Hence, to maintain the market efficiency, it is very important to trace the power flow in transmission line and to dispatch the generation optimally to load.

The phenomenon of economic dispatch of reactive power is observed in both vertically integrated and restructured power market. In a competitive electricity market, apart from main transactions of energy and power, Independent System Operator (ISO) has to arrange or procure certain services required for maintaining the quality and security of supply. Among different issues in restructured environments, ancillary services are one of the most important subjects which have essential role in power system operation and security [1]. The FERC rule defined six ancillary services and Reactive power provision is one of the important ancillary services which are essential in power system to maintain stability and security [2]. In restructured electricity markets, procurement of reactive power ancillary services is a multifaceted issue for the independent system operator due to various factors that need to be considered [3]. According to CERC, ancillary services are necessary to support the transmission of power from sellers to buyers given the obligation of control areas and transmission utilities to maintain a reliable operation of the interconnected transmission system [4]. Some methodologies have been proposed to allocate cost for reactive supply and voltage control services. These Methodologies make great differences which depend directly on considerations and mathematical models. Hernandez et al. proposed a methodology to allocate reactive power ancillary service into a deregulated environment with centralized decision-making and cost-based approach [5]. A novel reactive power market clearing algorithm for forward ancillary services market is presented in paper [6]. A nonlinear constrained optimization problem and sequential quadratic programming is used to solve the problem. However, it does not evaluate the reactive power service. A reactive bidding structure is established for which they define three operational regions in order to formulate the generator's expectation of payment function. A possible model for market settlement and obtaining uniform market clearing price for all the providers is given in [7]. The impact on nodal prices has been determined for hybrid electricity markets are presented in [8]. Based on power flow tracing, a cost allocation for reactive power service is given in [9]. Modified power flow tracing method is used for tracing reactive power flow in a meshed electrical network without adding fictitious nodes on transmission line [10]. Reactive power management and payment mechanisms differ from one electricity market to another and uniform structure or design is not yet evolved. A unified frame work to manage reactive power in deregulated electricity market is presented in paper [11]. The Profitable sale of reserve to the determination of the optimal level of security is discussed in paper [12].

Different countries use different methods for reactive power clearing price. As an example, New York ISO uses an embedded cost for their reactive power services [13]. In California market, when they are working in the range of 0.9 lagging to 0.95 leading power factor generators do not receive any payments for reactive power provision [14]. In Australia, both synchronous generators and synchronous condensers receive payments for reactive power provision [15].

Various optimization methods like genetic algorithm (GA) [16], artificial neural network (ANN) [17], evolutionary

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programming (EP) [18] and ant colony optimization [19] have been employed to find optimum dispatch of generation to load. Very recently, a new optimization concept, based on biogeography based optimization method, has been proposed by Simon [20]. In this paper, two methods are applied to find the final minimum ISO's total payment. The first method (Method-1) uses power flow tracing algorithm to identify generator contribution to the loads and is discussed in Section II. The second method (Method-2) employs Biogeography based optimization method to optimally dispatch the reactive power generation with minimization of ISO's total payment. It is described in Section III. Ancillary service market settlement is presented in Section IV. Finally, the summary of Biogeography based optimization algorithm to satisfy ISO requirement is examined in Section V.

II. MODIFIED POWER FLOW TRACING METHOD

Tracing methodology generally deals with a problem of distributing flows in a meshed network. The modified Power flow tracing method generally deals with a problem of distributing flows in a meshed network. It applies Kirchhoff's current law at the nodes and proportionality sharing principle to find the relationship between incoming and outgoing flows. The only assumption made is that the system is lossless.

This method presents upstream algorithm to evaluate the contribution of generators to nodal power, line flow and load. Also, it presents downstream looking algorithm to find the contribution of load to nodal power, line flow and generators [21].

The total inflow Q_i through node *i* can be expressed as

$$Q_i = \sum_{j\in\alpha_i^{(u)}} \left|Q_{i-j}\right| + Q_{Gi} = \sum_{j\in\alpha_i^{(u)}} C_{ji} Q_{j_j} + Q_{Gi} \quad i = 1, 2,3 \ldots n \tag{1}$$

where, $\alpha_i^{(u)}$ is the set of nodes supplying the power directly to the node '*i*'. Q_{i-j} is the power flowing from node *i* to node. Q_{Gi} is the ith bus generating power and

$$C_{ji} = \left|Q_{j-i}\right| / Q_j$$

Therefore, (1) can be rewritten as

$$Q_i - \sum_{j\in\alpha_i^{(u)}} C_{ji} Q_j = Q_{Gi} \quad \text{(or)} \quad A_u^P = Q_G \tag{2}$$

where A_u is an (n × n) upstream distribution matrix. *P* is the vector of nodal through flows and Q_G is the vector of nodal generations.

The Elements of upstream distribution matrix can be calculated by

$$[A_u]_{ij} = \begin{cases} 1 & \textit{for} \quad i = j \\ -C_{ji} = -\left|Q_{j-i}\right| \big/ Q_j & \textit{for} \quad l \in \alpha_i^{(u)} \\ 0 & \textit{otherwise} \end{cases}$$

The contribution of kth generator to ith load is found out using

$$Q_{Li} = \frac{Q_{Li}}{Q_i} Q_i = \frac{Q_{Li}}{Q_i} \sum_{k=1}^{n} \left[A_u^{-1}\right]_{ik} Q_{GK} \quad \text{for i=1,2,...n.} \tag{3}$$

where, A_u is upstream distribution matrix. The procedure to solve this equation is clearly given in [21].

For Reactive power tracing, it uses equivalent π model of the transmission line. The reactive power generated by shunt admittance is also considered as fictitious generator connected to that bus which is supplying Q_{shunt} amount of reactive power. These fictitious generators at the nodes modify the reactive power flows in transmission lines. Also, the responsibility share of k^{th} load for reactive power loss in transmission line $i-j$ can be expressed as

$$Q_{Dij,k} = QD_{ij,k} Q_{Dij}$$

where,

$$QD_{ij,k} = \frac{\left(Q_{ij,k} \big/ (\sin\phi)_k\right)^2}{\sum_{k=1}^{l} \left(Q_{ij,k} \big/ (\sin\phi)_k\right)^2} \tag{4}$$

$Q_{Dij,k}$ is the reactive power loss allocated to the k^{th} load for the total reactive power loss in the transmission line $i-j$.

Initially, the reactive power contribution from generator to base load is estimated by using this method. From the results, the reserve quantity for reactive power ancillary service is estimated and is tabulated in Section VI.

III. REACTIVE POWER ANCILLARY SERVICE

The capability of a prime mover of a synchronous generator limits its real and reactive power output and is illustrated in Fig. 1. The armature and field winding heating limits determine the reactive power capability of a synchronous generator. In Fig. 1, P_G and Q_G are real and reactive power outputs of the generator respectively. The generator's MVA rating is the point of intersection of the two curves, and therefore its real power rating is given by P_{GR}. At an operating point A, with real power output P_{GA} such that $P_{GA} < P_{GR}$, the limit is imposed by the generator's filed winding; when $P_{GA} > P_{GR}$, the limit on Q_G is imposed by the generator's armature winding heating limit. The shaded area represents the obligatory base reactive power provision range set by the system operator. Any reactive power beyond this area is eligible for payment due to the increased cost of losses in the windings. Such ancillary payment estimation is necessary for reactive power management.

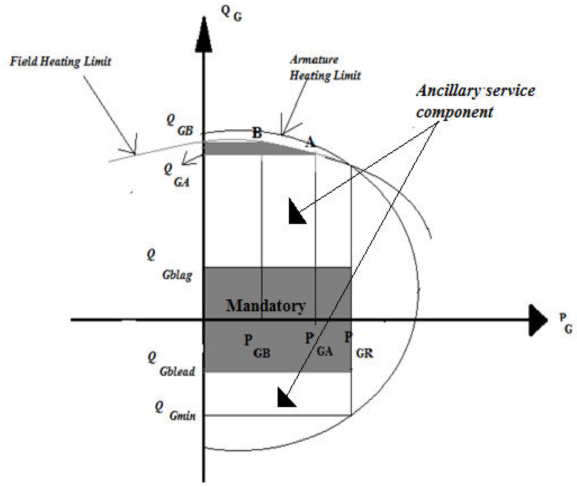

Fig. 1 Reactive generator capability curve

To facilitate an efficient trading of energy and ancillary services, a reasonable market structure is of great importance. In practice, market structures could differ according to their timing, the amounts of information individual suppliers provide to the ISO, and the role of ISO is in facilitating or controlling these markets. Energy trading is usually operated in forward markets, while ancillary services trading are operated in both forward and real-time markets. In forward markets, there are two different approaches to energy and ancillary services auctions: sequential and simultaneous depending on the amount of control delegated to the ISO. The sequential approach involves sequential computations in energy and ancillary services markets in which the results of one market would represent the starting point for the next market.

In a simultaneous auction market, the ISO would not redispatch the generation in an already closed market to adjust the second auction market. The simultaneous approach would simplify auction market and reduce auction market prices due to the integration of energy and ancillary services markets. In real-time markets, an important responsibility of the ISO is to maintain the real-time balance of energy and supply. This paper presents forward ancillary service scheduling using Power Flow Tracing with Biogeography Based Optimization (BPO) algorithm to minimize ISO's total payment.

IV. ANCILLARY SERVICE MARKET SETTLEMENT TO MINIMIZE PAYMENT

Since, ancillary service auctions are operated by the ISO, the ISO is a single buyer party to meet the reliability obligations. The ISO's objective is to minimize ancillary service payments to GENCOS while encouraging GENCOS to provide sufficient ancillary services. Based on the ISO's requirement for ancillary services, the participants' bids are submitted to the ISO, the price and quantity of each service is determined and payments are calculated by the ISO.

Then GENCOS submits two bids (capacity reservation bid and an energy payment) based on expected loads and ancillary services. Here, ISO is responsible for setting a reasonable value for weighting factor x to minimize the capacity reservation and energy payment while encouraging supplying enough ancillary services. Then, MRCP (Market Reactive Clearing Price) for the ancillary service is calculated by the ISO through a matching process between the participants' bids and GENCO's bids. If reliability requirements are met at this stage, capacity payment will be calculated and the final schedule will be published. Otherwise, the ISO will send signals to GENCOs to modify their bids. Energy payment will be calculated at the time of utilizations. The value of x will affect the ISO's energy payment indirectly and it assumes different values of real time utilization factor y. The value of y is between 0% and 100%, which corresponds to the reserved capacity not utilized at all or utilized fully respectively. This value is not known until the time of utilization. It affects the ISO's energy payment and has no effect on the Market reactive clearing price for the ancillary services or on the ISO's capacity payment. In this paper, modified power flow tracing method is applied to find reactive power reserve quantity. In order to estimate optimal reactive power dispatch of each generator, Biogeography based optimization method is employed.

A. Problem Formulation

The ARPS (Ancillary reactive power service) may be formulated as a nonlinear constrained problem. This ARPS problem works with the objective function of minimum ISO payment with quantity of reactive power, weighting factor and utilization factor constraint.

The objective of Minimum ISO's total payment F_t of ARPS problem may be written as

$$F_t = \min \sum_i \{[MRCP - x.E(i,t)] + [y.E(i,t)]\}.Q(i,t) \tag{5}$$

where, MRCP is the maximum reactive clearing price. $E(i,t)$ is energy bid (\$/M_{var}) component for the ancillary service offered by unit *i* at time 't',

The objective of ARPS problem consists in minimizing ISO's total payment subject to the following constraints

1) Quantity of Ancillary Service Constraint

$$\sum_i Q(i,t) \geq Q^{req}(t) \tag{6}$$

where, $Q(i,t)$ is the quantity of reactive power supply supplied by each generating unit at time t.
$Q^{req}(t)$ is the quantity of reactive power required for ISO.

2) Weighting Factor Constraint

$$0.0 \leq x \leq 1.0 \tag{7}$$

where x is the weighting factor. It will affect MRCP and the ISO's capacity payment directly. It affects the ISO's energy payment indirectly.

3) Real time Utilization Factor Constraint

$$0.0 \leq y \leq 1.0 \tag{8}$$

where 'y' is real time utilization factor.

4) Generator Capacity Constraint

$$Q_i^{\min} \leq Q_i \leq Q_i^{\max} \tag{9}$$

The reactive power generated by each generator shall be within their lower limit $Q_i^{\min}$ and upper limit $Q_i^{\max}$.

In order to solve this objective function, it is necessary to determine optimal dispatch of reactive power from the generator. This can be obtained using Biogeography Based Optimization method with the objective of

$$F_t = \min \sum_i \{[C(i,t) + \hat{x}.E(i,t)]Q(i,t)\}$$

V. REVIEW OF BIOGEOGRAPHY BASED OPTIMIZATION ALGORITHM

Biogeography Based Optimization (BBO) algorithm is developed by Simon [20]. Biogeography is a new kind of evolutional algorithm based on biogeography theory. In the context of biogeography, habitats are isolated from others and the distribution of kind among different habitats depend on their suitability index variables (*SIVs*) which include factors such as water resource, diversity of vegetation, diversity of topographic features etc. *SIVs* are considered as the independent variables of the habitat and can be used to calculate habitat suitability index *(HSI*).

Through sharing features information between good and poor solutions, a poor solution can obtain lots of good features and may become better one, and a good solution can also be improved by features from other better solutions than itself. *Ps*(*t*) denotes the probability that a habitat contains exactly *s* species at time *t*, then at *t*+Δt , *Ps* changes to:

$$P_s(t+\Delta t) = P_s(t)(1 - \lambda_s \Delta t - \mu_s \Delta t) + P_s - 1\lambda_s - 1\Delta t + P_s + 1\mu_s + 1\Delta t$$

where λ_s and μ_s are immigration rate and emigration rate respectively when there are kind in the habitat.

The optimization process in BBO is carried out with two mechanisms, viz migration and mutation. In Migration, population of candidate solution can be represented as vectors of real numbers. Each real number in the array is considered as one (SIV). Using this SIV, the fitness of each set of candidate solution, i.e., HSI value can be evaluated. In an optimization problem, high HSI solutions represent better quality solution and low HSI solutions represent an inferior solution. Then, due to some natural calamities or other events HSI of natural habitat might get changed suddenly. In BBO, such an event is represented by mutation of SIV and kind count probabilities are used to determine mutation rates.

Mutation rate of each set of solution can be calculated in terms of kind count probability using the following equation:

$$m(s) = m_{\max}\left(\frac{1 - P_s}{P_{\max}}\right) \tag{10}$$

where $m_{\max}$ is a user-defined parameter. This mutation scheme tends to increase diversity among the habitat. BBO algorithm for reactive power dispatch can be summarized as follows.

Step 1: Reactive power generations are taken as decision variables to represent individual habitat. It is represented as the *SIV* in a habitat. For initialization, number of *SIV* of BBO algorithm m , number of habitat is chosen. The complete habitat set is represented in the form of the following matrix:

$$H = \left[H^1, H^2, H^3, ... H^i, ... H^N\right]$$

where *i*=1,2,……*N* and *j*=1,2,3,…..*m* and H^i is the position vector of the habitat i . Size of the habitat is equivalent to the population size of GA. The element H^{ij} of H^i is the j^{th} position component of habitat i .

Step 2: Each element of the Habitat matrix, i.e., each *SIV* of a given habitat set H, is initialized randomly within the effective reactive power operating limits. For initialization, choose the number of generator units, i.e., number of *SIV* is *m*, number of habitat is *N.* Maximum and minimum capacity of each generator, power demand and B-coefficients matrix is specified for calculation of transmission loss. The BBO parameters like habitat modification probability Pmod, mutation probability, maximum mutation rate m_{max}, max immigration rate *I*, max emigration rate *E*, lower bound for immigration probability per gene, upper bound for immigration probability per gene, step size for numerical integration *dt*, elitism parameter 'p' etc are also initialized. Set maximum number of iteration. Each habitat represents a potential solution to the given problem.

Step 3: The *HSI* for each habitat set of the total habitat set for given emigration rate μ , immigration rate λ is calculated. HSI^i Indicates the capacity and energy cost due to the i^{th} set of generation value (i.e., i th set of habitat matrix *H*) in \$/h. If there are *m* units that must be operated to provide power to loads, then the i^{th} individual H^i can be defined as follows:

$$\begin{aligned} H^i = SIV^{ij} &= \left[SIV^{il}, SIV^{i2}, ...SIV^{im}\right] \\ &= \left[PG^{il}, PG^{i2}, PG^{i3}, ...PG^{im}\right] \\ &i = 1,2,.....N,.....S; j = 1,2,3,...m. \end{aligned} \tag{11}$$

The dimension of the habitat matrix is Sxm . All these components in each individual are represented as real values. The matrix represents the total habitat set.

Step 4: Based on the *HSI*, value elite habitats are identified. Here, elite term is used to indicate those habitat sets of generator power output which give optimum capacity and energy cost. After individual iteration, top "p" habitat sets are kept as they are without making any modification on them. Identification of valid species is a little interesting. Those habitats whose fitness values, i.e., *HSI* values are finite, are considered as valid species *S* in reactive power load dispatch problem.

Step 5: Probabilistically perform migration operation on those *SIVs* of each non-elite habitats, selected for migration. After migration operation, new habitat set is generated. In RPD (Reactive Power dispatch problem), these represent new modified generation values of generators (Q_G).Then Operating Limit Constraint $\sum_i Q(i,t) \geq Q^{req}(t)$ is satisfied.

Step 6: In mutation operation, that habitat set which is selected for mutation is simply replaced by another randomly generated new habitat set that satisfies both equality constraint and inequality constraints of ELD problems. *HSI* value of each new habitat set is recomputed, i.e., fuel cost of each power generation set.

Step 7: Go to step (3) for the next iteration. This loop can be terminated after a predefined number of iterations. After each habitat is modified (steps 5 and 6), its feasibility as a problem solution should be verified, i.e., each *SIV* should satisfy different operational constraints of generator as mentioned in the specific problem. Equality constraints should also be satisfied. The BBO simulation parameters employed in the present study are:

Habitat size=70
Habitat Modification probability=1
Immigration probability bounds per generator= [0, 1]
Maximum immigration & emigration rate for each island =1
Mutation probability =0.005.

VI. COMPUTATIONAL PROCEDURE

The Computational steps of scheduling ancillary service to obtain minimum ISO payment are listed below:

Step 1.Read system data, maximum limits on reactive power generation.

Step 2.Use Power flow tracing algorithm and obtain reserve reactive power quantity to each load during base load condition.

Step 3.From the results, the optimum value of reactive power from each generator is obtained using Biogeography based optimization algorithm for ancillary service.

Step 4.Initialize weighting factor x=0 and utilization quantity as y=0.

Step 5.Capacity bid $C(i,t)$, and energy bid $E(i,t)$ and quantity of each unit $Q(i,t)$ is taken from IEEE 30bus system.

Step 6.MRCP (Max Reactive clearing price) is calculated. It is the highest price among the accepted bids for ancillary service and is calculated as $[\max\{C(i,t) + \hat{x}.E(i,t)\}]$ and capacity payment is calculated using $[MRCP - \hat{x}.E(i.t)]$.

Step 7.ISO'S total payment for ancillary service is calculated using the expression as a function of y:

$$\sum_i \{[MRCP - \hat{x}.E(i,t)]] + [y.E(i,t)]\}.\hat{Q}(i,t)$$

where, $\hat{Q}(i,t)$ is the accepted quantity of each unit $'i'$ at time$'t'$.

Step 8.Increase x by a step size (Δx) (e.g.,0.1) to define the new x until x ≤ 1.0 and go to step 4.

Step 9.The ISO's total payment is listed as a function of x and y.

Step 10. The steps for different utilization factor from y=0.0 to y=1.0 are done and the ISO's Total payment is found.

VII. CASE STUDIES AND RESULT

A. 4 Bus System

In order to show the effectiveness of Reactive power tracing method, a sample 4 bus system is considered and is shown in Fig. 2. It has two generators at buses 1 and 4, four loads at buses 1, 2, 3, 4 and five transmission lines. Fig. 3 shows the lossless reactive power flow obtained from lossy flow of Fig. 2. Refer to (3), the upstream matrix (*Au*) for the 4bus system is found to be:

$$[A_u] = \begin{pmatrix} 1.0000 & 0 & 0 & -0.2224 \\ -0.1790 & 1.0000 & 0 & -0.3145 \\ -0.5390 & 0 & 1.0000 & -0.2500 \\ 0 & 0 & 0 & 1.0000 \end{pmatrix}$$

It shows the reactive power contribution from each generator to load.

B.30 Bus System

The proposed method for reactive power ancillary service is explained by taking IEEE 30 bus system [22] as test system. The system consists of 41 transmission lines, 23 load buses and 6 generators at buses 1, 2, 5, 8, 11, 13 with a load demand of 283.40 MW and 126.2 Mvar. The simulation is carried out using MATLAB environment. Equation (2) helps to determine the reactive power contribution to loads supplied by the individual generators and the results are given in Table I.

Reactive power tracing method is used to find actual contribution of generators to loads. Reserve capacity is the difference of $Q^{\max}$ and actually delivered. This value shows the availability of reactive power for ancillary service.

Table I shows the system consists of two generated companies (GENCOs): A and B, each has 3 generating units with a reserve capacity of 69.549 and 30.371.Then, ancillary service bids are submitted by each GENCO to the ISO. In case of 30 bus system, it consists of 6 generators and each generator's reserve capability is shown in Table II.

TABLE I
CONTRIBUTION OF GENERATOR TO LOADS OF 30 BUS SYSTEM

Generator	Capacity Bid ($/MVAr)	Energy Bid ($/MVArh)	Reserve capacity
Gen1	20	15	30.979
Gen2	25	10	28.059
Gen5	22	10	10.421
Gen8	20	12	16.9112
Gen11	12	11	0.491
Gen13	24	13	12.971

TABLE II
ANCILLARY SERVICE PRICE BIDS SUBMITTED BY GENCOS

UNIT	Generator	Delivered	Q^{max}	Reserve capacity
A	Gen1	19.021	50	30.979
	Gen2	11.941	40	28.059
	Gen5	19.579	30	10.421
B	Gen8	3.0888	20	16.9112
	Gen11	19.509	20	0.491
	Gen13	7.029	20	12.971

If the ISO has a reserve requirement is 65Mvar at the given hour, then it is chosen from reserve capacity.

TABLE III
REACTIVE POWER DISPATCH OF EACH GENERATOR UNIT TO SATISFY ISO REQUIREMENTS

ISO Requirement	GEN 1	GEN 2	GEN 5	GEN 8	GEN 11	GEN 13
65Mvar	30.979	0	10.42	16.91	0	6.68

The economic reactive dispatch from each GENCO is identified using Biogeography algorithm with minimum cost (i.e. minimum of capacity cost and energy cost) and the result is shown in Table III.

The accepted bidders with the corresponding MRCP and capacity payment for x=0.3 is presented in Table IV. Combined price is the combination of capacity bid and energy bid and is defined as $\{C(i,t) + \hat{x}.E(i,t)\}$. Maximum of combined Price is the Maximum reactive clearing price (MRCP). Equation (5) helps to find capacity payment.

TABLE IV
ACCEPTED BIDDERS AND PAYMENTS BY THE ISO(X=0.3)

GENCO		Combined Price $/MVAr	Capacity			
			Price $/MVAr	Quantity MVAr	Payment $	Sub-Total $
A	G1	21.5	23.4	30.979	724.9086	984.3
	G5	25	24.9	10.421	259.4829	
B	G8	23.6	24.3	16.9112	410.9422	571.4
	G13	27.9	24	6.6888	160.5312	
		MRCP =27.9		**Total =65**		**Total: 1555.8649**

Similarly, by varying weighting factor from x= 0 to 1with a change of 0.1 the result is obtained and is tabulated in Table V.

The minimum capacity payment for each weighting factor (X) is then estimated. The real time utilization factor(Y) which corresponds to the reserved capacity is varied. By varying X and Y, the total minimum ISO's payment is calculated and is tabulated in Table V.

TABLE V
CAPACITY PAYMENT FOR DIFFERENT VALUES OF 'X'

Units	x=0.1	x=0.2	x=0.3	x=0.4	x=0.5	x=0.6	x=0.7	x=0.8	x=0.9	x=1.0
1	1609.73	1594.24	1578.75	1563.26	1482.71	**1532.28**	**1516.79**	**1501.30**	**1485.82**	**1470.33**
2	1607.72	1590.44	1566.66	1568.88	1571.11	1573.33	1575.55	1577.77	1579.99	1603.54
3	1618.73	1612.47	1606.20	1612.94	1541.6	1639.41	1652.64	1665.88	1679.11	1692.35
4	**1558.62**	**1557.24**	**1555.86**	1554.48	1468.6	1551.73	1550.35	1548.97	1547.59	1546.21
5	1604.06	1584.65	1565.24	1558.81	1474.4	1558.95	1559.02	1559.09	1559.16	1559.23
6	1618.39	1611.79	1605.19	1611.59	1539.9	1637.39	1650.29	1663.19	1676.09	1688.98
7	1603.92	1582.85	1561.78	**1553.71**	**1467.6**	1550.56	1548.99	1547.42	1545.85	1544.28
8	1614.33	1603.66	1593.00	1595.33	1519.6	1613.00	1621.83	1630.67	1639.50	1648.34
9	1610.29	1593.08	1569.36	1571.68	1489.3	1576.32	1578.64	1580.96	1583.28	1585.60
10	1616.79	1608.60	1600.42	1592.23	1519.0	1575.86	1567.67	1559.49	1551.30	1543.118
	1558.6	**1557.24**	**1555.86**	**1553.71**	**1467.64**	**1532.28**	**1516.79**	**1501.30**	**1485.82**	**1470.33**

TABLE VI
MRCP AND TOTAL ISO PAYMENT

Real time utilization factor (Y)	**Weighting factor**									
	0.1	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
0	1558.62	1472.74	**1386.86**	1561.25	1638.21	1693.28	1516.79	1501.30	1485.82	1470.33
0.125	1665.97	1580.09	**1494.21**	1666.48	1745.80	1793.90	1617.42	1601.93	1586.44	1570.95
0.25	1773.31	1687.43	**1601.56**	1771.71	1853.39	1894.53	1718.04	1702.55	1687.06	1671.57
0.375	1880.66	1794.78	**1708.90**	1876.95	1960.98	1995.15	1818.66	1803.17	1787.68	1772.19
0.5	1988.01	1902.13	**1816.25**	1982.18	2068.57	2095.77	1919.29	1903.80	1888.31	1872.82
0.625	2095.36	2009.48	**1923.60**	2087.42	2176.16	2196.40	2019.91	2004.42	1988.93	1973.44
0.75	2202.70	2116.83	**2030.95**	2192.65	2283.75	2297.02	2120.53	2105.04	2089.55	2074.06
0.875	2310.05	2224.17	**2138.30**	2297.88	2391.34	2397.64	2221.16	2205.67	2190.18	2174.69
1	2417.40	2331.52	**2245.64**	2403.12	2498.93	2498.27	2321.78	2306.29	2290.80	2275.31
MRCP	**25.3**	**26.6**	**27.9**	**29.2**	**30.5**	**31**	**32**	**33**	**34**	**35**

Table VI shows the MRCP and the ISO's total payment for different values of 'Y'. This table also shows the effect of 'x' on the ISO's total payment for different value of 'Y'. The reserve MRCP is increasing with increasing x while the ISO's total payment is fluctuating. Here, the optimal value for the weighting factor x is 0.3 for all values of y. If the optimal value is not obtained then ancillary service bids must be changed.

VIII. CONCLUSION

This paper presents ancillary service scheduling for reactive power management. The generator contribution of reactive power to loads and reserve reactive power quantity is calculated based on upstream matrix using power flow tracing algorithm. The optimum reactive power dispatch for ISO requirement is satisfied using Biogeography based optimization algorithm. Market reactive clearing price (MRCP) is then estimated and minimum total ISO's payment is calculated for different utilization factor. This results in lesser number of generators participating in the process of optimal dispatch of generation thereby reducing the ancillary service cost to large extent. The proposed method is illustrated on IEEE 30 bus system. It is found that the Biogeography based optimization algorithm gives better optimal solutions when used with power flow tracing algorithm.

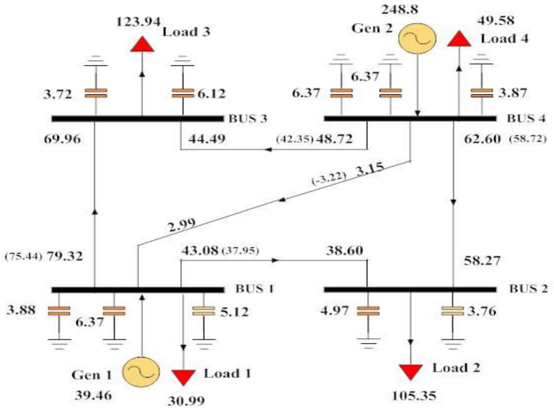

Fig. 2 Power flow diagram of 4 bus system

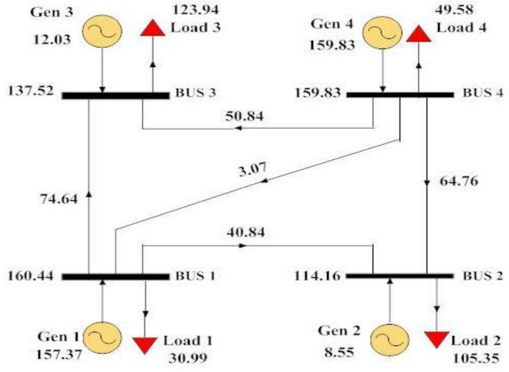

Fig. 3 Lossless Network of 4 bus system

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