

DEREGULATED ENVIRONMENT IPP SELECTION WHEELING TRANSACTION

S.Venkatesan

K.L.N.College of Engineering, Pottapalayam-630611, INDIA,
Email:svneee@gmail.com

Dr .N.Kamaraj

Thiagarajar College of Engineering, Madurai-625015, INDIA,
Email:nkeee@tce.edu

Abstract: Selection of Independent Power Producer (IPP) involves decision on location and maximum capacity of new generation in the existing system. This paper proposes a New Hybrid Particle Swarm Optimization (HPSO) with Cauchy mutation on the best particle has been utilized to determine the connecting point and the appropriate maximum capacity of IPP to the existing systems with the support of AC-optimal power flow (OPF) for IEEE 30-bus system and New England 39 bus utility systems. In addition, optimal wheeling transaction is evaluated based on Maximum IPP. This may encounter congestion in the transmission line and load curtailment technique is employed to relieve transmission congestion.

Key words: Cauchy mutation, Congestion management, IPP, Load curtailment, Locational Marginal Pricing, HPSO, Wheeling Transaction.

1. INTRODUCTION

In the deregulation environment, generation, transmission and distribution are independent of each other. The restructured power sector introduces competition among producers and offer choices to the consumers. The regulated utilities and deregulated utilities are combined to form the concept of wheeling. Wheeling is the transmission of electrical energy from a seller to buyer through a transmission network owned by third party [1]. Wheeling of electricity takes place, when a customer purchases electricity from a source other than its own serving utility. The utility whose transmission network is used for wheeling transaction has to be paid for its service and for meeting the losses. Electricity wheeling has become one of the indispensable elements of power system deregulation. Various mathematical models have been developed [2–10] for wheeling transaction.

In developing country like India, which has the largest electrical network it is the right time to think of effective utilization of electrical network with

restructured market developments. The change in government policy has permitted the Independent Power Producers (IPPs) to enter into the bulk transmission network. Further, awareness on the depletion of oil and coal resources for the power generation has been created and the utilization of non-conventional energy sources (especially wind and solar) have been entertained. Hence large numbers of private sectors have been participating into the electrical network by connecting their miniature units and utilizing that power at remote places, known as 'Firm transactions'. Some private sectors show interest to utilize the transmission network alone for their power transactions.. Under this situation, Independent Power Producer selectors (IPP) have to think about efficient connection to existing systems by which they have select IPPs considering the future demand. This problem concentrates mainly on location and capacity of generating unit to commit on line. In the restructured environment, location and capacity of generating unit to allow the transactions is also an important issue that remains unanswered. This problem is another form of firm bilateral wheeling transactions.

In a deregulated environment, the task of the Independent System Operator (ISO) is to ensure that contracted power transactions are carried out reliably. However, due to the large number of transactions that take place simultaneously, transmission networks may easily get congested. In these circumstances, the utility shall now focus their attention on the effective utilization of transmission line to reduce the cost of service provided by the utility. A number of methods dealing with congestion management in deregulated market have been proposed in the literatures. In [11], marginal signal was used for the generators to manage congestion and the solution under rational behaviour assumption was found to be identical to an OPF solution. A similar approach was suggested for the pool model [12], where the cost of congestion was bundled within the marginal cost at each bus. A bilateral model was also investigated,

and a congestion cost minimization approach was proposed. According to NERC (North American Electricity Reliability Council) operating policy-10 [13], interruptible load is generally accepted that these have an important role to play as a system ancillary service. The design of an optimal interruptible load contract has been used as discussed in [14-16] by using the mechanism design.

This paper proposes an integrated framework for optimal wheeling transaction based on estimated maximum generation of IPP and load curtailment for relieving congestion used for providing feasible transactions. An optimization-based scheme is proposed to estimate the maximum value of IPP. This solution is based on the evolutionary technique, the particle swarm Optimization (PSO). The PSO has been used in some power system applications such as economic dispatch, OPF, and reactive Power planning as reported in [17-20]. In this paper, a new hybrid PSO (HPSO) is proposed. HPSO uses an idea from fast evolutionary programming (FEP) [21-24] to mutate the best position by cauchy mutation. It is to hope that the long jump from cauchy mutation could get the best position out of the local optima where it has fallen. System congestion during transaction can be eliminated by load curtailment process. It identifies the most effective set of loads to be curtailed by using Mw marginal cost.

An IEEE 30 bus system and New England 39 utility bus system are used for numerical simulation as an example. Simulation results demonstrates that the proposed technique can be used for locating seller with maximum capacity, buyer and its transactions as well as a support tool for restructuring power system operation.

2. PROBLEM FORMULATION

The list of objectives include of estimating maximum value of IPP, Selection of buyer buses, load curtailment by using Mw marginal cost (LMP) for relieving congestion during selection of optimal wheeling transaction. All are presented here under,

Objective 1: Selection of seller bus:

The maximization of IPP is done only on load buses (k), where k is varied from 1 to N_d . The maximum generation and location of IPP has been evaluated using Hybrid Particle Swarm Optimization with Cauchy mutation (HPSOCM). The objective function is as follows

$$\text{Maximize } P_{Gk}^{\text{IPP}} \quad (1)$$

Subject to constraints listed below:

The basic load-flow equations are modified to

include the power generation by IPP as follows: Let f_{Pi} and f_{Qi} be two reformulated functions defined as follows,

$$f_{Pi} = \sum_{j=1}^{NB} |V_i| |Y_{ij}| |V_j| \cos(\theta_{ij} + \delta_j - \delta_i) - (P_{Gi} + P_{Gk}^{\text{IPP}}) + (1+\lambda)P_{Di} \quad (2)$$

$$f_{Qi} = \sum_{j=1}^{NB} |V_i| |Y_{ij}| |V_j| \sin(\theta_{ij} + \delta_j - \delta_i) - Q_{Gi} + Q_{Di} \quad (3)$$

$j \neq \text{slack}$

$$P_{Gi}^{\min} \leq P_{Gi} \leq P_{Gi}^{\max} \quad (4)$$

$$Q_{Gi}^{\min} \leq Q_{Gi} \leq Q_{Gi}^{\max} \quad (5)$$

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad (6)$$

$$S_l \leq S_l^{\max} \quad (7)$$

Where λ is load growth parameter, V_i and V_j are the voltage magnitude of bus i and j , δ_i and δ_j are the voltage angle of bus i and j , Y_{ij} and θ_{ij} are the magnitude and angle of Y_{ij} element in bus admittance matrix, P_{Gi} is the generated power at bus i , P_{Di} is the load power at bus i , P_{Gk}^{IPP} is the real power generation of IPP at bus k , N_d is number of load buses, Q_{Gi} is the generated reactive power at bus i , Q_{Di} is the load reactive power at bus i , NB is number of buses in the system, N_{pq} and N_{pv} are the set of PQ, PV buses, V_i^{\min} and V_i^{\max} are the minimum and maximum voltage limit at i^{th} bus, P_{Gi}^{\min} and P_{Gi}^{\max} minimum and maximum real power output of the generating unit at i^{th} bus, Q_{Gi}^{\min} and Q_{Gi}^{\max} are the minimum and maximum reactive power output of the generating unit at i^{th} bus and S_l^{\max} is maximum apparent power flow on line l .

Objective 2: wheeling transaction model:

Mathematically, each bilateral transaction between sellers at bus k and power purchaser at bus j satisfies the following power balance relationship. The conceptual modeling of wheeling transaction is that sellers and buyers encourage the trading between them without violating the transmission constraints

$$P_{Gk}^{\text{IPP}} - P_{Dj} = 0 \quad (8)$$

Where P_{Dj} is buyer power at j^{th} bus.

A simultaneous wheeling transaction has been included in a ' n ' bus system. With the seller at the bus k and the buyer with a load at bus j , where j may be varied from 1 to n and j is not equal to k . Then, run the power flow program with all the generators of the utility held at fixed optimal setting of base case under these conditions.

Objective 3: Congestion Relief Model:

The OPF algorithm conducts the economic dispatch by satisfying all the power flow constraints (MVA limits, voltage, etc) and finds the LMPs of each bus. Fuel cost equation is given by

$$f_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + c_i \quad (9)$$

The first order optimality condition of problem defined by equations (2) – (7) show that the LMPs are characterized by

$$\lambda_i = \text{LMP}_i = \frac{\partial f_i(P_{Gi})}{\partial P_{Di}} ; i = 1 \dots n \quad (10)$$

Where the (λ_i) LMPs are the Lagrangian multiplier.

The overload can be alleviated by load curtailment technique. The market uses LMPs, that reflect the value of energy at specific locations and at that time, it is delivered. When there is transmission congestion, energy cannot freely flow to certain locations. In such cases, electricity that is more expensive and it is ordered to meet that demand. Decreasing load at the maximum LMP bus will reduce the congestion as well as decrease the generating operating costs. Reduced flow to the loads at these buses creates counter flows that tends to mitigate congestion in an element.

3. Implementation of Hybrid Particle Swarm Optimization with Cauchy Mutation (HPSOCM)

The traditional PSO model was described by Dr.Kennedy and Dr.Eberhart in 1995. It consists of a number of particles moving around in the search space, each representing a possible solution to a numerical problem. Each particle has a position Vector $X_i = (x_{i1}, x_{i2}, \dots, x_{in})$, a velocity Vector $V_i = (v_{i1}, v_{i2}, \dots, v_{in})$. In the PSO, the collective best position of all the particles taken together is termed as the global best position given as $Gbest_i = (glb_{i1}, glb_{i2}, \dots, glb_{in})$ and the best position achieved by the individual particle is termed as the local best or position best and for i^{th} particle given as $Pbest_i = (p_{i1}, p_{i2}, \dots, p_{in})$. Particles uses both of these are information to update their positions and velocities are given in the following equations

$$V_i^{k+1} = \omega V_i^k + C_1 \times \text{rand}_1 \times (Pbest_i^k - X_i^k) + C_2 \times \text{rand}_2 \times (Gbest_i^k - X_i^k) \quad (11)$$

Where V_i^k is velocity of individual i at iteration k , ω is inertia weight parameters, C_1 and C_2 are the two positive constants called acceleration constants, $\text{rand}_1, \text{rand}_2$ are the random values different for each particle and each dimension, X_i^k is position of individual i at iteration

k , $Pbest_i^k$ is the best position of individual i at iteration k , $Gbest_i^k$ is the best position of group i at iteration k , ω_{\min} & ω_{\max} are the Initial weight and final weight respectively, iter^{\max} is the maximum iteration number and iter is the current iteration number.

The position of each particle is updated in the each iteration. This is done by adding the velocity vector to the position vector, i.e.

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (12)$$

The accuracy and rate of convergence of the algorithm depends on the appropriate choice of particle size, maximum velocity of particle size and the inertia constant. If the velocity is higher than a certain limit, called V^{\max} , this limit will be used as the new velocity for this particle in this dimension, thus keeping the particle within the search space. The particles have no neighborhood restrictions, meaning that each particle can affect all other particles.

Some theoretical results have shown that the particle in PSO will oscillate between their previous best particle and the global best particle found by all particles so far, before it converges. If the searching neighbors of the global best particle would be added in each generation, it would extend the search space of the best particle. It is helpful for the whole particles to move to the better positions. This can be accomplished by having a cauchy mutation on the global best particle in every generation.

The one dimensional cauchy density function centered at the origin is defined by

$$f(x) = \frac{t}{\pi(t^2 + x^2)}, -\infty < x < \infty \quad (13)$$

Where $t > 0$ is a scale parameter.

The Cauchy distribution function is

$$F_t(x) = \frac{1}{2} + \frac{1}{\pi} \arctan\left(\frac{x}{t}\right) \quad (14)$$

The Cauchy mutation operator used in HPSO is described as follows:

$$W(i) = \frac{\left(\sum_{j=1}^{\text{PopSize}} v[j][i] \right)}{\text{PopSize}} \quad (15)$$

Where $v[j][i]$ is the i^{th} velocity vector of the j^{th}

particle in the population, Pop Size is the Population Size. $w(i)$ is a weight vector within $[-w_{\max}, w_{\max}]$, and

w_{\max} is set to 1 in this paper.

$$gbest'(i) = gbest(i) + W(i) * N(X_{\min}, X_{\max}) \quad (16)$$

Where N is a Cauchy distributed function with the

scale parameter $t=I$, and $N(X_{\min}, X_{\max})$ is a random number within (X_{\min}, X_{\max}) , which is a defined domain of a test function.

The Pseudo code for HPSO algorithm with cauchy mutation is illustrated as below,

```

Begin
Initialize
While (not terminate-condition)
Evaluate
Calculate new velocity vectors
Update particle position
Update  $W[i]$ 
if  $W[i] > W_{\max}$ , then  $W[i] = W_{\max}$ 
If end
Mutate gbes
Select gbest from the  $N$  particles after having  $N$  mutation
If the fitness value of gbest' is better than gbest
Then gbest=gbest'
If end
While end
End

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4. STEP BY STEP ALGORITHM

The objective function is to maximize IPP at using HPSOCM and IPP is assumed as the particle to be optimized.

Step 1: Perform the load flow solution using the specified loads and generations.

Step 2: Calculate base case values.

Step 3: Set IPP point count $k=1$ and load growth parameter λ .

Step 4: Specify the maximum and minimum limits of generation power of each generation units and maximum number of iterations to be performed.

Step5: Particles are generated and initialized with position values and velocity.

Step6: The binding constraints fitness values for the particles are determined. If a particle does not satisfy the fitness requirement, it is regenerated.

Step7: Execute the PSO operator on the particles.

Step8: The optimal objective fitness values are calculated for all the particles. Then the values of position best and global best are determined.

Step 9: Position and velocities of particles are updated.

Step10: Perform mutation process to replace the worst particles.

Step11: If the maximum number of iteration is exceeded or some pre specified an exit criterion is satisfied, then goes to step 12. Else, update the time counter.

Step12: Output the particle with the maximum fitness values in the last generation. Calculate the optimum value with the objective function (Eq (8)) subjected to the constraints (Eq (2)-Eq (7)), using HPSOCM. Then

go to step 14, otherwise go to next step.

Step13: Increment k by 1, and if k is less than or equal to number of buses then go to step 5 otherwise go to next step.

Step14: Set load point count $j=1$ and set λ at bus j .

Step15: Simulating the bilateral transaction. If no congestion, go to step 19. Otherwise, identify the number of lines overloaded, then go to next step.

Step16: Evaluate the spot price using optimal power flow with all engineering constraints enforced through AC power flow computations as per equations (9) and (10).

Step17: The buses are ranked based on LMP

Step18: If Congestion is relieved by curtailing some portion of load serving entities by Maximum LMP. Go to next step otherwise stop

Step19: Increment j by 1 and if j is less than or equal to number of buses go to step 15.

5. RESULTS AND DISCUSSIONS

The proposed method has been illustrated on IEEE 30-bus and New England 39-bus utility systems. For both test systems, the results are obtained by first estimating maximum IPP of by HPSOCM algorithm and then determining optimal wheeling transaction.

The influence of the PSO parameters, the inertia weight, and population size, constants C_1 & C_2 , on the convergence of the algorithm has been studied. The size of particles has been increased from 10 to 100 in steps of 10 and the number of best particle for this problem is found to be 60, the inertia constant varied from 0.4 to 0.9 and optimal value for this problem is found to be 0.5, Maximum number of iteration has been taken as 100. The minimum solution was obtained for 100 trial runs. Simulation studies have been conducted on Intel(R) core i5, 2.27 GHz processor under Mat Lab 7.6 environment. The adopted parameters in the algorithms are given in Table1.

TABLE 1
Parameter Values for HPSOCM for the Test systems

| Parameters | IEEE 30 bus | New England 39 Bus |
|------------|-------------|--------------------|
| population | 60 | 60 |
| C_1 | 2 | 2 |
| C_2 | 2 | 2 |
| W | 0.5 | 0.5 |
| W_{\max} | 1 | 1 |
| N | 25 | 25 |
| X_{\min} | 0 | 0 |
| X_{\max} | 1 | 1 |
| Iterations | 100 | 100 |

| Transactions | No of lines over loaded | Transactions | No of lines over loaded |
|--------------|-------------------------|--------------|-------------------------|
| 10-2 | 0 | 10-17 | 2 |
| 10-3 | 0 | 10-18 | 9 |
| 10-4 | 0 | 10-19 | 6 |
| 10-5 | 0 | 10-20 | 6 |
| 10-6 | 1 | 10-21 | 3 |
| 10-7 | 2 | 10-22 | 4 |
| 10-8 | 2 | 10-23 | 10 |
| 10-9 | 1 | 10-24 | 8 |
| 10-11 | 2 | 10-25 | 9 |
| 10-12 | 6 | 10-26 | 8 |
| 10-13 | 7 | 10-27 | 7 |
| 10-14 | 13 | 10-28 | 3 |
| 10-15 | 11 | 10-29 | 6 |
| 10-16 | 4 | 10-30 | 10 |

V.1: IEEE 30- bus system

The numerical data for IEEE 30-bus system is taken from Ref. [25]. This system has 6 generators, 41 transmission lines. The generators are connected at the buses 1,2,13,22,23 and 27. For this system, bus 1 is slack bus and there are 24 load buses. The load growth parameter λ is assumed by 0.7 (70 % of the overall peak demand) and is distributed equally to all load buses. The maximum value of IPP has been estimated by using the HPSOCM algorithm. The algorithm conducts the economic dispatch by satisfying all the power flow Constraints (MVA limits, voltage, etc)

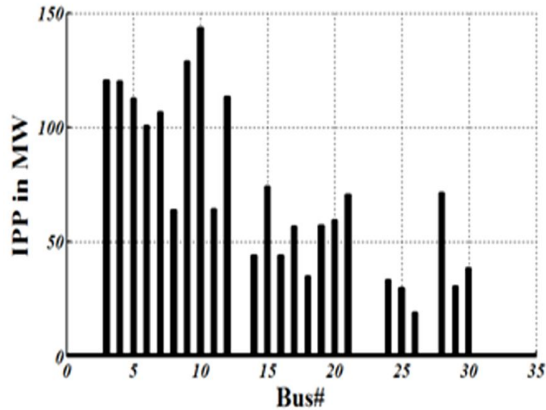


Fig 1. Estimation of IPP by HPSOCM

From Figure 1, it is evident that IPP of 143.4 MW has been determined at the 10th bus in the existing system. The problem of IPP is tested for optimal wheeling transaction. In this case, all the loads are set to original value. The IPP is interested to have a wheeling transaction with all the load buses. In each bilateral transaction, λ is set at 0.7.

TABLE 2:

Wheeling remarks for IEEE 30 bus System

In bilateral transaction, the private companies (IPPs) use the transmission line to transmit their power. A power transmission system model usually includes constraints such as thermal limits on transmission lines and power balances at each node of the network. In addition to single line constraints may be used for stability purposes to control the reliability of the network. The feasible transaction is determined based on the criteria with ability to eliminate the congestion while simulating the bilateral transaction. Table 2 shows summary of the number of transmission lines overloaded for each transaction. Transactions 10-2, 10-3, 10-4 and 10-5 have no overloading of lines and considered for feasible transaction.

Transactions 10-6 and 10-9 have single line congestion. In transaction 10-6, line between buses 10 and 6 is congested and it exceeds about 107.7% of their respective MVA limit. Therefore, Particular load for curtailment can be identified by maximum LMP of the system. The maximum and minimum load curtailment parameter P_{\max} and P_{\min} are assumed as 20% and 5% of the load at each load bus. LMPs various buses during curtailment 1 and curtailment 2 are shown in Figure 2

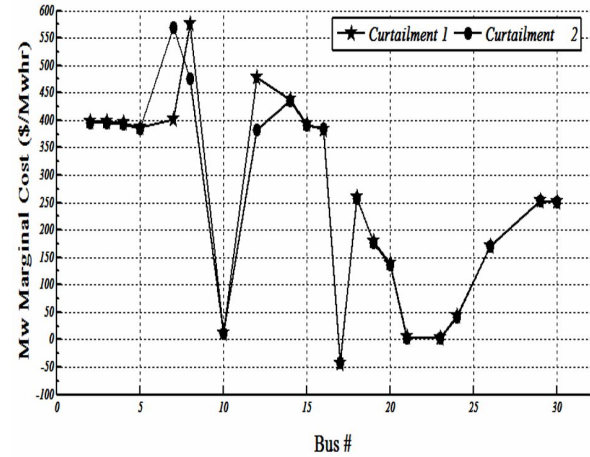


Fig 2: LMPs of various buses for transaction 10-6 of IEEE 30 bus system

Table 3 shows congested line, curtailment process, Maximum LMP, load bus at maximum LMP, curtailment load and percentage of overload after curtailment for the transaction between buses 10-6. The maximum LMP is identified at load bus 8 when the curtailment process 1 is around 575.06 \$/ MWhr. The load is identified at 8th bus and load is curtailed by 20%. The percentage of overload in the congested line is reduced to 103%. During second curtailment the maximum LMP is identified at load bus 7 and

corresponding Mw marginal cost is 569.07 \$/MWhr. The percentage of overload is reduced to 100%.

TABLE 3:

Congestion Elimination for the Transaction 10-6

| Curtailment process | Max LMP \$/Mwhr | Load Bus no | P _D Mw | ΔP_{Di} Mw | % Over Load (After curtailment) |
|---------------------|-----------------|-------------|-------------------|--------------------|---------------------------------|
| Curtailment1 | 575.06 | 8 | 30.0 | -6 | 103 |
| Curtailment2 | 569.07 | 7 | 22.8 | -4.56 | 100 |

In transaction 10-9, line 10-9 heavily overloaded and it exceeds about 171 % of their respective MVA limit. Moreover, overload could not be eliminated by the proposed technique. Other transactions between buses 10-7, 10-8 and from transactions between buses 10-10 to 10-30 have multi congestion with many heavily overloaded lines.

Overall, it is clear that the bilateral transactions 10-2, 10-3, 10-4, 10-5 and 10-6 are taken as feasible transactions under maximum capacity of IPP.

V.2. New England 39 bus System

The detail about 39-bus system is taken from [26]. It represents a greatly reduced model of the power system in New England. The 39-bus system has 10 generators, 19 loads, 36 transmission lines, and 12 transformers. The load growth parameter λ is assumed by 0.04 (4 % of the overall peak demand) and is distributed equally to all load buses. The maximum value of IPP has been estimated by using the HPSOCM algorithm. From Figure 3, it is evident that IPP of 210.54 Mw is determined at the 16th bus in the existing system.

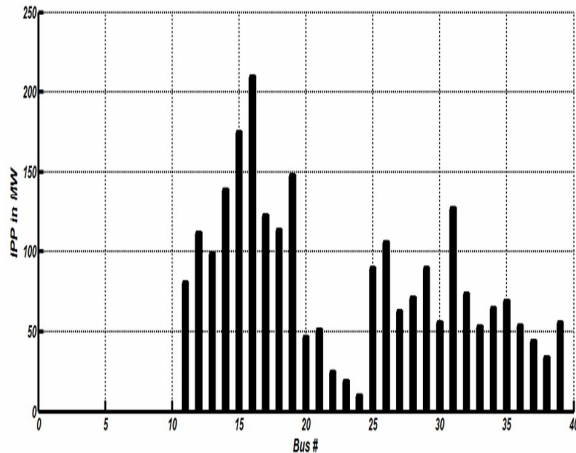


Fig: 3 Estimation of IPP by HPSOCM

In this case, congested line constraints are extended to two line constraints and it may be used for stability purposes to control the reliability of the network.

The IPP is interested to have a wheeling transaction with all the load buses. In each bilateral transaction, λ is set at 0.04.

Table 4 shows summary of the number of transmission lines overloaded for different transactions.

TABLE –4:

Wheeling remarks for New England 39 bus utility System

| Transaction | No of lines overloaded | Transaction | No of lines overloaded |
|--------------|------------------------|--------------|------------------------|
| 16-2 | 4 | 16-22 | 3 |
| 16-3 | 0 | 16-23 | 4 |
| 16-4 | 3 | 16-24 | 3 |
| 16-5 | 3 | 16-25 | 3 |
| 16-6 | 4 | 16-26 | 4 |
| 16-7 | 5 | 16-27 | 4 |
| 16-8 | 3 | 16-28 | 4 |
| 16-9 | 4 | 16-29 | 4 |
| 16-10 | 2 | 16-30 | 3 |
| 16-11 | 3 | 16-31 | 0 |
| 16-12 | 3 | 16-32 | 4 |
| 16-13 | 3 | 16-33 | 3 |
| 16-14 | 1 | 16-34 | 3 |
| 16-15 | 1 | 16-35 | 4 |
| 16-17 | 0 | 16-36 | 3 |
| 16-18 | 1 | 16-37 | 3 |
| 16-19 | 4 | 16-38 | 4 |
| 16-20 | 0 | 16-39 | 5 |
| 16-21 | 4 | | |

Transactions between buses 16-3, 16-17, 16-20 and 16-31 are with no overloading and considered for feasible transaction.

Transactions between buses 16-14, 16-15, 16-18 with single line congestion are assumed as feasible transaction.

The transactions between buses 16-10 resulted in two-line congestion i.e., lines between buses 34-35 and 15-14. The MVA flow in the transmission lines 34-35 and 15-14 exceeds their respective MVA flow limits by 233% and 122 % respectively.

LMPs for the transaction of the lines 16-10 for the curtailment 1 and curtailment 2 are shown in Figure 4, the maximum LMP at load bus 35 when the curtailment1 is around 5724.02 \$/MWh. During second curtailment the maximum LMP at load bus 13 is 623.38 \$/MWh.

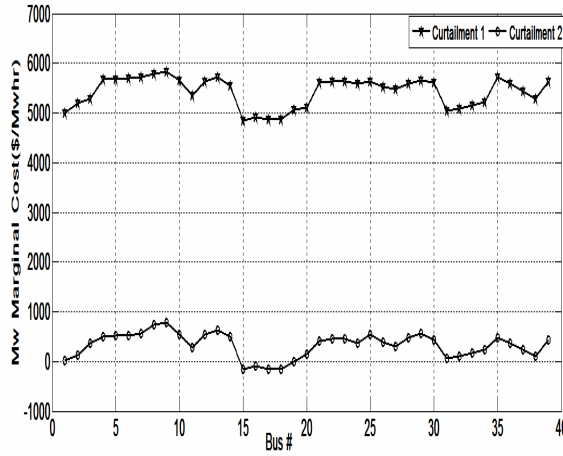


Fig 4: LMPs of various buses of transaction 16-10 of New England 39 bus

Table 5 shows maximum LMP, total load, curtailed load and percentage of overloaded in the congested lines. The maximum and minimum load curtailment parameters P_{\max} and P_{\min} are assumed to be 20% and 5% of the load at each load bus respectively. During curtailment 1, the congestions are reduced enormously. In curtailment 2, both lines are completely relieved from overload.

TABLE 5:

Congestion Elimination for the Transaction 16-10 of New England 39 bus

| Curtailment process | Congested Line | Load Bus No | Max LMP \$/MWh | P_D Mw | ΔP_{Di} MW | % Over load (After curtailment) |
|---------------------|----------------|-------------|----------------|----------|--------------------|---------------------------------|
| Curtailment 1 | 34-35, 15-14 | 35 | 5724.02 | 320 | 64 | 101.1, 107 |
| Curtailment 2 | 34-35, 15-14 | 13 | 623.38 | 322 | 64.4 | 70.8, 7.3 |

Overall, it is clear that the bilateral transactions 16-3, 16-10, 16-14, 16-15, 16-17, 16-18, 16-20 and 16-31 are taken as feasible transactions. under maximum capacity of IPP.

6. CONCLUSION

The proposed method could specifically identify the feasible transactions for the estimated maximum value

of IPP. HPSOCM algorithm is employed as it can easily handle all types of variables either real or integer. In this paper, congestion relief procedure is introduced by the method of load curtailment. It is evident from the results that, this scheme would be very effective in handling transmission congestion during wheeling transaction. The validity of the method has been illustrated with IEEE 30 and New England 39 bus test systems. The proposed model is mainly free from complex mathematical formulation and provides quite encouraging results, which will be useful for all feasible transactions in deregulated environment.

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