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Power Generation Pricing in Deregulated Environment for Hydrothermal Scheduling

Gopi Krishna Allaboyena

SRM University, School of Engineering & Technology, Kattankulathur, Chennai 603203, India

Abstract: ***With the increasing competition in each market the processes of competition has been introduced in the Power Market too. This results in the change of mechanism for the power system economics. With the inclusion of the competition in the market the energy is considered as the basic commodity for the daily life. This assumption of assuming the energy as a basic commodity evolves the new concept of bilateral contracts, bidding and auction etc…This work shows the profit obtained by the GENCO's in a deregulated environment. A proper difference in the profit has been shown what happens and how the profit changes with the implementation of bidding and without bidding. In order to show the effectiveness of this technique, the proposed approach is applied to test systems implementing different algorithms. The required computations were performed using MATLAB 2014 software. Numerical results obtained from this approach are compared with previously published papers form certified publications. LRPSO seems to give a better result with better social profit.***

Keywords: Power systems economics, hydrothermal scheduling, unit commitment, bidding strategies, EP and PSO algorithms, LR coupled algorithms.

1. Introduction

1.1 Hydrothermal Scheduling

Hydrothermal scheduling of a power system is concerned with thermal unit commitment and dispatch and hourly generation of hydro units. The main objective is to minimize the total operating cost of thermal units over a period of up to one week, subjected to system wide demand and reserve requirements and individual unit constrains. The importance of efficient generation scheduling is well recognized. An efficient generation scheduling not only reduces the production cost but also increases the system reliability, securing valuable reserves, regulating margins, and maximizing the energy capability of the reservoirs. During the last two decades the hydrothermal scheduling problem has attracted the research community. Until now the majority of the proposed solutions use the decomposed schemes based on the two specific characteristics of the problem [7].

- Only unit commitment state variables are restricted to be integers while the remaining problem is considered as a continuous process.
- Power balance and security requirements only "coupling" constrains linking the operation of different generating units.

1.2 Unit Commitment Problem in Deregulated Environment

The problem of unit commitment involves the least-cost dispatch of the available generation resources to meet the electricity load. Deregulation and restructuring of the electricity supply industry is one of the most important global energy developments of the last century [1]. The optimal operations and planning of the power systems are ranked high among the major task in the electric power generation now days. This is because the new market mechanism has changed the economics of power generation.

In the past, utilities have an obligation to serve their customers. That means all the demand and spinning reserves must be completely met. But this is not the necessary in the restructured system. Generation companies can now consider a schedule that produces less than the predicted load demand but creates the maximum profit. This problem is referred as Profit Based Unit Commitment (PBUC) problem. It is much more difficult to solve than the traditional Unit Commitment problem. Depending on the type of the deregulated power market the profit of the generation companies varies because of the involvement of different bidding strategies by different market players.

1.3 Bidding Strategies

With the deregulation of the power systems, market participants bid, energy to the Independent System Operator (ISO). In the daily market, participants submit bids to the ISO who then decides Energy Clearing Price (ECP) and hourly generation levels of each participant over a 24-hour period [13]. In the regions like New England, a utility bids part of the energy and self-schedules the rest, whereas an independent power producer (IPP) bids all its energy. For each participant, bidding strategies ideally should be selected to maximize its profit. Game theory is the natural platform to model such an environment. In the literature matrix games have been used for its simplicity, and bidding strategies are discredited, such as "bidding high", "bidding medium", or "bidding low". With discrete bidding strategies, payoff matrices are constructed by enumerating all possible combinations of strategies and "equilibrium" of the "bidding game" can be obtained. Bids are selected to minimize total system cost, and the ECP is determined as the price of highest accepted bid.

2. Problem Formulation

The trading mechanism of suppliers and customers are modeled based on central auction mechanism. These central auction mechanisms are in identical function to a simple economic dispatch (ED) algorithm and dispatched is

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performed based on the bids received from different entities and so model is termed as Bid Based Dynamic Economic Dispatch (BBDED). The solution is to maximize BBDED problem aims to maximize the social profit

2.1 Objective Function

The problem of BBDED can be modeled as [8]

Maximize
$$PF = \sum_{t=1}^{T}\left[\sum_{j=1}^{N_c} BC_j(D_j^t) - \sum_{i=1}^{N} BG_i(P_i^t)\right] \quad (2.1)$$

Where N_c and N and are the number of customers and generators, D^t_j is the bid quantities of the customer j at period t, P^t_i is the bid quantity of the generator i at period t, BC_j and BG_i are the functions submitted by customers and generators.

2.2 Constraints

There are three constrains:

- Power balance
- Generator and customer bid quantities
- Ramp rate limits

2.2.1 Power Balance constraints

The power balancing constraints is an equality constraint that reduces the power system to a basic principal of equilibrium, between total generation of GENCO and customers participating in the electricity markets. These constrain depends on the load demand, power losses and power generation and is given by the equation

$$\sum_{i=1}^{N} P_j^t = \sum_{j=1}^{N_c} D_i^t + P_l \quad \text{Where, } t=1, 2, 3, \ldots T \quad (2.2)$$

Where, P_l is the transmission losses in the system.

2.2.2 Generator and Customer Bid Quantities Constraints

Generation units have lower and upper limits that are directly related to generator design. These bounds can be directly defined as a pair of inequality constrains,

$$P^t_{i\_min} \le P^t_t \le P^t_{i\_max} \quad (2.3)$$

Customer bid quantities are subjected to minimum and maximum limits and is given by,

$$D^t_{j\_min} \le D^t_j \le D^t_{j\_max} \quad (2.4)$$

2.2.3 Ramp Rate Limits Constraints

In order to keep thermal gradients inside the turbine within safe limits and to avoid shortening the life, the rate of increase /decrease of the power output of generators are limited within a range. These ramp rate constrains can be defined as,

$$UR^t_{iii} \le P^t - P^{t-1} \le UR_i \quad (2.5)$$

Where, DR_i and UR_i are the maximum decrease and increase in the output of the i[th] generator in a particular hour.

2.3 Bidding Strategies in Deregulated Markets

A number of different bidding strategies can be framed by specifying the parameters for the capacities and prices to be bid into the market for the different generation plants in the system. The strategies can either be static of dynamic and they will typically vary by generation technology and need of the customer participating in the competition. In deregulated electricity market participants submit their bids to an ISO. A bid consists of price offers and the amount of load demand by the customers, which can be matched by the ISO.

2.3.1 Representation of Supply Side Bids

The production cost bidding strategy of generator is used to represent the supply side bids. Under this strategy the GENCO acts as a pure price taker in the market, and bid according to marginal production cost of its plants as specified by the heat rate curve. Many generating utilities present their bid function as peace-wise linear bidding cost function is approximated by a quadratic function. Thus bid price curves of generators are approximated as quadratic function of their bid quantities and given as.

$$BG_i(P_i^t) = a_{pi}(P_i^t)^2 + b_{pi}P_i^t + c_{pi} \quad (2.6)$$

Where a_{pi}, b_{pi} and c_{pi} are the bid price coefficients of generator i.

2.3.2 Representation of Demand Side Bids

The bid function of customers are expressed as,

$$BC_j(P_i^t) = a_{dj}(D_j^t)^2 + b_{dj}D_j^t \quad (2.7)$$

Where, a_{dj} and b_{dj} are the bid price coefficients of customer j. For customers participating in electricity markets, the bidding strategies are classified as "bidding high (H)","bidding low (L)" and "bidding medium (M)" based on the bid price coefficients. The authors have concluded that by experiments the value of bid coefficient of customer $a_{dj} \ge 0.09$, medium value of the bid coefficient of the customer can be in a range of 0.05 and the low value of the bid coefficient of customer $a_{dj} \le 0.01$.

3. Solution Methodology

As the power system is considered as the most complex network ever constructed, the problems corresponding to network can't be solved by normal conventional methods.

Thus the reason we try to implement soft computing techniques that are applied with the help of computer science which are characterized by use on inexact solutions to complex computational task. Thus these techniques give the most optimized solutions to the objective functions which are subjected to the constraints. The problem of maximizing the profit and is done using the different

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algorithms which are explain below briefly.

3.1 Particle Swarm Optimization

The particle swarm concept originated as a simulation of a simplified social behavior of a bird flock. PSO is initialized with a population of random solutions. In this, each potential solution is also assigned a randomized velocity and the potential solutions, called particles, are then "flown" through the problem space. Each particle keeps track of its coordinate's *xp* in the problem space that are associated with the best solution (fitness or score) it has achieved so far. The fitness value is also stored. This value is called *pbest*.

Another "best" value that is tracked by the global version of the particle swarm optimizer is the overall best value, and its location, obtained so far by any particle in the population. This location is called *gbest*.

3.1.1 PSO ALGORITHM

Step 1 Initialize randomly the partials of the population according to the limit of each unit including the individual dimension, searching points and velocities.

Population= min limit + (max limit – min limit)*rand (3.1)

Step 2 Calculate the cost function value for each individual in the population.
Step 3 The individual corresponding to maximum cost function is known as the positional best value (pbest).
Step 4 Compare each particle's cost value with that of its Positional Best value that of its positional best. The particle with best cost value among of all the positional best is denoted as global best (gbest).
Step 5 Modify the member population velocity of each particle according to the equation

$$V^{k+1} = w * V^{k} + C1*rand\,()*(pbest - x^{k}) + C2*rand\,()*(gbest - x^{k}) \quad (4.2)$$

Where x' represents the position of kth particle. *C1 C2* are the acceleration constants *rand()* is the uniform number value ranging from 0 to 1 and w is the inertia weight factor which often decreases linearly form 0.3 to -2 which is generally set according to the equation

$$w = w_{max} - \frac{w_{max} - w_{min}}{ite_{max}} \times ite \quad (3.3)$$

Where *ite* represents iterations.
Step 6 Modify the member position using the following equation

$$x^{k+1} = x^{k} + V^{k+1} \quad (3.4)$$

Step 7 If the new cost values any k^{th} particle is less than its previous value, the new coordinates for the particle will be stored as its pbest. Also compare the cost values of all the pbest for each particle k and then determine new gbest.
Step 8 If the number of iteration reaches the maximum, then go step 9. Otherwise go to step 4
Step 9 The individual that generates the latest gbest is the solution of the problem.

The figure 1 shows the flow chat for the above explained algorithm.

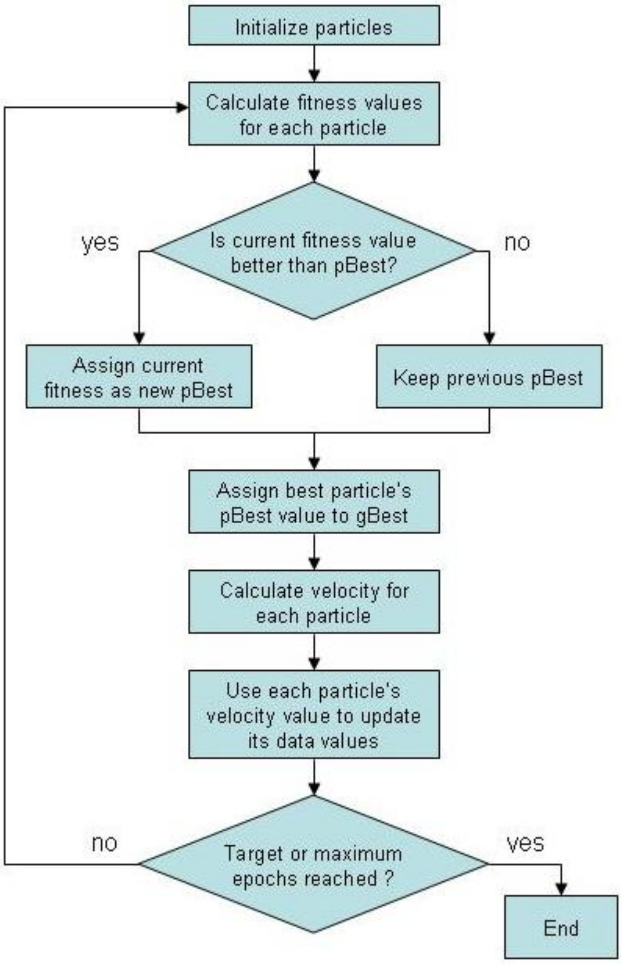

Figure 1: PSO algorithm flowchart

3.1.2 EP Algorithm

The step-by-step Evolutionary Programming approach is described below
Step 1 Read parameters, upper and lower limits for each generation unit.
Step 2 Set up the EP parameters such as population size and Mutation factor.
Step 3 Set the iteration count k=0.
Step 4 Fitness value is determined for each individual in the Initial population. Store the individuals having maximum fitness value in vector.
Step 5 Increment the generation count (i.e. k=k+1)
Step 6 Select the parents for mutation based on the fitness values
Step 7 Gaussian Distribution function is used for mutation to generate offspring using the relation given by

$$X^{new} = X^{old} + \beta \left(\frac{2r - r_m}{r_m} \right) \times \left(\frac{X^{min}}{X^{old}} \right) \times (X^{max} - X^{min}) \quad (4.5)$$

Where, β *is* Adaptive scaling factor, r is random between 0 to rm, *rm* is 2 to 3
Step 8 Evaluate the fitness values for the new solution

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vectors. Combine the N number of parent solutions and N number of child solutions. Among the 2N individuals, the best N individuals are selected based on their fitness values.

Step 9 The end conditions considered are:

a. The fitness value of particular individual should be almost same for two consecutive iterations.
b. If condition is not fulfilled then repeat from step 4. Otherwise, update X vector.
c. Find the maximum fitness value of X vector and the corresponding individual is stored as the best optimal solution.

The figure 2 shows the flowchart for the above explained algorithm

Step 6 The difference between primal and dual problem (duality gap) is used as a terminating criteria. If the duality gab is greater than a predefined tolerance value then stop else go to step 3.

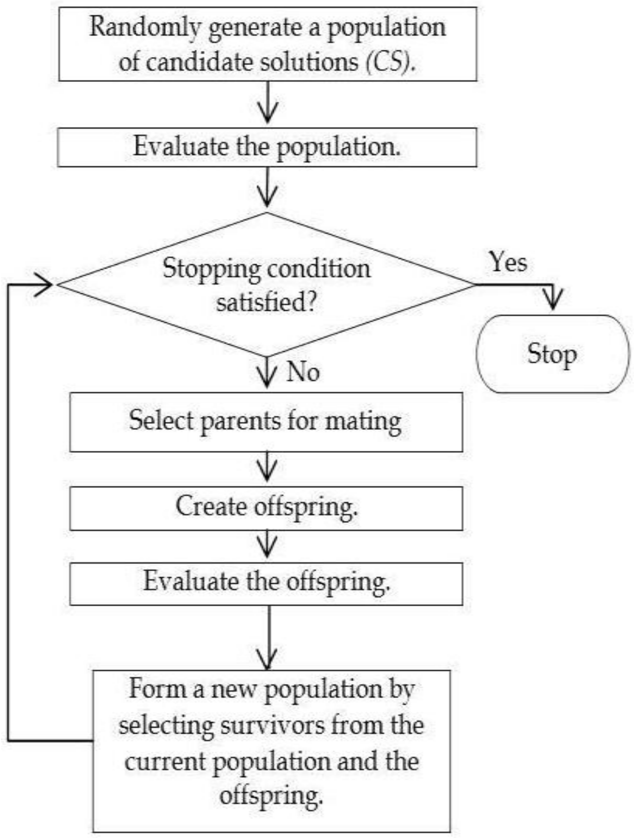

Figure 2: EP algorithm flowchart

3.1.3 Lagrang Relaxation Coupled Algorithms

The step-by-step Lagrange Relaxation Evolutionary Programming approach is described below:

The method is divided in two parts.

Step 1 A forward dynamic programming method is used to solve the dual problem. The objective of this problem is to minimize the effect of equality and inequality constraints.
Step 2 The adjustment of Lagrange multipliers must be done so as to maximize q(λ,μ). We use conventional algorithms to achieve this task.

$$\min q(\lambda, \mu) = \sum_{t=1}^{T}[(1-r)F(P_{it}) + rF(P_{it} + R_{it}) + ST_i - P_{it}SP_t - rRP_t + \lambda P_{it} + \mu P_{it}]X_{it} \tag{3.5}$$

Where, P_{it} is power generation of generator t and R_{it} is reserve generation of generator t; $F(P)$ is the fuel cost of for the generation in the particular t[th] hour by unit i; $F(P+R)$ is the fuel cost of for the generation and reserve in the particular t[th] hour by unit I; ST is the start-up cost; and, SP is forecasted spot price.

Step 3 The population of chromosomes is uniformly random initialized. This population of chromosome is called parent.

Step 4 The value of is used to indicate the fitness of the candidate solution of each individual.

Step 5 A new population of chromosomes (same amount as parent) is produced from the existing population by adding Gaussian random number.

$$\lambda_{t+1} = \lambda_t + N(0, \sigma_t^2)$$
$$\mu_{t+1} = \mu_t + N(0, \sigma_t^2) \tag{3.6}$$

Where the function $N(0, \sigma_t^2)$ depends on the conventional algorithm opted for updating the Lagrange variables.

4. Results and Discussion

The discussed algorithms have been implemented for IEEE 10 units system and 6 units systems for a fixed period of time and the same systems have been integrated with 4 Hydro systems for the betterment of results.

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4.1 EP and PSO Scheduling

Table 1: Thermal scheduling for 6 unit system using Evolutionary

Hour (s)	*EP Scheduling Units Allocation in MW*						*Load Demand*
	Ps 1	**Ps 2**	**Ps 3**	**Ps 4**	**Ps 5**	**Ps 6**	
1	166	0	0	0	0	0	166
2	196	0	0	0	0	0	196
3	193.6963	35.30372	0	0	0	0	229
4	191.4755	75.52452	0	0	0	0	267
5	186.7713	76.68704	19.94166	0	0	0	283.4
6	186.7713	75.57655	9.652148	0	0	0	272
7	186.7713	59.2287	0	0	0	0	246
8	186.7713	26.2287	0	0	0	0	213
9	192	0	0	0	0	0	192
10	161	0	0	0	0	0	161
11	147	0	0	0	0	0	147
12	160	0	0	0	0	0	160
13	170	0	0	0	0	0	170
14	185	0	0	0	0	0	185
15	186.7713	21.2287	0	0	0	0	208
16	186.7713	45.2287	0	0	0	0	232
17	186.7713	59.2287	0	0	0	0	246
18	186.7713	54.2287	0	0	0	0	241
19	186.7713	49.2287	0	0	0	0	236
20	186.7713	38.2287	0	0	0	0	225
21	186.7713	17.2287	0	0	0	0	204
22	182	0	0	0	0	0	182
23	161	0	0	0	0	0	161
24	131	0	0	0	0	0	131

Table 2: Thermal Scheduling of 6 units using Particle Swamp Optimization

Hour (s)	*PSO Scheduling*						*Load Demand*
	Ps 1	*Ps 2*	*Ps 3*	*Ps 4*	*Ps 5*	*Ps 6*	
1	200	50	0	0	0	0	166
2	200	70	0	0	0	0	196
3	177.9617	51.03827	0	0	0	0	229
4	192.8396	74.16036	0	0	0	0	267
5	181.7906	69.82617	31.78319	0	0	0	283.4
6	189.8021	69.82617	12.37173	0	0	0	272
7	183.9588	62.04116	0	0	0	0	246
8	190.8261	22.17393	0	0	0	0	213
9	192	0	0	0	0	0	192
10	161	0	0	0	0	0	161
11	147	0	0	0	0	0	147
12	160	0	0	0	0	0	160
13	170	0	0	0	0	0	170
14	185	0	0	0	0	0	185
15	191.5062	16.49384	0	0	0	0	208
16	184.7284	47.27163	0	0	0	0	232
17	180.4584	65.54159	0	0	0	0	246
18	194.1578	46.84221	0	0	0	0	241
19	178.824	57.17598	0	0	0	0	236
20	192.7457	32.25433	0	0	0	0	225
21	194.4975	9.502498	0	0	0	0	204
22	182	0	0	0	0	0	182
23	161	0	0	0	0	0	161
24	131	0	0	0	0	0	131

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Table 3: Comparison of social economic profit

	EP Scheduling			PSO scheduling		
Customer	*Low bid*	*Medium bid*	*High bid*	*Low Bid*	*Medium Bid*	*High Bid*
1	38573.51	37377.84348	41076.63	40206.33	41464.68	42131.88
2	35782.56	37662	38512	36466.53	39103	40662

Table 4: Hydrothermal Scheduling with 4 hydro and 6 Thermal using LREP without ramp limits

	Hydro Scheduling				*Thermal Scheduling*					
	Units Allocation in MW									
Hour	*Ph1*	*Ph2*	*Ph3*	*Ph4*	*Ps5*	*Ps 6*	*Ps7*	*Ps8*	*Ps9*	*Ps10*
1	86.31913	51.19691	120.7233	202.5651	0	0	0	0	0	50
2	65.46412	51.54502	120.1166	199.6969	0	0	0	0	0	0
3	75.51307	62.6347	114.5111	201.8384	0	0	0	0	0	50
4	67.28717	52.97631	116.9193	197.3681	0	0	200	150	50	50
5	84.22872	73.97283	119.1001	212.0042	0	350	200	150	50	50
6	72.0286	73.54711	118.7725	228.0818	0	350	200	150	50	50
7	82.44486	51.22825	115.6796	202.4608	0	350	200	150	50	50
8	53.29845	79.70843	109.6033	229.8847	400	350	200	90	0	0
9	70.00269	82.247	97.27917	215.5534	400	350	200	150	50	50
10	70.71257	78.83929	105.5629	237.162	400	350	200	150	50	50
11	74.92034	77.8676	100.6473	233.096	0	0	0	150	50	50
12	64.80782	51.09847	112.1364	237.0245	0	0	0	0	0	50

Table 5: Hydrothermal Scheduling for 4 hydro 6 Thermal using LREP with ramp limits

	Hydro Scheduling				*Thermal scheduling*					
	Units Allocation in MW									
Hour	*Ph1*	*Ph2*	*Ph3*	*Ph4*	*Ps5*	*Ps6*	*PS7*	*Ps8*	*Ps9*	*Ps10*
1	86.31913	51.19691	120.7233	202.5651	0	0	0	150	50	50
2	65.46412	51.54502	120.1166	199.6969	0	0	0	0	0	50
3	75.51307	62.6347	114.5111	201.8384	0	0	0	150	50	50
4	67.28717	52.97631	116.9193	197.3681	0	0	200	150	50	50
5	84.22872	73.97283	119.1001	212.0042	0	0	200	150	50	50
6	72.0286	73.54711	118.7725	228.0818	0	350	200	150	50	50
7	82.44486	51.22825	115.6796	202.4608	0	350	200	150	50	50
8	53.29845	79.70843	109.6033	229.8847	400	350	200	90	0	0
9	70.00269	82.247	97.27917	215.5534	0	0	200	150	50	50
10	70.71257	78.83929	105.5629	237.162	400	350	200	150	50	50
11	74.92034	77.8676	100.6473	233.096	0	0	0	150	50	50
	64.80782	51.09847	112.1364	237.0245	0	0	0	0	0	0

Table 6: Reserve allocation for 10 unit Hydrothermal Scheduling

	Ps 1	*Ps 2*	*Ps 3*	*Ps 4*	*Ps 5*	*Ps 6*
Hour 1	0	0	0	0	0	0
Hour 2	0	0	0	0	0	0
Hour 3	0	0	0	0	0	0
Hour 4	0	0	0	0	0	0
Hour 5	0	0	0	0	0	0
Hour 6	0	0	0	0	0	0
Hour 7	0	0	0	104	0	0
Hour 8	0	0	0	104	0	0
Hour 9	0	0	0	0	0	0
Hour 10	0	0	0	0	0	0
Hour 11	0	0	0	0	0	0
Hour 12	0	0	0	0	0	0

Table7: Social Economic profit for Hydrothermal Scheduling

Bidding Strategies	*Customer 1 without Ramp Limits*	*Customer 1 withRamp Limits*	*Customer 2 with Ramp Limits*	*Customer 2without Ramp Limits*
	($)	*($)*	*($)*	*($)*
Low	44286.46835	46518.24294	58468.02505	59431.46835
Medium	43323.02505	46431.61336	59431.46835	58468.02505
High	46029.39867	47501.38691	58468.02505	59431.46835

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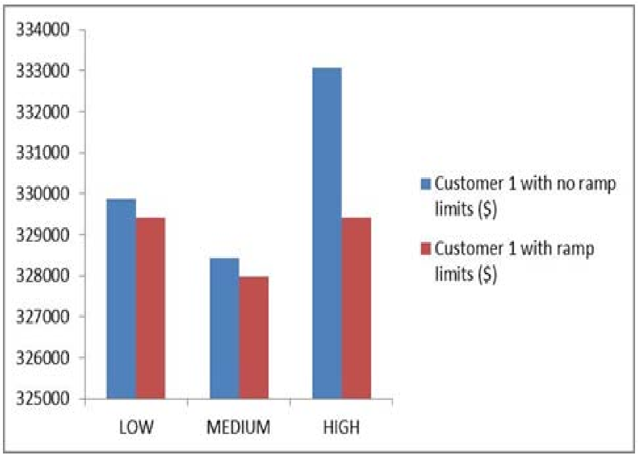

Figure 3: Graphical representation of Social Economic profit for10 unit

Hydrothermal Scheduling

Table 8: Hydrothermal scheduling using LRPSO without ramp limits

Hour(s)	*Hydro Scheduling*				*Thermal Scheduling*					
	Units Allocation in MW									
	Ph 1	*Ph 2*	*Ph 3*	*Ph 4*	*Ps 5*	*Ps 6*	*Ps 7*	*Ps 8*	*Ps 9*	*Ps 10*
1	86.31913	51.19691	120.7233	202.5651	0	0	0	0	0	50
2	65.46412	51.54502	120.1166	199.6969	0	0	0	0	0	50
3	75.51307	62.6347	114.5111	201.8384	0	0	0	150	50	50
4	67.28717	52.97631	116.9193	197.3681	0	0	0	150	50	50
5	84.22872	73.97283	119.1001	212.0042	0	0	200	150	50	50
6	72.0286	73.54711	118.7725	228.0818	400	350	200	90	0	0
7	82.44486	51.22825	115.6796	202.4608	0	0	200	150	50	50
8	53.29845	79.70843	109.6033	229.8847	400	350	200	90	0	0
9	70.00269	82.247	97.27917	215.5534	0	350	200	150	50	50
10	70.71257	78.83929	105.5629	237.162	0	350	200	150	50	0
11	74.92034	77.8676	100.6473	233.096	0	0	200	150	50	50
12	64.80782	51.09847	112.1364	237.0245	0	0	0	0	0	50

Table 9: Hydrothermal Scheduling LRPSO for 10 units with ramp limits

Hydro Scheduling					*Thermal Scheduling*					
Hour(s)	*Units Allocation in MW*									
	Ph 1	*Ph 2*	*Ph 3*	*Ph 4*	*Ps 5*	*Ps 6*	*Ps 7*	*Ps 8*	*Ps 9*	*Ps 10*
1	86.31913	51.19691	120.7233	202.5651	0	0	0	0	0	50
2	65.46412	51.54502	120.1166	199.6969	0	0	0	0	0	50
3	75.51307	62.6347	114.5111	201.8384	0	0	0	150	50	50
4	67.28717	52.97631	116.9193	197.3681	0	0	0	150	50	50
5	84.22872	73.97283	119.1001	212.0042	0	0	200	150	50	50
6	72.0286	73.54711	118.7725	228.0818	400	350	200	90	0	0
7	82.44486	51.22825	115.6796	202.4608	0	0	200	150	50	50
8	53.29845	79.70843	109.6033	229.8847	400	350	200	90	0	0
9	70.00269	82.247	97.27917	215.5534	0	350	200	150	50	50
10	70.71257	78.83929	105.5629	237.162	0	350	200	150	50	0
11	74.92034	77.8676	100.6473	233.096	0	0	200	150	50	50
12	64.80782	51.09847	112.1364	237.0245	0	0	0	0	0	50

Table 10: Comparison of Social Economic profit Using LRPSO for 4 hydro 6 Thermal units

Bidding Strategies	*Customer 1 with no ramp limits*	*Customer 1 with ramp limits*	*Customer 2 with ramp limits*	*Customer 2 with no ramp limits*
	($)	**($)**	**($)**	**($)**
Low	50319.668	51149.20889	52837.98618	54109.668
Medium	49047.98618	54228.98315	54109.668	52837.98618
High	53495.98656	51795.73896	52837.98618	54109.668

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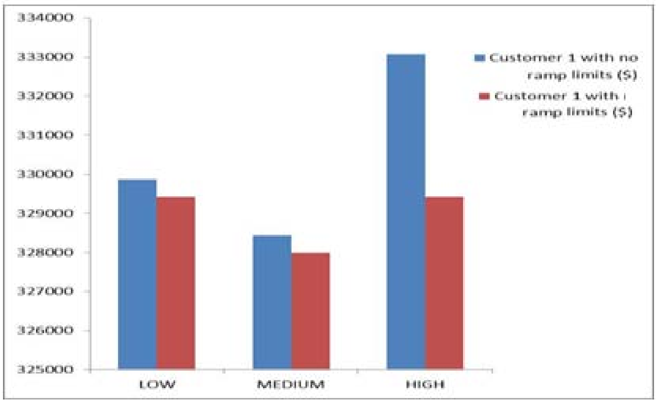

Figure 4: Comparison of Social Economic profit Using LRPSO 10 unit

Table 11: Hydrothermal Scheduling LRPSO for 14 units without ramp limits

Hydro Scheduling					*Thermal Scheduling*									
Hour(s)	*Units Allocation in MW*													
	Ph 1	*Ph 2*	*Ph 3*	*Ph 4*	*Ps 5*	*Ps 6*	*Ps 7*	*Ps 8*	*Ps 9*	*Ps 10*	*Ps 11*	*Ps 12*	*Ps 13*	*Ps 14*
1	85.87675	62.05105	81.74364	203.3618	455	313	0	0	0	0	0	0	0	0
2	91.65913	54.48727	79.34373	200.7258	455	363	0	0	0	0	0	0	0	0
3	81.89605	49.51195	76.00521	199.0765	455	455	8	0	0	0	0	0	0	0
4	88.34138	63.05681	77.96068	197.2436	455	455	68	0	0	0	0	0	0	0
5	70.63074	54.93571	111.9922	197.4343	455	455	130	28	0	0	0	0	0	0
6	70.1231	48.98575	83.85422	197.2746	455	455	130	121	0	0	0	0	0	0
7	55.88705	65.05386	118.9253	196.9066	455	455	130	115	0	0	0	0	0	0
8	65.60781	50.46624	108.624	197.0154	455	0	130	130	0	0	0	0	0	0
9	84.23952	49.12272	106.9893	196.9642	455	455	130	130	0	0	0	0	0	0
10	86.92249	71.61428	109.7994	197.96	455	455	130	130	162	80	0	0	0	0
11	86.30037	50.01402	105.0328	199.5646	455	455	130	130	162	80	0	55	0	0
12	56.28674	49.91443	112.7448	196.9896	455	455	130	130	162	80	0	55	0	0
13	86.31913	51.19691	120.7233	199.3416	455	455	130	130	93	0	0	0	0	0
14	65.46412	51.54502	120.1166	196.956	455	455	130	130	100	0	0	0	0	0
15	75.51307	62.6347	114.5111	199.9861	455	455	130	130	64	0	0	0	0	0
16	67.28717	52.97631	116.9193	197.3681	455	455	125	0	0	0	0	0	0	0
17	84.22872	73.97283	119.1001	212.0042	455	455	130	0	0	0	0	0	0	0
18	72.0286	73.54711	118.7725	228.0818	455	455	120	0	0	0	0	0	0	0
19	82.44486	51.22825	115.6796	202.4608	455	455	110	0	0	0	0	0	0	0
20	53.29845	79.70843	109.6033	229.8847	455	455	93	0	0	0	0	0	0	0
21	70.00269	82.247	97.27917	215.5534	455	455	100	0	0	0	0	0	0	0
22	70.71257	78.83929	105.5629	237.162	455	455	120	0	0	0	0	0	0	0
23	74.92034	77.8676	100.6473	233.096	455	455	58	0	0	0	0	0	0	0
24	64.80782	51.09847	112.1364	237.0245	455	413	0	0	0	0	0	0	0	0

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Table 12: Hydrothermal Scheduling LRPSO for 14 units with ramp limits

	Hydro Scheduling				*Thermal Scheduling*									
Hour(s)	*Units Allocation in MW*													
	Ph 1	*Ph 2*	*Ph 3*	*Ph 4*	*Ps 5*	*Ps 6*	*Ps 7*	*Ps 8*	*Ps 9*	*Ps 10*	*Ps 11*	*Ps 12*	*Ps 13*	*Ps 14*
1	85.87675	62.05105	81.74364	203.3618	455	313	0	0	0	0	0	0	0	0
2	91.65913	54.48727	79.34373	200.7258	455	363	0	0	0	0	0	0	0	0
3	81.89605	49.51195	76.00521	199.0765	455	443	8	0	0	0	0	0	0	0
4	88.34138	63.05681	77.96068	197.2436	455	455	68	0	0	0	0	0	0	0
5	70.63074	54.93571	111.9922	197.4343	455	455	130	28	0	0	0	0	0	0
6	70.1231	48.98575	83.85422	197.2746	455	455	130	78	0	0	0	0	0	0
7	55.88705	65.05386	118.9253	196.9066	455	455	130	115	0	0	0	0	0	0
8	65.60781	50.46624	108.624	197.0154	455	455	130	110	0	0	0	0	0	0
9	84.23952	49.12272	106.9893	196.9642	455	455	130	130	100	0	0	0	0	0
10	86.92249	71.61428	109.7994	197.96	455	455	130	130	162	80	52	0	0	0
11	86.30037	50.01402	105.0328	199.5646	455	455	130	130	162	80	68	0	0	0
12	56.28674	49.91443	112.7448	196.9896	455	455	130	130	162	80	68	0	0	0
13	86.31913	51.19691	120.7233	199.3416	455	455	130	130	93	0	0	0	0	0
14	65.46412	51.54502	120.1166	196.956	455	455	130	130	100	0	0	0	0	0
15	75.51307	62.6347	114.5111	199.9861	455	455	130	130	0	0	0	0	0	0
16	67.28717	52.97631	116.9193	197.3681	455	455	125	0	0	0	0	0	0	0
17	84.22872	73.97283	119.1001	212.0042	455	455	130	0	0	0	0	0	0	0
18	72.0286	73.54711	118.7725	228.0818	455	455	120	0	0	0	0	0	0	0
19	82.44486	51.22825	115.6796	202.4608	455	455	110	0	0	0	0	0	0	0
20	53.29845	79.70843	109.6033	229.8847	455	455	93	0	0	0	0	0	0	0
21	70.00269	82.247	97.27917	215.5534	455	455	100	0	0	0	0	0	0	0
22	70.71257	78.83929	105.5629	237.162	455	455	120	0	0	0	0	0	0	0
23	74.92034	77.8676	100.6473	233.096	455	455	58	0	0	0	0	0	0	0
24	64.80782	51.09847	112.1364	237.0245	455	413	0	0	0	0	0	0	0	0

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Table 13: Reserve for 10 bus thermal system

Hour(s)	*Units Allocation in MW*									
	Ps 1	*Ps 2*	*Ps 3*	*Ps 4*	*Ps 5*	*Ps 6*	*Ps 7*	*Ps 8*	*Ps 9*	*Ps 10*
1	0	76.8	0	0	0	0	0	0	0	0
2	0	81.8	0	0	0	0	0	0	0	0
3	0	0	91.8	0	0	0	0	0	0	0
4	0	0	97.8	0	0	0	0	0	0	0
5	0	0	0	106.8	0	0	0	0	0	0
6	0	0	0	116.1	0	0	0	0	0	0
7	0	0	0	115.5	0	0	0	0	0	0
8	0	0	0	115	0	0	0	0	0	0
9	0	0	0	0	127	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	148	0	0	0
12	0	0	0	0	0	0	0	0	148	0
13	0	0	0	0	126.3	0	0	0	0	0
14	0	0	0	0	127	0	0	0	0	0
15	0	0	0	0	123.4	0	0	0	0	0
16	0	0	103.5	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0
18	0	0	103	0	0	0	0	0	0	0
19	0	0	102	0	0	0	0	0	0	0
20	0	0	100.3	0	0	0	0	0	0	0
21	0	0	101	0	0	0	0	0	0	0
22	0	0	103	0	0	0	0	0	0	0
23	0	0	96.8	0	0	0	0	0	0	0
24	0	86.8	0	0	0	0	0	0	0	0

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Table 14: Hydrothermal Scheduling LREP for 14 units without ramp limits

Hour(s)	Hydro Scheduling				Thermal Scheduling									
	Units Allocation in MW													
	Ph 1	Ph 2	Ph 3	Ph 4	Ps 5	Ps 6	Ps 7	Ps 8	Ps 9	Ps 10	Ps 11	Ps 12	Ps 13	Ps 14
1	85.87675	62.05105	81.74364	203.3618	455	245	0	0	0	0	0	0	0	0
2	91.65913	54.48727	79.34373	200.7258	455	295	0	0	0	0	0	0	0	0
3	81.89605	49.51195	76.00521	199.0765	455	395	0	0	0	0	0	0	0	0
4	88.34138	63.05681	77.96068	197.2436	455	455	0	0	0	0	0	0	0	0
5	70.63074	54.93571	111.9922	197.4343	455	415	0	0	0	0	0	0	0	0
6	70.1231	48.98575	83.85422	197.2746	455	455	130	0	0	0	0	0	0	0
7	55.88705	65.05386	118.9253	196.9066	455	455	130	0	0	0	0	0	0	0
8	65.60781	50.46624	108.624	197.0154	455	455	130	0	0	0	0	0	0	0
9	84.23952	49.12272	106.9893	196.9642	455	455	130	130	130	0	0	0	0	0
10	86.92249	71.61428	109.7994	197.96	455	455	130	130	162	68	0	0	0	0
11	86.30037	50.01402	105.0328	199.5646	455	455	130	130	162	80	0	0	0	0
12	56.28674	49.91443	112.7448	196.9896	455	455	130	130	162	80	0	0	0	0
13	86.31913	51.19691	120.7233	199.3416	455	455	130	130	162	0	0	0	0	0
14	65.46412	51.54502	120.1166	196.956	455	455	130	130	130	0	0	0	0	0
15	75.51307	62.6347	114.5111	199.9861	455	455	130	130	0	0	0	0	0	0
16	67.28717	52.97631	116.9193	197.3681	455	455	130	0	0	0	0	0	0	0
17	84.22872	73.97283	119.1001	212.0042	455	455	90	0	0	0	0	0	0	0
18	72.0286	73.54711	118.7725	228.0818	455	455	130	0	0	0	0	0	0	0
19	82.44486	51.22825	115.6796	202.4608	455	455	130	0	0	0	0	0	0	0
20	53.29845	79.70843	109.6033	229.8847	455	455	130	0	0	0	0	0	0	0
21	70.00269	82.247	97.27917	215.5534	455	455	130	0	0	0	0	0	0	0
22	70.71257	78.83929	105.5629	237.162	455	455	130	0	0	0	0	0	0	0
23	74.92034	77.8676	100.6473	233.096	455	435	0	0	0	0	0	0	0	0
24	64.80782	51.09847	112.1364	237.0245	455	345	0	0	0	0	0	0	0	0

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Table 15: Hydrothermal Scheduling LREP for 14 units with ramp limits

Hour(s)	*Hydro Scheduling*				*Thermal Scheduling*									
	Units Allocation in MW													
	Ph 1	*Ph 2*	*Ph 3*	*Ph 4*	*Ps 5*	*Ps 6*	*Ps 7*	*Ps 8*	*Ps 9*	*Ps 10*	*Ps 11*	*Ps 12*	*Ps 13*	*Ps 14*
1	85.87675	62.05105	81.74364	203.3618	455	245	0	0	0	0	0	0	0	0
2	91.65913	54.48727	79.34373	200.7258	455	295	0	0	0	0	0	0	0	0
3	81.89605	49.51195	76.00521	199.0765	455	375	0	0	0	0	0	0	0	0
4	88.34138	63.05681	77.96068	197.2436	455	455	0	0	0	0	0	0	0	0
5	70.63074	54.93571	111.9922	197.4343	455	415	0	0	0	0	0	0	0	0
6	70.1231	48.98575	83.85422	197.2746	455	455	130	0	0	0	0	0	0	0
7	55.88705	65.05386	118.9253	196.9066	455	455	130	0	0	0	0	0	0	0
8	65.60781	50.46624	108.624	197.0154	455	455	130	0	0	0	0	0	0	0
9	84.23952	49.12272	106.9893	196.9642	455	455	130	130	130	0	0	0	0	0
10	86.92249	71.61428	109.7994	197.96	455	455	130	130	162	68	0	0	0	0
11	86.30037	50.01402	105.0328	199.5646	455	455	130	130	162	80	0	0	0	0
12	56.28674	49.91443	112.7448	196.9896	455	455	130	130	162	80	0	0	0	0
13	86.31913	51.19691	120.7233	199.3416	455	455	130	130	162	0	0	0	0	0
14	65.46412	51.54502	120.1166	196.956	455	455	130	130	130	0	0	0	0	0
15	75.51307	62.6347	114.5111	199.9861	455	455	130	130	0	0	0	0	0	0
16	67.28717	52.97631	116.9193	197.3681	455	455	130	0	0	0	0	0	0	0
17	84.22872	73.97283	119.1001	212.0042	455	455	90	0	0	0	0	0	0	0
18	72.0286	73.54711	118.7725	228.0818	455	455	130	0	0	0	0	0	0	0
19	82.44486	51.22825	115.6796	202.4608	455	455	130	0	0	0	0	0	0	0
20	53.29845	79.70843	109.6033	229.8847	455	455	130	0	0	0	0	0	0	0
21	70.00269	82.247	97.27917	215.5534	455	455	130	0	0	0	0	0	0	0
22	70.71257	78.83929	105.5629	237.162	455	455	130	0	0	0	0	0	0	0
23	74.92034	77.8676	100.6473	233.096	455	435	0	0	0	0	0	0	0	0
24	64.80782	51.09847	112.1364	237.0245	455	345	0	0	0	0	0	0	0	0

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Table 16: Comparison of Social Economic Profit Using LR-PSO for 4 Hydro Units and 10 Thermal Units

Bidding Strategies	*Customer 1 with no ramp limits*	*Customer 1 with ramp limits*	*Customer 2 with ramp limits*	*Customer 2 with no ramp limits*
	($)	**($)**	**($)**	**($)**
LOW	339529.9002	341313.5257	337757.2981	59431.46835
MEDIUM	338369.8731	341313.5257	338917.3252	58468.02505
HIGH	341696.9722	341313.5257	337757.2981	59431.46835

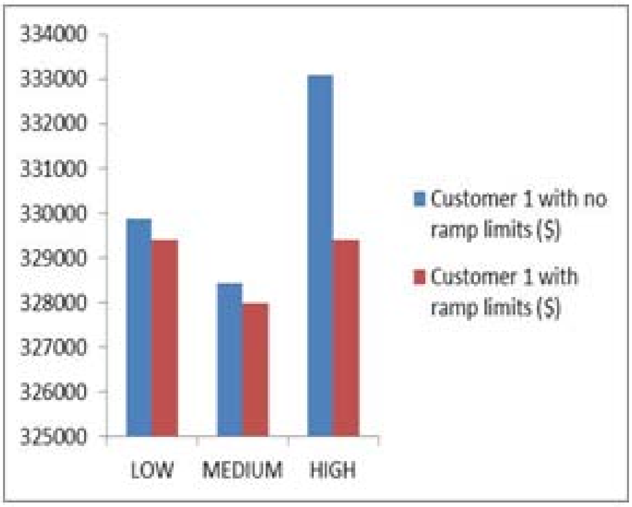

Table 5: Comparison of Social Economic profit Using LRPSO for 4 hydro 10 thermal

Table 17: Comparison of Social Economic profit Using LREP for 4 hydro 10 thermal

Bidding Strategies	*Customer 1 with no ramp limits*	*Customer 1 with ramp limits*	*Customer 2 with ramp limits*	*Customer 2 with no ramp limits*
	($)	**($)**	**($)**	**($)**
LOW	329860.32	329415.32	330646.69	327993.05
MEDIUM	328438.05	327993.05	333817.16	329415.32
HIGH	333075.25	329415.32	331326.27	327993.05

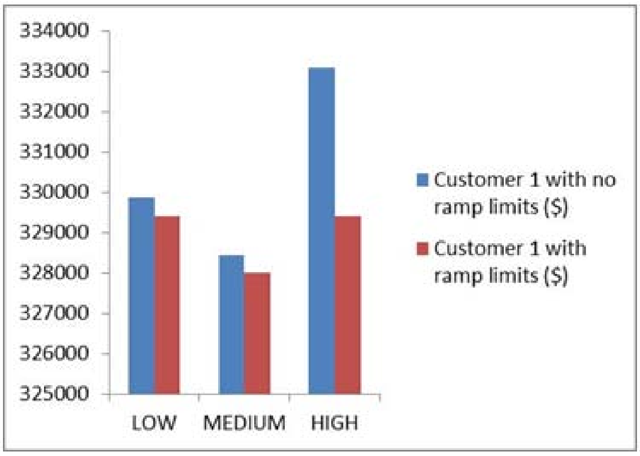

Figure 6: Comparison of Social Economic profit Using LREP for 4 hydro 10 thermal units

5. Introduction

The proposed solution methodology has been implemented on the 6 units thermal system 10 units thermal systems. The same thing has been implemented modifying the above mentioned systems by integrating them with 4 hydro units.

Table 1 and 2 shows the scheduling of a 6 units systems using EP and PSO scheduling. Table 3 shows the social economic profit of the Table 1 and 2 scheduled systems which shows that PSO is more efficient when compared to EP. Now the same systems have been integrated with 4 hydro systems and resulting in hydrothermal scheduling. Table 4, 5 and 6 shows the scheduling with 4 hydro units and 6 thermal units without ramp and with ramp limits using LR-EP and reserve allocation respectively. Table 7 shows the combine social economic profit with bidding strategies of high low medium for two customers. Fig 3 shows the pictorial representation of the profit compression. Table 8, 9 shows the scheduling with 4 hydro units and 6 thermal units without ramp and with ramp limits using LR-PSO and allocation respectively. Table 10 shows the combine social economic profit with bidding strategies of high low medium for two customers. Fig 4 shows the pictorial representation of the profit compression. Table 11, 12 and 13 shows the scheduling with 4 hydro units and 10 thermal units without ramp and with ramp limits using LR-PSO generation and allocation respectively. Table 14 shows the combine social economic profit with bidding strategies of high low medium for two customers. Fig 5 shows the pictorial representation of the profit compression. Table 15, 16 shows the scheduling with 4 hydro units and 10 thermal units without ramp and with ramp limits using LR-EP and allocation respectively. Table 17 shows the combine social economic profit with bidding strategies of high low medium for two customers. Fig 6 shows the pictorial representation of the profit compression. From the above discussion it is evident that PSO is more efficient when compared to EP and combined with Lagrange relaxation the convergence is much faster. Out of the hybrid LRPSO is more efficient than that of a LREP.

6. Conclusion

With the introduction of the competition in the power market, the over profit of the GENCO's has been increased. But focusing our vision on the only thermal scheduling many researchers have proved that the overall profit of the thermal unit can be increased. This has been accomplished by integrating the thermal systems with hydro systems resulting in hydro-thermal scheduling, where the overall revenue cost of the thermal system has been reduced over a fixed period of time by scheduling the hydro units.

Hydrothermal scheduling in deregulated environment has the advantage of increasing the overall social profit of the generation companies by implementing different bidding and power marketing strategies

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Author Profile

Gopi Krishna Allaboyena received his graduation B.Tech degree in Electrical & Electronics Engineering from Amrita University in 2012 and post-graduation M.Tech degree majoring in Power Systems Engineering from SRM University in 2015. He has worked on Indian Traction Railway Systems. His major areas of interest are Power Systems Economics, power quality, electromagnetic transients, overhead transmission lines, and underground cable systems.

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