# PLC-SCADA Based Supply Side Management in Deregulated Power Market

VIJAYA CHANDRAKALA K.R.M., BALAMURUGAN S.
ABHILASH R., ADITHYA K., KRISHNA KUMAR O. AND BALAJI T.J.
Department of Electrical and Electronics Engineering
Amrita Vishwa Vidyapeetham
Amrita School of Engineering, Coimbatore
INDIA
s_balamurugan@cb.amrita.edu http:// http://www.amrita.edu/faculty/dr-balamurugan-s

*Abstract:* - The deregulation of power industry is restructuring of rules of monopoly, hence bringing in more private players to sell or buy the electricity as a commodity. The power and price values are bid by the respective generation companies (GENCO's) and distribution companies (DISCOM's) through the electronic mode. There are various complex computing methods for determining the optimum price among which the power exchange curve method is discussed herewith. By plotting demand and supplier power characteristics curves, the intersection point, MCP (Market clearing price) can be determined. MCP calculation is one of the most important functions of a power pool operator. Its main objective is to maximize the Global welfare function where the generating companies and the consumers are benefited and unbiased. The MCP is calculated using MATLAB software and the winning bidders of the current market are found. The power obtained for the winning supplier then undergoes optimum scheduling for generation optimization namely, supply side management. The power optimization includes Unit Commitment (UC) and selected units to be committed undergo Economic Load Dispatch (ELD). For practical implacability, the supply side power management is implemented using Programmable Logic Controller (PLC) communicated through the Supervisory Control and Data Acquisition (SCADA) system.

*Key-Words:* - Deregulation, Market Clearing Price, Generating Companies, Distribution Companies, Programmable Logic Controller, Supervisory Control and Data Acquisition System.

## 1 Introduction

Deregulation and restructuring of utility industry has been an important aspect for the past decades. Previously, production and distribution of electricity had been considered as natural monopoly of the government due to the economic scale [1]. Many electrical utilities had the complete control over power generation and distribution. These utilities are known as vertically integrated systems since power is provided from a central station having control over generation, transmission and distribution. But the regulatory body [2-3], operating environment, improved technologies, and the nature of electricity business have changed very fast in the recent world. Therefore, it is very tedious and almost unimaginable to use the old rules or regulations, which were designed decades ago, even before the creation of computers, to manage and control the current power industry [4-6]. Deregulation in power industry, is restructuring of the rules and economic incentives that government set up to control and drive the electric power industry. In other words, it is building an environment of privatization. Deregulation of the electric power sector offers the possibility of improving the system operation efficiency by integrating the private players to compete and supply a reliable power supply to the end consumers. This infrastructure includes new and sophisticated measurement techniques and standards for tracking transactions in electricity markets and monitoring the performance of the electric power system [7]. The main economical benefits expected from deregulation include improved quality of electricity service at an optimum price, closely tracks the true cost of service, offering new products with different degrees of power reliability [7-8]. Restructuring in the electricity industry is

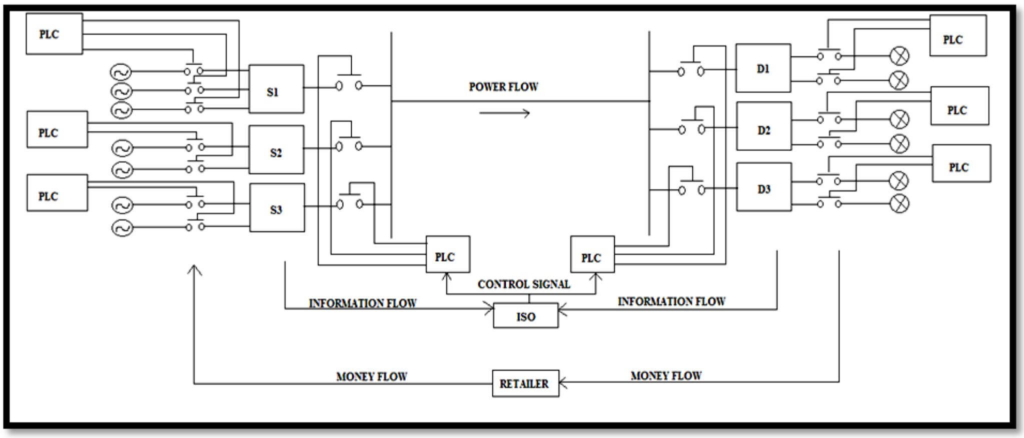



Fig 1. Single line diagram of a deregulated power system

spreading across the United States and around the world. Some of these initiatives are well under way, in California, Pennsylvania, Australia, Norway, and the United Kingdom [9-11]. The main entities of Deregulation are considered into four different categories: Generation Company (GENCO), Distribution Company (DISCO), Transmission Company (TRANSCO), and Power traders [12-13]. Power Market can be restructured in different model: Single Buyer Model, Bilateral Model, Power pool Model, Hybrid Model. This paper focuses on power pool model of deregulated power system. The power pool model is more efficient than the bilateral and single buyer model because of its increased power reliability, scheduled power transfer and transparency in the market functioning. The graphical method of finding the optimum price is opted since it eases the complexity without sacrificing the accuracy [13-14]. In this work, the Market Clearing Price (optimum price) [15-16] is found by using MATLAB software. PLC is chosen for controlling the network because of its direct compatibility with the high voltage systems, and its efficiency in communication with the SCADA [17-18].

Therefore, the real time power management in the deregulated system is been carried out on an innovative platform using Programmable Logic Controller (PLC) and Supervisory Control and Data Acquisition (SCADA) software. The paper discusses about the simulation of deregulated power market using MATLAB, integrating it with the PLC-SCADA combination to optimize the supply side power management. The supply side power management is carried out in stages: First the optimum scheduling of the generators is dealt using Unit Commitment (UC) and then Economic Load Dispatch (ELD) is processed for the scheduled number of generators obtained from the Unit Commitment.

## 2 System Layout

Simulating a restructured power market with efficient power management techniques so as to accomplish optimal power flow in the system is the prime focus of the paper. A model of a restructured electricity market is designed as shown in Fig 1._The GENCO's are named S1, S2 and S3 while D1, D2 and D3 are represented as DISCOM's. The Independent System Operator (ISO), a non-profit organisation, manages the transfer of electricity and the ancillary services in the deregulated market. Each GENCO and DISCOM would quote bids so as to participate in the market. Each of these bids will be received by the ISO through the internet and the ISO takes necessary decisions for determining the allowed power transactions. The ISO conducts the market and computes the Market Clearing Price (MCP) from the Power Exchange (PX) curve, the optimum price at which both GENCO's and DISCOM's would benefit [12]. All the power transfer and trade would take place at this rate. Once the market decides the clearance price, a control system using PLC-SCADA supports the ISO to connect the winning GENCO's and DISCOM's to the grid and carries out power management by performing UC and ELD [19-20]. This work utilises MATLAB software which completely supports the decision that has to be made by the ISO in the determination of Market Clearing Price and also to simulate a power market model to bring out an optimised solution to schedule the generating units.

## 3 Software Implementation

An automated system for managing the optimum scheduling and transfer of electricity in power trading is established using PLC. The work utilizes the support of MATLAB and PLC-SCADA programming for developing a simulated model of a restructured electricity market with optimized generator scheduling.

### 3.1 Determination of Market Clearing Price

For obtaining the Market Clearing Price (MCP) from the power exchange curve, simulation of a restructured electricity market with strategic traders interacting with the ISO is modelled using MATLAB. The bids quoted from the GENCO's and DISCOM's are tabulated in Table 1 and Table 2 respectively.

Table 1. GENCO's Quotation

| SLOT No. | GENCO's NAME | POWER QUOTED (MW) | PRICE QUOTED (Rs/MW) |
|---|---|---|---|
| SLOT 1 | Supplier 1 | 200 | 2400 |
| SLOT 2 | Supplier 1 | 50 | 3000 |
| SLOT 3 | Supplier 1 | 50 | 4000 |
| SLOT 1 | Supplier 2 | 150 | 3200 |
| SLOT 2 | Supplier 2 | 50 | 3400 |
| SLOT 1 | Supplier 3 | 100 | 2600 |
| SLOT 2 | Supplier 3 | 50 | 3600 |

Table 2. DISCOM's Quotation

| SLOT No. | DISCOM's NAME | POWER QUOTED (MW) | PRICE QUOTED (Rs/MW) |
|---|---|---|---|
| SLOT 1 | Consumer 1 | 50 | 2600 |
| SLOT 2 | Consumer 1 | 100 | 4600 |
| SLOT 1 | Consumer 2 | 50 | 2200 |
| SLOT 2 | Consumer 2 | 150 | 4400 |
| SLOT 1 | Consumer 3 | 50 | 2000 |
| SLOT 2 | Consumer 3 | 200 | 5000 |

Based on the bids and offers quoted by the GENCO's and DISCOM's, the power exchange curve [13-14] is plotted and MCP is calculated using MATLAB programming. The steps involved in the algorithm for determining the MCP is as follows:

Step 1: Read the bids quoted by the GENCO's and DISCOM's.

Step 2: Arrange the GENCO's bids of power in the ascending order w.r.t price and DISCOM'sbids of power in the descending order w.r.t price for plotting the Power Exchange (PX) curve.

Step 3: The intersection point of the PX curve decides the MCP.

Step 4: The Winning Suppliers and consumers are selected based on the corresponding MCP obtained from the plot.

Step 5: If the MCP > supplier price, the respective supplier has won the bid similarly if the MCP < Consumer price, the respective consumer has won the bid.

Step 6: Display the respective winning supplier and consumer.

The bids quoted by the GENCO's and DISCOM's shown in Table 1 and Table 2 is considered and routed through the algorithmic steps as explained above for finding the GENCO's and DISCOM's who would win the market.

Using MATLAB programming the PX curve is plotted as shown in Fig 2. The MCP is determined from the point of intersection of the GENCO's and DISCOM's curves.

From the above figure, it clearly shows the Market Clearing Price to be Rs 3200 / MW with optimum scheduling of power to be 450 MW.

With the MCP as reference price, the ISO carries out its decision making process in order to determine those companies who have won the bid in the electricity market.

The GENCO's (Suppliers) and DISCOM's (Consumers) who have won the bid with the above quoted MCP are tabulated in Table 3 and Table 4.

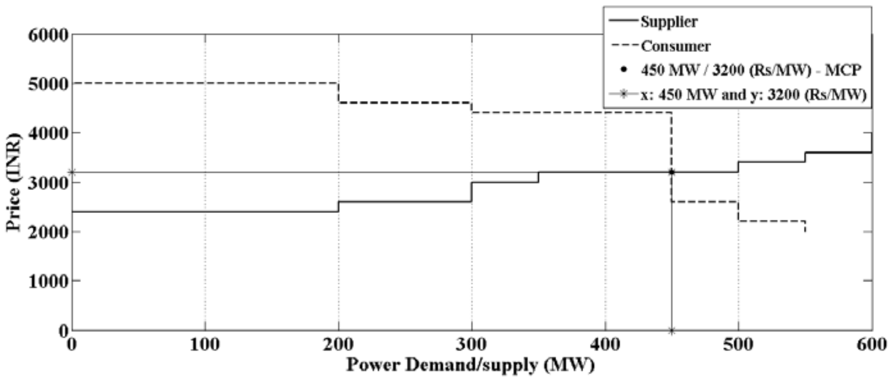



Fig 2. Power Exchange Curve

Table 3. Winning Suppliers with their respective bid values

| SLOT No. | GENCO's NAME | POWER (MW) | PRICE (Rs./MW) |
|---|---|---|---|
| SLOT 1 | Supplier 1 | 200 | 2400 |
| SLOT 2 | Supplier 1 | 50 | 3000 |
| SLOT 1 | Supplier 2 | 100 | 3200 |
| SLOT 1 | Supplier 3 | 100 | 2600 |

Table 4. Winning consumers with their respective bid values

| SLOT No. | DISCOM's NAME | POWER (MW) | PRICE (Rs./MW) |
|---|---|---|---|
| SLOT 2 | Consumer 1 | 100 | 4600 |
| SLOT 2 | Consumer 2 | 150 | 4400 |
| SLOT 2 | Consumer 3 | 200 | 5000 |

For efficient supply side management among the GENCOM's, optimum scheduling of the generators is required.

Priority wise commissioning the plants to generate power would help optimum committing of units and fuel cost minimization.

## 3.2 Optimized Scheduling of Generators

There are various methods for obtaining the optimized scheduling of power from the generators. Economical ways of generating power had always been the top most priority for GENCO's.

On combining UC and ELD mode of scheduling the power, the optimal units obtained is appreciable because the number of generators participating in the power transfer would be minimum, hence the operational costs.

Referring to Table 3, the winning suppliers consider computing methods such as UC and ELD, in order to operate their units in the most economical manner.

Renewable energy units of the suppliers are also taken into account to supplement the demand and are given top priority.

### 3.2.1 Unit Commitment

The suppliers choose or commit those generating units to get connected to the grid based on the cost of fuel, start-up costs and resource availability.

An optimized solution for choosing these units for economic operation is obtained by Priority List Method [12, 15-16].

For any complex systems the priority listing method gives the results with less computation time and complexity.

Table 5 highlights the fuel cost equations with their maximum and minimum power generation capabilities for three thermal generating units owned by supplier 1.

Table 5. Generating units cost equations of supplier 1

| UNIT | Cost Coefficients | | | Min. Power (MW) | Max. Power (MW) | Fuel cost (Rs.) |
|---|---|---|---|---|---|---|
| | a | b | C | | | |
| 1 | 0.00142 | 7.2 | 510 | 50 | 200 | 1.1 |
| 2 | 0.00194 | 7.85 | 310 | 50 | 200 | 1 |
| 3 | 0.00482 | 7.97 | 78 | 25 | 100 | 1.2 |

The priority list method is very fast and efficient method.

The Priority list method follows a priority listing of units based on their ranking in fuel production cost by rating the least with higher priority, from which the combination of units which are to be committed can be determined.

Table 6 shows the priority list based on fuel production cost. This method is primarily based on the principle that unit with the least value of average full load cost should be loaded to the maximum level and the unit with the least value should be lightly loaded as this may fetch more economical unit commitment solution.

Table 6. Priority based on fuel production cost (Rs./MW)

| RANK | UNIT | Rs./MWh | Min. Power (MW) | Max. Power (MW) |
|---|---|---|---|---|
| 1 | 2 | 9.48 | 50 | 400 |
| 2 | 1 | 9.79 | 150 | 600 |
| 3 | 3 | 11.188 | 50 | 200 |

And, Table 7 shows units based on lowest fuel production cost are combined to be switched ON if the demand lies in the set of power limits.

Table 7. Committing the units based on combinations of units

| PRIORITY | COMBINATION OF UNITS | Min. MW From combination | Max. MW From combination |
|---|---|---|---|
| 3 | 2+1+3 | 250 | 1200 |
| 2 | 2+1 | 200 | 1000 |
| 1 | 1 | 50 | 400 |

The UC by the winning supplier (GENCO's) using Priority List Method is adopted under MATLAB programming and the committed units of supplier 1 are shown in Fig 3.

### 3.2.2 Economic Load Dispatch

After the prescribed units are chosen for generation to meet the demand in a deregulated system, the optimal value of power that is to be generated from each of the units is obtained using MATLAB by performing Economic Load Dispatch (ELD). Lambda Iteration method is used for ELD because the degree of accuracy is more.

Fig 3. Optimal generation scheduling using Unit Commitment by the supplier 1

```
Optimum Generation scheduling using Unit Commitment

The total power to be supplied by the supplier 1= (MW)
  250


Enter the no of generating units for supplier 1= 4

Any renewable unit present(Y/N)? Y
Enter the no of renewable units = 1

Enter the power(MW) of renewable unit(HYDRO,SOLAR,WIND) 1 = (MW) 20

Enter the unit number(1,2,3..etc) = 1
Enter the value of a1 = 0.00142
Enter the value of b1 = 7.2
Enter the value of c1 = 510
Enter the minimum value of power generation 1 = (MW) 50
Enter the maximum value of power generation 1 = (MW) 200
Enter the fuel cost(R/MBtu)for unit 1 = Rs 1.1

Enter the unit number(1,2,3..etc) = 2
Enter the value of a2 = 0.00194
Enter the value of b2 = 7.85
Enter the value of c2 = 310
Enter the minimum value of power generation 2 = (MW) 50
Enter the maximum value of power generation 2 = (MW) 200
Enter the fuel cost(R/MBtu)for unit 2 = Rs 1

Enter the unit number(1,2,3..etc) = 3
Enter the value of a3 = 0.00482
Enter the value of b3 = 7.97
Enter the value of c3 = 78
Enter the minimum value of power generation 3 = (MW) 25
Enter the maximum value of power generation 3 = (MW) 100
Enter the fuel cost(R/MBtu)for unit 3 = Rs 1.2

The following units are to be switched ON for optimal operation

Unit 1
Unit 2
```

The steps involved in Lambda Iteration method for ELD is as follows:

Step 1: Input the total number of generators participating in the Economic Dispatch
Step 2: Input the cost equation for each unit
Step 3: From the cost equation calculate the initial value of lambda ($\lambda$) (incremental cost)
Step 4: Calculate $P_{Gi}$ using the initial $\lambda$ value
Step 5: Check for the inequality constraints $Pmin<P_{Gi}<Pmax$
Step 6: Set $P_{Gi}$ = Pmin if Pmin > $P_{Gi}$ or else set $P_{Gi}$ = Pmax if $P_{Gi}$ > Pmax
Step 7: Calculate $\sum P_{Gi}$
Step 8: Check whether $\sum P_{Gi} - P_D = \varepsilon$ (tolerance value)and go to step 11 if the tolerance value is satisfied or else go to next step;
Step 9: If $\sum P_{Gi} < P_D$ set a new value for $\lambda = \lambda + \Delta\lambda$ and repeat from the step 4;
Step 10: If $\sum P_{Gi} > P_D$ set a new value for $\lambda = \lambda - \Delta\lambda$ and repeat from the step 4;
Step 11: Display the individual generation values.

The lambda iteration process gets iterated until the total amount of power generated from the committed units of each supplier becomes equal to their offer quoted. Economic dispatch determines the best way to minimize the current generator operating costs.

The ELD performed on the units committed by the winning supplier (GENCO's) is adopted under MATLAB programming and the economically scheduled generators of the supplier 1 are shown in Figure 4.

Fig 4. Economic Load Dispatch of Supplier 1

```
Economic Load Dispatch for the Supplier

Respective power supplied from each generator of supplier 1
Generator 1 power = (MW) 180.0007
Generator 2 power = (MW) 50
```

This concludes the simulation part of the model of the electricity market using MATLAB software with primary focus on obtaining the MCP and optimization in scheduling of generating units among the suppliers.

In the next section, an automated approach of the simulated power deregulated system is adopted on hardware platform using PLC-SCADA system.

## 4 Hardware Implementation

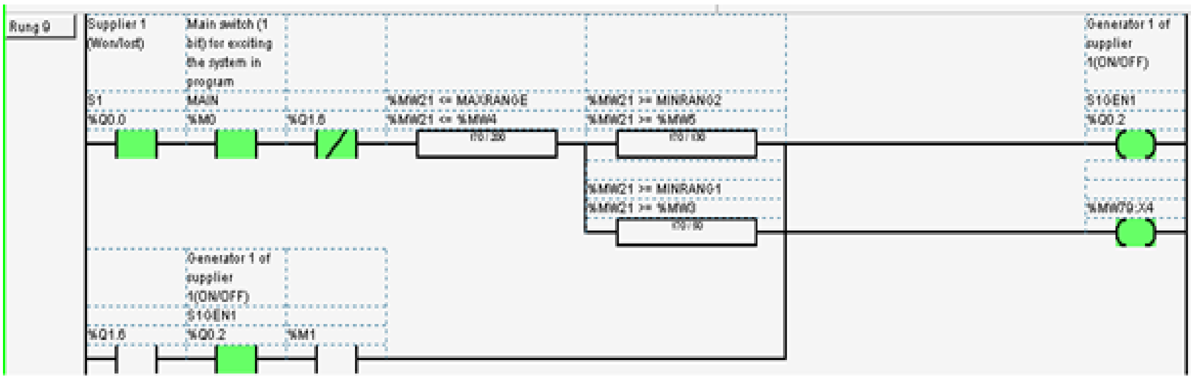
### 4.1 Integration of PLC-SCADA System

A hardware prototype model of a deregulated market shown in Fig 1 with the support of PLC-SCADA system integrated with the MATLAB simulated results as discussed in section 3 is set up. An automated control system for a restructured market enables the system operator to manage the transaction of power between traders in an optimised manner.

The SCADA allows the ISO to interact with the GENCO's and DISCOM's by acquiring the bids quoted to the market.

The MCP and the generating unit cost characteristics is also fed to SCADA using the results obtained from the simulated Power market model experimented in MATLAB as explained in

Fig 5. Ladder logic diagram for Operation of unit 1 of supplier 1 in the PLC




section 3. The SCADA is interfaced with the PLC to carry out the control action as per the results obtained from the simulated market which includes optimised scheduling of generating units and allowing the winning GENCO's and DISCOM's to get connected to the power system network. Fig 5 shows switching ON of a generating unit 1 of supplier 1 based on unit commitment [17].

From the Fig 5 it reflects the PLC ladder logic diagram for switching ON a generating unit (S1GEN1) of the winning supplier 1(S1).The SCADA window shown in Fig 6 enables Graphical User Interface (GUI), to show the respective GENCO's with their generating units as well as the DISCOM's through indicating lamps. The SCADA allows the operator to feed all the data to its window such as the MCP, prices bid by each of the companies and the generator characteristics of each GENCO during the period of bidding.

Fig 6. GUI interface of SCADA

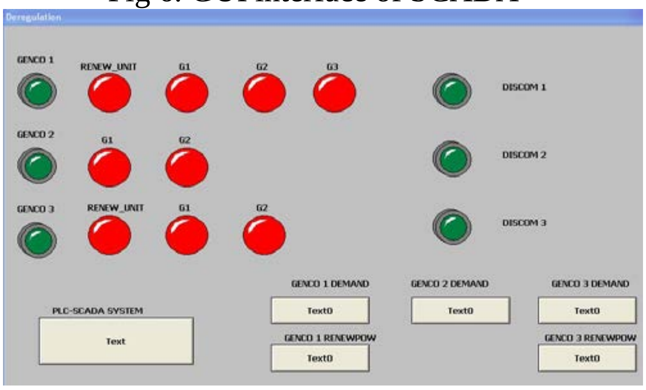
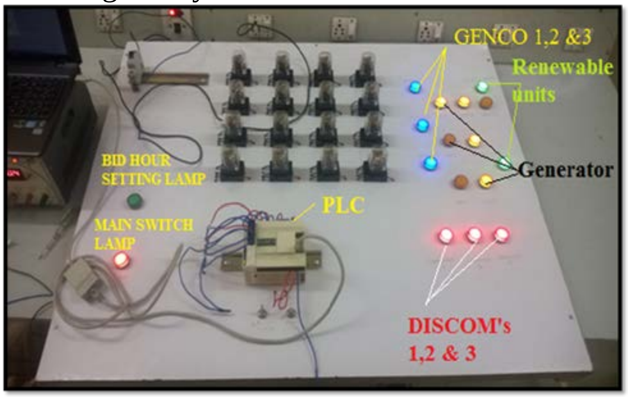



Figure 6 shows the SCADA window where the glowing lamps indicates the winning GENCO's and DISCOM's and also the corresponding committed units (G1, G2, G3) for each GENCO with the renewable unit (labelled as RENEW_UNIT) as well.

Fig 7 shows the hardware layout of the PLC-SCADA system using Schneider Electric Twido PLC, Industrial based relays, LED's and PLC-SCADA interfacing cable [18].

Fig 7. Layout of the ISO control unit




The glowing blue LED's indicate the winning GENCO's ; Yellow LED's for the committed thermal generating units; Green LED's for renewable units and the Red LED's for indicating the winning DISCOM's. Further, there are two LED's placed to the left most portion of the hardware layout; one for indicating the main switch ON/OFF and the other for indicating the bidding period which hereby facilitates a time based deregulated market [8].

## 5 Conclusion

Optimal ways of managing power in a deregulated environment have been a major challenge in deregulated power markets. Use of new algorithms for determining an optimised solution, for the present challenges faced in power market, is complex and has to be developed for satisfying the demands of fast changing power markets around the world.

This paper emphasize on bringing in an innovative approach for the supply side power management in a restructured power system. The MCP and the power exchange curve which forms the basis for decision making in an electricity market was obtained using MATLAB programming. From the winning suppliers and consumers, UC and ELD operation is performed on the won generating units of the suppliers using MATLAB programming for economic operation.

A prototype model of a restructured power market was established by integrating the simulated power market model with PLC-SCADA system for providing a flexible and better control of managing power. Bringing in renewable energy units and their role in providing energy in a deregulated system was also taken into consideration. Use of automation in decision making process will be an alternative method which would allow the operator in a power market to take the complete responsibility of managing the delivery of electricity between traders so as to achieve transparency. It would also reduce the complexity in establishing an optimal power flow in the power system network.

**Appendix**

$\lambda$ = Incremental fuel cost;
$P_{Gi}$ = Generated power in MW of Unit 'i';
Pmax= Maximum power of generator in MW;
Pmin= Minimum power of generator in MW;
$P_D$= Total power demand in MW;
$\varepsilon$ = Tolerance;

*References:*

[1] R. Tabors, Lessons from the UK and Norway, *IEEE Spectrum*, August 1996.
[2] E. Banovac, Ž. Bogdan and I. Kuzle, Choosing the Optimal Approach to Define the Methodology of a Tariff System for Thermal Energy Activities, Strojarstvo, Vol. 49, No. 6, 2007, pp. 409-420.
[3] E. Banovac, I. Štritof: Implementation of Performance Based Regulation in Distribution of Electricity in Croatia, Proceedings of the 5th WSEAS International Conference on Power Systems & Electromagnetic Compatibility (PSE 2005), Corfu, Greece, August 23-25, 2005, pp. 359-364.
[4] Felix Wu, Chris Yeung, Ada Poon and Jerome Yen, A Multi-agent Approach to the Deregulation and Restructuring of Power Industry, *The 31st Annual Hawaii International Conference on System Sciences*, Vol. 3, $6^{th}$ – $9^{th}$ January 1998, Kohala Coast, Hawaii, pp.122-131.
[5] Y. Gu and J. McCalley, Market-Based Transmission Expansion Planning, *In Proceedings of the IEEE PES Power Systems Conference & Exhibition (PSCE)*, Phoenix, AZ, USA, 20–23 March 2011, pp. 1–9.
[6] R.J. Thomas and T.R. Schneider, Underlying Technical Issues in Electricity Deregulation, *Proceedings of the HICSS-30*, 1997, pp. 561-570.
[7] Jordan Shikoski, Vladimir Katic and Risto Rechkoski, New Infratechnologies in the Deregulated Power Sector, *Turk. J. Elec. Engin.*, Vol.11, No.2, 2003, pp. 131-141.
[8] T. McGovern and C. Hicks, Deregulation and restructuring of the global electricity supply industry and its impact upon power plant suppliers, *International Journal of Production Economics*, Vol.89, No. 3, June 2004, pp. 321-337.
[9] A.R. Abhyankar and S.A. Khaparde, Electricity transmission pricing: tracing based point-of-connection tariff, *International Journal of Electric Power Energy Systems*, Vo. 31, 2009, pp. 59–66.
[10] Fabio Stacke and Pablo Cuervo, A Combined Pool / Bilateral / Reserve Electricity Market Operating Under Pay –as –Bid Pricing, *IEEE Transactions on Power Systems*, Vo.l.23, No.4, November 2008, pp. 1601-1610.
[11] Roy H. Kwon and Daniel Frances, Optimization Based Bidding in Day –Ahead Electricity Auction Markets : A Review of Models for Power Producers, *Handbook of Networks in Power Systems I, Energy Systems*, Springer-Verlag Berlin Heidelberg 2012.
[12] William W. Hogan, Market Design and Electricity restructuring, *Annual Conference*, Center for Business and Government, Association of Power Exchanges (APEx) Harvard University, Cambridge, November 2005.
[13] CALPOL Market Report, No.1, San Francisco, June 1998.
[14] Allen J. Wood, Bruce F. Wollenberg, Power Generation Operation and Control, Wiley-Interscience Publication, 1986.
[15] A.R. Abhyankarand and Prof. S.A. Khaparde, Introduction to deregulation in power industry, *www.nptel.ac.in*, Indian Institute of Technology-Bombay, Mumbai.

[16] Tanay Joshi and Gagan Uberoi, Graphical scheme for determination of market clearing price using quadratic bid functions, *International Journal of Advances in Engineering and Technology*, Vol. 1, No. 2, May 2011, pp.144-150.
[17] L.A. Bryan and E.A. Bryan, Programmable Controllers - Theory and Implementation, *Industrial Text Company Publication*, 2nd Edition, USA.
[18] Introduction to MODBUS TCP/IP, ACROMAG, *Technical reference*, http://www.prosoft-technology.com.
[19] Dan Werner, Electric Market Price Volatility: The Importance of Ramping Costs, *Agricultural & Applied Economics Association's 2014, AAEA Annual Meeting, July 27-29, 2014*.
[20] Syed Basit Ali Bukhari, Aftab Ahmad, Syed Auon Raza and Atta Ul Munim Zaki, Genetic Algorithm Based Generator Scheduling – A Review, *World Applied Sciences Journal*, Vol.30, No.12, 2014, pp.1826-1833.