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***Research Paper***

# Power quality based optimal nodal pricing in tradable electricity market

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## Abstract

Optimal Power Flow method described the nodal transmission pricing into different related factors, such as congestion, generation, power and electric load limitations. These details of each bus transmission prices can be used for to improve the proper usage of transmission congestion and power grid and to get reasonable transmission pricing for power structure. The proposed methodology is demonstrated on IEEE57 bus system and Maharashtra utility electric 400/765kv network.

***Keywords:*** *Locational marginal pricing, power quality.*

## 1. Introduction

Many developed and developing countries have spent substantial resources and efforts on implementing market-oriented reforms in their electric power sectors since 1990. Today most of the electricity reform processes are based on the market-orientation approaches to meet variety of objectives i.e. efficiency (techno-economic), competition, privatization, and new regulatory structure [4]. In general, reforms involve the introduction of competition into electricity generation; establishment of regulation; organization of markets for Generation (G), Transmission (T) and Distribution (D); network regulation; privatization of existing assets; promotion of new investments, and allowing for cost-reflective electricity tariffs. The drivers of reforms in developed countries differ from those of developing countries. Enhanced competition and consumer choice have dominated the reform rationale in the former while improved financial and operational performance and increased investment capital for improving electricity service levels are the main driving forces in developing countries. Also the reform programmes adopted by these countries include the elements like introduction of competition into electricity Generation, Transmission, Distribution and supply providers, restructuring the industry in order to enable the introduction of competition, privatization of the unbundled generators and suppliers, development of a new regulatory framework etc. It discover new solution to require load demand at low cost, which satisfied conditions, by adjustment of power system control variables or to find the problem deals with an optimal operating point of a power system that minimizes cost function like generation and transmission loss. This paper design with implementation of electricity pricing in regulated electricity market.

## 2. Electricity Spot Pricing

In regulated markets, pricing required for to solve the bidding issues and get current market values to buyers and sellers. Pricing depends on generator, loads , congestion, private sectors, fuels. Constraints variation gives energy prices from electricity network. The given work is depends on AC-DC power flow transmission pricing. The following modelling for spot pricing is derived for accurate and minimize form for the buyers and sellers. From this pricing sellers and buyers concentrates on actual generation and transmission costing.

## 3. Modelling of Spot Pricing

### A. Electricity Nodal Price Equations

$$
\begin{aligned}
L = {} & \sum_{i=1}^{NG} (a_i P_{gi}^2 + b_i P_{Gi} + c_i) + \sum_{i=1}^{NB} \lambda_{pi} ( P_{di} - P_{gi} + P_{dci} + P_L ) \\
& + \sum_{i=NV+1}^{NB} \lambda_{qi} ( Q_{di} - Q_{gi} + Q_{dci} + Q_L ) \\
& + \sum_{i=1}^{NG} \rho\, p_{li} ( P_{gi}^{\min} - P_{gi} ) + \sum_{i=1}^{NG} \rho\, p_{ui} ( P_{gi} - P_{gi}^{\max} ) \\
& + \sum_{i=1}^{NG} \rho\, q_{li} ( Q_{gi}^{\min} - Q_{gi} ) + \sum_{i=1}^{NG} \rho\, q_{ui} ( Q_{gi} - Q_{gi}^{\max} ) \\
& + \sum_{i=1}^{NB} \rho\, v_{li} ( \left| V_i^{\min} \right| - \left| V_i \right| ) + \sum_{i=1}^{NB} \rho\, v_{ui} ( \left| V_i \right| - \left| V_i^{\max} \right| ) \\
& + \sum_{i=1}^{NB} \rho\, \delta_{li} ( \delta_i^{\min} - \delta_i ) + \sum_{i=1}^{NB} \rho\, \delta_{ui} ( \delta_i - \delta_i^{\max} ) \\
& + \sum_{i=1}^{Nodc} \rho\, p_{fli} ( P_{fi}^{\min} - P_{fi} ) + \sum_{i=1}^{Nodc} \rho\, p_{fui} ( P_{fi} - P_{fi}^{\max} )
\end{aligned}
$$

## 4. Problem identify and numerical Results

### A. OPF based Electricity Spot Price: Problem Simulation and Results

This research methodology has been simulated in Matlab software and results are obtained

**Table 1.** AC-DC OPF based Electricity Spot Prices for IEEE57 bus system

| Bus no. | voltage | Real power | Reactive power | Angle | Real spot price ($/Mwh) |
|---|---|---|---|---|---|
| 1 | 1.09 | 0.0929 | -0.001 | 0.13 | 20.65 |
| 2 | 1.08 | | 0.4351 | 0.12 | 21.48 |
| 3 | 1.07 | 0.4001 | 0.2991 | 0.06 | 24.21 |
| 4 | 1.07 | | 0.001 | 0.04 | 23.85 |
| 5 | 1.08 | | 0.001 | 0.02 | 23.09 |
| 6 | 1.09 | | 0.501 | 0.02 | 22.57 |
| 7 | 1.07 | | 0.001 | 0.05 | 21.68 |
| 8 | 1.09 | 3.5302 | 0.501 | 0.09 | 20.17 |
| 9 | 1.07 | 0.0001 | 0.501 | 0.04 | 27.16 |
| 10 | 1.07 | | 0.001 | 0.03 | 26.21 |
| 11 | 1.06 | | 0.001 | 0.03 | 26.89 |
| 12 | 1.08 | 4.7001 | 0.501 | 0.07 | 25.08 |
| 13 | 1.06 | | | 0.04 | 26.41 |
| 14 | 1.06 | | | 0.04 | 26.55 |
| 15 | 1.07 | | | 0.06 | 26.37 |
| 16 | 1.08 | | | 0.06 | 24.05 |
| 17 | 1.08 | | | 0.08 | 22.54 |
| 18 | 1.06 | | | -0.02 | 24.05 |
| 19 | 1.01 | | | -0.03 | 25.69 |
| 20 | 1 | | | -0.02 | 26.28 |
| 21 | 1.02 | | | -0.02 | 27.02 |
| 22 | 1.02 | | | -0.01 | 27.08 |
| 23 | 1.02 | | | -0.01 | 27.08 |
| 24 | 1.02 | | | -0.01 | 26.38 |
| 25 | 0.97 | | | -0.1 | 26.96 |
| 26 | 0.98 | | | -0.01 | 26.18 |
| 27 | 1.03 | | | 0.01 | 23.99 |
| 28 | 1.06 | | | 0.02 | 22.96 |
| 29 | 1.08 | | | 0.03 | 22.22 |
| 30 | 0.95 | | | -0.11 | 27.75 |
| 31 | 0.93 | | | -0.12 | 28.93 |
| 32 | 0.95 | | | -0.11 | 28.55 |
| 33 | 0.95 | | | -0.11 | 28.65 |
| 34 | 0.97 | | | -0.03 | 28.73 |
| 35 | 0.98 | | | -0.03 | 28.51 |
| 36 | 0.99 | | | -0.03 | 28.16 |
| 37 | 0.99 | | | -0.02 | 27.88 |
| 38 | 1.02 | | | -0.01 | 27.11 |
| 39 | 0.99 | | | -0.02 | 27.95 |
| 40 | 0.98 | | | -0.03 | 28.21 |
| 41 | 1.03 | | | -0.03 | 26.77 |
| 42 | 0.99 | | | -0.05 | 28.04 |
| 43 | 1.05 | | | 0.01 | 26.86 |
| 44 | 1.03 | | | 0 | 26.91 |
| 45 | 1.06 | | | 0.02 | 26.12 |
| 46 | 1.04 | | | 0.01 | 26.44 |
| 47 | 1.03 | | | 0 | 26.84 |
| 48 | 1.02 | | | 0 | 26.92 |
| 49 | 1.03 | | | 0 | 26.72 |
| 50 | 1.02 | | | -0.01 | 27.09 |
| 51 | 1.06 | | | 0.01 | 26.16 |
| 52 | 1.05 | | | 0.08 | 23.44 |
| 53 | 1.04 | | | 0.11 | 23.81 |
| 54 | 1.08 | | | 0.21 | 22.37 |
| 55 | 1.04 | | | 0.08 | 26.46 |
| 56 | 0.98 | | | -0.06 | 28.46 |
| 57 | 0.97 | | | -0.07 | 28.74 |

**Table 2.** AC-DC OPF for IEEE57 bus system with different voltage limitations

| Bus no | Nodal price dollar/kwh | Nodal price dollar/kwh | Nodal price dollar/kwh |
|---|---|---|---|
| 1 | 20.65 | 20.45 | 20.30 |
| 2 | 21.48 | 21.28 | 21.13 |
| 3 | 24.21 | 24.01 | 23.86 |
| 4 | 23.85 | 23.65 | 23.50 |
| 5 | 23.09 | 22.89 | 22.74 |
| 6 | 22.57 | 22.37 | 22.22 |
| 7 | 21.68 | 21.48 | 21.33 |
| 8 | 20.17 | 19.97 | 19.82 |
| 9 | 27.16 | 26.96 | 26.81 |
| 10 | 26.21 | 26.01 | 25.86 |

| | | | |
|---|---|---|---|
| 11 | 26.89 | 26.69 | 26.54 |
| 12 | 25.08 | 24.88 | 24.73 |
| 13 | 26.41 | 26.21 | 26.06 |
| 14 | 26.55 | 26.35 | 26.20 |
| 15 | 26.37 | 26.17 | 26.02 |
| 16 | 24.05 | 23.85 | 23.70 |
| 17 | 22.54 | 22.34 | 22.19 |
| 18 | 24.05 | 23.85 | 23.70 |
| 19 | 25.69 | 25.49 | 25.34 |
| 20 | 26.28 | 26.08 | 25.93 |
| 21 | 27.02 | 26.82 | 26.67 |
| 22 | 27.08 | 26.88 | 26.73 |
| 23 | 27.08 | 26.88 | 26.73 |
| 24 | 26.38 | 26.18 | 26.03 |
| 25 | 26.96 | 26.76 | 26.61 |
| 26 | 26.18 | 25.98 | 25.83 |
| 27 | 23.99 | 23.79 | 23.64 |
| 28 | 22.96 | 22.76 | 22.61 |
| 29 | 22.22 | 22.02 | 21.87 |
| 30 | 27.75 | 27.55 | 27.40 |
| 31 | 28.93 | 28.73 | 28.58 |
| 32 | 28.55 | 28.35 | 28.20 |
| 33 | 28.65 | 28.45 | 28.30 |
| 34 | 28.73 | 28.53 | 28.38 |
| 35 | 28.51 | 28.31 | 28.16 |
| 36 | 28.16 | 27.96 | 27.81 |
| 37 | 27.88 | 27.68 | 27.53 |
| 38 | 27.11 | 26.91 | 26.76 |
| 39 | 27.95 | 27.75 | 27.60 |
| 40 | 28.21 | 28.01 | 27.86 |
| 41 | 26.77 | 26.57 | 26.42 |
| 42 | 28.04 | 27.84 | 27.69 |
| 43 | 26.86 | 26.66 | 26.51 |
| 44 | 26.91 | 26.71 | 26.56 |
| 45 | 26.12 | 25.92 | 25.77 |
| 46 | 26.44 | 26.24 | 26.09 |
| 47 | 26.84 | 26.64 | 26.49 |
| 48 | 26.92 | 26.72 | 26.57 |
| 49 | 26.72 | 26.52 | 26.37 |
| 50 | 27.09 | 26.89 | 26.74 |
| 51 | 26.16 | 25.96 | 25.81 |
| 52 | 23.44 | 23.24 | 23.09 |
| 53 | 23.81 | 23.61 | 23.46 |
| 54 | 22.37 | 22.17 | 22.02 |
| 55 | 26.46 | 26.26 | 26.11 |
| 56 | 28.46 | 28.26 | 28.11 |
| 57 | 28.74 | 28.54 | 28.39 |

**Graph 1.** AC-DC OPF for IEEE57 bus system with different voltage limitations

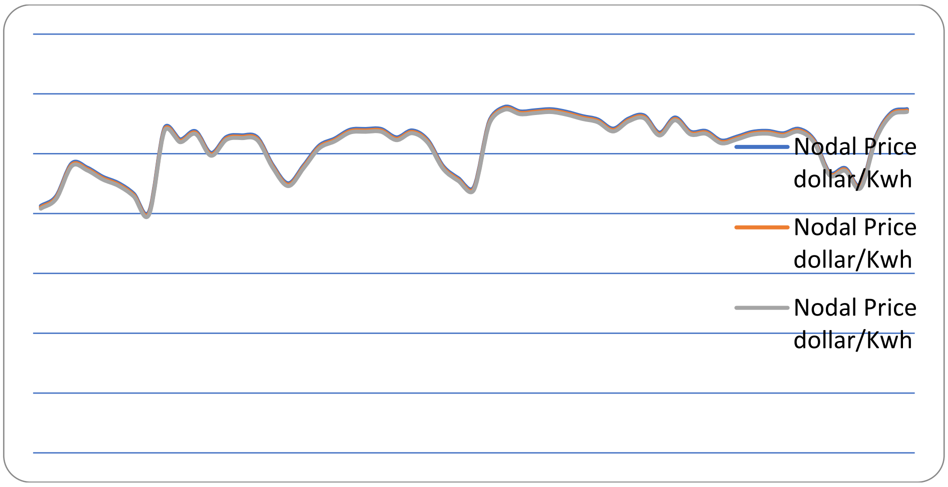


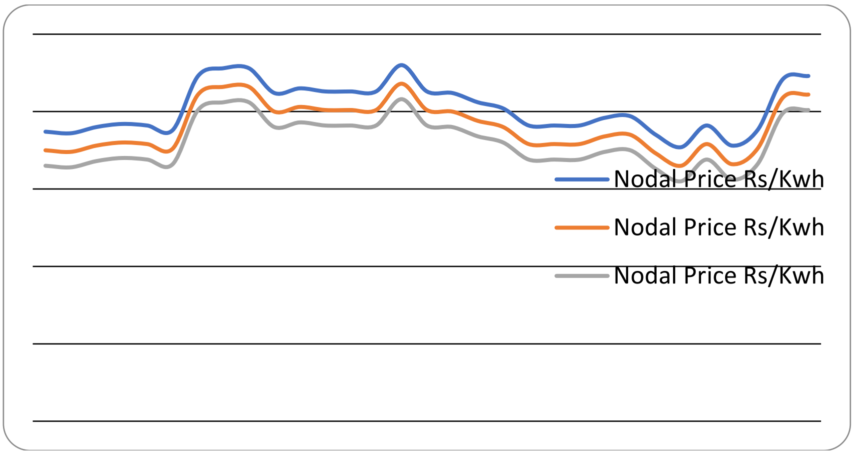
**Table 3.** OPF based electricity spot transmission pricing using for Maharashtra Network Electricity Network

| Bus No. | Voltage | Real power | Reactive power | Angle | Spot price (Rs./kwh) |
|---|---|---|---|---|---|
| 1 | 418.39 | 2.59 | 1.97 | 0.15 | 1.88 |
| 2 | 413.66 | 2.66 | 0.54 | 0.27 | 1.87 |
| 3 | 420.01 | 2.54 | | | 1.91 |
| 4 | 412.57 | 2.5 | | | 1.93 |
| 5 | 416.72 | 2.55 | | | 1.92 |
| 6 | 417.92 | 2.66 | | | 1.89 |
| 7 | 400.73 | 1.85 | | | 2.24 |
| 8 | 394.13 | 1.84 | | | 2.29 |
| 9 | 393.7 | 1.83 | | | 2.29 |
| 10 | 413.44 | 1.88 | | | 2.13 |
| 11 | 409.4 | 1.86 | | | 2.16 |
| 12 | 415.08 | 1.94 | 0.8 | 0.13 | 2.14 |
| 13 | 414.34 | 1.93 | | | 2.14 |
| 14 | 413.73 | 1.93 | 0.1 | 0.18 | 2.14 |
| 15 | 394.61 | 1.89 | | | 2.31 |
| 16 | 420.01 | 1.82 | | | 2.14 |
| 17 | 409.15 | 1.94 | | | 2.13 |
| 18 | 406.22 | 2.09 | | | 2.07 |
| 19 | 408.76 | 2.19 | | | 2.03 |
| 20 | 389.82 | 2.6 | 0.4 | 0.41 | 1.92 |
| 21 | 400.7 | 2.57 | | | 1.92 |
| 22 | 403.76 | 2.54 | | | 1.92 |
| 23 | 420.01 | 2.38 | | | 1.97 |
| 24 | 418.59 | 2.34 | | | 1.98 |
| 25 | 420.01 | 2.6 | 0.4 | 0.12 | 1.86 |
| 26 | 420.01 | 2.92 | 0.51 | 0.03 | 1.78 |
| 27 | 389.25 | 2.55 | 0.11 | 0.6 | 1.92 |
| 28 | 420.01 | 3.01 | 0.85 | 0.14 | 1.79 |
| 29 | 409.13 | 2.69 | 0.1 | 0.25 | 1.89 |
| 30 | 401.55 | 1.91 | 0.2 | 0.01 | 2.22 |
| 31 | 401.38 | 1.87 | 0.2 | 0.01 | 2.24 |

**Table 4.** AC-DC OPF based Electricity Spot Prices for 400/765kv MSTECL different voltage limitations

| Bus no. | Nodal price Rs/kwh | Nodal price Rs/kwh | Nodal price Rs/kwh |
|---|---|---|---|
| 1 | 1.88 | 1.76 | 1.63 |
| 2 | 1.87 | 1.75 | 1.62 |
| 3 | 1.91 | 1.79 | 1.66 |
| 4 | 1.93 | 1.81 | 1.68 |
| 5 | 1.92 | 1.8 | 1.67 |
| 6 | 1.89 | 1.77 | 1.64 |
| 7 | 2.24 | 2.12 | 1.99 |
| 8 | 2.29 | 2.17 | 2.04 |
| 9 | 2.29 | 2.17 | 2.04 |
| 10 | 2.13 | 2.01 | 1.88 |
| 11 | 2.16 | 2.04 | 1.91 |
| 12 | 2.14 | 2.02 | 1.89 |
| 13 | 2.14 | 2.02 | 1.89 |
| 14 | 2.14 | 2.02 | 1.89 |
| 15 | 2.31 | 2.19 | 2.06 |
| 16 | 2.14 | 2.02 | 1.89 |
| 17 | 2.13 | 2.01 | 1.88 |
| 18 | 2.07 | 1.95 | 1.82 |
| 19 | 2.03 | 1.91 | 1.78 |
| 20 | 1.92 | 1.8 | 1.67 |
| 21 | 1.92 | 1.8 | 1.67 |
| 22 | 1.92 | 1.8 | 1.67 |
| 23 | 1.97 | 1.85 | 1.72 |
| 24 | 1.98 | 1.86 | 1.73 |
| 25 | 1.86 | 1.74 | 1.61 |
| 26 | 1.78 | 1.66 | 1.53 |
| 27 | 1.92 | 1.8 | 1.67 |
| 28 | 1.79 | 1.67 | 1.54 |
| 29 | 1.89 | 1.77 | 1.64 |
| 30 | 2.22 | 2.1 | 1.97 |
| 31 | 2.24 | 2.12 | 1.99 |

**Graph 2.** OPF based Electricity Spot Prices for 400/765kV MSETCL with different voltage limitations




## 5. Conclusion

The paper presented power quality based optimal electricity pricing methodology suitable for Indian real power systems. For power quality, changes the different voltage values and according the nodal prices are get suitable transmission pricing. The power quality improves the system as well as grid with proper voltages. For better quality assumed different load conditions, generation and transmission congestion.

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