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# New Approach towards Transmission Pricing

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**ABSTRACT:** Today in order to improve economic efficiency, reliability of power systems and accountability, electricity industries around the world significantly become restructured. To know the system operation and price volatility in the restructured market, accurate prediction of electricity nodal price has now become an important activity. Estimation of risk and have better market oriented decision making has been possible.

Many developing countries including India are adopting HVDC in order to meet the electricity demand and other benefits. Based on nodal pricing theory marginal cost, an approach is proposed in this paper in which the transition costs of both active and reactive power are calculated.

**KEYWORDS:** Nodal Pricing, Optimum Power Flow(OPF), Marginal Cost, Locational Marginal Price(LMP), System Security.

## I. INTRODUCTION

In different parts of world power system has faced with complete restructuring [1]. The electric power industry has now entered in an increasingly competitive environment under which it becomes more realistic to improve economics and reliability of power systems by enlisting market forces [2]. In the new era, a supplier may wish to use a ‘third party’ grid, to transmit the electrical power to a specific consumer. Also in developing countries, the trend of electricity market is heading towards *Transmission Open Access* whereby transmission providers will be required to offer the basic transmission service (i.e. operational and/or ancillary services) and pricing [3]. Optimal nodal pricing in this context is one of the effective pricing schemes for providing a higher profit to both the utility and the customers,which[4] covers long term transit pricing procedure, while [5] reviews various transit transactions. All references apply about a marginal cost based OPF procedure, ignoring the reactive power prices. Nodal prices contain valuable information useful for independent system operator (ISO) operation and, hence the scheme is to accurately determine them, continue to be an active area of research [2]-[10]. The purpose to develop nodal price theory is to bring efficient use of transmission grid and generation resources by providing correct economic signals.

In the coming years, in developing and transition countries power consumption is expected to more than double, whereas in developed countries, it will increase only for about 35-40%. Due to inadequate investments incurred in the past many developing and transition countries are facing the problems of infrastructure investment especially in transmission and distribution segment. To reduce the gap between transmission capacity and power demand, trend is to adopt HVDC transmission system in the existing AC networks to gain technical and economical advantages of the investment. Under such scenario, it is obvious to address this trend in designing optimal nodal pricing scheme.

This study proposed optimal electricity nodal pricing scheme can be more suitable for similar developing countries including India. Consumer load modelling is considered to extend OPF formulation, while various operational constraints are still observed. Marginal cost, based on nodal pricing strategy is adopted to cover active power as well as reactive power pricing.

## II. ELECTRICITY NODAL PRICE FORMULATION

Nodal price or spot price theory for the deregulated power systems was developed to induce efficient use of the transmission grid and generation resources by providing correct economic signals[10]. Nodal pricing is a method to determine marketclearing prices for several locations on thetransmission grid called nodes. Each node representsa physical location on the transmission systemincluding generators and loads. The price at eachnode reflects the locational value of energy, whichincludes the cost of the energy and the cost ofdelivering it. This pricing provides marketparticipants a clear and accurate signal of the price ofelectricity at every location on the grid. These prices,in turn, reveal the value of locating new generation,upgrading transmission, or reducing electricityconsumption, elements

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needed in a well-functioningmarket to alleviate constraints, increase competitionand improve the systems' ability to meet power demand. It increases the efficiency of a competitive wholesale energy market. Method also provides greater transparency for regulators seeking to ensure reliability and affordability of energy.

## III. PROBLEM FORMULATION

Let P = ($p_1$,…..,$p_n$) and Q =($q_1$,…..,$q_n$) for a n buses system, where pi andqi be active and reactive power demands ofbus-i, respectively. The variables in powersystem operation to be X = ($x_1$,….,$x_m$), suchas real and imaginary parts of each busvoltage. So the operational problem of apower system for given load (P, Q) can beformulated as OPF problem [11].

$$\text{Minimize } f\ (X, P, Q) \text{ for } X(1)$$
$$\text{Subject to } S\ (X, P, Q) = 0(2)$$
$$T\ (X, P, Q) \le 0(3)$$

Where

S (X) = ($s_1$(X, P, Q),…,$s_{n1}$(X,P,Q))$^T$ and

T (X) = ($t_1$(X, P, Q),… $t_{n2}$(X, P,Q))$^T$ have $n_1$ and $n_2$ equations respectively,and are column vectors. Here AT represents the transpose of vector A.

$f$ (X, P, Q) is a scalar, short term operatingcost, such as fuel cost. The generator costfunction $fi(P_{Gi})$ in $/MWh is considered tohave cost characteristics represented by,

$$f=\sum_{i=1}^{NG} a_i P_{Gi}^{2} + b_i P_{Gi} + c_i (4)$$

Where, $P_{Gi}$is its real power output; $a_i$,$b_i$and $c_i$represents the cost coefficient ofthe ith generator, $NG$ represents thegeneration buses.

The various constraints to be satisfied duringoptimization are as follows,

(1) Vector of equality constraint such aspower flow balance (i.e. Kirchoff’s laws) isrepresented as:

S (X, P, Q) = 0 or

$$P_G = P_D + P_{DC} + P_L \text{ and}$$
$$Q_G = Q_D + Q_{DC} + Q_L (5)$$

Where suffix *D* represents the demand, *G* isthe generation, *DC* represents dc terminaland *L* is the transmission loss.

(2) The vector, inequality constraints including limits of all variables i.e. all variables limits and function limits such as, upper and lower bounds of transmission lines, generation outputs, stability and security limits may be represented as,

$$T\ (X, P, Q) \le 0\ (6)$$

(i) The maximum and minimum real and reactive power outputs of the generating sources are given by,

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} (i\ G \in B\ ) \text{ and}$$
$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max} (i, G \in B)(7)$$

Where, $P_{Gi\ \min}$,$P_{Gi\ \max}$are the minimum and maximumreal power outputs of the generating sources and$Q_{Gi\ \min}$ , $Q_{Gi\ \max}$are the minimum and maximumreactive power outputs.

(ii) Voltage limits (Min/Max) signals the system bus voltages to remain within a narrow range. These limits may be expressed by the following constraints,

$$V_{Gi}^{\min} \le V_{Gi} \le V_{Gi}^{\max} (i=1,\ldots,NB)(8)$$

Where, NB represents number of buses.

(iii) Power flow limits refer to the transmission line’s thermal or stability limits capable of transmitting maximum power represented in terms of maximum MVA flow through the lines and it is expressed by the following constraints,

$$P_f^{\min} \le P_f \le P_f^{\max}(\text{f=1,..,}Noele) \quad (9)$$

Where, *Noele*represents number of transmission lines connected to grid.
The operating condition of the combined ac-dc electric power system is described by the vector

$$X = [\delta, V, x_c, x_d]^t (10)$$

Where, δ and *V* are the vectors of the phases andmagnitude of the phasor bus voltages; $x_c$is thevector of control variables and $x_i$is the vector of dcvariables.

## IV. NODAL PRICE

The real and reactive power prices at bus ' *i*' is theLagrangian multiplier value ofthe equality and in-equality constraints. The Lagrangian multiplier values are calculated by solving the first order condition of the Lagrangian, partial derivatives of theLagrangianwith respect to every variables concerned. Therefore the Lagrangian function (orsystem cost) of equation (1) - (3) defined as,

$$L(X ,\lambda,\rho , P,Q) = f (X, P,Q) +\lambda S(X, P,Q) + \rho T(X , P,Q)$$

Or

$$\begin{aligned} L = {} & \sum_{i=1}^{NG}(a_i P_{gi}^2 + b_i P_{Gi} + c_i + \sum_{i=1}^{NB} \lambda_{pi}\left(P_{di} - P_{gi} + P_{dci} + P_L\right) + \sum_{i=NV+1}^{NB} \lambda_{qi}\left(Q_{di} - Q_{gi} + Q_{dci} + Q_L\right) \\ & + \sum_{i=1}^{NG} \rho\, p_{li}\left(P_{gi}^{min} - P_{gi}\right) + \sum_{i=1}^{NG} \rho\, p_{ui}\left(P_{gi} - P_{gi}^{max}\right) + \sum_{i=1}^{NG} \rho\, q_{li}\left(Q_{gi}^{min} - Q_{gi}\right) \\ & + \sum_{i=1}^{NG} \rho\, q_{ui}\left(Q_{gi} - Q_{gi}^{max}\right) + \sum_{i=1}^{NB} \rho\, v_{li}\left(\left|V_i^{min}\right| - \left|V_i\right|\right) + \sum_{i=1}^{NB} \rho\, v_{ui}\left(\left|V_i\right| - \left|V_i^{max}\right|\right) \\ & + \sum_{i=1}^{NB} \rho\, \delta_{li}\left(\delta_i^{min} - \delta_i\right) + \sum_{i=1}^{NB} \rho\, \delta_{ui}\left(\delta_i - \delta_i^{max}\right) + \sum_{i=1}^{Noele} \rho\, p_{fli}\left(P_{fi}^{min} - P_{fi}\right) \\ & + \sum_{i=1}^{Noele} \rho\, p_{fui}\left(P_{fi} - P_{fi}^{max}\right) (11) \end{aligned}$$

Where, '*l*'and '*u*' are the lower and upperlimits; λ= ($\lambda_1$, …….,$\lambda_n$) is the vector of Lagrangemultipliers concerning the equality (power balance)constraints; ρ = ($\rho_1$, ……….,$\rho_n$) are the Lagrangemultipliers concerning to the inequality constraints.
Then at an optimal solution (*X* ,λ,ρ) and for a set ofgiven (*P*,*Q*) , the nodal price of real and reactivepower for each bus are expressed below for *i* =1,…..…, n.

$$\pi_{p,i} = \frac{\partial L(X,\lambda,\rho,P,Q)}{\partial pi} = \frac{\partial f}{\partial pi} + \lambda \frac{\partial S}{\partial pi} + \rho \frac{\partial T}{\partial pi} \; (12)$$

$$\pi_{q,i} = \frac{\partial L(X,\lambda,\rho,P,Q)}{\partial qi} = \frac{\partial f}{\partial qi} + \lambda \frac{\partial S}{\partial qi} + \rho \frac{\partial T}{\partial qi} \; (13)$$

Here $\pi_{p,i}$and $\pi_{q,i}$are active and reactivenodal prices at bus ' *i* ', respectively. The differencei.e. $\pi_{p,i}$-$\pi_{p,j}$and $\pi_{q,i}$-$\pi_{q,j}$represents active andreactive power transmission charges from bus-j tobus-i. Equation (17) can be viewed as the systemmarginal cost created by an increment of real powerload at bus *i*. The above formulation wasimplemented in MATLAB using the '*fmincon*'function available in the optimization toolbox. Anadvantage of using the '*fmincon*' is that theconstraints can be directly evaluated as functions ofthe state variables which can be separate modulesreducing programming complexity.

## V. PROBLEMS, SIMULATION AND EXAMPLE

### Modified IEEE 30 Bus system:

The given scheme is tested overmodified IEEE 30-bus system. It consists of 4generators and 40 transmission lines areshown in Fig. A1.The upper and lower bounds(real power) for generators $G_1$, $G_2$,$G_{22}$, and $G_{27}$ are shown in Table A1.

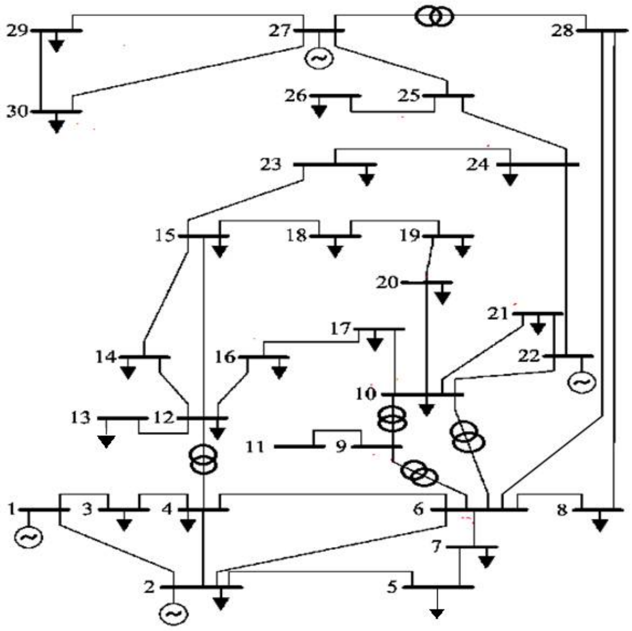

Figure A-1 IEEE 30 Bus test system

**Table 1 Nodal Price: IEEE 30-Bus Test System**

| Bus No. | Real Nodal Price ($/MWh) | | Bus No. | Real Nodal Price ($/MWh) | | Bus No. | Real Nodal Price ($/MWh) | |
|---|---|---|---|---|---|---|---|---|
| | Without Losses | With Losses | | Without Losses | With Losses | | Without Losses | With Losses |
| 1 | 19.68 | 20.73 | 11 | 18.78 | 19.19 | 21 | 18.76 | 19.16 |
| 2 | 19.53 | 20.76 | 12 | 17.59 | 17.83 | 22 | 17.15 | 19.21 |
| 3 | 21.00 | 21.07 | 13 | 19.96 | 20.34 | 23 | 18.11 | 18.18 |
| 4 | 19.85 | 20.04 | 14 | 20.07 | 20.22 | 24 | 18.34 | 18.54 |
| 5 | 22.81 | 25.38 | 15 | 19.47 | 19.66 | 25 | 17.93 | 17.93 |
| 6 | 19.82 | 19.82 | 16 | 18.01 | 18.09 | 26 | 19.51 | 19.59 |
| 7 | 21.66 | 22.26 | 17 | 18.14 | 18.33 | 27 | 19.47 | 21.33 |
| 8 | 21.90 | 23.02 | 18 | 17.51 | 17.58 | 28 | 19.08 | 19.083 |
| 9 | 21.13 | 21.13 | 19 | 18.32 | 18.53 | 29 | 18.57 | 18.62 |
| 10 | 17.89 | 18.02 | 20 | 17.76 | 17.80 | 30 | 18.10 | 18.33 |

Also the upper and lower bounds (reactive power) for all generators i.e. $G_1$, $G_2$, $G_{22}$ and $G_{27}$ are $-0.4 \le Q_{Gi} \le 0.4$ . The voltage values for all buses are bounded between 0.95 and 1.05. The fuel cost function for generators is expressed as ( 2 ) $fi = a_i P_{Gi} + b_i P_{Gi} + c_i$in ($/MWh) is shown in table A1. The demand at various buses is shown in table A2. All of the values are indicated by p.u. For this system there are 2×26 equalities constraints of S corresponding to their respective real and reactive power balances of the buses without a generator, and about 78 inequalities constraints of T corresponding of 30 pairs of voltage, 2 × 4 pairs of generation output and one pair of line flow upper and lower bounds respectively.

By applying the nodal pricing methodology, the optimal nodal prices of real power with and without losses are computed and compared as shown in the Table 1.

## VI. CONCLUSION

This study presented basics of optimal nodal pricing based on OPF. The purpose was (1) To formulate optimal Nodal pricing scheme suitable to real transmission networks for developing countries like India; (2) To contribute andsuggest the importance of nodal pricing information to system operator, regulatory commissions and utilities and (3) To suggestthe techno-commercial advantages of nodalpricing scheme for development of wholesale electricity markets in developing countrieslike India. Finally the proposed optimalscheme can ensure to achieve technical objectives,lower and uniform electricity nodal prices. This pricebehaviour also provides vital information to themarket participants about techno-commercialadvantages of generation addition and investment in transmission sector, one of the prime requirements topromote competition in the electricity market fordeveloping or transition economy.

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