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Ac-Dc Optimal Power Flow Based Nodal Pricing in Deregulated Power System

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Abstract: In This Paper an AC-DC Optimal power flow based nodal pricing methodology is presented. The active and reactive power generated and purchased at each bus is calculated by using OPF. Also, nodal prices can be obtained by using OPF. Here the nodal prices are important because they reflect the marginal generation and load at each bus. In general, these prices are also known as locational marginal Prices and spot prices. In this paper, for the load flow analysis well-known Newton-Raphson method is used and is modified to achieve compatibility for a.c.-d.c. systems with integrated d.c. links in the a.c. network. This Paper use the MATLAB Software to determine the OPF based Nodal pricing scheme without violating system constraints. This approach has been demonstrated by simulating the study with IEEE30 bus system and conclusions are drawn.

Keywords: Optimal Power flow, Nodal Pricing, Deregulation MATLAB, IEEE 30Bus.

I. INTRODUCTION

Nowadays electric utilities have experienced a period of rapid changes especially in market structure and regulatory Policies in many parts of the world. Because of the uprising of independent power producers as well as the changing structure of the electricity supply industry, the power industry has entered an increasingly competitive environment under which it becomes more important to improve economics and reliability of power systems by enlisting market resources.(1)

To induce efficient use of both the transmission grid and generation resources by providing correct economic signals, a nodal price or spot price theory for the deregulated power systems was developed.(1) The primary goal of an OPF is to minimize the costs of meeting the load demand for a power system while maintaining the security of the system. The costs associated with the power system may depend on the situation, but in general, they can be attributed to the cost of generating power (megawatts) at each generator. From the viewpoint of an OPF, the maintenance of system security requires keeping each device in the power system within its desired operation range at steady-state. This will include maximum and minimum outputs for generators, maximum MVA flows on transmission lines and transformers, as well as keeping system bus voltages within specified ranges. Nodal pricing is a branch of transmission pricing which tries to give more cost reflective prices at the grid substations. The prices thus calculated essentially include the losses due to network flows and uncertainties associated with power transmission. A secondary goal of an OPF is the determination of system marginal cost data. This marginal cost data can aid in the pricing of MW transactions as well as the pricing ancillary services such as voltage support through MVAR support.

II. OPTIMAL POWER FLOW PROBLEM

Optimal pricing method tries to maximize consumer net benefit, taking into account transmission losses and generator uncertainty. The main Objective of an optimal power flow is to minimize the total operating cost of the system. In OPF, when the load is light, the cheapest generators are always the ones chosen to run first. As the load increases, more and more expensive generators will then be brought in.

In this paper, the problem formulation and solution procedure for the OPF problem of ac-dc power systems with multiterminal HVDC transmission systems are presented. The algorithm described is suitable for determining the optimal power flow solution of large-scale power systems with one or more multiterminal dc systems.

    a) AC System Formulation

For n bus system, let $P = (p_1, ..., p_n)$ and $Q = (q_1, ..., q_n)$, where p_i and q_i be active and reactive power demands of the bus-i respectively. The variables in power system operation defined as $X = (x_1, ..., x_m)$ i.e. real and imaginary parts of each bus voltage. Then the problem of a power system for given load (P, Q) can be formulated as OPF problem.

Minimize $\qquad f = (X, P, Q) \qquad\qquad for\ X$ (Objective function) $\qquad\qquad$ (1)

Subject to $\qquad S(X, P, Q) = 0 \qquad$ (Equality constraints) $\qquad\qquad$ (2)

$$T(X, P, Q) \leq 0 \qquad \text{(Inequality constraints)} \qquad\qquad (3)$$

The objective function of an OPF is the cost associated with generating powers in the system. Generator cost function $f_i(P_{gi})$ having cost characteristics represented by

$$F = \sum_{i=1}^{NG} F_i = \sum_{i=1}^{NG} (a_i P_{gi}^2 + b_i P_{gi} + c_i)$$

Where Pgi is the amount of generation in megawatts at generator i. and a,b and c are the cost coefficients and NG is no. of the generator. Also, the important Characteristic of the generator is an incremental cost which can be obtained by taking derivative of cost characteristic function. Which is expressed in \$/MWhr. Optimal dispatch is a constrained optimization problem. When solving a constrained optimization problem, the two general type of constraints is equality constraints and inequality constraints. Constraints that always need to intensify are equality constraints.

1) Vector of equality constraint i.e. power flow balance is,

$$P_g = P_d + P_{dc} + P_L \qquad\qquad (4)$$
$$Q_g = Q_d + Q_{dc} + Q_L \qquad\qquad (5)$$

Here suffix 'd' represents the demand, 'g' is the generation, 'dc' represents dc terminal and 'L' is transmission loss.

2) Vector of inequality constraint as

(i) Minimum and maximum limits on real and reactive power generations is

$$P_{gi}^{\min} \leq P_{gi} \leq P_{gi}^{\max} \qquad (i = 1, 2, ..., NG) \qquad\qquad (6)$$

$$Q_{gi}^{\min} \leq Q_{gi} \leq Q_{gi}^{\max} \qquad (i = 1, 2, ..., NG) \qquad\qquad (7)$$

(ii) Minimum and maximum limits on bus voltage magnitudes is,

$$V_i^{\min} \leq V_i \leq V_i^{\max} \qquad (i = NV + 1,\ NV + 2, ..., NB) \qquad\qquad (8)$$

(iii) Limits on transmission line power flow (MVA) limits is,

$$P_f^{\min} \leq P_f \leq P_f^{\max} \qquad (f = 1, 2, ..., Noele) \qquad\qquad (9)$$

In general, for the buses n and i connected by a controllable transformer with tap ratio $1 : t_{ki}$, the expressions for real and reactive power injection at these buses into the ac network are as follows

$$P_n = V_n \sum_{\substack{i=1 \\ j \neq n \\ j \neq i}}^{N} V_j (G_{nj} \cos \delta_{nj} + B_{nj} \sin \delta_{nj})$$

$$- V_n V_i t_{ni} (g_{ni} \cos \delta_{ni} + b_{ni} \sin \delta_{ni}) \qquad\qquad (10)$$

$$+ V_n^2 (G_{nn} + t_{ni}^2 g_{ni})$$

$$Q_n = V_n \sum_{\substack{i=1 \\ j \neq n \\ j \neq i}}^{N} V_j (G_{nj} \sin \delta_{nj} - B_{nj} \cos \delta_{nj})$$

$$- V_n V_i t_{ni} (g_{ni} \sin \delta_{ni} + b_{ni} \cos \delta_{ni}) \qquad\qquad (11)$$

$$+ V_n^2 (B_{nn} + t_{ni}^2 b_{ni})$$

$$P_i = V_i \sum_{\substack{i=1 \\ j \neq n \\ j \neq i}}^{N} V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij})$$

$$- V_i V_n t_{ni} (g_{ni} \cos \delta_{in} + b_{ni} \cos \delta_{in}) \qquad (12)$$

$$+ V_i^2 (G_{ii} + g_{ni})$$

$$Q_i = V_i \sum_{\substack{i=1 \\ j \neq i \\ j \neq n}}^{N} V_j (G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij})$$

$$- V_i V_n t_{ni} (g_{ni} \sin \delta_{in} - b_{ni} \cos \delta_{in}) \qquad (13)$$

$$- V_i^2 (B_{ii} + t_{ni}^2 b_{ni})$$

The operating condition of the combined AC-DC electric power system is the vector

$$X = [\delta, V, x_c, x_d]T \qquad (14)$$

where, δ and V are the vectors of the phase angles and magnitude of the phasor bus voltages; x_c is the vector of control variables such as those on TCUL transformers, generators, shunt reactive sources, and phase shifting transformers; and x_d is the vector of dc variables.

  a) DC System Formulation:

Using per unit (p.u.) system, the average value of dc voltage of a converter connected to bus 'i' is

$$V_{dci} = a_i V_i \cos \alpha_i - r_{ci} I_{di} \qquad (15)$$

here, α_i is the gating delay angle for rectifier operation/extinction advance angle for inverter operation; r_{ci} is commutation resistance, and a_i is converter transformer tap setting. Assuming a lossless converter, the equation of dc voltage is given by,

$$V_{dci} = a_i V_i \cos \varphi_i \qquad (16)$$

Where $\varphi_i = \delta_i - \xi_i$, and φ is the angle by which fundamental line current lags line-to-neutral source voltage. The real and reactive power flowing into or out of the dc network at terminal 'i' is

$$P_{dci} = V_i I_i \cos \varphi_i \qquad (17)$$

$$Q_{dci} = V_i I_i \sin \varphi_i \quad \text{or} \quad Q_{dci} = V_i a_i I_i \sin \varphi_i \qquad (18)$$

The equations (17) and (18) could be substituted in equation (4) and (5) to form part of the equality constraints. Then the operating condition of dc system can be described by the vector

$$X_d = [V_d, I_d, a, \cos \alpha, \varphi]T \qquad (19)$$

Equations (1) to (3) are an OPF problem for the demand (P, Q). Newton-based OPF approaches can be used to get an optimal solution.

III. MARGINAL COSTING

Marginal costing principals are very popular in the electricity sector due to its economic efficiency. The basic theory behind marginal costing can be explained using the following figure.
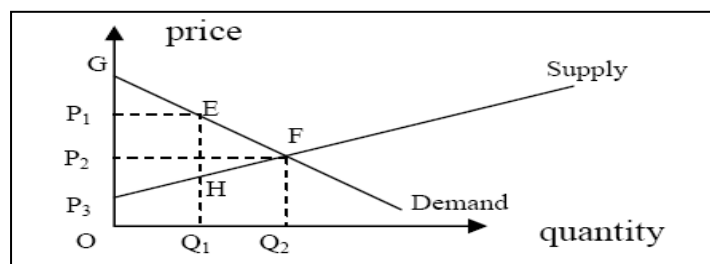

Fig 1. Typical marginal cost curve

Marginal cost is the cost of supplying an extra unit of energy. In the above graph, the supply curve represents the marginal cost curve. The total benefit of consumption is the consumers' willingness to pay. For a price of P1 it is given by the area OQ1E P1 . The cost of supplying the required quantity Q1 is given by the area OQ1H P3. Therefore the area P3HEG gives the net benefit. This indicates the maximum net benefit can be obtained when the price is P2. i.e. when the price equals marginal cost.

Nodal Pricing Methodology:

The real and reactive power cost at bus '*i* ' is the Lagrange multiplier function of the equality and inequality constraints calculated by solving first order condition of the Lagrangian, function of equations (1) to (3) are defined as a cost function as

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

Where $\lambda = (\lambda_1,\ldots,\lambda_n)$ is the vector of Lagrange multipliers concerning equality constraints; $\rho = (\rho_1,\ldots,\rho_n)$ are the Lagrange multipliers concerning inequality constraints. Then at an optimal solution (X,λ,ρ) for a set of given (P,Q), nodal price of real and reactive power for bus is expressed for $i = 1,\ldots,n$ are

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

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

The difference ($\pi_{p,i}$ - $\pi_{p,j}$) represents real transmission charges from bus-j to bus-*i*.

IV. TEST RESULTS

Owing to the space limitation, we can only present in brief the results of test cases on the IEEE 30 bus systems. As validation of the algorithm developed and also as an illustration of the potential economic benefits obtainable with the use of a coordinated dc dispatch. Two dc systems were added to the standard IEEE 30 bus system. The first system, a dc link, was connected between buses 1 and 28. The second system, a 3-terminal dc system, was connected to buses 2, 4 and 6. Here Following cases are considered and discussed for assessment of HVDC transmission and its impact on electricity nodal prices for test systems.

Case 1: Nodal prices with HVDC link And Transmission Line loading: The Total Load demand is increasing by 10%, 20%, 30% from its original Value here Assume all generators are committed for dispatch; and the cheaper generator will be selected to meet demand first.

Case 2: Nodal Prices with Increment and decrement in generation available condition: The Total generation is increased by 10% also decreased by 10% and 20% of its original value

Case 3: Nodal Price with Increment and decrement in generation cost characteristic condition: Increase in Generation cost characteristics by 10% and decrement in generation cost characteristics by 20%.

Case 4: Nodal prices with HVDC link and increment and decrement in transmission line capacity.

In all these cases, the lower and upper limits on the ac bus voltages were set at 0.95 and 1.05, those on V, were 0.9 and 1.1. These results are given in the graphical form, are as below:
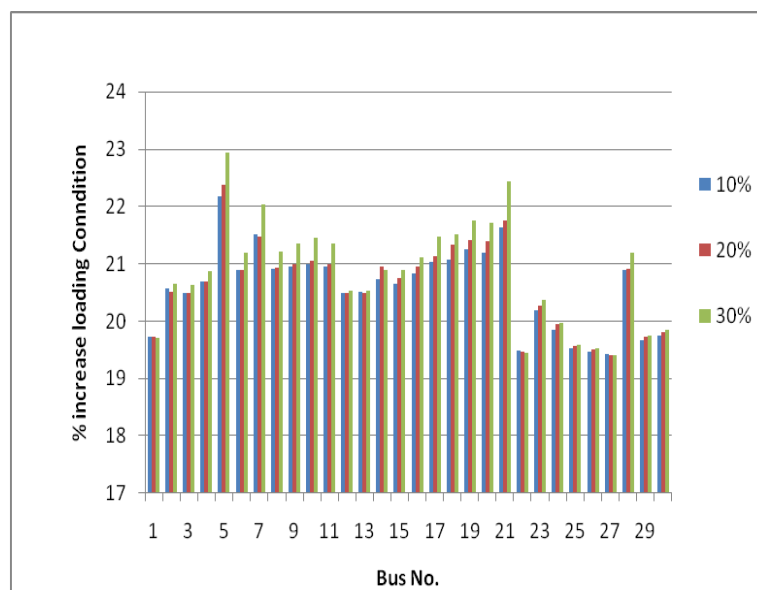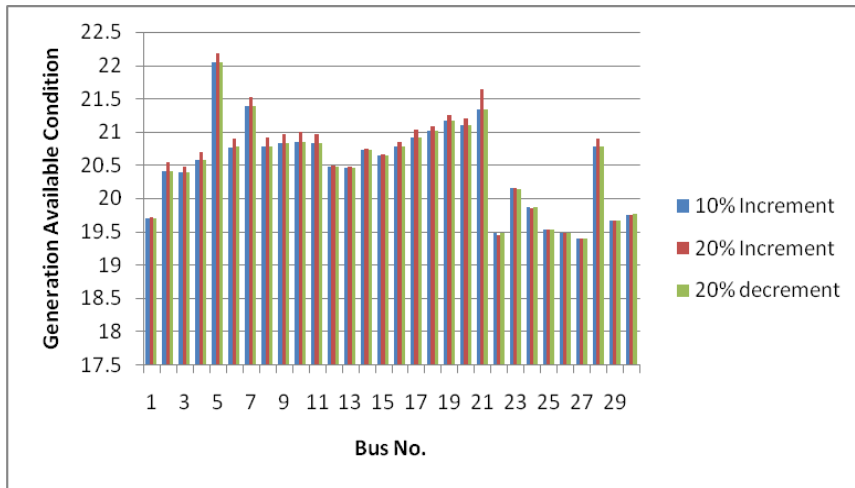

Fig 2.Percentage increase In Loading Condition
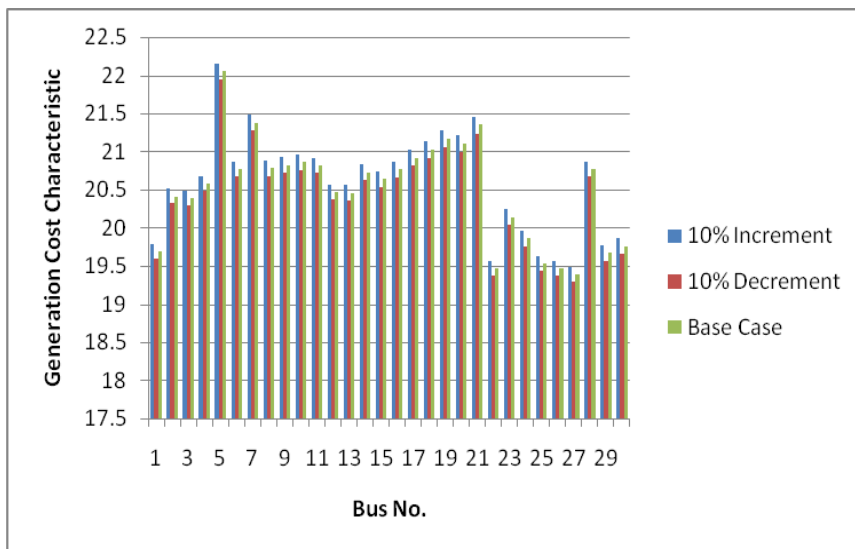
Fig 3: Generation Available Condition

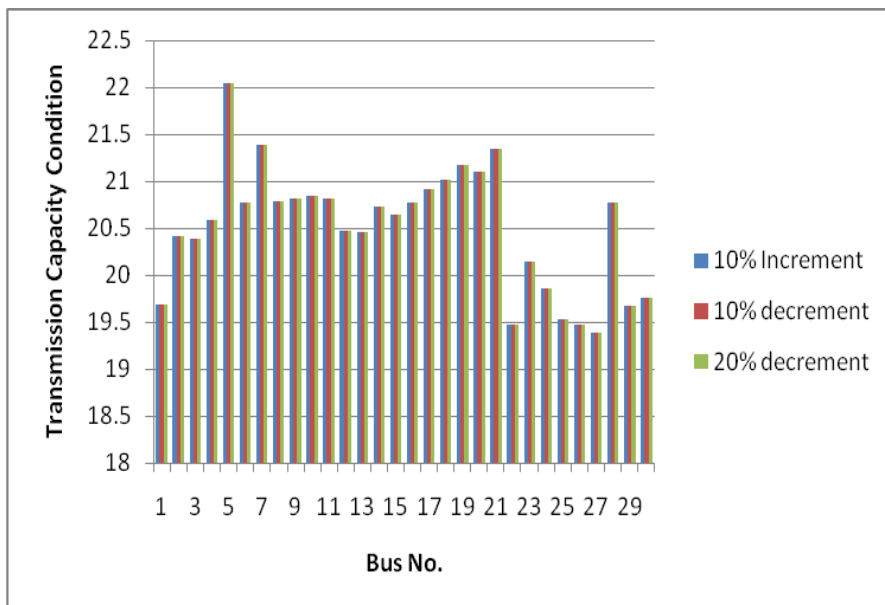**Fig 3: Generation Cost Characteristic Condition**

Fig 4: Transmission Capacity Condition

CONCLUSION

In this after an investigation of transmission pricing methods, it has been revealed that the optimal transmission pricing method is the most appropriate one because it considers Economic efficiency, optimal transmission investment, and return, Transmission Pricing security and stability & Losses due to power flows.

The formulation and solution procedure for the OPF problem using Newton-Raphson Method technique for an ac-dc power system with multiterminal dc systems have been presented. The algorithm developed has been tested on a number of sample ac-dc systems.

The convergence characteristic is very good for Newton-Raphson Method Based on the results presented on the modified 30 bus systems, it is seen that additional economic advantage could be obtained by **a** coordinated dispatch of the dc power transfers and traditional controllable sources. The numerical results presented are meant to validate the proper working of the algorithm developed; it is not the authors' intention to use these results as a quantitative measure.

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