OPTIMAL PRICING OF TRANSMISSION

E.M.C.P.Edirisigha, C.D.Herath, Y.S.K.Hettiarachchi, A.G.L.H.Amarasingha

SUPERVISED BY : Prof. Priyantha Wijayatunga, Mr. J. Nandakumar

Abstract

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. Hence this method of pricing allows the supplier to charge the correct price from consumers without bearing unnecessary burden. On the other hand, by having a structured pricing strategy consumers will not suffer from ad-hoc changes to their electricity prices and they will be charged the correct price. Hence fairness & equity could be established for both parties, while maintaining the economic efficiency.

The importance of Nodal pricing becomes vital, for the restructured Sri Lankan power sector. The formation of separate entities for Generation, Transmission and Distribution gives rise to transfer prices of electricity between each entity.

Electricity transmission is considered to be the only monopoly and hence open access to transmission system and fair, cost reflective pricing of transmission services are important for healthy competition in the power sector.

Among the numerous approaches proposed for the pricing of transmission services, methods based on marginal costing have gained wide acceptance due to their economic efficiency. The optimal pricing methodology based on maximizing consumer net benefit is a marginal costing approach, which has the capability of providing optimal transmission investment & return, stability of pricing and transmission security.

This paper describes about the optimal power flow method and how it is implemented using software.

INTRODUCTION

This project is aimed at developing a software which would be used to formulate the transmission prices at each node/ grid substation of a given power network. The project is carried out in two stages.

1) Literature Survey.

2) Development of the software.

The first phase, focused on the methods used to formulate transmission prices.

After obtaining a comprehensive knowledge in this area, the optimal transmission pricing was selected as the most suitable method for our country.

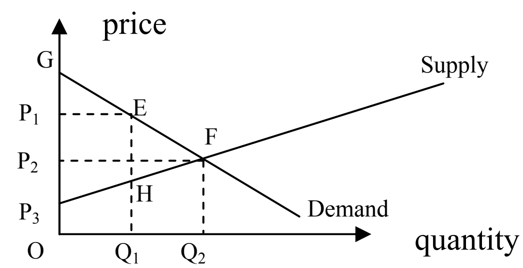
In the second phase, we developed a software as a prototype, which calculates and presents nodel prices of substantially large power networks using MATLAB, M/S EXCEL & VISUAL BASIC programming tools. The goal of this project is to implement this software at the system control branch of the Ceylon Electricity Board.

TRANSMISSION PRICING METHODS

Over the past, several methods of costing the use of transmission services have been proposed in literature. Among them the Postage Stamp method, MW-Mile method and Optimal Transmission Pricing method were compared in our study. The Optimal Transmission Pricing method was selected for the nodal price calculation due to its inherent good features over the others.

Marginal Costing in Electricity Pricing

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.



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 P_1 it is given by the area $OQ_1E\,P_1$.

The cost of supplying the required quantity Q_1 is given by the area $OQ_1H\,P_3$.

Therefore the area P_3HEG gives the net benefit.

This indicates the maximum net benefit can be obtained when the price is P_2, i.e. when the price equals marginal cost.

OPTIMAL POWER FLOW METHOD

This methodology is based on marginal costing principle.

Optimal pricing method tries to maximize consumer net benefit, taking into account transmission losses and generator uncertainty. The benefit to users of having a transmission system is the total reduction in electricity costs. Without a network, these users would incur a cost equivalent to the cost of supplying power using local generators. In this context 'users' refer to both generator suppliers and consumers.

Mathematical Analysis

Transmission benefit function:

Consumer net benefit is defined as the total benefit less the price paid for the use of the transmission service.

The total benefit over a specified tariffing period is given by,

$$\Omega(g) = \sum_{k=1}^{N}\Phi(L_k) - \sum_{k=1}^{N} C_k(g_k) \;\dots\dots\dots.(1)$$

Where

$$\Phi_k(L_k) = C_k(L_k) \qquad \text{if } L_k < G_{k,\,max}$$
$$= C_k(G_{k,\,max}) + VLL\,(L_k - G_{k,\,max}) \qquad \text{if } L_k > G_{k,\,max} \;\dots\dots\dots\;(2)$$

Here, $C_k(g_k)$ is the cost of electricity for g_k MW at node k and $G_{k,\,max}$ is the total capacity available at the node. VLL is the value of lost load if no supply is available.

Using Kirchoff's laws, the nodal balance relation can be derived using the network flows l (MW) and the demand L , as given by

$$g = L + A^t\, l + \alpha(l) \;\dots\dots\dots\dots\dots\dots..\;(3)$$

Where α(l) is half the losses in all the circuits connect to node k and A is the branch node incidence matrix.

The generation constraint is given by

$$0 \le L + A^t\, l + \alpha\,(l) \le G_{k,\,max} \dots\dots..\;(4)$$

Using a DC load flow model of the network we get,

$$M^t Z^b\, l = 0 \;\dots\dots\dots\dots\dots\dots\dots\dots\dots..\;(5)$$

Where M^t is the transpose of the branch incident matrix for a set of basic mesh and Z_b is the diagonal matrix of the branch series impedance. Using constraints (4) & (5) we can obtain an objective function with Lagrange multipliers μ_m and λ_k to obtain a transmission utility function for one tariffing period as;

$$UT(l) = V(l) + \sum_{m=1}^{M} \mu_m \sum_{b=1}^{B} M_{b,\,m} Z_b\, l_b + \sum_{k=1}^{N} \lambda_k \Big[L_k + \sum_{b=1}^{B} A_{b,\,k}\, l_b + \alpha_k(l)\Big] \;\dots\dots\dots\;(6)$$

Here $V(l) = \Omega\,[L + A^t\, l + \alpha(l)]$ which explicitly expresses the benefit function Ω in terms of the transmission flows l.

To obtain a consumer net benefit, CNB we need to subtract the price the consumer pays for the use of the system given by p. l where p is the price for flow l. Thus,

$$CNB = UT(l) - p^t\, l \;\dots\dots\dots\;(7)$$

CNB subjected to constraints (4) and (5). This result in

$$p_b = \frac{\partial\,(UT(l))}{\partial l_b} \dots\dots\dots\dots\dots\dots.(8)$$

Where p_b is the price for power flow on the branch b during a given tariffing period.

Now it is possible to define the global net benefit, NB which is the total benefit enjoyed both by the transmission service provider and network users. Here the investment cost and the operating cost of the transmission network need to subtracted from the summation of transmission benefit and the CNB. The NB is given by

$$NB[l, l_{max}] = \sum_t UT(l) - \sum_t \sum_{b=1}^{B} \beta_b(l_b) - \sum_{b=1}^{B} k_b\, l_{b,\,max} \;\dots\dots\dots\;(9)$$

Where β_b is the flow dependent operating cost and k_b and $l_{b,\,max}$ are the investment cost per MW and capacity of the branch respectively. This global net benefit, NB now can be optimized subject to transmission flow constraints given by

$$f_b\,|l_b(t)| \le l_{b,\,max} \qquad V\; b,t \qquad \dots\dots\dots(10)$$

Where f_b is the security factor. Then it can be seen that both the CNB and NB will be maximized when

$$p_b = \frac{\partial\,(UT(l))}{\partial l_b(t)} = \frac{\partial \beta}{\partial l_b(t)} + f_b\; \lambda_b(t) \;..(11)$$

Where λ_b (t) is the Lagrange multiplier associated with constraint (10) for a given tariffing period. If the flow dependent operating costs are neglected then

$$p_b = f_b \ \lambda_b(t) \ \ldots\ldots\ldots\ldots(12)$$

SIMPLIFIED APPROACH OF OTP

The above stated theory need some simplifications and modifications for the purpose of software implementation. Hence the same objective function and constraints can be derived in the following manner.

Maximising the consumer net benefit is the same as minimizing the total cost of supplying power. i.e. cost of generation , transmission line investment cost and value of lost load.

$$\sum_{k=1}^{Ng} C_k(g_k) + \sum_{k=1}^{Nl} C'_k(l_{max}) + VLL(L-G_{k,max}) \quad \ldots\ldots\ldots\ldots(a)$$

The nodal power balance equation; (3) can be simplified and written as

$$\sum_{k=1}^{Nb} d_k + Losses - \sum_{k=1}^{Ng} g_k = 0 \quad \ldots\ldots\ldots\ldots (b)$$

But the real power loss in a given transmission line can be approximately given by

$$L_i = R_i l^2_i$$

Where

l_i = Power flow in line 'i'

R_i = Resistance on line 'i'

L_i = Loss on line 'i'

Hence

$$Losses = \sum_{k=1}^{nl} R_i l^2_i$$

The relationship between the nodal power injections and the transmission line flows is given by

$$[l] - [D]\,[P] = 0 \quad \ldots\ldots\ldots\ldots(c)$$

Where;

[D] = sensitivity matrix derived using DC load flow approximations.

[l] = vector of line flows.

[P] = vector of nodal power injections.

Transmission flow constraint is given by

$$l_i \le l_{i,\,max} \quad \ldots\ldots\ldots\ldots(d)$$

Generation constraint is given by

$$g_i \le g_{i,\,max} \quad \ldots\ldots\ldots\ldots(e)$$

Let λ & μ be the Lagrangian multipliers associated with optimal levels of power generation and line flows. Then the price of electricity can be obtained as follows.

Price = Energy Cost + Transmission line Investment Cost

$$= \lambda \left[1 + \frac{\partial (Losses)}{\partial d_k} \right] + \sum_{j=1}^{nl} \mu_j \frac{\partial l_i}{\partial d_k}$$

$$= \lambda \left[1 + \sum_{j=1}^{nl} 2Rl_i \frac{\partial l_i}{\partial d_k} \right] + \sum_{j=1}^{nl} \mu_j \frac{\partial l_i}{\partial d_k}$$

But $\frac{\partial l_i}{\partial d_k} = D_{ik}$

Hence

$$Price = \lambda \left[1 + \sum_{j=1}^{nl} 2Rl_i D_{ik} \right] + \sum_{j=1}^{nl} \mu_j D_{ik}$$

SOFTWARE IMPLEMENTATION ALGORITHM

1. Insert tx. Line, generator and bus bar data to the system via Visual Basic interface
2. Input objective function, equality and inequality constraints, upper and lower boundaries of generator and line flows to the MATLAB linear programming routine and execute this optimization routine.
3. The out put of step 2 will give the Lagrangian multipliers associated with generation level at each node (λ) & line flows (μ) .
4. Calculate the energy cost & transmission line investment cost which gives the total price of electricity at each node.
5. Results are displayed on Visual Basic interface.

CONCLUSION

The investigation of transmission pricing methods revealed, the most appropriate one is the optimal transmission pricing method, as it considers

- Economic efficiency.
- Optimal transmission investment and return.
- Stability of pricing
- Transmission security &
- Losses due to power flows.

The developed software can be used to evaluate the prices at grid sub stations, which reflect the actual costs involved in power generation and transmission. The user is given the flexibility to choose his own power system and hence this software can be used in the developing and expanding power system of Sri Lanka.

In developing the software we included line losses implicitly. But, if it can be included explicitly the accuracy of the out put can be improved. The other method we suggest to improve the accuracy of results is to multiply the obtained nodal prices by a factor given by,

$$\frac{\text{Actual cost}}{\text{Total cost recovered by using OTP}}$$

This software tool can be further modified and made more user friendly by adding features such as

- Display the power system when the user input data.
- Calculate prices online when linked to the data base of the system control branch.

The future work would enhance the quality of this piece of software. We are confident that the implementation and future development of this software would add a considerable value to the Sri Lankan power sector.

ACKNOWLEDGEMENT:

We are grateful to Mr. Jayasiri Karunanayaka for giving us the opportunity to meet Mr. Nandakumar, Chief Engineer – System Control branch of CEB who exposed us to the concepts of transmission pricing. We would be equally thankful to Professor Priyantha Wijayatunga for his guidance and provision of relevant information to achieve our target. We would also like to thank Dr. Jahan Peris for providing us necessary literature for initial reading and introducing Mr. Nishantha for his assistance through out the project. Finally we would be thankful to the staff members of CEB system control branch and transmission planning division for their kind co-operation in gathering necessary information during the initial stage of our project.

REFERENCES :

1. Optimal pricing of transmission and distribution services in electricity supply. (E.D. Farmer, B.J. Cory, B.L.P.P. Perera)
2. Probabilistic costing of Transmission Services. (Dr. P.D.C. Wijayatunga)
3. Nodal pricing and transmission losses. (Jean-Thomas Bernard)
4. MVA power flow and loss analysis for electricity market (Z.Q. Wu & G.Z. Chen)