Long-Run Marginal Cost Pricing Based on Network Spare Capacity

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Abstract—**This paper proposes a novel approach for providing long-run marginal cost (LRMC) pricing in network charges. The proposed approach makes use of the unused capacity of an exiting network to reflect the cost of advancing or deferring future investment consequent upon the perturbation of generation or load at each study node on a distribution or transmission network. Compared with existing approaches to LRMC pricing, the proposed approach produces forward-looking charges that reflect both the extent of the network needed to service the generation and/or load, and the degree to which that network is utilized.**

Index Terms—**Equilibrium, long-run marginal cost pricing, network charges.**

I. Introduction

THE majority of research on network charges is to reflect the extensiveness of the use of an existing network by network users; they are generally referred as usage-based MW-Miles or MVA-Miles charging methodologies [1]. The major drawback of these models is that they cannot discriminate between network users who incur additional operating costs or network reinforcement and those who reduce or delay otherwise needed network upgrades. As a result, there is a constant desire to extend or move to a marginal or incremental cost pricing [2], [3].

Developing a long-run marginal cost (LRMC) pricing model has been viewed as a formidable task. Existing LRMC approaches tend to require knowledge concerning the pattern of future generation and demand. This knowledge is far from certain in a competitive environment and any projected pattern of generation and demand could prove very different in the outturn. Consequently, such an approach can produce wholly inappropriate charges [3].

This paper proposes a novel approach to LRMC pricing by considering the unutilized capacity or headroom within an existing network to create a forward-looking pricing message for prospective generation and demand. The unutilized capacity is used to gauge the length of time before investment to reinforce the network is required. For any given rate of load growth, the period until investment will be needed is the time taken for the loading of the network component to reach its maximum rated capacity. The proposed approach seeks to reflect the cost of advancing or deferring future investment consequent upon the perturbation of generation or load at each study node on a distribution or transmission network. For network components that support a nodal power injection or withdrawal of power, there will be an associated cost if investment is advanced, or a benefit if it can be deferred. The LRMC charges are determined as the difference in the present value of the future investment as a result of nodal power perturbation for generation or demand.

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II. Mathematical Formulation of LRMC Pricing Based on DC Power Flow

The proposed charging model can be implemented through the following four steps.

A. Deriving the Future Network Cost to Support Existing Customers

If a network component l has a capacity of C_l and supports a power flow of D_l, then the number of years it takes to grow from D_l to C_l for a given load growth rate r can be determined by the following:

$$C_l = D_l \times (1+r)^{n_l} \tag{1}$$

where n_l is the number of years D_l takes to reach C_l.

Rearranging (1) gives

$$(1+r)^{n_l} = \frac{C_l}{D_l}. \tag{2}$$

Taking the logarithm of both sides of (2) and rearranging the equation, gives the value of n_l as

$$n_l = \frac{\log C_l - \log D_l}{\log(1+r)}. \tag{3}$$

It is assumed that reinforcement will occur when the circuit is fully loaded. It is also assumed that a duplication of the network component is taken as the future investment that will be required.

B. Evaluating the Present Value of Future Investment Cost

The future investment can be discounted back to its present value. For a given discount rate of d, the present value of the future investment PV_l in n_l years will be

$$PV_l = \frac{\text{Asset}_l}{(1+d)^{n_l}} \tag{4}$$

where Asset_l is the modern equivalent asset cost.

C. Difference in Present Value as a Result of Nodal Perturbation

As a result of nodal perturbation from busbar N, the changes in present value of future investment along circuit l will be

$$\frac{\partial PV_l}{\partial D_l} = \frac{\partial PV_l}{\partial n_l} \times \frac{\partial n_l}{\partial D_l} \tag{5}$$

where

$$\frac{\partial n_l}{\partial D_l} = -\frac{1}{D_l \times \log(1+r)}. \tag{6}$$

From (4), the present value can also be represented in the following form:

$$PV_l = \text{Asset}_l \times e^{-n_l \times \log(1+d)}. \tag{7}$$

Taking derivative of PV_l with respect to n_l, gives the following:

$$\begin{aligned}\frac{\partial PV_l}{\partial n_l} &= \text{Asset}_l \times [-\log(1+d)] \times e^{-n_l \times \log(1+d)} \\ &= -\text{Asset}_l \times \log(1+d) \times (1+d)^{-n_l}.\end{aligned} \tag{8}$$

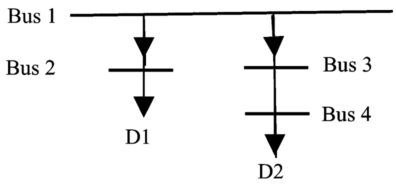

Fig. 1. Demands using different amounts of network.

Substituting (6) and (8) to (5) gives the sensitivity of changes in present value along circuit l as a result of marginal injection from node N

$$\frac{\partial PV_l}{\partial D_l} = \frac{\partial PV_l}{\partial n_l} \times \frac{\partial n_l}{\partial D_l} = \frac{\text{Asset}_l}{D_l} \times \frac{\log(1+d)}{\log(1+r)} \times (1+d)^{-n_l}. \tag{9}$$

Again, substitute n_l with $(\log C_l - \log D_l)/(\log(1+r))$ from (1) and (9) becomes

$$\begin{aligned}\frac{\partial PV_l}{\partial D_l} &= \frac{\text{Asset}_l}{D_l} \times \frac{\log(1+d)}{\log(1+r)} \times \left(\frac{D_l}{C_l}\right)^{(\log(1+d)/\log(1+r))} \\ &= \frac{\text{Asset}_l}{C_l} \times \frac{\log(1+d)}{\log(1+r)} \times (U_l)^{(\log(1+d)/\log(1+r))-1}\end{aligned} \tag{10}$$

where U_l is the percentage utilization of circuit l.

Equation (10) gives a relationship between the sensitivity of future network cost with respect to circuit utilization.

D. Long-Run Marginal Cost for Node N

If there are a total of m circuits and transformers to support nodal injection from node N, then annual LRMC price for node N is the product of accumulated changes in present value as a result of the nodal perturbation and annuity factor. This is represented by (11)

$$\text{LRMC}_N = \text{annuity} \times \sum_m \frac{\partial PV_l}{\partial D_l}. \tag{11}$$

III. Equilibrium Between Extent of Network Use and Degree of Circuit Utilization

Considering the network depicted in Fig. 1, demand D1 is supported by one circuit, while D2 is supported by two circuits. All three circuits are assumed to be identical, having a same investment cost of £3 193 400 and a maximum rating of 45 MW.

Varying D1, D2 from 0 to 45 MW, representing circuit utilization changing from 0% to 100%, the proposed charging model gives the LRMC charges for demand connecting at bus 2 and bus 4 respectively shown in Fig. 2. Both buses have monotonically increasing charges with increasing circuit utilization. Since bus 4 is supported by double circuits and uses the network more extensively, it will incur more network cost to accommodate additional demand at bus 4 compared to bus 2 for the same loading level.

Flipping the double circuit charges to the left gives Fig. 3, where a 10% utilization of the single circuit corresponds to a 90% utilization of the double circuit. Fig. 3 indicates that the cost to the network will be the same for a node that is supported by two circuits loaded at 39%, or by a single circuit loaded at 61%.

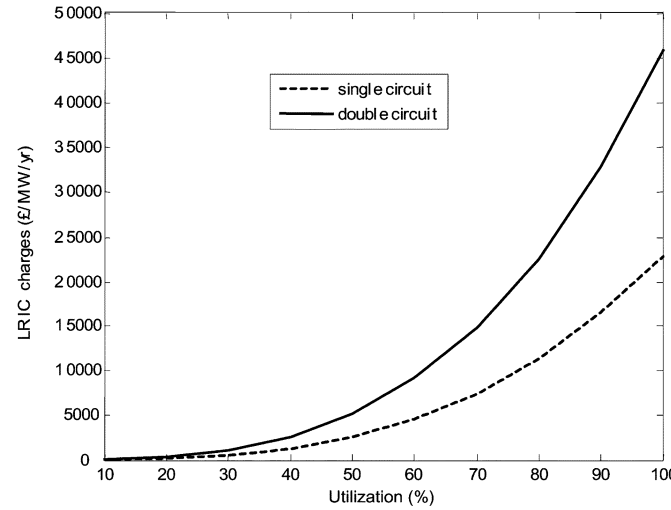

Fig. 2. Cost comparison for single and double circuit network.

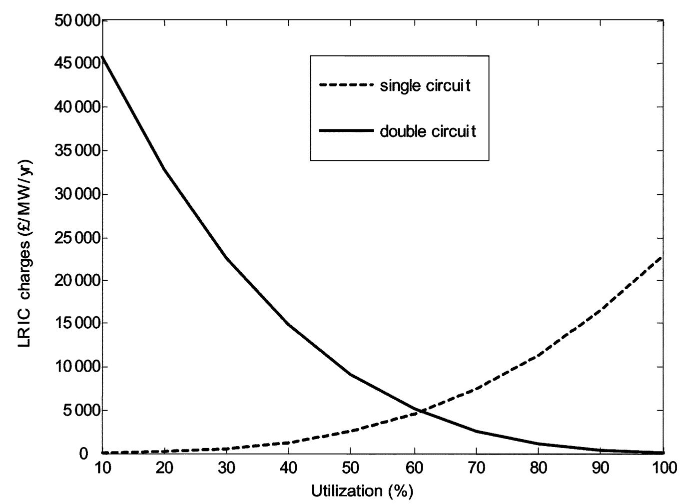

Fig. 3. Equilibrium between the extent of the use of a network and the degree of network utilization.

IV. Conclusions

This paper presents a novel method for providing long-run marginal cost (LRMC) pricing in network charges. The novelty of the method lies that for the first time a method to evaluate long-run marginal cost is proposed based on the spare capacity of an exiting network. The resulting network charging model is able to provide forward-looking economic messages, reflecting the extent of the network used by a connected party and the degree of network utilization.

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