LRMC PRICING BASED ON MW+MVAR-MILES METHODOLOGY IN OPEN ACCESS DISTRIBUTION NETWORK

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ABSTRACT

In the light of UK's cleaner energy policies, embedded generators are expected to play an increasingly important role in future energy supply. They can benefit a network from loss reduction and deferred or delayed investment. Equally, they can also increase network investment through inappropriate locations, requiring extensive network upgrading and expansion. This cost/benefit of embedded generator is not reflected by any of the existing distribution network pricing model. The aim of this paper is to develop a long-run marginal cost (LRMC) pricing model for distribution network that can reflect the long-term cost/benefit of a network user based on AC power flow analysis. The economic efficiency of the proposed pricing model is demonstrated on a subset of a practical system and validated through the comparison with the LRMC model based on the DC power flow. The case studies with pseudo embedded generators are also presented to estimate the proposed pricing model. This paper results from work undertaken in a project on distribution charging methodologies for Western Power Distribution (WPD) Company. The views in the paper expressed are not those of WPD.

INTRODUCTION

Distribution network charges are charges against generation companies, large industrial customers and suppliers for their use of a network. The charges are to recover the cost of installation, operation and maintenance of the distribution network. The aim of any charging model is to closely reflect the extent of the use of a network by network user, help to release constraints and congestion in the network and be able to provide correct economic signals for efficient network expansion and reinforcement.

The current distribution reinforcement model adopted by majority of distribution companies in the UK has two major drawbacks [1], [2]:

1) They are not economically efficient as they do not discriminate customers who benefit a network from customers who cause problems to a network.

2) They are unable to support the potential increases in embedded generation.

Because of these concerns, extensive consultation is carrying out by Office of Gas and Electricity Markets (Ofgem) since 2003, exploring cost-benefit reflective charging models that provide locational signals to future demand and generation, facilitating the ease of connection of embedded generation [3]-[5].

The Investment Cost Related Pricing (ICRP) used for charging transmission network in the UK is based on long-run marginal cost (LRMC) pricing principle [6]. ICRP provides a good balance in reflecting the extensiveness of the use of a network by a network user and acknowledging the benefits introduced by generators. The charging model starts with cost evaluation of the year ahead reinforced network. The charging model then allocates the network cost among all network customers according to their extent of the use of the reinforced network using MW-Miles methodology. This is achieved by inspecting which circuits support the marginal increase in demand/generation at a node, and at what degree the circuits support the marginal increase through a DC load flow. The locational ICRP charges are the accumulated incremental charges over all supporting circuits.

Despite the much improved locational signal that the ICRP-DC model offers, it can be misleading by completely ignoring the cost due to reactive power flow in the circuit, especially. A circuit rating is determined by the maximum MVA power flow over the circuit [7]. A charging method based on pure real power will inevitably introduce errors in tracing true cost contribution towards network reinforcement [8]. In the case of distribution network, circuits are generally operated at a poorer power factor compared with that of transmission network. Additionally, a significant proportion of embedded generators are wind farms, where the reactive power drawn can be significant. As a result, if only real power flow is considered in a charging model, it will credit embedded generators' active power contribution, but fails to penalize users for their reactive power drawn, this would result in misleading locational signals, hence, economic inefficient network charging methodologies.

This paper presents a LRMC charging model for distribution network, where the cost allocation is based on AC power flow, considering both real and reactive power injection/drawn along network circuits. The charging model was developed with an emphasis of offering a better cost and benefit evaluation of a network user, especially for embedded generators.

This paper results from work undertaken in a project on distribution charging methodologies for Western Power Distribution (WPD) Company. The views in the paper expressed are not those of WPD Company.

MATHEMATICAL FORMULATION OF LRMC MODEL FROM DC LOAD FLOW

The LRMC model will firstly formulate a reinforced network according to the forecasted year ahead generation/demand, secondly allocate the cost among existing and new customers according to their extent of the use of the reinforced network. The principle of this charging model is to inspect the changes of network power flow with respect to one unit power injection/drawn at a node. Essentially, this shows which circuits support power injection/drawn from the study node, and at what degree they support the unit power injection/drawn. Then the LRMC prices at node N is the accumulated product of the power change of each line, the line's length and the line's unit cost over all affected circuit. The basic steps of LRMC-DC implementation are shown as follows:

Set up original network

1. Define the total asset of each distribution line, included both the overhead circuit and underground cable between two nodes.
2. Evaluate the unit cost of accommodating one unit power for each circuit or transformer. Here, the capacity of network facility is assumed using by real power, regardless of reactive power.

$$UC_l = \frac{AssetCost_l \cdot AnnuityFactor}{Capacity_l} \quad (1)$$

Determine the power flow change

3. Calculate original power flow $OriginalP_l$ of each circuit or transformer.
4. Inject unit real power *n* (MW) into a certain node N, assuming it is a demand connected node, and the power will withdraw from the slack bus, which is GSP in the distribution network.
5. Calculate new real power $NewP_l$ of each circuit or transformer.
6. Determine the real power changes of each circuit or transformer.

$$\Delta P_l = NewP_l - OriginalP_l \quad (2)$$

Nodal marginal cost calculation

7. Sum up all the costs (£/(year)) corresponding to real power change.

$$MCMW = \sum_{l=1}^{L} \left(\Delta P_l \cdot UC_l \right) \quad (3)$$

8. Define the marginal cost (£/(year*MW)) according to real power *n* (MW) injection for this node N.

$$MC = \frac{MCMW}{n} \quad (4)$$

9. Inject unit real power *n* (MW) into each demand connected nodes. If it is a generator connected node, the result will reversed by draw unit real power *n* (MW) from the node, instead of injection. Repeat step 4~8 until get the marginal costs for all the nodes.

MW+MVAR-MILES METHODOLOGY

It has been recognized that the use of distribution network has been best measured by monitoring both real and reactive power. The MW+MVAR-Miles methodology has been introduced in the paper [9] recently. There will be more detailed formulation for the purpose of LRMC calculation presented in this section.
For a circuit, the apparent power *S* in the vector formulation is showed below in equation 5 and figure 1.

$$\overrightarrow{S_l} = RealPower_l \cdot i + ReactivePower_l \cdot j \quad (5)$$

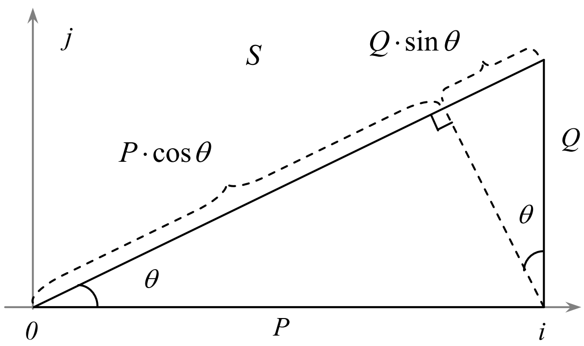

Fig. 1. Contribution of real and reactive power to apparent power

From the above diagram, the magnitude of apparent power *S* for the circuit *l* can be described as:

$$S_l = P_l \cdot \cos\theta_l + Q_l \cdot \sin\theta_l \quad (6)$$

Which,

$\cos\theta_l$: Power factor of circuit *l*;

$\sin\theta_l = \sqrt{1-\cos^2\theta_l}$.

Using unit cost multiple the both side of equation 6,

$$S_l \cdot UC_l = P_l \cdot \cos\theta_l \cdot UC_l + Q_l \cdot \sin\theta_l \cdot UC_l \quad (7)$$

Finally, the unit cost of each line for real and reactive power contribution are:

$$UCP_l = UC_l \cdot \cos\theta_l \quad (8)$$

$$UCQ_l = UC_l \cdot \sin\theta_l \quad (9)$$

Where,

UCP_l: unit cost of line *l* for real power contribution;
UCQ_l: unit cost of line *l* for reactive power contribution.

LRMC MODEL BASED ON MW+MVAR-MILES METHOD

Based on the MW+MVAR-Miles methodology, the long-run marginal cost can be extended to a more comprehensive formulation (LRMC-AC). The differences from LRMC-DC model are shown below.

Set up original network

Here is the same as LRMC-DC model, except the unit cost of accommodating one unit power for each circuit or transformer are spilt into two parts, as described in equation (8) and (9).

Determine the power flow change

In LRMC-AC model, the injection is the unit apparent power *np* (MW) + *nq* (MVAR) into a certain node N. Beside the determination of real power change, the change of reactive power is also calculated:

$$\Delta Q_l = NewQ_l - OriginalQ_l \qquad (10)$$

Nodal marginal cost calculation

When nodal LRMC is based on MW+MVAR-Miles, the usage cost for each distribution line are contributed from both real and reactive power, which is determined by the power factor of the circuit *l*.

$$MCMW = \sum_{l=1}^{L} \left(\Delta P_l \cdot UCP_l \right) \qquad (11)$$

$$MCMVAR = \sum_{l=1}^{L} \left(\Delta Q_l \cdot UCQ_l \right) \qquad (12)$$

In the last stage, define the real power's marginal cost (£/(year*MW)) and reactive power's marginal cost (£/(year*MVAR)) according to apparent power *np* (MW) + *nq* (MVAR) injection for this node N.

$$MCP = \frac{MCMW}{np} \qquad (13)$$

$$MCQ = \frac{MCMVAR}{nq} \qquad (14)$$

CASE STUDY

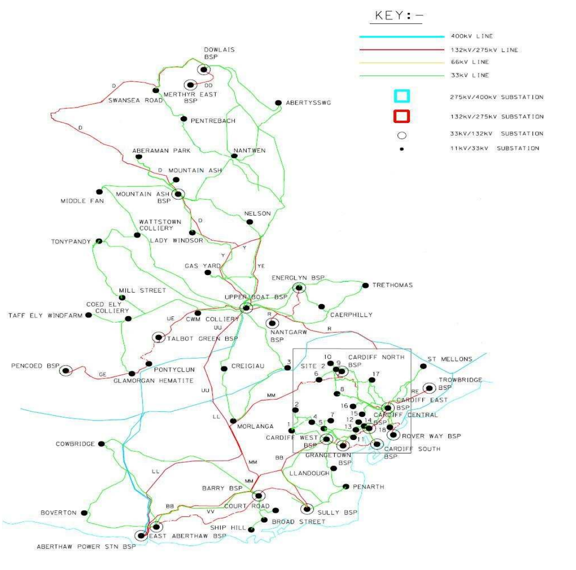

Fig. 2. Geographic map of the test system

To demonstrate the results of above two different LRMC pricing mechanisms, a practical network is chosen to be the test network. The criterion of the test network should truly reflect the configuration of distribution network. It should contain the various characteristics of the typical demands, which include the urban, rural and average customers. A test network based on a south Wales distribution network supplied by Western Power Distribution (WPD) Company, U.K., is modified to match the criterion of a typical network. It covers from 132KV to 11KV network. The geographic map is shown in figure 2 [10].

LRMC results

In figure 3, the unit marginal cost of LRMC-DC and LRMC-AC methods are presented together, where No.1~21 are load connected points, and No.22~24 are generator connected points. The negative value means the customer will be paid by use the network, which is the case when the usage of network from these customers will reduce the network congestion.

Compared with LRMC-DC method, the real power's cost of LRMC-AC method is very similar, which means both methods are locational based methodologies. Besides the locational signal, the reactive power price of LRMC-AC method will be decided by the line's power factor, which is more close to the nature of distribution network. For example, No. 2 load with the poorest power factor among all the nodes, is penalized (-0.61 £/KVAr/Yr) by large reactive power consumption.

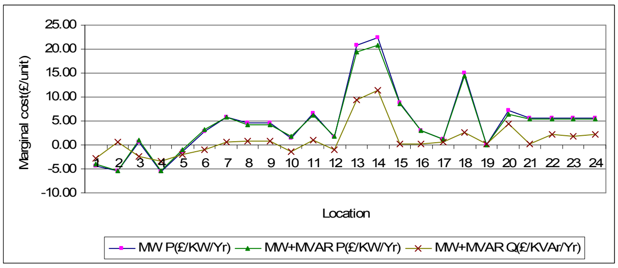

Fig. 3. Price comparison of each node

In the present charging statement of the distribution company, the final tariff is evaluated from the yardstick calculation, which is a fixed price for each voltage level [11]. In the LRMC results, either paying or rewarded by the distribution company is distinguish from how the network is truly used regardless of the customers' voltage level. Load No.1~5 can consume the network generators' output and encourage the local generation meeting local demand, so they are rewarded from their usages. Load No.13 and No.14 get the highest unit cost because they use more facilities than others, which also indicate these sites will attract embedded generators with most benefits.

Analysis with pseudo generators

Regard of the embedded generators, the location of No. 14 is more attractive for embedded generators than others. In this section, the pseudo generator with 20MW, 40MW and

60MW will be introduced into the location No. 14, which are demonstrated as three scenarios as table I and the rest node's load or generator keeps the same as original network. It means that there are potential embedded generators with different capacity to join the network. The cost of using network will be relocated with contribution of new generators. Using LRMC-AC pricing method, the marginal cost for demand and generator according to these scenarios are shown in table II.

TABLE I PSEUDO GENERATOR SCENARIOS

NO. 14	Scenario 1		Scenario 2		Scenario 3	
	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)
Dem	26.10	6.50	26.10	6.50	26.10	6.50
Gen	20	0	40	0	60	0
Total(D-G)	6.10	6.50	-13.90	6.50	-33.90	6.50

TABLE II COST FOR LOCATION NO. 14

	Scenario 1		Scenario 2		Scenario 3	
NO. 14	P(£/KW/Yr)	Q(£/Kvar/Yr)	P(£/KW/Yr)	Q(£/Kvar/Yr)	P(£/KW/Yr)	Q(£/Kvar/Yr)
Dem						
	19.35	12.15	13.10	15.12	-0.63	17.49
Gen						
	-19.35	-12.15	-13.10	-15.12	0.63	-17.49

To compare the three scenarios with the original network, the original result is marked as scenario 0, and then marginal costs for generator in location No. 14 of four scenarios are described in figure 4.

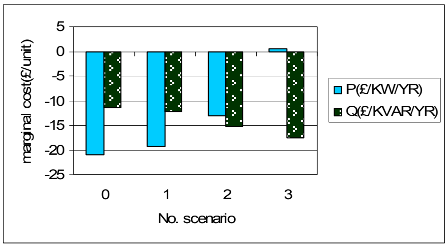

Fig. 4. Comparison of the generator's marginal cost at location No. 14

In four scenarios for generators at location No. 14, the marginal cost of real power keep increasing, which means the generator gets less profit with more power output. when the local generator meet the local demand, more generator output will be charged by using other network facilities to dispatch power and generator begin to pay for network use as seen in scenario 3. In table II for the demand's marginal cost at location No. 14, they are opposite to generator and get advantage from more embedded generators' contribution. But they are expected to operate at a better power factor.

From these scenarios studies, the LRMC-AC shows its comprehensive ability to provide the economic signal for embedded generators. According to these pricing signals, generator companies are able to decide their future location and capacity of embedded generators. It also benefits the distribution company from delay the network updating and expansions by encouraging the local generators meet the local demand.

CONCLUSIONS

This paper proposed a MW+MVAR-Miles cost allocation methodology, deriving charges based on long-run marginal cost (LRMC) charging principle. By incorporating reactive power into the cost allocation, the charging model can fully recognize the cost and benefit introduced by potential users, either generator or demand. In general, the MW+MVAR-Miles method recovers revenue closer to the required due to its better account for network users' true circuit utilization, hence leaves scope for averaging the unused capacity among the network users. The demonstration on the South Wales distribution network indicates that the LRMC MW+MVAR-Miles methodology is capable of deriving economically efficient charges to encourage customers to improve the circuits' operating power factor and embedded generator to set up in more benefit location.

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