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Coincident Demand based Smart Long Run Incremental Cost Pricing Model

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Abstract—Impending Smart Grid environment can offer innovative solutions to alleviate network congestion through efficient network management. This paper proposes a coincident demand based Smart Long Run Incremental Cost (LRIC) pricing mechanism to provide efficient pricing signal to users for mitigating network congestion. Considering that future smart meters would measure user’s coincident peak demand, the user is offered a coincident demand based Smart Pricing signal in a LRIC pricing framework. The proposed approach is applied on 22-bus practical Indian reference network. Users connected at the various nodes face network charges based on their coincident demand to each upstream asset. The results encourage users to modify their consumption pattern, and reduce their coincidence to network peak usage.

Index Terms—coincidence factor, LRIC, network pricing, smart grid

I. INTRODUCTION

Smart Grids (SG) are modernized electricity delivery system to improve monitoring, control, and self healing capability of the system. These grids are integrated with information and communication technologies to gather information about behaviour of energy suppliers and consumers, and hence improve efficiency, reliability, and sustainability of generation and distribution of electricity. Two way flow of information and electricity helps the SG’s to efficiently manage consumers’ end use of electricity as well as efficiently utilise grid to manage supply demand imbalances on a real time basis. SG’s can respond to events that occur anywhere in the system, *viz.* generation, transmission, distribution, and consumption [1]-[2].

In the evolving SG environment potential for efficient management, planning, and operation of power transfer corridors open up. An important component of modern-day system operation is dependent on an efficient and responsive electricity pricing mechanism [3]. This employs cost-reflective electricity pricing as an integral tool to offer effective demand side management. Advent of smart meters enables the utilities to offer dynamic prices to customers for the electricity supply. Customers respond to these prices by optimizing their consumption, with an aim to minimize their electricity charges.

Electricity prices offered to customers are reflective of generation and network costs involved [4]. Network cost consists of transmission and distribution network cost. This cost forms a significant component of electricity prices. Users respond to these network charges by modifying their usage pattern. Network charges invariably reflect the impact of network congestion. Thus, the customers effectively respond to network congestion, caused by simultaneous peak usage of network components. Transmission pricing models based on nodal pricing mechanism do provide price signal to customers, reflecting the impact of network congestion. However, distribution pricing models differ from transmission pricing models, because of inherent technical differences between these two networks, and are unable to provide a true reflection of network congestion costs [5].

Various distribution network pricing models have been developed and tested to compute distribution network charges *ex-ante viz.* Distribution Reinforcement Model, Investment Cost Related Pricing, Long Run Incremental Cost Pricing, and Forward Cost Pricing. Among these, LRIC is the most advanced pricing model till date, with a verified potential to save hundreds of millions of pounds, in terms of investment [6]. This approach is recognized as an economically efficient approach for allocating network cost, as it determines network charges as the difference in present value of future investment, consequent upon the nodal power perturbation for generation or demand [7].

LRIC methodology is further enhanced to consider network security, component reliability and nodal unreliability tolerance [8]-[9]. This model also respects user’s security preferences while assessing their impact on network development cost [10]. In calculating nodal LRIC charges, diversity factor is used to calculate the maximum demand at individual locations on network hierarchy. This factor does not reflect actual network usage; rather it computes demand that may not be coincident to network peak demand [11]. Thus, the approach does not charge users on the basis of their contribution to network peak.

Networks are designed to satisfy peak load on system, so prices are reflective of this peak usage. Users connected at different network locations contribute to this period in a different way, and hence be reflected in network charges [5]-[12]. Distribution user’s contribution to upstream asset

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peak usage can effectively be determined using Coincidence Factor (CF), which is defined as the fraction of customer demand at asset peak usage to customer peak demand. CF reflects that there exists diversity in pattern and nature of usage by users at various nodes [13].

Traditional network infrastructure cannot track coincident network usage. In a SG environment, network cost component can be reflected as a component of smart network prices when actual network usage is known. Smart meters at different network levels can capture user's contributions to asset peak usage, and can be used to compute network usage charges [14]-[15].

Considering the developments in SG technologies for Smart Network Pricing, this paper proposes a coincident demand based Smart LRIC pricing model, where the CF is reflective of users' contribution to network component peak usage. In this approach, network users would be responsible for component reinforcement, when their peak coincides with peak asset usage. This would help to generate smart and efficient network pricing signal for the distribution network users.

II. SMART LONG RUN INCREMENTAL COST PRICING MODEL

The mechanism for Smart LRIC charges calculation is shown in Fig. 1, illustrating integration of network user's contributions to each upstream asset usage in network charging. User's contributions are determined using CF.

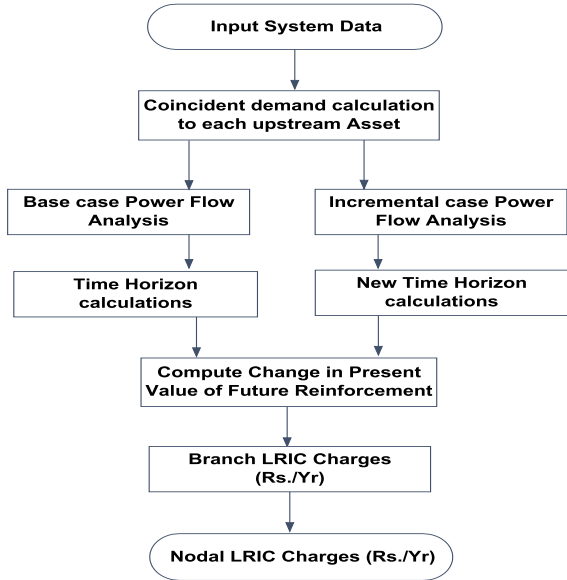


Fig. 1. Flow chart for smart LRIC pricing model

A reflection of the above flowchart, in the form of mathematical formulation, is discussed below.

From the load profile data available at various nodes coincident demand to each upstream asset is calculated using coincidence factor. Coincidence factor is calculated as

$$\text{Coincidence Factor} = \frac{\text{Node demand at Asset Peak Usage}}{\text{Nodal Peak Demand}} \quad (1)$$

$$\text{Coincident Demand} = \text{CF} * \text{Peak Demand at the Node} \quad (2)$$

Now these coincident demands are used as load flow input data to accommodate actual asset usage.

Further, load flow output is used for time horizon calculations. Network component is supporting current power flow D_c , with capacity C_c , and load growth r . Then time horizon required for the reinforcement of component is given by

$$n_c = \frac{\log C_c - \log D_c}{\log(1+r)} \quad (3)$$

Future investment is discounted back to present value according to time horizon required for asset reinforcement. For the discount rate d present value of future investment is determined as

$$PV_c = \frac{\text{Asset}_c}{(1+d)^{n_c}} \quad (4)$$

Nodal Injection alters power flow along the associated network components; hence new horizon for reinforcement is calculated as

$$n_{c_{\text{new}}} = \frac{\log C_c - \log(D_c + \Delta P_c)}{\log(1+r)} \quad (5)$$

This in turn affects present value of future investment as

$$PV_{c_{\text{new}}} = \frac{\text{Asset}_c}{(1+d)^{n_{c_{\text{new}}}}} \quad (6)$$

The change in present value of future investment as a result of nodal increment is given by

$$\begin{aligned} \Delta PV_c &= PV_{c_{\text{new}}} - PV_c \\ &= \text{Asset}_c \times \left(\frac{1}{(1+d)^{n_{c_{\text{new}}}}} - \frac{1}{(1+d)^{n_c}} \right) \end{aligned} \quad (7)$$

The annualized incremental cost of the each network component c is given as

$$IC_c = \Delta PV_c * \text{annuity factor} \quad (8)$$

Hence incremental charges for the branches supplying to any node are calculated from (8).

Long-run incremental cost to support node N is the summation of incremental cost over all supporting circuits, given as

$$LRIC_N = \frac{\sum IC_c}{\Delta P_{in}} \quad (9)$$

Finally, nodal charges for the users at the nodes are computed using (9).

III. RESULTS AND ANALYSIS

A. System Description

The proposed approach is applied to a part of practical Indian reference network [14]. Reference network was formed with practical data available for Jodhpur district, located in the Rajasthan State of Northern India for the months of October, and November in 2007. Network has four voltage levels, 220 kV, 132kV, 33kV, and 11kV, consisting of 22 buses, 11 transformers, 10 distribution lines, and 11 load points as shown in Fig. 2. Each load point comprises of various category users, viz. General,

Industrial, Agricultural, and Water-Works. General category users represent group of Domestic, Non-Domestic, Public Street Lightening, and Mixed Load Customers. Similarly, Metered Agricultural, Flat Rate Agricultural and Agricultural Nursery comprise of Agricultural category, while Small Industrial, Medium Industrial, and High Tension Industrial are grouped into Industrial category. Water-Works consists of all type of Water-Works connections for supplying water supplies [17].

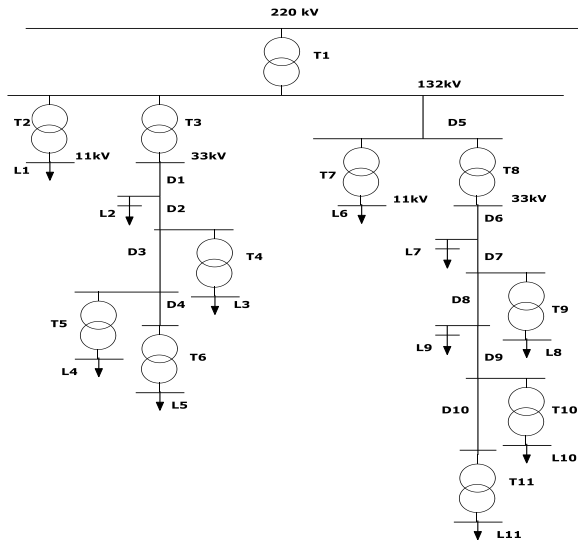


Fig. 2. 22-bus practical Indian network [16]

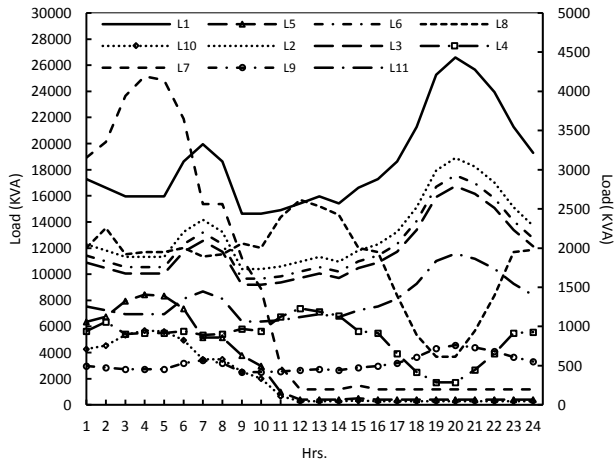


Fig. 3. Load profile at various nodes

Load profile data for the users connected at various nodes are shown in Fig. 3 [13]. Coincidence of load connected at any node to each upstream asset is calculated using CF.

B. Smart LRIC Charges Implementation

From the input data available at various nodes, coincident demand to each upstream asset is calculated for the users connected at the nodes. First, CF's for loads connected at the nodes to each upstream asset are calculated from (1). From these CF's, coincident demand of the users connected at various nodes, to their each upstream shared asset are calculated as (2).

TABLE I. COINCIDENCE FACTOR TO EACH UPSTREAM ASSET FOR LOADS AT VARIOUS NODES

Nodes	T1	T3	D1	D2	D3	D5	T8	D6	D7	D8	D9
L1	0.70	-	-	-	-	-	-	-	-	-	-
L2	0.70	0.60	0.60	-	-	-	-	-	-	-	-
L3	0.70	0.60	0.60	0.60	-	-	-	-	-	-	-
L4	0.77	0.74	0.74	0.74	0.74	-	-	-	-	-	-
L5	0.87	1.00	1.00	1.00	1.00	-	-	-	-	-	-
L6	0.70	-	-	-	-	0.70	-	-	-	-	-
L7	0.87	-	-	-	-	0.87	1.00	1.00	-	-	-
L8	0.77	-	-	-	-	0.77	0.74	0.74	0.86	-	-
L9	0.70	-	-	-	-	0.70	0.60	0.60	0.63	0.60	-
L10	0.87	-	-	-	-	0.87	1.00	1.00	0.80	1.00	1.00
L11	0.70	-	-	-	-	0.70	0.60	0.60	0.63	0.60	0.60

Using coincident demand as input data, AC Load flow is performed to compute flows as required for calculating LRIC charges. Discount rate, load growth rate, and annuity factor are assumed as 6.9%, 1.6%, and 7.4% respectively [7]. Branch charges are calculated for the loads connected at all nodes with due consideration of coincident demand.

Branch incremental charges are calculated with a consideration of coincident demand imposed on each upstream asset from (8). For simplicity branch charges are shown only for users connected at node 8. It can be seen from Fig. 4 that incremental charges for the components supplying to users at this node are lower with a consideration of coincident demand to each upstream shared asset.

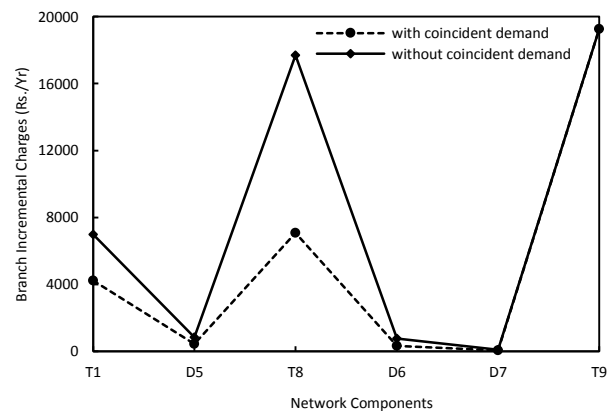


Fig. 4. Branch incremental charges at node 8

Transformer T9 is an individual asset for supplying users connected at this node, so charges for this component are same for the two cases, of with and without coincident demand consideration.

After computing branch charges for all the loads, nodal LRIC charges are computed from (9). These charges with a consideration of coincident demand reflect distance, utilization of network components, and user's contributions to asset peak usage.

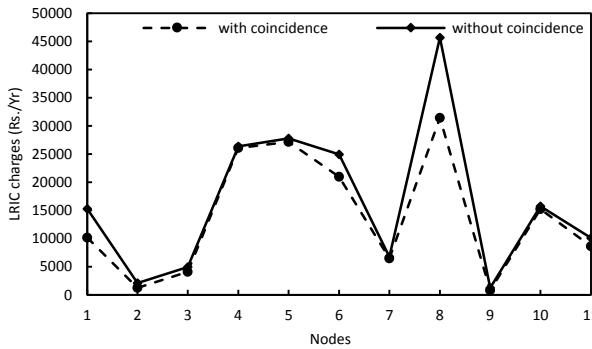


Fig. 5. Nodal LRIC charges with and without consideration of coincident demand

As can be seen from Fig. 5, nodal LRIC charges paid by users connected at the nodes considering coincident demand at each upstream asset usage are lower than that without coincidence consideration. LRIC charges without consideration of coincident demand reflect both distance and utilization of network components. These charges do not reflect actual network usage, and hence does not give users a pricing signal based on peak coincident demand. Network users are responsible for reinforcement of components when their demand imposed on network approaches component capacity. Coincident demand consideration reflects user's contribution towards asset peak usage. With coincident demand consideration, users contributing less towards network peaks face lower incremental charges. Such tariff structure encourages users to modify usage for minimizing network charges.

IV. CONCLUSION

Considering the potential of SG technologies for providing Smart Network Pricing, this paper proposes a coincident demand based LRIC pricing model, to be integrated in a Smart Grid environment. The coincidence factor is reflective of user's contribution to network component peak usage. The price signal would encourage users to improve their demand profile, to minimize their contribution to network congestion. This smart pricing signal is beneficial to both utility and users, as users would face reduced network charges, and the utility would face lower network congestion. Such modified behavior has the potential to provide effective demand side management aiming reduced network investment.

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