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# Transmission Wheeling Pricing in Embedded Cost Using Modified Amp-Mile and MVA Utility Factor Methods

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## Abstract

Transmission wheeling pricing is one of the decisive aspects of present open access electricity market. Various methods are available for transmission; however, no method is proved to diverse operating conditions of the power system. These methods are not able to quantify the full recovery of embedded cost. All the variables i.e. remaining charges, used circuit capacity are not counted in the existing methods. This paper explicates two methods, Modified Amp-Mile method, and MVA Utility Factor method, to recover the embedded cost. Modified Amp-Mile method is a customized form of existing Amp-Mile method. In the MVA Utility Factor method, cost allocation is based on Marginal Participation (MP). It evaluates the cost, using sensitivity analysis of network power. The proposed methods are tested on an IEEE 6-bus system and further verified on Hadoti region real 37-bus system. All the results are presented in Full Recovery Model (FRM) and Partial Recovery Model (PRM).

**Keywords**: transmission wheeling pricing, embedded cost recovery, open access, power system economics

## 1. Introduction

In reference to the Indian electrical network, Power Plant and electrical utilities are connected to the same transmission network. A nodal point is required to decide transmission pricing by independent power producers and electrical utilities both. The action of one buyer creates an effect on other participants; hence practical cost allocation becomes difficult to investigate [1]. However, transmission cost allocation is a complicated issue in deregulated power system [2]. In past years, different methods for allocation of transmission cost in electric networks are proposed by researchers. Capacity usage related to each transaction is calculated for all transmission lines by applying existing methods i.e. Average Participation method, Marginal Participation method, Distribution Factors, Equivalent Bilateral Exchange method, Z-bus method, and Cooperative Game Theory.

In open access, electricity market allotment of embedded cost is one of the important aspects [3]. Each utility has to find a solution with the characteristics of its transmission system and degree of deregulation adopted. Various methods are employed at all operational conditions of diverse power systems to obtain such a solution. No technique is capable of evaluating the entire embedded cost. Any usage-based cost allocation method must contain three features, i.e. accurate algorithms for transmission usage evaluation, equitable allocation rules and full recovery of embedded cost. Based on the above features, cost allocation signifies to identify cost causer for incurring these costs. To determine the causer may be complicated because the non-linear nature of power flow equalities causes difficulty to nature of power flow equations [4].

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Existing methodologies used for transmission wheeling pricing are classified into rolled-in methods and usage-basedmethods. The rolled-in methods do not provide price signals that are cost reflective and are subdivided into two methods, i.e. Postage Stamp Method and Contract Path Method. In Postage Stamp Method, electric utilities allocate the fixed cost among its users having firm contracts [5]. Whereas, in Contract Path Method [6] managed power would be confined to an artificially specified path through the transmission system. On the other hand, usage-based methods require power flow execution of the transmission system and divided into various sub-categories, i.e. MW-Mile, Modulus, MVA-Mile, and Amp-Mile methods. MW-Mile methodology [7] is the pricing strategy for the recovery of fixed transmission costs on the basis of actual power flow of the transmission network. In the Modulus method, all mediators have to pay for the actual capacity use and additional reserve [8]. MVA-Miles method is an augmented version of MW-miles; it takes into account the range of the use of network due to their active and reactive power injection/drawn [9]. Whereas, Amp-Mile method is based on the current flow in the system.

Marginal Participation (MP) methods dominate tracing flow methods as there is no electrical principle behind the tracing flow [10]. It is implemented where tracing flow is significantly less. It allocates transmission charges to either generators or demand nodes. The allocation between generators and demands is decided exogenously, therefore it distorts the vocational signal. It assigns power flow sensitivity in each line due to power injection at each bus and the network usage cost. Sensitivities or utility factors evaluated as per MP are used to predict the changes in losses, voltages and different branch flow due to change in loads and generations [11]. These sensitivities capture the effects of unbalanced network parameters, load and generator locations. In marginal participation methods, the Amp-Mile method is enough to attain the aim for the transmission network. Even though it has some limitation, i.e. it cannot be implemented on EHV networks and cannot allocate entire embedded cost. Hence, additional charges are required to be imposed on agents. In practice, the Extent of Use (EU) is never 100% of the circuit’s capacity. Therefore, the grid looks underutilized and lastly service cost based on the network usage will be smaller than embedded cost. Other costs are incurred through supplementary charges [12].

In transmission wheeling, there are many challenges occur to find out proper coat allocation. Some challenge is to promote the efficiency of the day-to-day operation of the bulk power market. To resolve the problem of signal locational advantages for investment in generation and demand. To increase the investment in the transmission system for saving customer cost in the energy market. Recover the costs of existing transmission assets, which has been investment by the transmission company. In transmission pricing, incremental cost is directly available from economic dispatch. These pricing methods are well suited for rapid on line costing, but limited to presenting economic effects on the wheeling utility’s production cost and total system losses. The main focus is to find ways and means to generate and inject more competition, thereby forcing the conventional monopolistic power market to a competitive market. The transmission of open access has been introduced into the electric power supply industry to alter the traditionally monopolized market. It is desired that transmission prices and payment do not disturb decisions for new generation investment, for generator and for consumer demand. At same time charging must be achieved in a simple and fair form, realistic and adequate for real-time application as well as transparent enough to be politically acceptable. In wheeling,methodology compute a high priority problem due to growth in transmission facilities, cost differentials between utility companies, and dramatic growth in non-utility generation capacity.

The Modified Amp method in the full recovery model and MVA utility factor method in full/partial recovery model is analyzed in this paper. Cost comparison analysis of the different method is show benefits of Modified Amp method in transmission pricing. The embedded cost allocations using a different method at different percentage loading are evaluated. A real 37-bus system and IEEE 6-bus system network is used in the case study to prove efficiency and applicability of the proposed method. In this paper, the nonlinearity of sensitivity indices of Modified Amp method and MVA utility factor has been established and analyzed.

## 2. Wheeling Pricing Methodologies

The pricing methodology adopted by each utility is depending on the characteristic of the transmission or distribution network. Therefore, a particular pricing methodology cannot be applied for all conditions as each methodology has its specific characteristics. Deregulated environment reduces the tariff for consumers and improves the efficiency for power suppliers in the long run. Transmission pricing has been categorized on the basis of their operating principles i.e. Marginal/Incremental cost-based pricing [13], Embedded cost-based pricing [14], and combination of Embedded with Incremental cost-based pricing [15].

Table 1 Literature methodology in embedded wheeling pricing from past to present

| S.No | Year | Author | Literature Points of Embedded Wheeling Pricing |
|---|---|---|---|
| 1 | 1989 | D. Shrimohammadi | • Analysis of MW-Mile Method<br>• Cost allocated is proportional to the MW flows<br>• This method doesn't take care of Reactive power<br>• Fail to reflect technical operational conditions of network |
| 2 | 2001 | Ching- Tzong Su, and Ji-HorngLiaw | • Analysis of MVA-Mile Method<br>• Considering apparent power (MVA) for wheeling pricing<br>• More reasonable and valid than the commonly used MW-MILE method<br>• Unable to consider direction of Reactive power flow<br>• Not providing true pricing |
| 3 | 2006 | Yog R. Sood | • Modified analysis in MW-cost method or MVA-cost method<br>• Instead of multiplying the changes in the flow in the facility by length, it is multiplied by its cost unlike MW-Mile or MVA-Mile method |
| 4 | 2006 | F. Li | • Analysis of MW + MVAr-Mile<br>• This method takes care of power factor of network users<br>• It separates the MW and MVAr power flows<br>• Distinguishes direction of Reactive power flow<br>• Acknowledges full cost-benefit of network users, especially DG |
| 5 | 2009 | Paul M. Sotkiewicz and J.Mario Vignlo | • Analysis of Amp-Mile Method<br>• Cost allocation is based on Amp flow caused by individual customer<br>• Explicitly account for counterflows and reward DG<br>• Drafts the direction of Reactive Power<br>• But applicable only on distribution network |
| 6 | 2007-2010 | Florin and Cutsem, Xiao and Mccalley, K. Singh | • Analysis of Congestion Management in transmission pricing<br>• Probabilistic risk indices to assess real power level security system<br>• Congestion management in deregulation environment by utilizing impedance matrix |

### *2.1. Marginal/ incremental cost-based pricing methods*

Marginal pricing or marginal wheeling rates are also called an extension of the spot-pricing theory. Spot pricing is a method for pricing electricity that maximizes the economic efficiency of the power system [16]. It is difficult to estimate transmission pricing using marginal cost based pricing method as the income would not be sufficient for financing the investment. However, a theory of social benefit, which maximizes real-time price of real and reactive powers, is considered [17]. It flattens the peak power demand and fills the valley of demand. The allocation of transmission payments among different agents depends upon the total energy consumed. An algorithm for optimal pricing includes transmission cost beside generation cost in electricity supply. The report of optimal pricing calculation has to be sent to all the participants. The marginal cost could be minimized with the inclusion of FACTS devices in an overloaded transmission system. FACTS devices can change power flows by using system parameters. Using spot pricing and marginal cost theories active and reactive power transition costs is calculated while voltage-dependent load models were observed [18].

Incremental cost methodologies are defined in two parts as short run and long run cost. Short run marginal/incremental cost or spot pricing is economic. It has some bidding to power transmission systems such as entire transmission costs not recovered, the charges acquired exceedingly volatile, rationale for transmission charges and the transmission system is frequently not in most favorable condition, etc. On the other hand, long-run incremental cost methodology depends on forecast data with uncertainties. It is difficult to obtain convincing prices as many non-deterministic factors are involved [19]. All system costs (existing transmission system, operation, and expansion) are allocated among the system users in proportion to their EU (Extent of Use) of the transmission resources. The charge for basic transmission service is usually the component of overall transmission service charges.

### *2.2. Embedded cost-based pricing methods*

Embedded cost is defined as the revenue required paying for all existing or any new facilities added to the power system during the contract for transmission service. In general form adequate remuneration of transmission systems and easy to implement. The embedded cost methods allocate the total system cost among the transmission customers, based on Extent of Use (EU) rule. In embedded methods, all system costs (existing transmission system, operation, and expansion) are allocated among the system users in proportion to their Extent of Use (EU) of the transmission resources. They can be classified as rolled-in methods and usage-based methods. The main shortcoming of the rolled-in methods is ignorance of actual system operation. As a result, they are likely to send incorrect economic signals to transmission customers. But this problem has overcome by usage-based methods as it evaluates EU in the framework of either load flow or optimal power flow. Embedded costs methods are used by the utilities to allocate existing transmission facilities to the transmission wheeling transaction. Table 1 represents the literature survey of embedded wheeling pricing. This table easily describes embedded wheeling cost strategy in electricity market from past to present stage.

#### *2.2.1. Active power flow based methods*

The capacity of transmission network used for a transaction is a function of the magnitude of electric power, transmission lines length, and facilities involved in the active power transaction. Capacity value provides an equitable means of allocating the cost of transmission facilities among users of the firm transmission service. It takes full account of current generation cost and capacities as well as the transmission of the demand in space and time. The mw-mile method is used to evaluate the transmission pricing leads to the effective recovery of all embedded costs. It includes an analysis of relative reliability contributions of each generator to the unscheduled transmission capacity in a circuit. All transmission users are liable to wages the actual use of capacity and transmission reserves. In practice, it is improper for those who make limited usage of the network.

#### *2.2.2. Real power flow based methods*

J. Bialek proposed a tracing flow method for evaluating the flow of electricity through power networks [20]. It allows quantification of active or reactive power flows from a particular source to a specific load, the contribution from each generator, power load flow and losses in a line. Kirschen’s method is based on the solution of a series of load flows. It calculates the contribution of the generator to the loads, line flows and transmission pricing. J. Bialek proposed another tracing flow methodology is known as Unifying Tracing-based methodology of transmission pricing for inter-system trades. It is easy, transparent and fast. It can also deal effectively with circular flows.

An up-gradation of MW-Mile method was introduced in the year 2001. The upgrade technique is called a MVA-Mile method which reflects the EU of transmission facilities in the system. It enforces to power flow and considers apparent power. It is reasonable and valid in comparison to the commonly used MW-mile method, but big wheeling charge may pick up the total generation cost. Monetary Path method is also based on tracing flow concept, which proposes an even measurement for transmission usages by active and reactive powers. Reactive power allocation method determines real and imaginary currents to handle the system losses and loop flow. The traces from current sources to current sinks are then converted to power contributions. MVA method is economic to resolve difficult reactive power pricing and costing issues. All the methods are based on tracing flow concept for usage quantification.

*2.3. Composite embedded and marginal cost-based pricing methods*

TThis methodology includes both the existing system cost and marginal costs of transmission transactions to evaluate the collective transmission pricing part by embedded cost and marginal pricing method. The marginal cost based pricing is used to transmission price services. It requires supplement revenue generation as a pricing scheme is not able to care financially to the transmission service providers. This approach discriminates between operating and embedded costs. It develops separate methods in respect of each of these components. The capacity utilized as well as consistency benefits derived by different users for investment recovery payout of charges for investment recovery are considered. It also includes marginal pricing approach to the recovery of operating cost. It is a simple novel method used for topological analysis of power flows based transmission supplement charge allocation in the network. Its result is positive in counter-flow contributions from all the users. Revenue of transmission company divided into marginal cost and supplementary charges. The marginal cost is evaluated by FRM model to estimate the total transmission cost (cost allocation and remaining charges). In supplementary charges, the cost is evaluated by PRM model. Whereas, locational charges and post stamp charges method is used to estimate the supplementary charges. Both methods are used to evaluate remaining charges in supplementary cost. The supplementary charges are allocated in real power as well as reactive power load through MW-Mile, MVA-Mile method. This charge for usage of a separate transmission asset is divided into a locational and non-locational component. Wheeling charging strategy and unused capacity of the asset are shown in Fig. 1.

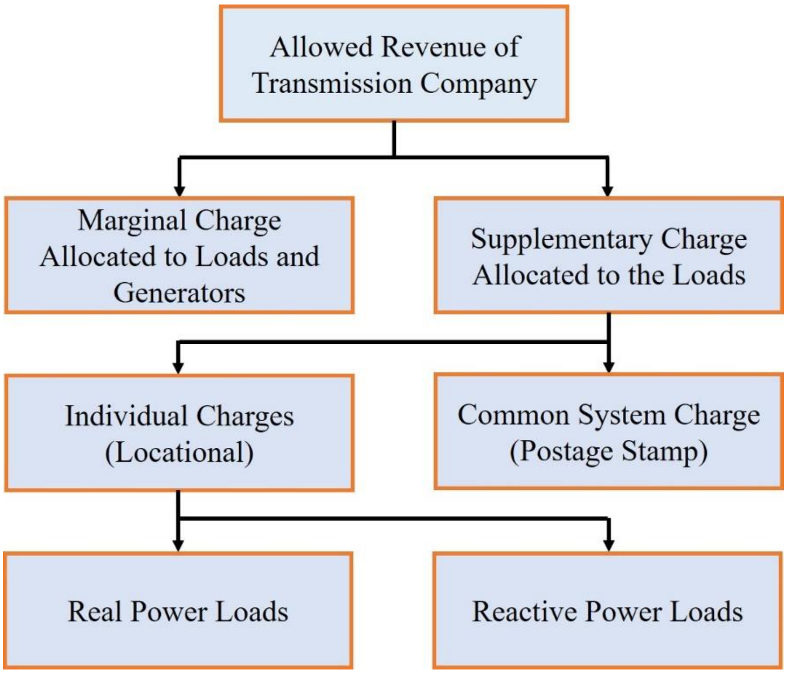



Fig. 1 Wheeling charging strategy

*2.4. Amp-mile method*

The Amp-Mile method is an embedded cost allocation method for the medium voltage distribution network. It is based on the Extent of Use (EU) for circuits is measured in terms of the contribution of each customer to the current flow i.e. the power to current distribution factors ($APIDF^{t}_{lk}$& $RPIDF^{t}_{lk}$), at any instant of time. It is the least control of system stability (steady state and transient) in the distribution system. Current capacity increases up to the thermal limit. So current flows may attribute network customers, therefore method is acknowledged as “Amp-mile” or “I-mile” methodology [1]. Thus different Extent of Use (EU) is found out using current distribution factors and used to accomplish allocation of cost. Unambiguously accounts for flow direction to provide better long-term price signals and to alleviate potential constraints [20]. Steps to allocate embedded cost, as well as remaining cost are as follows

$$AEoUL_{lk}^{t} = \frac{APIDF_{lk}^{t} \times PL_{k}^{t}}{AI_{l}^{t}} \tag{1}$$

$$AEoUG_{lk}^{t} = \frac{APIDF_{lk}^{t} \times PG_{k}^{t}}{AI_{l}^{t}} \tag{2}$$

$$REoUL_{lk}^{t} = \frac{RPIDF_{lk}^{t} \times QL_{k}^{t}}{AI_{l}^{t}} \tag{3}$$

$$REoUG_{lk}^{t} = \frac{RPIDF_{lk}^{t} \times QG_{k}^{t}}{AI_{l}^{t}} \tag{4}$$

where, $AEoUL_{lk}^{t}$ is Active EU of circuit $l$ at time $t$ due to demand at $k^{th}$ bus, $AEoUG_{lk}^{t}$ is Active EU of circuit $l$ at time $t$ due to generation at $k^{th}$ bus, $REoUL_{lk}^{t}$ is Reactive EU of circuit $l$ at time $t$ due to demand at $k^{th}$ bus, $REoUG_{lk}^{t}$ is Reactive EU of circuit $l$ at time $t$ due to generation at $k^{th}$ Bus, $APIDF_{lk}^{t}$ is Active power to current distribution factor of circuit $l$ at time $t$ due to demand at $k^{th}$ bus, $RPIDF_{lk}^{t}$ is Active power to current distribution factor of circuit $l$ at time $t$ due to demand at $k^{th}$ bus.

Various methods are not able to quantify the EU of a transmission network for both active and reactive power flows. The Amp-Mile method became the base of the research. Limitations of Amp-Mile method have been identified through numerical value. Based on these corrections Modified Amp-Mile method is proposed. It recommends applicability on EHV networks by putting more prominence on stability limits. A step ahead introduced a new usage-based cost allocation technique- MVA Utility Factor method with two models: Full Recovery and Partial Recovery Model. It carries the advantages of Modified Amp-Mile method. It is based on marginal participation; therefore obtained utility factors are prone to the choice of slack bus. Therefore distinct slack bus notion has been proposed to allocate the embedded cost of EHV networks. Distinct slack bus notion is different from dispersed slack bus concept. The intermediate stages of nonlinear sensitivities are found using modified NR based load flow. The relationship between flow and power injection/withdrawal is nonlinear. The novel sensitivity patterns could assist ISO to forecast day-ahead transmission. In full recovery model total EU for all the lines remains unity under all loading conditions.

## 3. Proposed Methodology

The amp-mile method has some limitations. When the system has fully loaded this method do not recover the full embedded cost. It is relevant only on radial networks since currents are comparative to the thermal capacity of the distribution network (high R/X ratio). It is stated that circuit currents are an approximately linear function of active and reactive power at the bus in a radial network. In Amp-Mile a reconciliation factor is needed to find EU factors for a given line sum to unity. It confers only two types of sensitivities (Eq.(5)) in the form of Transmission factors CUPF (Current Utility Active Factor) and CUQF (Current Utility Reactive Factor). The common transmission factor for demand/generation transmutation at the same bus with a difference of sign.

$$\left|\partial I_{l} / \partial P_{dk}\right| = \left|-\partial I_{l} / \partial P_{gk}\right| \tag{5}$$

$$\left|\partial I_{l} / \partial Q_{dk}\right| = \left|-\partial I_{l} / \partial Q_{gk}\right| \tag{6}$$

where, $I_l$ is the absolute value of the current through circuit l, $P_{dk}$ is the active power withdrawal due to demand at $k^{th}$ bus, $P_{gk}$ is the active power withdrawal due to generation at $k^{th}$ bus, $Q_{dk}$ is the reactive power withdrawal due to demand at $k^{th}$ bus, $Q_{gk}$ is the reactive power withdrawal due to generation at $k^{th}$ bus.

### 3.1. Modified amp-mile method

The modified Amp-Mile method identifies the nonlinear or linear nature of sensitivities depending on location and topological conditions. Its charges allocation has not been stable at variable load levels and different period of time. It indicates that the current sensitivity indices CUPFtlk and CUQFtlk are exhibiting nonlinear nature with respect to active and reactive powers (injection/withdrawal) at a bus of EHV network. Modified NR based load flow is used to find current sensitivity indices. In the modified Amp-Mile method, reconciliation factor is not required to furnish the total EU for a given line equal to unity. It selects new distinct slack bus perception to resolve the load flow values. Entire embedded cost of EHV networks is allocated by using non-linear sensitivities and new distinct slack bus notion.

If a system has large chances of increase in load and generation on the same bus, comparisons could be made between $\partial I_l/\partial P_{dk}$ and $\partial I_l/\partial P_{gk}$. Therefore, current sensitivity indices are expressed as

$$CUPF_{ldk}^{t} = \partial I_l / \partial P_{dk} \tag{7}$$

$$CUPF_{lgk}^{t} = \partial I_l / \partial P_{gk} \tag{8}$$

$$CUQF_{ldk}^{t} = \partial I_l / \partial Q_{dk} \tag{9}$$

$$CUQF_{lgk}^{t} = \partial I_l / \partial Q_{gk} \tag{10}$$

where, $CUPF_{ldk}^{t}$ is Current utility active factor of $l^{th}$line w.r.t.$k^{th}$ demand bus at $t^{th}$instant, $CUPF_{lgk}^{t}$is Current utility active factor of $l^{th}$line w.r.t.$k^{th}$ generator bus at $t^{th}$ instant, $CUQF_{ldk}^{t}$is Current utility reactive factor of $l^{th}$line w.r.t.$k^{th}$ demand bus at $t^{th}$instant, $CUQF_{lgk}^{t}$ is Current utility reactive factor of $l^{th}$line w.r.t.$k^{th}$ generator bus at $t^{th}$instant.

The applicability of the modified Amp-Mile method is on EHV networks, by putting more prominence on stability limits, instead of thermal capability. In Eq. (5), there should be dissimilarity between $\mathrm{CUPF_{lk}^{t}}$ and $\mathrm{CUQF_{lk}^{t}}$ for load/generation given in Eqs. (7-10). The expressions of dissimilar EU's are

$$AEUD_{lk}^{t} = CUPF_{ldk}^{t} \times P_{dk}^{t} / I_l^t = ?\, \partial I_l / \partial P_{dk}) \times P_{dk}^{t} / I_l^t \tag{11}$$

$$AEUG_{lk}^{t} = CUPF_{lgk}^{t} \times P_{gk}^{t} / I_l^t = ?\, \partial I_l / \partial P_{gk}) \times P_{gk}^{t} / I_l^t \tag{12}$$

$$REUD_{lk}^{t} = CUQF_{ldk}^{t} \times Q_{dk}^{t} / I_l^t = ?\, \partial I_l / \partial Q_{dk}) \times Q_{dk}^{t} / I_l^t \tag{13}$$

$$REUG_{lk}^{t} = CUQF_{lgk}^{t} \times Q_{gk}^{t} / I_l^t = ?\, \partial I_l / \partial Q_{gk}) \times Q_{gk}^{t} / I_l^t \tag{14}$$

where, $AEUD_{lk}^{t}$ is Active extent of use by $k^{th}$ bus demand for $l^{th}$ line at $t^{th}$ instant, $AEUG_{lk}^{t}$ is Active extent of use by $k^{th}$ bus generation for $l^{th}$ line at $t^{th}$ instant, $REUD_{lk}^{t}$ is Reactive extent of use by $k^{th}$ bus demand for $l^{th}$ line at $t^{th}$ instant, $REUG_{lk}^{t}$ is Reactive extent of use by $k^{th}$ bus generation for $l^{th}$ line at $t^{th}$ instant, $P_{dk}^{t}$ is Active demand on $k^{th}$ bus at $t^{th}$ instant, $P_{gk}^{t}$is Active generation on $k^{th}$ bus at $t^{th}$instant, $Q_{dk}^{t}$ is Reactive demand on $k^{th}$ bus at $t^{th}$ instant, $Q_{gk}^{t}$ is Reactive generation on $k^{th}$ bus at $t^{th}$instant, $I_l^t$ is Absolute current in $l^{th}$ line at $t^{th}$instant.

The reconstruction of the algorithm to evaluate $\mathrm{CUPF_{lk}^{t}}$ and $\mathrm{CUQF_{lk}^{t}}$ inherently attributes the efficacy of slack bus power. It provides true sensitivities, re-establishing and offered a close approximation of circuit currents.

The expression of the absolute value of $\mathrm{I_l^t}$ will turn to

$$I_l^t = \sum_{k=1}^{nbus} [CUPF_{ldk}^{t} \times P_{dk}^{t} + CUPF_{lgk}^{t} \times P_{gk}^{t}] + [CUQF_{ldk}^{t} \times Q_{dk}^{t} + CUQF_{lgk}^{t} \times Q_{gk}^{t} \tag{15}$$

Substitute used circuit cost at $\mathrm{t^{th}}$ instant ($\mathrm{UCC_l^t}$) equal to unity to find the allocation of embedded cost. Consequently adapted circuit cost at $\mathrm{t^{th}}$instant ($\mathrm{ACC_l^t}$) would be equal to $\mathrm{CC_l^t}$ and therefore the relation of locational charges change as given below

$$AL_k^t = \sum_{l=1}^{n_{line}} AEUD_{lk}^t \times CC_l^t \tag{16}$$

$$AG_k^t = \sum_{l=1}^{n_{line}} AEUG_{lk}^t \times CC_l^t \tag{17}$$

$$RL_k^t = \sum_{l=1}^{n_{line}} REUD_{lk}^t \times CC_l^t \tag{18}$$

$$RG_k^t = \sum_{l=1}^{n_{line}} REUG_{lk}^t \times CC_l^t \tag{19}$$

where, $AL_k^t$ is Active Locational charge due to active demand on $k^{th}$ bus at $t^{th}$ instant, $AG_k^t$ is Active Locational charge due to active generation on $k^{th}$ bus at $t^{th}$ instant, $RL_k^t$ is Reactive Locational charge due to reactive demand on $k^{th}$ bus at $t^{th}$ instant, $RG_k^t$ is Reactive Locational charge due to reactive generation on $k^{th}$ bus at $t^{th}$ instant, $CC_l^t$ is a level cost for each hour.

The expression of remaining circuit charges ($RCC^t$) are

$$RCC^t = \sum_{l=1}^{n_{line}} [CC_l^t - CC_l^t] = 0 \tag{20}$$

So the total cost of the modified Amp-Mile method in the full recovery model is

$$Total?Cost = AL_k^t + AG_k^t + RL_k^t + RG_k^t \tag{21}$$

The modified Amp-Mile method increases allocation equivalent to full recovery model in proportion to assorted EU's. The EU's of all circuits would be unity under all loading conditions and no need to calculate remaining (supplementary or non-vocational) charges. Therefore, keeping UCC equal to unity and evaluate transmission charges plus capacity charges simultaneously. Transmission network participants have to pay for used/unused capacity in proportion to their EU. It is justified by the need for system meeting reliability, stability and security criteria for all customer.

*3.2. MVA utility factor method*

The MVA Utility Factor method allocates the entire embedded cost of transmission networks. It carries the advantages of previously discussed modified Amp-Mile method. The non-linear patterns of MVA utility factors have been furnished and distinct slack bus notion has been promoted to allocate the embedded cost of power networks. It provides better promises for payments to counterflow creators and gives assurance for prudent implementation.

In the proposed technique individual participant's impact on the system is recognized through MVA flow caused by them. Therefore, a method is called an MVA Utility Factor method. It is a significant method because no question arises in relation to current limits for the reason that MVA flows can be increased under specified constraints of the power network. It wiped out limits of the modified Amp-Mile method and exploits load flow and derives non-linear sensitivities (MVAUF).

This illustrates a true understanding of the network and causes a fair allocation. In MVA utility factor method, unequal sensitivities at a bus having active/reactive generation and load are represented as [21].

where, $MVAPUF_{ldk}^t$ is MVA utility active factor of $l^{th}$ line w.r.t. $k^{th}$ bus demand at $t^{th}$ instant, $MVAPUF_{lgk}^t$ is MVA utility active factor of $l^{th}$ line w.r.t. $k^{th}$ bus generator at $t^{th}$ instant, $MVAQUF_{ldk}^t$ is MVA utility reactive factor of $l^{th}$ line w.r.t. $k^{th}$ bus demand at $t^{th}$ instant, $MVAQUF_{lgk}^t$ is MVA utility reactive factor of $l^{th}$ line w.r.t. $k^{th}$ bus generator at $t^{th}$ instant.

$$\left|MVAPUF_{lgk}^t\right| = -\left|MVAPUF_{ldk}^t\right| \tag{22}$$

$$\left|MVAQUF_{lgk}^t\right| = -\left|MVAQUF_{ldk}^t\right| \tag{23}$$

The transmission network though EHV network does not follow the same for some of the generator buses using load flow. It obtains either equal or unequal sensitivities at generator buses in EHV networks. Therefore, Eqs. (22-23) does not reflect true operating conditions. Many cost allocation methodologies suggested following load flow to avoid unequal sensitivities. It established four different utility factors corresponding to generator buses in EHV networks irrespective of equal or unequal sensitivities. MVA flow of a line can be expressed using utility factors of Eqs. (24-27) are

$$MVAPUF_{ldk}^{t} = \partial MVA_{l}^{t} \big/ \partial P_{dk}^{t} \tag{24}$$

$$MVAPUF_{lgk}^{t} = \partial MVA_{l}^{t} \big/ \partial P_{gk}^{t} \tag{25}$$

$$MVAQUF_{ldk}^{t} = \partial MVA_{l}^{t} \big/ \partial Q_{dk}^{t} \tag{26}$$

$$MVAQUF_{lgk}^{t} = \partial MVA_{l}^{t} \big/ \partial Q_{gk}^{t} \tag{27}$$

where, $MVA_l^t$ is the absolute value of MVA through circuit l, $P_{dk}^t$ is the active power withdrawal due to demand at $k^{th}$ bus at $t^{th}$ instant, $P_{gk}^t$ is the active power withdrawal due to generation at $k^{th}$ bus at $t^{th}$ instant, $Q_{dk}^t$ is the reactive power withdrawal due to demand at $k^{th}$ bus at $t^{th}$ instant, $Q_{gk}^t$ is the reactive power withdrawal due to generation at $k^{th}$ bus at $t^{th}$ instant.

Formulation of MVAUF's is evaluated using modified NR based load flow. Thus attributes the effect of slack bus power. These buses are self-regulating and bounds for each of the generators. It maintains a constant voltage at buses; consequently, no change in line flow occurs due to change in a reactive generation. Expression of Absolute MVA in $\mathrm{l^{th}}$line at $\mathrm{t^{th}}$instant ($\mathrm{MVA_l^t}$) are

$$?MVA_{l}^{t} = \sum_{k=1}^{nbus} \{MVAPUF_{ldk}^{t} \times P_{dk}^{t} + MVAPUF_{lgk}^{t} \times P_{gk}^{t} + MVAQUF_{ldk}^{t} \times Q_{dk}^{t} + MVAQUF_{lgk}^{t} \times Q_{gk}^{t} \tag{28}$$

The MVAUF's from Eqs. (24-27) are employed for the evaluation of EOU by each participant, equations given as:

$$AEUD_{lk}^{t} = MVAPUF_{ldk}^{t} \times P_{dk}^{t} \big/ MVA_{l}^{t} \tag{29}$$

$$AEUG_{lk}^{t} = MVAPUF_{lgk}^{t} \times P_{gk}^{t} \big/ MVA_{l}^{t} \tag{30}$$

$$REUD_{lk}^{t} = MVAQUF_{ldk}^{t} \times Q_{dk}^{t} \big/ MVA_{l}^{t} \tag{31}$$

$$REUG_{lk}^{t} = MVAQUF_{lgk}^{t} \times Q_{gk}^{t} \big/ MVA_{l}^{t} \tag{32}$$

Both models by a utility depend on its transmission system and extent of deregulation espoused.

It is concluded that total EU due to all participants is unity even though the system is not fully loaded. This methodology is utilized to develop two types of allocation models; Partial Recovery Model (PRM) and Full Recovery Model (FRM).

#### *3.2.1. Partial recovery model (PRM)*

In this modal, a part of the embedded cost is allocated on the basis of electricity usage and remaining charges are imposed on the participants. The two types of charges are;

PUBC: Charge allocated to participants based on the real usage of the network.

RC: This portion of allocation reflects a charge to recover the cost of the unused network capacity. It is revealing the security issue of the power system and has to be imposed on all participants. Expressions of PUBC and RC are:

$$PUBCP_{dk}^{t} = \sum_{l=1}^{nline} AEUD_{lk}^{t} \times ACC_{l}^{t} \tag{33}$$

$$PUBCP_{gk}^{t} = \sum_{l=1}^{nline} AEUG_{lk}^{t} \times ACC_{l}^{t} \tag{34}$$

$$PUBCQ_{dk}^{t} = \sum_{l=1}^{nline} REUD_{lk}^{t} \times ACC_{l}^{t} \tag{35}$$

$$PUBCQ_{gk}^{t} = \sum_{l=1}^{nline} REUD_{lk}^{t} \times ACC_{l}^{t} \tag{36}$$

where, $PUBCP_{dk}^{t}$ is Partial recovery usage-based charges for active demand on $k^{th}$ bus at $t^{th}$ instant, $PUBCP_{gk}^{t}$ is Partial recovery usage-based charges for active generation on $k^{th}$ bus at $t^{th}$ instant, $PUBCQ_{dk}^{t}$ is Partial recovery usage-based charges for reactive demand on $k^{th}$ bus at $t^{th}$ instant, $PUBCQ_{gk}^{t}$ is Partial recovery usage-based charges for reactive generation on $k^{th}$bus at $t^{th}$ instant.

Let $CC_{l}^{t}$ is levelized hourly cost of $l^{th}$circuit and annual circuit cost will be$CC_{l}^{t} \times 8760$.Then corresponding adapted circuit cost $ACC_{l}^{t}$ at $t^{th}$ instant is

$$ACC_{l}^{t} = UCC_{l}^{t} \times CC_{l}^{t} \tag{37}$$

where$UCC_{l}^{t}$ is the used circuit capacity of line $l$ for time $t$, and defined by

$$UCC_{l}^{t} = MVA_{l}^{t} / CAP_{l} \tag{38}$$

where $CAP_{l}$ is MVA capacity of the line. The Remaining Charge (RC) express as

$$RC^{t} = \sum_{l=1}^{nline} \left[ CC_{l}^{t} - ACC_{l}^{t} \right] \tag{39}$$

*3.2.2. Full recovery model (FRM)*

Accomplishes total recovery of embedded cost by substituting $UCC_{l}^{t}$ unity in Eq. (37); consequently, $ACC_{l}^{t}$ would be equal to $CC_{l}^{t}$. Expressions of FUBC are:

$$FUBCP_{dk}^{t} = \sum_{l=1}^{nline} AEUD_{lk}^{t} \times CC_{l}^{t} \tag{40}$$

$$FUBCP_{gk}^{t} = \sum_{l=1}^{nline} AEUG_{lk}^{t} \times CC_{l}^{t} \tag{41}$$

$$FUBCQ_{dk}^{t} = \sum_{l=1}^{nline} REUD_{lk}^{t} \times CC_{l}^{t} \tag{42}$$

$$FUBCQ_{gk}^{t} = \sum_{l=1}^{nline} REUG_{lk}^{t} \times CC_{l}^{t} \tag{43}$$

where $FUBCP_{dk}^{t}$ is Full recovery usage-based charges for active demand on $k^{th}$bus at $t^{th}$instant, $FUBCP_{gk}^{t}$ is Full recovery usage-based charges for active generation on $k^{th}$bus at $t^{th}$instant, $FUBCQ_{dk}^{t}$ is Full recovery usage-based charges for reactive demand on $k^{th}$bus at $t^{th}$Instant, $FUBCQ_{gk}^{t}$is Full recovery usage-based charges for reactive generation on $k^{th}$bus at $t^{th}$instant.

In FRM, the Eq. (38) for Remaining Charges can be modified accordingly and expressed as:

$$RC^{t} = \sum_{l=1}^{nline} \left[ CC_{l}^{t} - CC_{l}^{t} \right] = 0 \tag{44}$$

Using an analysis of both methodologies a flow chart is shown in Fig. 2. Data input and newton raphson analysis is the same in both methods. Current utility factor logic has been used in mod amp mile method similarly;

MVA sensitivity analysis has been used to calculate the MVA utility factor method. Used circuit capacity (UCC=1) unity value is used to calculate annual circuit cost which is defined FRM wheeling value in both methods. MVA utility factor PRM model represent adapted circuit cost to evaluate Cost Allocation (CA) and Remaining Charges (RC) in the network.

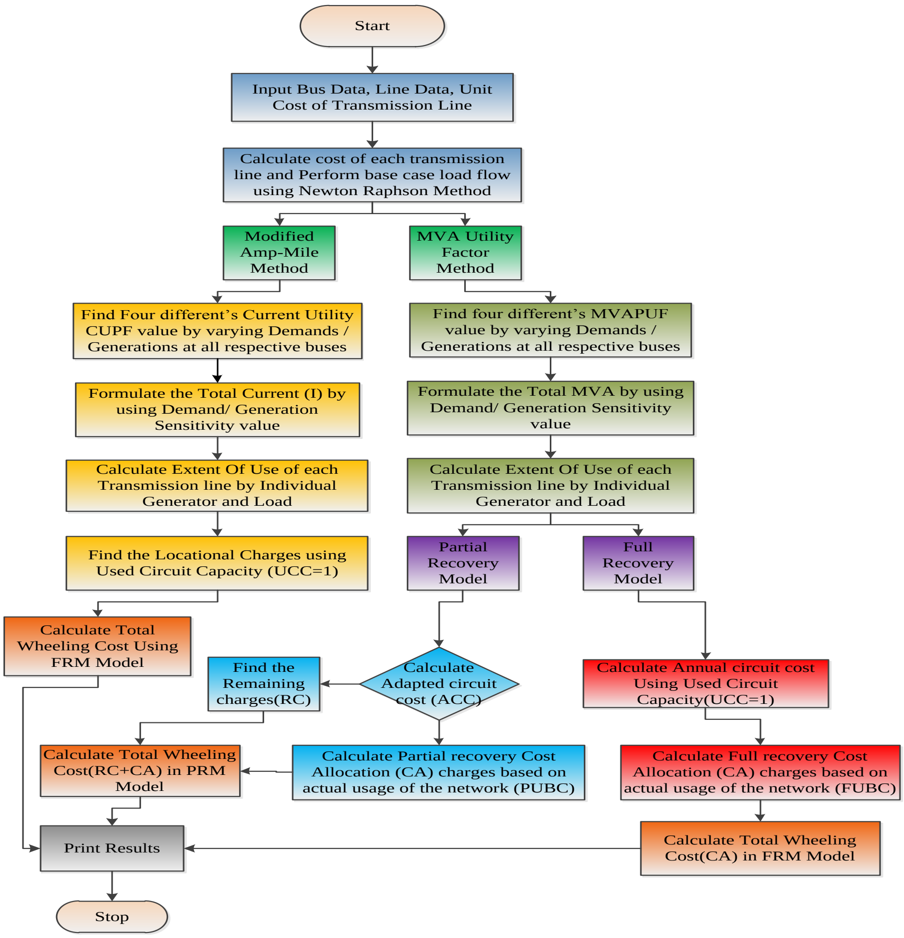



Fig. 2 Flow chart of mod amp-mile and MVA utility factor methods

## 4. Case Study and Results

The proposed methodologies have to be employed on some real-time system or IEEE standard bus system to prove its efficiency and reliability. In this paper, a real-time 37 bus system and one IEEE standard 6 bus system is used as a case study and respective results are discussed. In the case study, Modified Amp-Mile method is applied using full recovery modal, whereas, MVA utility factor method is applied using both modals i.e. full and partial recovery modal. Single line diagram of real-time 37 bus system is shown in Fig.3. The system has 2 generation bus and 48 transmission corridors at 220 kV and 132 kV voltage level. The generation capacity of 1300 MW is assumed as base load condition and total load connected on the system is 911 MW. It is assumed in this analysis that load customer would pay 100% of the transmission cost of services to the transmission utility. The annual revenue requirement of transmission facility is 843.56 Crs-INR. The embedded cost to be allocated is assumed proportional to the length of individual transmission lines in Rupee/hr. The comprehensive detail and various parameters of the 37 bus system are given in Table 2. Data of total load connected is collected of each feeder Whereas, bus data represent the bus voltage, active/reactive value of generated power and total load connected in different buses. In line data values represent the load connection information for every node , value of the impedance in each line of the system and line charging value in the transmission network. Voltage and power factor value is collected for evaluating the bus data.

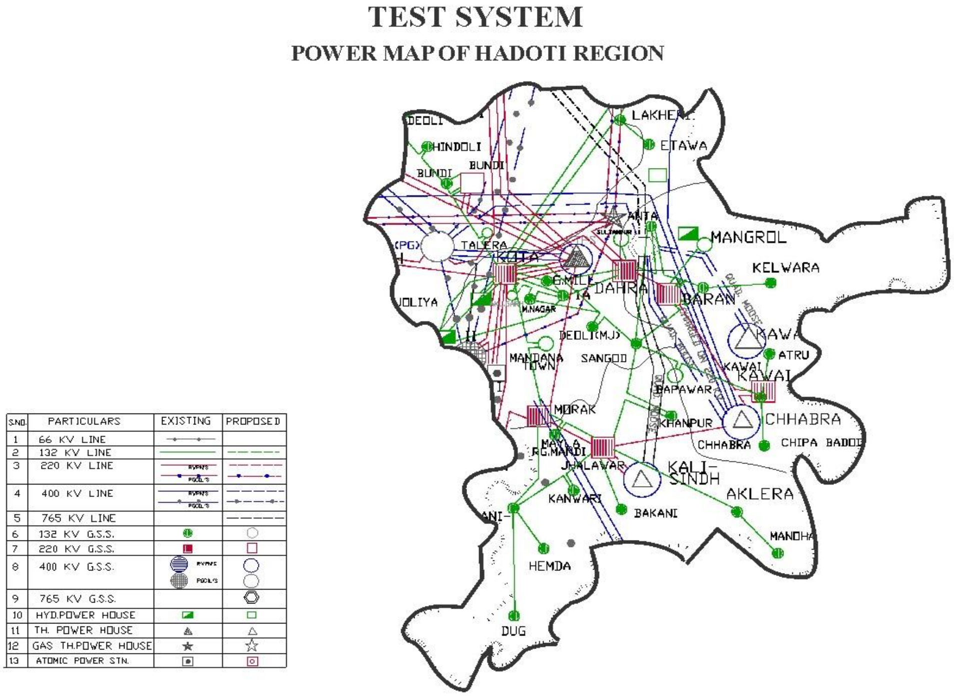



Fig. 3 North Indian Real Test System (Power Map of 37 bus Hadoti Region)

Table 2 Cost of generation and load (Rupee / hr.) for real 37 bus system

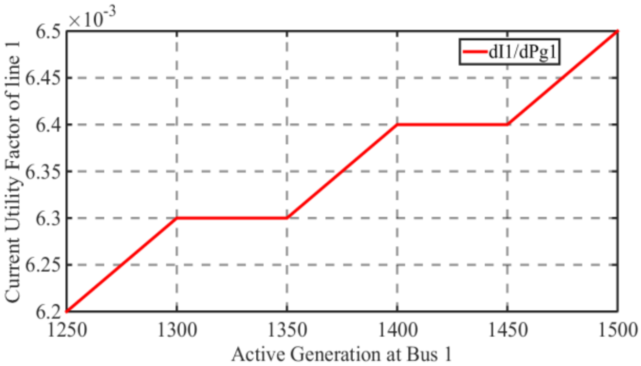
| Bus data of 37-bus Transmission System | | | | | | | Line Data of 37-bus Transmission System | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bus no. | Bus voltage | | Power generated | | Load | | Node Connection | | Impedance(p.u.) | | Line Charging |
| | Magnitude | Angle | P | Q | P | Q | From | To | R | X | (p.u.) B/2 |
| | (pu) | (deg) | (MW) | (MVAr) | (MW) | (MVAr) | 1 | 2 | 0.00024 | 0.001275 | 0 |
| 1 | 1 | 0 | 1300 | 0 | 0 | 0 | 1 | 5 | 0.0056 | 0.02975 | 0 |
| 2 | 1.01 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 0.00896 | 0.0476 | 0 |
| 3 | 1.02 | 0 | 0 | 0 | 0 | 0 | 2 | 6 | 0.00672 | 0.0357 | 0 |
| 4 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 15 | 0.0306397 | 0.0794612 | 0 |
| 5 | 1.02 | 0 | 0 | 0 | 0 | 0 | 2 | 21 | 0.0132314 | 0.0343144 | 0 |
| 6 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 22 | 0.01001 | 0.02596 | 0 |
| 7 | 1 | 0 | 0 | 0 | 18 | 7.1 | 2 | 23 | 0.0206388 | 0.0535248 | 0 |
| 8 | 0.98 | 0 | 0 | 0 | 28 | 10.17 | 2 | 7 | 0.0295022 | 0.0765112 | 0 |
| 9 | 0.99 | 0 | 0 | 0 | 10 | 3.3 | 2 | 18 | 0.03822 | 0.09912 | 0 |
| 10 | 0.98 | 0 | 0 | 0 | 20 | 7.27 | 2 | 36 | 0.000455 | 0.00118 | 0 |
| 11 | 0.98 | 0 | 0 | 0 | 20 | 7.24 | 3 | 4 | 0.00456384 | 0.0242454 | 0 |
| 12 | 0.99 | 0 | 0 | 0 | 26 | 8.52 | 3 | 8 | 0.0352625 | 0.09145 | 0 |
| 13 | 1 | 0 | 0 | 0 | 20 | 6.57 | 3 | 17 | 0.00864045 | 0.0224082 | 0 |
| 14 | 1.03 | 0 | 0 | 0 | 14 | 4.61 | 3 | 35 | 0.000455 | 0.00118 | 0 |
| 15 | 0.98 | 0 | 0 | 0 | 40 | 11.68 | 4 | 28 | 0.01630064 | 0.0865972 | 0 |
| 16 | 0.98 | 0 | 0 | 0 | 20 | 5.82 | 4 | 9 | 0.0186732 | 0.0484272 | 0 |
| 17 | 1 | 0 | 0 | 0 | 35 | 12.69 | 4 | 12 | 0.05027295 | 0.1303782 | 0 |
| 18 | 1 | 0 | 0 | 0 | 25 | 9.87 | 4 | 13 | 0.03069976 | 0.079617 | 0 |
| 19 | 0.98 | 0 | 0 | 0 | 30 | 7.53 | 4 | 17 | 0.0142506 | 0.0369576 | 0 |
| 20 | 0.98 | 0 | 0 | 0 | 40 | 10.04 | 4 | 19 | 0.03586401 | 0.09301 | 0 |
| 21 | 1 | 0 | 0 | 0 | 42 | 16.6 | 4 | 34 | 0.000455 | 0.00118 | 0 |
| 22 | 1 | 0 | 0 | 0 | 80 | 31.64 | 5 | 15 | 0.00728 | 0.01888 | 0 |
| 23 | 0.99 | 0 | 0 | 0 | 85 | 33.6 | 6 | 31 | 0.00738848 | 0.0392513 | 0 |
| 24 | 0.98 | 0 | 0 | 0 | 29 | 7.28 | 6 | 21 | 0.0219583 | 0.0569468 | 0 |
| 25 | 1 | 0 | 0 | 0 | 20 | 4.98 | 6 | 23 | 0.0219583 | 0.0569468 | 0 |
| 26 | 0.99 | 0 | 0 | 0 | 35 | 8.76 | 6 | 24 | 0.0281372 | 0.0729712 | 0 |
| 27 | 1 | 0 | 0 | 0 | 30 | 7.53 | 6 | 37 | 0.000455 | 0.00118 | 0 |
| 28 | 1 | 0 | 300 | 0 | 0 | 0 | 8 | 9 | 0.175266 | 0.0454536 | 0 |
| 29 | 1.02 | 0 | 0 | 0 | 0 | 0 | 8 | 10 | 0.0219947 | 0.0570412 | 0 |
| 30 | 0.98 | 0 | 0 | 0 | 35 | 8.76 | 8 | 11 | 0.053235 | 0.13806 | 0 |
| 31 | 1.02 | 0 | 0 | 0 | 0 | 0 | 12 | 14 | 0.0344799 | 0.0894204 | 0 |
| 32 | 0.98 | 0 | 0 | 0 | 25 | 6.25 | 15 | 16 | 0.02548 | 0.06608 | 0 |
| 33 | 1 | 0 | 0 | 0 | 35 | 8.76 | 18 | 20 | 0.02002 | 0.05192 | 0 |
| 34 | 1 | 0 | 0 | 0 | 42 | 13.8 | 19 | 20 | 0.02928289 | 0.0759424 | 0 |
| 35 | 1 | 0 | 0 | 0 | 25 | 9.09 | 20 | 24 | 0.0228046 | 0.0591416 | 0 |
| 36 | 1 | 0 | 0 | 0 | 50 | 19.75 | 20 | 25 | 0.0154245 | 0.040002 | 0 |
| 37 | 1 | 0 | 0 | 0 | 32 | 8.02 | 20 | 30 | 0.0250068 | 0.0648528 | 0 |
| | | | | | | | 22 | 23 | 0.00455 | 0.0118 | 0 |

Table 2 Cost of generation and load (Rupee / hr.) for real 37 bus system (continued)

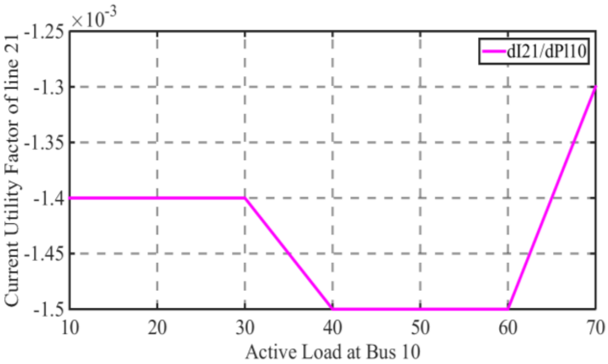
| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 24 | 31 | 0.0153517 | 0.0398132 | 0 |
| | | | | | | | 25 | 29 | 0.0336245 | 0.087202 | 0 |
| | | | | | | | 26 | 29 | 0.0104923 | 0.0272108 | 0 |
| | | | | | | | 27 | 29 | 0.0173628 | 0.0450288 | 0 |
| | | | | | | | 28 | 29 | 0.00668 | 0.0354875 | 0 |
| | | | | | | | 29 | 31 | 0.0079472 | 0.0422195 | 0 |
| | | | | | | | 29 | 33 | 0.000455 | 0.00118 | 0 |
| | | | | | | | 30 | 32 | 0.042345868 | 0.1098533 | 0 |
| | | | | | | | 30 | 31 | 0.00637 | 0.01652 | 0 |

### *4.1. Non-linear nature of sensitivity indices*

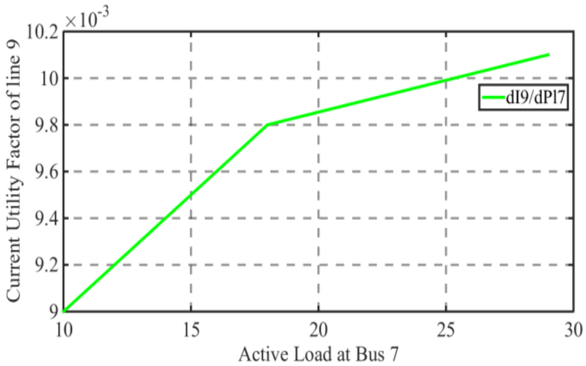
Load flow is being used either for transmission network or EHV network to obtain equal sensitivities and unequal sensitivities. An inequality in curve nature is depending upon magnitude. Whereas, magnitude depending on the choice of slack bus, location of generator bus and transmission line.During load flow, any bus can be assigned as a slack bus. Load flow neglects longitudinal resistance, the conductance of network elements, reactive power flow and considers all voltages equal to unity. In result, the magnitude of injection/withdrawal variation at any generation bus directly influences loss compensation. Lines connected to the slack bus would have different flow variations and lines away from the slack bus would have less impact. The equivalent feature is narrated in Rudnick's method [4]. The evaluation of the total impact of injection/withdrawal of electrical power is independent for each bus. Amount of allocation depends on currency cost impact. At bus payments are made by the utility to participants, reflecting the proposed technique identifies the negative EU due to reactive demand.



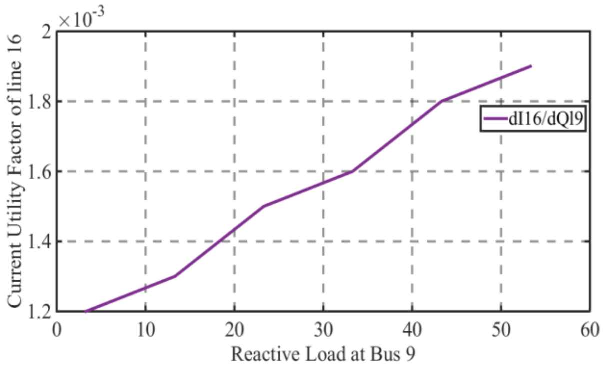

(a) Non Linear CUPF$^t_{1g1}$ for 37 bus system




(b) Non Linear CUPF$^t_{21d10}$ for 37 bus system




(c) Non Linear CUPFt9d7 for 37 bus system




(d) Non Linear CUQFt16d9 for 37 bus system

Fig. 4 Nonlinear CUPF curve of generation and load in 37 bus system

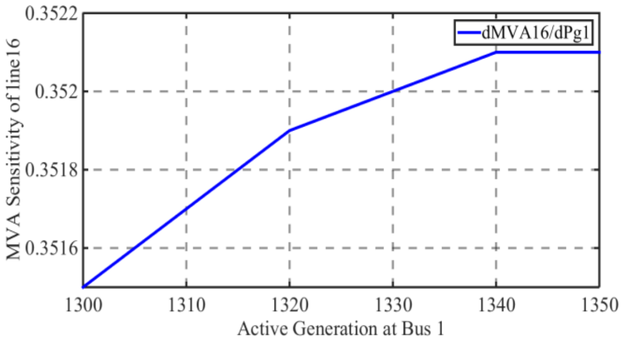
Fig. 4(a-d) shows the nonlinear sensitivity behavior curves for modified Amp-Mile method. The real or reactive MVA sensitivities would not be identical at generator buses. It exhibits nonlinear nature of sensitivities depending upon location and topological conditions. Fig. 4(a-d) shows the nonlinear sensitivity curves for MVA utility factor method. The estimation and recognition pattern for MVAUF's of non-linear lines with respect to different injections/withdrawals at each bus is obtained with the help of the NR algorithm. Moreover, allocated charges would not radically be stable over differing load level due to non-linear sensitivities. Patterns of sensitivities assessed for variation of P and Q at all buses for different loading by employing load flow analysis. The sensitivity patterns have many advantages for a deregulated market.

(a) Provide price signals for the future generation/demand expansion.

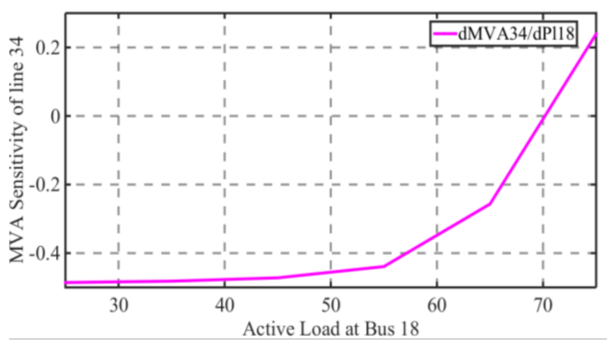
(b) Forecast transmission pricing, if used along with EU values.

(c) Congestion anticipation and used to manage congestion either by curtailing the demand.

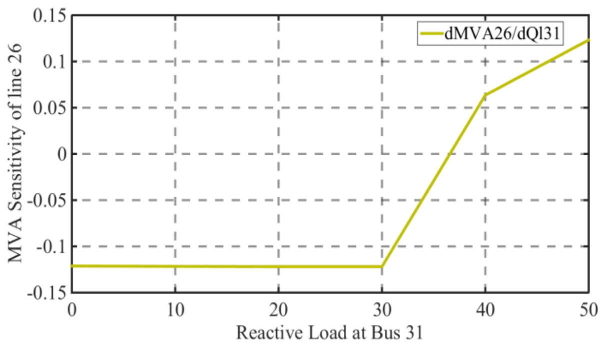
(d) Assist ISO to carry out the day ahead scheduling in the deregulated electricity market.



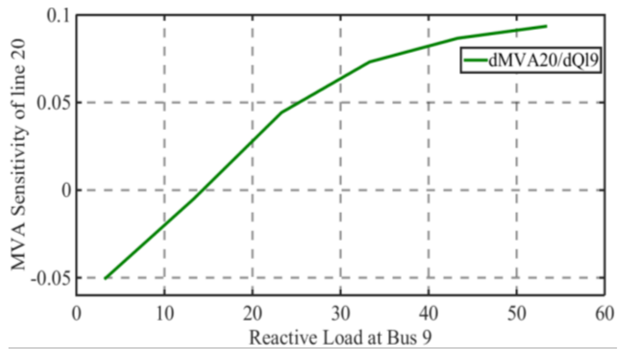

(a) Non Linear MVAPUFt16g1 for 37 bus system




(b) Non Linear CUPFt21d10 for 37 bus system




(c) Non-Linear CUPFt9d7 for 37 bus system




(d) Non-Linear CUQFt16d9 for 37 bus system

Fig. 5 Nonlinear MVAPUF curve of generation and load in 37 bus system

### *4.2. Cost allocation andcost curve*

Evaluate the total cost in Rupee/hr by using mathematical operation of both the proposed methods. For IEEE 6 bus standard system, comparison of the proposed model (Partial Recovery Model and Full Recovery Model) has been brought down. Cost Allocated (CA), Remaining Charge (RC), and Embedded Cost (EC) are to be compared for at all buses by employing different techniques. Table 3 shows the comparison of all the costs including RC and % EC of each bus.

By observing Table 3, execution of the MVA Utility Factor method causes a striking reduction in cost allocated to Bus 1 (slack bus), as positive payments by all other methods are turning to negative payments. Likewise, cost allocation is negative to Bus 5 load and positive to the first generator in Amp-Mile method. It shows reflecting payments are made by transmission utility to load and recovered from generators, which seems unjustified. This problem gets resolved through proposed MVA Utility Factor method using either Partial Recovery model or Full Recovery model. Realization of proposed modified Amp-Mile and MVA utility factor method proved to be superior over MW-Mile method, MVA-Mile method, and Amp-Mile method. Its advantages like FRM of EHV networks contrasting Amp-Mile tackles reactive power unlike MW-Mile and anticipates the direction of reactive power not like MVA-Mile. The cost to be allocated in modified Amp-Mile and MVA utility factor method is assumed proportional to the length of transmission lines in Rupee/hr. In IEEE 6 bus system the total cost evaluated in modified Amp-Mile and MVA utility factor methods in FRM condition is 5435 Rupee/hr. Whereas, In PRM condition, MVA utility factor allocated cost is 948.137 Rupee/hr. It has been observed from Table 2, that 100% cost is assigned as cost allocated or zero amount as remaining charges in modified Amp-Mile and MVA Utility Factor method (FRM only). All the other existing methods along with proposed MVA Utility Factor method (PRM) have a significant amount as remaining charges. Hence, these methods do not allocate 100% embedded cost. The negative sign represent the return cost given by the transmission company.

Table 3 Comparison of cost allocation in IEEE 6-bus system by different methodologies under 100% loading

| Bus No. | MW-Mile (Rupee/hr.) | MVA-Mile (Rupee/hr.) | Amp- Mile (Rupee/hr.) | Amp-Mile (LF) (Rupee/hr.) | Modified Amp-Mile (Rupee/hr.) | MVA UF Method (PRM) (Rupee/hr.) | MVA UF Method (FRM) (Rupee/hr.) |
|---|---|---|---|---|---|---|---|
| Bus 1 | 281.5 | 27.1 | 239.31 | 206.0269 | 1001.3 | -119.75 | -286.9 |
| Bus 2 | 145.8 | 227.9 | 19.65 | -99.7790 | -485.1 | 66.96 | 69.1 |
| Bus 3 | 350.0 | 487.2 | 116.36 | -152.8764 | -1050.8 | 133.47 | 814.7 |
| Bus 4 | 254.7 | 411.7 | 100.47 | 253.0793 | -103.1 | 220.202 | 664.0 |
| Bus 5 | 588.8 | 592.9 | -13.13 | 440.9396 | 4519.0 | 388.798 | 3024.7 |
| Bus 6 | 553.7 | 400.3 | 2.04 | 271.1701 | 1553.6 | 258.456 | 1149.4 |
| CA | 2174.5 | 2146.6 | 462.67 | 918.5604 | 5435 | 948.137 | 5435 |
| RC | 3260.5 | 3288.4 | 4972.33 | 4516.4396 | 0 | 4486.86 | 0 |
| %EC | 40 | 39.5 | 8.51 | 16.90 | 100 | 17.45 | 100 |

The locational and remaining charges allocation at different loadings has been estimated using diverse cost allocation techniques. The evaluated cost allocated under the different percentage of Base Case (BC) loading conditions by different methodologies is shown in Table 4. It has been observed that the cost allocation by employing Modified Amp-Mile method is constant for all loading conditions. The percentage embedded cost is 100% are zero remaining charges are allocated in modified Amp-Mile method irrespective of loading of the system. Hence, Modified Amp-Mile method is seen to be the most excellent method for full recovery modal only, under each loading condition. Before evaluating the cost of the system, check the degree of congestion at BC loading specifically for overloading, to keep the system secured.

Table 4 Embedded cost (Rupee/hr.) allocation in IEEE 6-bus system by different methods at different % loading

| Loadings \ Methods | 50% | 75% | 100% | 125% | 150% |
|---|---|---|---|---|---|
| MW-Mile | 1488.6 | 1860.6 | 2174.5 | 3045.2 | 2980.0 |
| Rem. Cost (MW) | 3946.4 | 3574.4 | 3260.5 | 2389.8 | 2455 |
| MVA-Mile | 1288.8 | 1672.6 | 2146.6 | 4100.3 | 3371.6 |
| Rem. cost (MVA) | 4146.2 | 3762.4 | 3288.4 | 1334.7 | 2063.4 |
| Amp-Mile (Base) | 190.153 | 252.19 | 462.67 | 713.08 | 1107.6 |
| Rem. Cost(I-Mile) | 5244.8 | 5182.8 | 4972.33 | 4721.9 | 4327.4 |
| Amp-Mile(LF) | 882.8 | 847.6 | 918.56 | 1098.9 | 1264.1 |
| Rem. Cost (Amp-Mile(LF)) | 4552.2 | 4587.4 | 4516.44 | 4336.1 | 4170.9 |
| Mod. Amp-Mile | 5435.0 | 5435.0 | 5435.0 | 5435.0 | 5435.0 |
| Rem. cost (Mod. Amp-Mile) | 0 | 0 | 0 | 0 | 0 |

Any generator bus can be assigned as a slack bus for estimation of cost and to find CUF's. Consider another generator bus as the new slack bus and then cost allocation associated withthe new slack bus has been evaluated. All the costs, CA, RC, and %EC has been evaluated for the new slack bus by employing different methodologies and compare the results as shown in Table 5.

The utilities have a different region with significant local load and generation. The injection in a given region may cause an increment in the circuit flows all around the country. Resulting tariffs are sometimes nonspontaneous with generators that are close to load centers in a given region receives high tariffs. Therefore the currency cost impact of the different slack bus by implementing distinct slack bus notion is used. Results for depiction on the IEEE 6 bus system are given in Table 4 at Base Case (BC) loading.

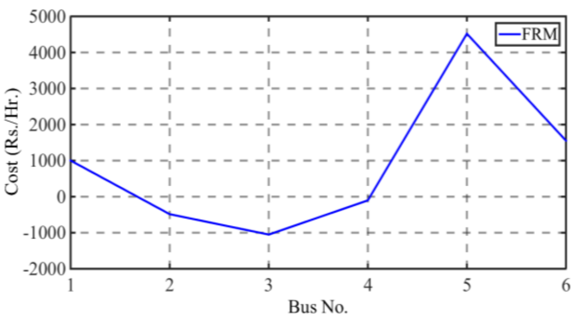
Embedded cost is evaluated using modified Amp-Mile and MVA utility factor method for 37 bus system in a similar manner employed in IEEE 6 bus system. FRM costs were evaluated using both the above method are shown in Table 6 (a) and

Table 6(c). Whereas, PRM costs are shown in Table 4 (b) for MVA utility factor method only. Table 4 illustrates the generation and load cost allocates at different buses for active and reactive power. The allocations by FRM at all busses are given in Table 6(a) and (c).

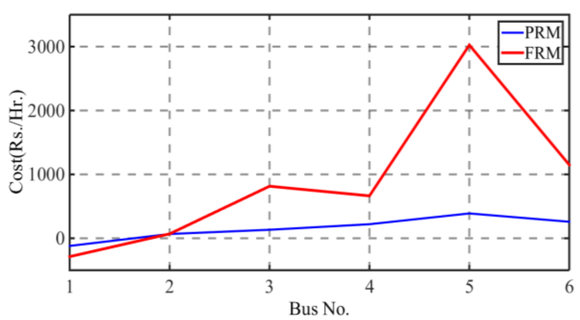
Table 5 Cost impact (Rupee/ hr) of the new slack bus at 100% base

| Bus No. | Amp-Mile (LF) Slack Bus -Bus1 | Mod. Amp-Mile Slack Bus-Bus1 | Amp-Mile(LF) Slack Bus –Bus 2 | Mod. Amp-Mile Slack Bus –Bus 2 |
|---|---|---|---|---|
| Bus 1 | 206.0269 | 1001.3 | 60.4148 | 360.1 |
| Bus 2 | -99.7790 | -485.1 | 234.5645 | 1042.3 |
| Bus 3 | -152.8764 | -1050.8 | -87.6418 | -2317.3 |
| Bus 4 | 253.0793 | -103.1 | 144.6832 | -272.8 |
| Bus 5 | 440.9396 | 4519.0 | 344.1372 | 4615.5 |
| Bus 6 | 271.1701 | 1553.6 | 157.5987 | 2007.2 |
| CA | 918.5604 | 5435 | 853.7567 | 5435 |
| RC | 4516.4396 | 0 | 3727.4866 | 0 |
| %EC | 16.90 | 100 | 15.71 | 100 |

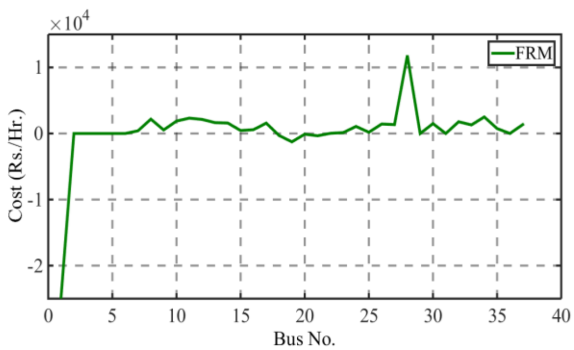
It has been observed that the payments are made by transmission utility to participants due to the counter flow of power. In 37 bus system, the total cost evaluated is 13699 Rupee /hr. in Modified Amp-Mile and MVA Utility Factor methods (FRM condition only.) Whereas, In PRM condition, MVA utility factor allocated cost is12699 Rupee/Hr. In Table 6 real 37 bus system FRM model are recover the full Allocation Cost (AC) in both the technique. This result analysis represents the beneficial effect of the proposed work. The remaining charges are also calculated by the postage stamp method. Compare the remaining charges cost in IEEE 6 bus and real 37 bus system. The low remaining charges in real 37 bus test system are showing the good stability in pricingwheeling market. That is more beneficial for generators and consumer in the electrical energy market (real-world strategies).



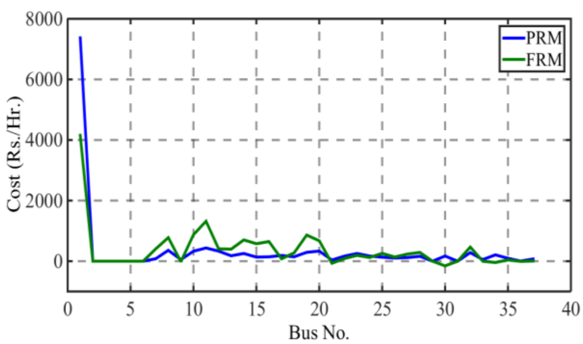

(a) Modified Amp-Mile cost curve using FRM in 6 bus system




(b) MVA utility factor cost curve using PRM & FRM in 6 bus system




(c) Modified Amp-Mile cost curve using FRM in 37 bus system




(d) MVA utility factor cost curve using PRM & FRM in 37 bus system

Fig. 6 PRM and FRM Cost Curves of MVA Utility Factor Methods

Table 6 Cost of generation and load (Rupee / hr.) for real 37 bus system

| (a)Modified Amp-Mile Cost (FRM) | | | | (b) MVA Utility Factor Cost(PRM) | | | | (c) MVA Utility Factor Cost (FRM) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bus No. | Active Load | Active Gen | Reactive Load | Bus No. | Active Load | Active Gen | Reactive Load | Bus No. | Active Load | Active Gen | Reactive Load |
| 1 | 0 | -24761 | 0 | 1 | 0 | 7371 | 0 | 1 | 0 | 4155 | 0 |
| 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 4 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 5 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 6 | 0 | 0 | 0 |
| 7 | 306.5 | 0 | 102.1 | 7 | 69.996 | 0 | 10.63 | 7 | 352.1 | 0 | 53.52 |
| 8 | 1832.8 | 0 | 339.4 | 8 | 311.17 | 0 | 48.64 | 8 | 674.9 | 0 | 103.3 |
| 9 | 495.7 | 0 | 39.2 | 9 | 48.233 | 0 | 5.087 | 9 | -6 | 0 | -8.438 |
| 10 | 1570.8 | 0 | 308.8 | 10 | 285.67 | 0 | 42.96 | 10 | 763.2 | 0 | 110.2 |
| 11 | 1929.3 | 0 | 397.1 | 11 | 380.01 | 0 | 56.01 | 11 | 1153.3 | 0 | 164.8 |
| 12 | 1892.2 | 0 | 236 | 12 | 294.2 | 0 | 37.56 | 12 | 359.9 | 0 | 45.51 |
| 13 | 1459.2 | 0 | 181.8 | 13 | 160.03 | 0 | 18.95 | 13 | 358.8 | 0 | 38.64 |
| 14 | 1372.9 | 0 | 210.7 | 14 | 226.81 | 0 | 27.36 | 14 | 632.1 | 0 | 70.26 |
| 15 | 404.9 | 0 | 46.7 | 15 | 124.06 | 0 | 10.79 | 15 | 529.7 | 0 | 46.38 |
| 16 | 507.9 | 0 | 70.7 | 16 | 132.13 | 0 | 11.11 | 16 | 597.2 | 0 | 50.32 |
| 17 | 1413.5 | 0 | 157.8 | 17 | 159.57 | 0 | 29.63 | 17 | 56.7 | 0 | 22.32 |
| 18 | -272.2 | 0 | -31.5 | 18 | 127.24 | 0 | 17.02 | 18 | 237.7 | 0 | 37.08 |
| 19 | -1100.4 | 0 | -165.4 | 19 | 270.3 | 0 | 22.51 | 19 | 797.9 | 0 | 64.66 |
| 20 | -52.1 | 0 | -51.6 | 20 | 311.26 | 0 | 22.83 | 20 | 617.9 | 0 | 54.82 |
| 21 | -326.2 | 0 | -17.3 | 21 | 34.024 | 0 | 3.751 | 21 | -56.1 | 0 | -11.68 |
| 22 | 37 | 0 | -11.5 | 22 | 132.65 | 0 | 34.6 | 22 | 59.7 | 0 | 28.67 |
| 23 | 209.8 | 0 | -74.8 | 23 | 203.7 | 0 | 51.1 | 23 | 142.4 | 0 | 48.96 |
| 24 | 997 | 0 | 74.2 | 24 | 160.32 | 0 | 9.624 | 24 | 121.6 | 0 | 1.48 |
| 25 | 202.8 | 0 | -14.9 | 25 | 122.56 | 0 | 9.513 | 25 | 238.3 | 0 | 19.57 |
| 26 | 1384.6 | 0 | 49.9 | 26 | 95.874 | 0 | 8.288 | 26 | 130.1 | 0 | 7.14 |
| 27 | 1290.4 | 0 | 54.1 | 27 | 110.22 | 0 | 8.769 | 27 | 221.2 | 0 | 12.6 |
| 28 | 0 | 11822 | 0 | 28 | 0 | 162.1 | 0 | 28 | 0 | 289.1 | 0 |
| 29 | 0 | 0 | 0 | 29 | 0 | 0 | 0 | 29 | 0 | 0 | 0 |
| 30 | 1441.2 | 0 | 54.3 | 30 | 161.64 | 0 | 8.622 | 30 | -119.7 | 0 | -35.27 |
| 31 | 0 | 0 | 0 | 31 | 0 | 0 | 0 | 31 | 0 | 0 | 0 |
| 32 | 1623.4 | 0 | 154.4 | 32 | 267.23 | 0 | 16.05 | 32 | 457.1 | 0 | 10.19 |
| 33 | 1252.2 | 0 | 45.4 | 33 | 47.783 | 0 | 5.438 | 33 | -1.6 | 0 | -0.64 |
| 34 | 2253.4 | 0 | 253.3 | 34 | 189.05 | 0 | 21.16 | 34 | -38.8 | 0 | -4.04 |
| 35 | 656.5 | 0 | 93.1 | 35 | 79.808 | 0 | 15.34 | 35 | 30.3 | 0 | 11.71 |
| 36 | 1.4 | 0 | 1.1 | 36 | 4.022 | 0 | 0.582 | 36 | -4.9 | 0 | -0.71 |
| 37 | 14.6 | 0 | 1336 | 37 | 71.246 | 0 | 1.159 | 37 | 14.6 | 0 | -9 |
| Total Cost | 22799.1 | -12939 | 3839 | Total Cost | 4580.8 | 7533.1 | 555.1 | Total Cost | 8321.6 | 4445 | 933.3 |
| CA | | 13699 | | CA | 12669 | | | CA | 13699 | | |
| RC | | 0 | | RC | 1030 | | | RC | 0 | | |
| %EC | | 100 | | %EC | 92.48 | | | %EC | 100 | | |

Fig. 6 show cost curve nature of PRM and FRM for MVA utility factor method, whereas, only FRM for Modified Amp-Mile method. Fig. 6(a) and (b) are drawn by using data of Table 3, whereas, Fig. 6(c) and (d) are drawn by using data of Table 6.

The price instability significantly affects the results of both the proposed methods. Fundamentally Modified Amp-Mile and MVA Utility method shows different characteristics with the fluctuations in demand. Therefore, transmission price and demand are the essential characteristics for the estimation of cost allocation. Variations in the curve are depending on the magnitude. Proposed methodologies are fair, accurate and feasible for estimation of cost if the cost allocation is prepared as per the demand. MVA utility factor technique is simple in application and provides price signals. The dissimilarity in the cost curve shown in Fig. 6(b) is due to PRM allocation is 17.45% of the entire embedded cost and remaining 82.55% allocate through supplementary charges, whereas, FRM allocated 100% embedded cost for both the methods. Similarly, in Fig. 6(d), FRM allocates 100% embedded cost, but PRM allocates 92.48% of the entire embedded cost. In PRM energies due to the amount of allocation in both the models depends on circuit capacity. The decrement proportionality is with Used Circuit

Capacity (UCC), which is always less than unity. Hence, the quality of decrement may cause a disparity in the sign of allocation of both the model as shown in Fig. 6.

In results, current utility factor and EU's are also used in both techniques. Implementation of this technique proved to be superior over MW-Mile and MVA-mile method along with full recovery. Table 7 shows the current utility factor and EU's of reactive power, reflecting the direction of reactive power. Through cost allocation by these existing methods appear to be uniform but due to mentioned limitations well through-out to be inexcusable.

Table 7 Current Utility Factors and EU's for Reactive Load at bus 34 of 37 Bus System

| Line No. | $\partial I_l/\partial Q_{d34}$ | Extent of use of Load 34 | Line No. | $\partial I_l/\partial Q_{d34}$ | Extent of use of Load 34 | Line No. | $\partial I_l/\partial Q_{d34}$ | Extent of use of Load 34 |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.0006 | 0.0020 | 17 | -0.0001 | -0.0046 | 33 | 0.0000 | 0.0000 |
| 2 | 0.0000 | 0.0000 | 18 | 0.0002 | 0.0052 | 34 | 0.0002 | 0.0219 |
| 3 | 0.0027 | 0.0332 | 19 | 0.0001 | 0.0057 | 35 | 0.0008 | 0.0524 |
| 4 | 0.0002 | 0.0040 | 20 | -0.0009 | 0.0167 | 36 | 0.0003 | -0.0481 |
| 5 | 0.0000 | 0.0000 | 21 | -0.0005 | 0.2119 | 37 | 0.0001 | -0.0009 |
| 6 | 0.0001 | 0.0027 | 22 | 0.0045 | 0.1239 | 38 | 0.0003 | -0.0385 |
| 7 | 0.0001 | 0.0013 | 23 | 0.0000 | 0.0000 | 39 | 0.0001 | 0.0025 |
| 8 | 0.0000 | 0.0000 | 24 | 0.0002 | 0.0871 | 40 | 0.0001 | -0.0021 |
| 9 | 0.0000 | 0.0000 | 25 | 0.0001 | 0.0124 | 41 | 0.0002 | -0.0023 |
| 10 | 0.0002 | 0.0076 | 26 | -0.0002 | 0.0049 | 42 | 0.0000 | 0.0000 |
| 11 | 0.0000 | 0.0000 | 27 | 0.0002 | 0.0163 | 43 | 0.0000 | 0.0000 |
| 12 | 0.0014 | 0.4823 | 28 | 0.0000 | 0.0000 | 44 | 0.0003 | -0.0009 |
| 13 | 0.0005 | 0.0108 | 29 | -0.0001 | -0.0090 | 45 | 0.0001 | -0.0003 |
| 14 | 0.0007 | 0.0381 | 30 | 0.0001 | 0.0051 | 46 | 0.0000 | 0.0000 |
| 15 | 0.0001 | 0..0047 | 31 | 0.0001 | 0.0050 | 47 | 0.0000 | 0.0000 |
| 16 | 0.0013 | -0.0053 | 32 | 0.0001 | 0.0076 | 48 | 0.0002 | 0.0042 |

By evaluating the non-linear curve, cost allocation, remaining charges, current utility factor, and EU's. Some important factors are originated. Both methods recover 100 embedded costs in a comparison to the existing method. When compare the IEEE 6-bus and 37-bus system in MVAPUF PRM model. The cost allocation value is 17.45% and 92.48 % respectively. Therefore 37-bus practical system cost allocation is more suitable as a comparison to the IEEE system. So both methodologies are reliable for the practical transmission network. The non-linear nature of curve is used to assessing true portrayal of operating condition load flow has followed to develop fair allocation. The sensitivity patterns can help ISO to forecast day-ahead transmission cost as well as plan for day-ahead setting up of open access electricity market.

## 5. Conclusions

In open access, electricity market allotment of embedded cost is one of the momentous facets. The two methodologies for allocation of the embedded cost of transmission network i.e. Modified Amp-Mile method and MVA Utility Factor method with two models: Full Recovery and Partial Recovery, has been employed in this paper.

- The proposed method exploits marginal participation in the load flow framework. The nonlinear sensitivities for the current utility of active and reactive powers have been discussed in this paper. The nonlinear sensitivities in power networks which are used to anticipate congestion and transmission price forecasting.
- Fair cost allocation in the presence of nonlinear sensitivities is solved by employing proposed Modified Amp-Mile methodology. It is implemented on prices and sensitivities with respect to injections/withdrawals of power in the modern electricity market.
- MVA Utility Method in two different modals i.e. FRM and PRM is employed for estimation of fair cost allocation. Non-linear sensitivities and distinct slack bus notion are promoted to allocate the partial or entire embedded cost of the transmission network.

- Results show that the wheeling charges for Modified Amp-Mile and MVA Utility Factor method have approached more close solutions to MW-Mile, MVA-Mile and Amp-Mile methods for the 6-bus and 37-bus test system.
- Comparison of other existing techniques for IEEE 6-bus system confirms the effectiveness of the proposed method. The impact of loading on cost allocation by different methods has also been discussed.
- Both methodologies also justify new distinct slack bus notion and negative payment to evaluate currency cost impact as choice of slackbus affects cost allocation.
- Proposed methods allocate 100% embedded cost and zero remaining charges. The outcomes of standard IEEE 6-bus and real-time 37-bus systems show the validity and efficacy of the proposed techniques.

## Conflicts of Interest

"The authors declare no conflict of interest."

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