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Modification in existing two part tariff structure incorporating the effect of locational marginal pricing for Indian utility system

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This paper proposes an approach for the modification in existing Two Part Tariff (TPT) structure incorporating the effect of Locational Marginal Pricing (LMP). LMP can represent economic signal for instant to instant variation of generation, transmission and load scenarios. Conventionally TPT consists of fixed and operating prices, obtained on annual basis. In this paper, it has been proposed to replace the operating price of TPT by LMP. LMP at various buses which represents the actual price of power delivery, can be obtained from the solution of AC optimal power flow. LMP value at any bus is added to fixed price to obtain the modified TPT structure at that bus. The load payments are obtained by utilizing modified TPT for an Indian utility 62-bus system, and the results are compared with and without considering loading and considering the effect of energy conservation. The simulated results show that huge benefit is obtained by modified TPT structure as compared to existing TPT structure in case when line loading and energy conservation are considered. Moreover with modified TPT structure costumers will be able to respond more accurately according to the prevailing electricity market scenarios.

Keywords: *AC optimal power flow, locational marginal pricing, two part tariff.*

1.0 INTRODUCTION

The evolution of power system from vertically integrated utility to the smart grid structure has brought numerous changes, benefits and challenges in its planning, operation, control and management. To extract the benefits of the smart grid concepts like demand response and demand side management, it is essential to implement an efficient and reliable dynamic tariff structure in the Indian electricity markets. The existing two part tariff structure is the sum of fixed cost and variable cost. In almost all the regions of India the existing Two Part Tariff structure (TPT) is implemented due to its advantages like it encourages the customers not to over declare their demands and provides a balanced approach for the recovery of cost due to the fixed cost paid [1]. On the other hand locational marginal pricing structure comprises of energy, losses and the transmission line congestion cost. In PJM market of US, Locational Marginal Pricing (LMP) method is used because of its merits like in this method price depends upon location and time of use. Moreover LMP based method is able to help the electricity market evolve into a more efficient one and the enhanced market efficiency will lead to social welfare for both generation companies and consumers. This method will also improve elasticity on the demand side to offer the customer with lower energy cost and provide the market with increased social welfare [2].

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Demand side management is one of the key tasks, which can be utilized to handle the demand-supply imbalances and maintaining security and reliability of power system [3]. It is very common to accomplish the demand response implementation in smart grid system using dynamic pricing structure [4-8]. LMP is a pricing scheme, which represents marginal cost of unit increment of power supplied at any location [9]. LMPs at various buses of power system are the by-products of the solution of optimal power flow problem and is widely used in electricity market settlement and congestion management [10,11].

The major portion of demand payments in a power system comes from the energy usage over a given period [12]. However, the impact of real time use of electricity is missimg in existing Indian TPT structure. Hence, the existing tariff structure, being static in nature, is unable to provide correct economic signal of power availability situation to the customers.

This paper proposes a modified TPT structure which includes the effect of real time price of electrical energy. In this proposed tariff structure, the unit operating price at any bus is taken as its LMP. In a power system, bus LMPs can be easily obtained by running ACOPF program. The modified TPT structure is obtained by adding the LMPs (variable prices) to fixed price. The modified TPT scheme is used to determine the load payments for the Indian utility system. The results are carried out while considering different cases, viz. with and without line loading and considering the effect of energy conservation. The simulation results obtained clearly indicates many benefits by making use of modified TPT structure in comparison to existing TPT structure. Moreover, consumers will be able to play their role more responsively when subjected to modified TPT structure for energy management system.

The rest of the paper is organized as follows: Section 2 presents the proposed modified TPT structure. Section 3 explains the ACOPF problem and Section 4 lists the procedure to obtain load payments using modified TPT. Section 5 presents the results of modified TPT and its comparison with existing TPT structure. Section 6 presents the conclusions of the paper.

2.0 MODIFIED TPT STRUCTURE

In the existing TPT structure, unit price of power generation is calculated on annual basis as:

$$unit\ price = \frac{Annual\ cost}{Annual\ energy\ generated} \qquad ...(1)$$

The annual cost used in equation (1) composed of annual cost of generation, transmission and distribution.

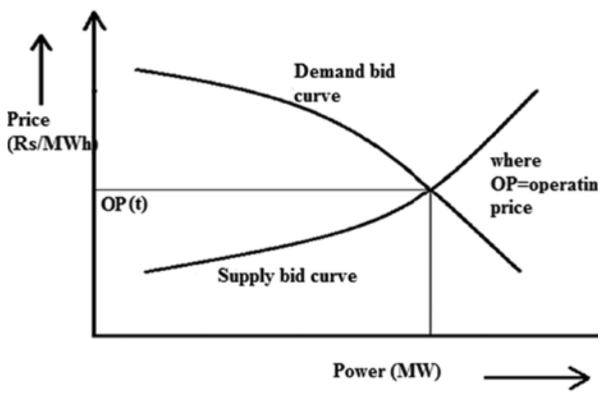

FIG.1 DEMAND AND SUPPLY BID CURVES

But in actual power system operation, the cost of generation, transmission and distribution and hence unit price, can vary from one instant to another [9]. In a deregulated power system operation, the schedule of power generation and consumption, and LMPs are obtained from the demand and supply bid curves. In particular, Figure 1 shows a case, when power system is free from transmission constraints, the intersection of demand and supply bid curves gives the LMP of electricity [13, 14].

Neglecting losses, The LMP values are same thougout the system in uncongested case. But if the effect of losses and transmission constraints is included, the LMPs can vary from one location to another [7,8,10,11]. In general, an AC optimal power flow problem can be solved to obtain the LMPs. As LMP is defined as marginal increase in cost of power at any bus with respect to the marginal increase in power withdrawn at that bus, it serves the purpose of OP in proposed modified TPT structure. Now the unit price (UP) of electricity at a particular instant t can be obtained by the sum of fixed price (FP) and OP(t), as shown in Figure 2.

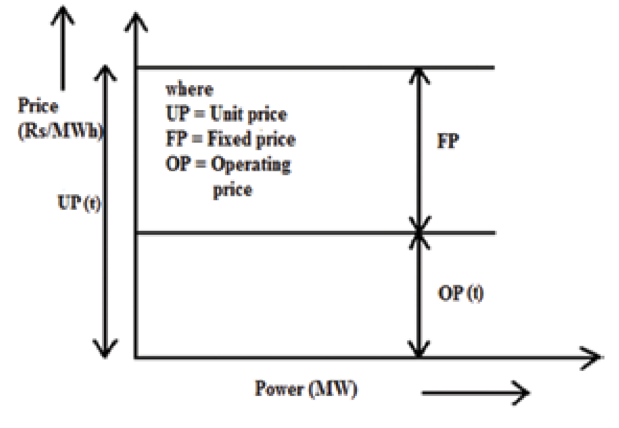

FIG.2 RELATION BETWEEN UP, FP AND OP

3.0 AC OPTIMAL POWER FLOW (ACOPF)

The ACOPF problem optimizes the flow of power in transmission system based on specified objective function, subject to the set of equality and inequality constraints. The objective function of this ACOPF can be maximization of social welfare or minimization of generation cost. In this paper, generation cost as obtained from supply bids of generator companies is used as the objective function to be minimized. The mathematical formulation is given as follows:

$$Minimize\ \sum_{l=1}^{N_G} C_l\,(P_l) \qquad \text{...(2)}$$

Where, is the total number of generating units, is the generation cost of the generating unit given as quadratic cost function and is obtained from the supply bids of generating unit.

$$C_l(P_l) = a_l.(P_{G_l})^2 + b_l.(P_{G_l}) + c_l \qquad \text{...(3)}$$

Where, and are the cost coefficients and is the amount of electricity generation of generating unit.

The power balance equation of all the buses for real and reactive power in the system are given by equations (4) and (5), respectively.

$$P_{Gl} - P_{Dl} = \sum_{j=1}^{N} V_l V_j Y_{lj} \cos(\delta_l - \delta_j - \theta_{lj}); \quad i = 1,2,...N \qquad \text{...(4)}$$

$$Q_{Gl} - Q_{Dl} = \sum_{j=1}^{N} V_l V_j Y_{lj} \sin(\delta_l - \delta_j - \theta_{lj}); \quad i = 1,2,...N \qquad \text{...(5)}$$

Where N is total number of system buses. The line flow limit of inequality constraints are represented by

$$-S_{ij}^{max} \le f_s(V,\delta) \le S_{ij}^{max}; l - j \in N_c \qquad \text{...(6)}$$

Where N_c is the set of congested lines.

The real and reactive power generation bounds are represented by equations (7) and (8), respectively. The bus voltage bounds are represented by equation (9).

$$P_{Gl}^{min} \le P_{Gl} \le P_{Gl}^{max}; l = 1,2,...Ng \qquad \text{...(7)}$$

$$Q_{Gl}^{min} \le Q_{Gl} \le Q_{Gl}^{max}; l = 1,2,...Ng \qquad \text{...(8)}$$

$$V_l^{min} \le V_l \le V_l^{max}; l = 1,2,...N \qquad \text{...(9)}$$

The ACOPF optimization problem for minimization of the objective function given by equation (2), subject to the $2N$ equality constraints (equations (4) and (5)), $2N_c$ inequality constraints (equation (6)) and (N+2*Ng) bounds on variables (equations (7)-(9)) can be solved using Lagrangian multiplier method.

$$\begin{aligned}
L = {} & \sum_{l=1}^{NG} C_l(P_l) + \\
& \sum_{l=1}^{N} \lambda_{pl}\left(\sum_{j=1}^{N} V_l V_j Y_{lj} \cos(\delta_l - \delta_j - \theta_{lj}) - P_{Gl} + P_{Dl}\right) + \\
& \sum_{l=1}^{N} \lambda_{ql}\left(\sum_{j=1}^{N} V_l V_j Y_{lj} \sin(\delta_l - \delta_j - \theta_{lj}) - Q_{Gl} + Q_{Dl}\right) + \\
& \sum_{l-j\in N_c} \mu_{lj}^{min}\left(-S_{ij}^{max} - f_s^{lj}\right) + \sum_{l-j\in N_c} \mu_{lj}^{max}\left(f_s^{lj} - S_{ij}^{max}\right) + \\
& \sum_{l=1}^{NG} \mu_{pl}^{min}(P_{Gl}^{min} - P_{Gl}) + \sum_{l=1}^{NG} \mu_{pl}^{max}(P_{Gl} - P_{Gl}^{min}) + \\
& \sum_{l=1}^{NG} \mu_{ql}^{min}(Q_{Gl}^{min} - Q_{Gl}) + \sum_{l=1}^{NG} \mu_{ql}^{max}(Q_{Gl} - Q_{Gl}^{min}) + \\
& \sum_{l=1}^{N} \mu_{vl}^{min}(V_l^{min} - V_l) + \sum_{l=1}^{N} \mu_{vl}^{max}(V_l - V_l^{min})
\end{aligned} \qquad \text{...(10)}$$

The Lagrangian function converts the constrained problem into unconstrained problem as given by equation (10). The first order Kuhn-tucker conditions employed to the Lagrangian function give the solution of ACOPF problem.

The symbols λ and μ used in equation (10) are Lagrangian multipliers vectors associated with equality constraints and inequality constraints respectively. In this paper, the solution of ACOPF problem is obtained by developing a case file of Indian utility 62-bus system and running "runopf.m" m-file of MATPOWER software package [15]. The λ values associated with real power constraints at various buses are nothing but the LMPs at these buses, and are readily obtained from the solution of ACOPF problem. The LMPs obtained at any bus can differ from one instant to another depending upon the demand and supply scenarios at these instant. In the modified TPT structure, The LMP at any ith bus and during any tth inverval is used to represent OP and is added to FP to obtain UP. In general, the algorithmic procedure used to obtain load payments using modified TPT, is given in Section 4.

4.0 ALGORITHMIC PROCEDURE

The following algorithmic procedure has been used to obtain load payments using proposed modified TPT:

Step 1: Take a suitable daily load profile (Pd(i,t), for i=1,2,…NL; t=1,2,…24). Where Pd(i,t) is power demand at i^{th} bus during t^{th} time. Scheduling interval $\Delta t = 1h$; total scheduling period is 24h.

Step 2: Run ACOPF for each scheduling interval and determine LMP(i,t) for t=1,2,…24; i=1,2,.. NL, where NL is number of load buses.

Step 3: Operating price is obtained as OP(i,t) = LMP(i,t) Rs./MWh for t=1,2,…24; i=1,2,..NL.

Step4: Consider a typical value of fixed price (FP). In this paper, the FP is taken as Rs. 1420/ MWh as per the calculations available in [16].

Step 5: The unit price is obtained as: UP(i,t) = FP + OP(i,t) Rs./MWh for t=1,2,…24; i=1,2,.. NL. It is clear from this step that UP(i,t) is location and time dependent, hence it becomes dynamic in nature. The plot of UP(i,t) in results and discussion (Section 5) also proves this fact.

Step 6: Payments from load buses for their power consumptions are obtained as: LP(i,t) = UP(i,t)* Pd(i,t) Rs./h, taking Pd(i,t) in MW.

Step 7: Total load payment (TLP(i)) from ith bus load for 24 h is given by:

$$\text{TLP(i)}= \sum_{t=1}^{24} LP(i,t) \text{ Rs.}$$

Step 8: Total load payment from all the load buses is obtained as:

$$\text{TTLP} = \sum_{i=1}^{NL} TLP(i) \text{ Rs.}$$

5.0 RESULTS AND DISCUSSION

The algorithmic procedure discussed in section 4 is simulated on Indian utility 62- bus system [17] for obtaining the load payments. The bus data, line data, generator data and rated load data of various buses of this system is available on the web-link given in [17]. Generally, the daily load of a system has morning peak and evening peak [18]. The load during day time and night time remains comparatively low. Hence, for obtaining the OP using modified TPT, a load profile as shown in Figure 3 is considered, which consists of four intervals:

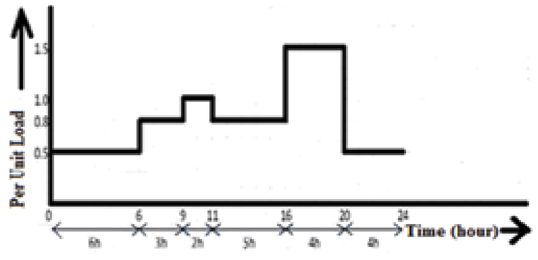

FIG.3 LOAD PROFILE FOR 24 HOURS

1. Load is 0.5 times the rated load and time duration is 10 hours.
2. Load is 0.8 times the rated load and time duration is 8 hours.

3. Load is same as the rated load and time duration is 2 hours.
4. Load is 1.5 times the rated load and time duration is 4 hours.

In this paper, the simulation results are discussed with the aid of three Cases, viz. Case 1: Effect of line loadings not considered, Case 2: Transmission line loading capabilities are considered, and Case 3: Effect of transmission line loading capabilities and energy conservation is taken into account. These three Cases are used to investigate the effect of various scenarios of availability of generation and transmission capabilities and energy conservation on the load payments under the proposed modified TPT structure.

CASE 1: Effect of Line Loadings Not Considered

In this Case, the solution of ACOPF problem is obtained (as explained in Section 3) but without including inequality constraints gien by equation (6). The solution of ACOPF problem gives OP(i,t), which is added to FP to get (UP(i,t), i=1,2,…NL; t=1,2,…24) as explained in Step 5 of Section 4. The variation of UP in Rs./MWh with respect to load buses and time intervals is shown in Figure 4, which shows that the UP depends upon location of the bus as well as time interval of the day. Whereas the UP with existing TPT structure comes to be Rs. 1812.80/MWh and is independent of the bus location and time of day. The total load payments (TLP) for 24 hours obtained using modified TPT structure is shown in Figure 5.

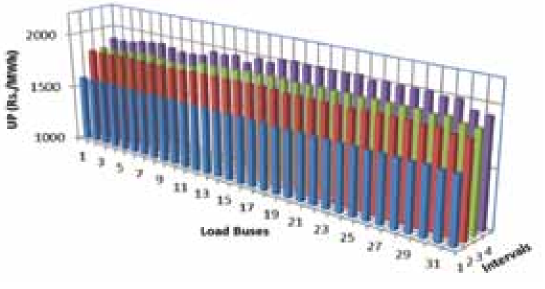

FIG. 4 VARIATION OF UP WITH RESPECT TO LOAD BUSES AND INTERVALS UNDER CASE 1

In this Case, TLP obtained from modified and exisiting TPT are similar. This Case has been primarily used to prove the fact that modified TPT structure is able to recover all the generation and transmission costs as that required under existing TPT structure.

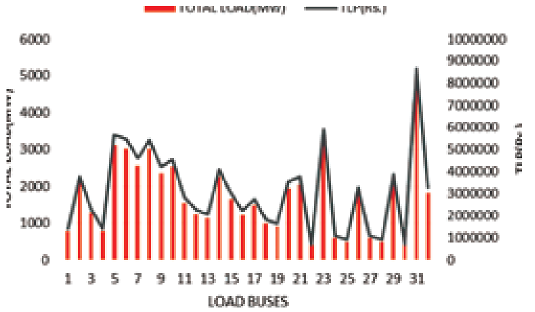

FIG.5 TLP FOR 24 HOURS IN CASE 1

CASE 2: Transmission Line Loading Capabilities are Considered

In this Case, the UP at certain buses becomes high, due to consideration of transmission congestion, as shown in Figure 6. The highest UP comes to be Rs. 8484.82/MWh at 24th bus during 4th interval. Whereas existing TPT gives UP of Rs. 2093.4/MWh uniform at all buses. The TLP obtained from laod buses with modified and existing TPT structures are shown in Figure s 7 and 8, respectively. It is clear from Figure 8 that load payments

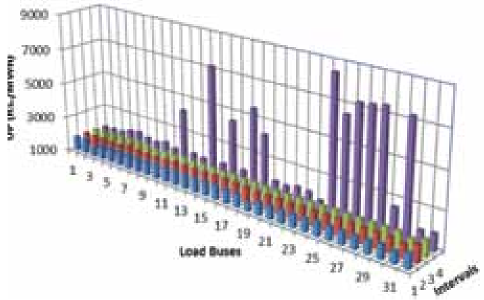

FIG.6 VARIATION OF UP WITH RESPECT TO LOAD BUSES AND INTERVALS UNDER CASE 2

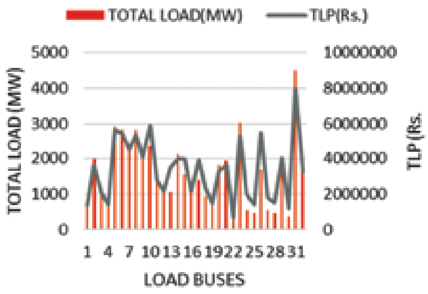

FIG.7 TLP FOR 24 HOURS IN CASE 2(MODIFIED TPT)

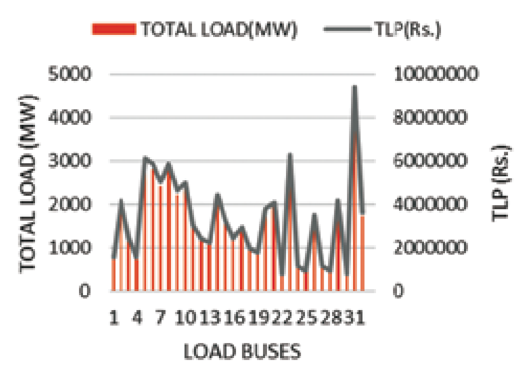

FIG.8 TLP FOR 24 HOURS IN CASE 2(EXISTING TPT)

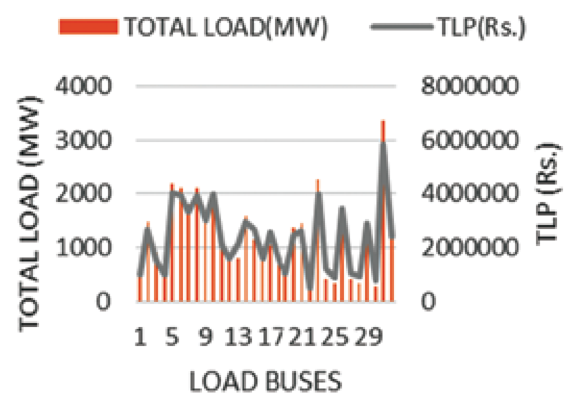

FIG.9 TLP FOR 24 HOURS IN CASE3 (MODIFIED TPT)

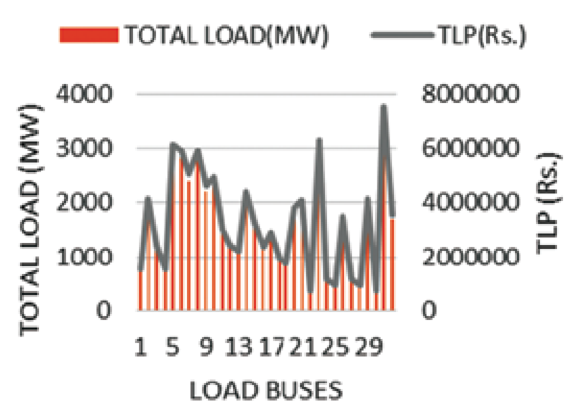

FIG.10 TLP FOR 24 HOURS IN CASE 3 (EXISTING TPT)

depends upon MW load and the fact that whether a particular bus lies within congestion zone or not. Whereas, existing TLP takes load payments irrespective of this fact. In existing system, load payments depends on fixed UP and MW load. The drawback of existing TPT is that all the buses have to bear the increased tariff due to the congestion at a few locations. On the other hand, in modified TPT, the effect of congestion predominantly effects those locations, which lies within congestion zone. This increases the accountability of the tariff structure. Moreover, this fact also helps in locating the buses which are highly useful for taking energy conservation measures.

CASE 3: Effect of transmission line loading capabilities and energy conservation is taken into account

In this Case, it has been assumed that demand takes energy conservation measure by reducing 20% of initial load. The TLP for 24 hours in modified and existing TPT are shown in Figure s 9 and 10, respectively. The load payment obtained by modified and existing TPTs are Rs. 7.5 crore and Rs. 10.5 crore, respectively. Hence energy conservation measures becomes more benefitial with modified TPT structure. Moreover, it also proves that savings in generation and transmission costs obtained by energy conservation are more accurately paased on to the demands in modified TPT method.

6.0 CONCLUSION AND FUTURE SCOPE

In this paper, the exisiting TPT structure has been modified to include the variable price, which is time and location dependent. Such a variable price, which accurately represents the marginal cost of generation and transmission has been obtained from the solution of ACOPF problem. The comparison of modified and exsiting TPT structure simulation on India utility 62-bus system proves the following points:

1. The proposed modified TPT structure gives UP, which is dynamic in nature. The UP varies with the bus location and time of day, hence the transparency of the tariff structure has been improved.

2. In case the system is free from transmission congestion and other constraints, similar load payments are obtained using modified and existing TPT. This Case has been primarily used to prove the fact that modified TPT structure is able to recover all the generation and transmission costs as that required under existing TPT structure.

3. Considering the effect of transmission line loading capability limits, price at certain buses which comes under the congestion zone, becomes high. Hence, only those buses (not all), which come under congestion zone, have to bear the increased tariff due to the congestion. This increases the accountability of the modified tariff structure.

4. With modified TPT method, it becomes easy to locate the buses, which are highly useful to take energy conservation measures. With modified TPT method, total load payment comes out to be 7.5 crore which is quite less in comparison to existing TPT method that is 10.5 crore.

This paper focuses on demand side payments and can be easily extended for generation side payments using proposed modified TPT structure.

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