

An Advanced Method of Congestion Management for Optimal Energy Pricing

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1. Introduction

As one of the electricity infrastructure, a robust power network is needed to support the sustainability of energy supply. Compared to other common customer goods, electric energy has some unique features that require specific consideration. Unlike most products, electricity cannot be stored in large amounts in an economical manner. Accordingly, electricity has to be simultaneously produced and distributed on demand. Transmission and distribution network systems are then used to deliver the power. The operating capability of generation, transmission and distribution systems must be adequate to meet the fluctuating demands of the customers. As illustrated in Figure 1, a simple configuration of an interconnected power system has basically three important parts, namely: generator as source of the electrical energy, transmission line for transmitting power to remote areas and the load which consumes the power.

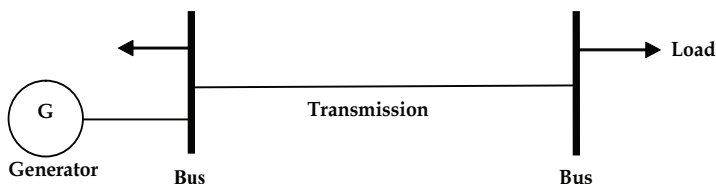


Fig. 1. A simplified interconnected power system

Tie lines are utilized to make interconnection of the transmission networks in order for utilities to either exchange power or share spinning reserves between one and another. A fundamental issue for an interconnection system as shown above is how to minimize the cost of production. Because the energy may come from different resources such as fossil fuel, gas, water, coal, tidal, geothermal, sun power and radioactive, the alternative option of one or the other is based on economic, technical or geographic points of view.

Hence an efficient, low-cost and reliable operation of a power system by adjusting the available electricity generation resources to supply demand of the system is needed to

ensure economic plant dispatching. The main idea of the importance of economic dispatch is to minimize the total cost of generation while meeting the operational constraints of the available generation resources. Economic dispatch is the process to allocate generation levels to the generating units in the mix, so that the system load may be supplied entirely and most economically (Chowdhury & Rahman, 1990). It is performed as an optimization problem in terms of minimizing the total fuel cost of all committed plant while satisfying both losses and demand. In addition, it determines a set of active power delivered by the committed generators to satisfy the required demand subject to the unit technical limits and at the lowest production cost at any time. Consequently, this problem should be solved as fast and precisely as possible.

Locational Marginal Prices (LMP) is the key factor to identify the spot price and to manage transmission congestion (Ristanovic & Waight, 2006; Sun, 2006). LMP methodology has been implemented or is under implementation at some independent system operators, for example: California ISO, PJM, New York ISO, ISO-New England, Midwest ISO, ERCOT, etc (Jun, 2006; Litvinov, 2006; Xie et al., 2006; Yong & Zuyi, 2006). Reference in (Gedra, 1999) gives a tutorial review of the use of optimal power flow approximation to calculate optimal locational prices and congestion costs.

Many researchers have proposed various methodologies to assess locational marginal pricing under a competitive market. Nevertheless, the determination of energy price, and transmission cost seems to be rigid and are based on many assumptions such as: ignored network losses, power pool operation is carried out on one-sided bidding, and market price is cleared in separated calculation. Furthermore, transmission management is required to ensure sufficient control over producers and customers to maintain the security level of power system while maximising market efficiency.

Independent system operators (ISOs) usually observe the transactions and control the state of the system, take a part in handling the network congestion management (Stamtsis & Erlich, 2004; Lin et al., 2006). ISOs are being challenged to develop a set of regulations to control the security level of power systems and ensure they are at an acceptable level while keeping the efficiency of the power market high (Conejo et al., 2006; Xusheng et al., 2006). This implies that market operators should alleviate network congestion; maintain the security and efficiency of power system operation (Kumar et al., 2004) in order to ensure all market participants have the same rights to access a transmission system without any discrimination (Shirmohammadi et al., 1998). Congestion levels typically determine the security of a power system, which would have further consequences on market transaction and energy prices.

Market operators have been using the DC-OPF for dispatching power and clearing energy (Farmer et al., 1995; Hogan, 1998; Singh et al., 1998; Karaki et al., 2002; Niimura & Niu, 2002; Fonseca & Shrestha, 2004; Hamoud & Bradley, 2004; Dan et al., 2006) to determine the LMP due to its speed and robustness, particularly in market simulation and planning (Wu et al., 2004; Junjie & Tesfatsion, 2007; Li & Bo, 2007). Generally, the DC-OPF is used for security constrained economic dispatch and redispatch when controlling transmission congestion while maximising the economic power transfer capability of the transmission system without violating its constraints (Kafka, 1999; Yajing et al., 2006; Gomes & Saraiva, 2007; Rodrigues & Silva, 2007). However, DC-OPF does not consider the network losses. Consequently, when the DC-OPF is modified by incorporating the line losses, the linearity

and superposition features of the LMP model, which is advantageous for the simplicity, robustness and efficiency are no longer exist anymore due to the non-linear, quadratic relationship between line loss and line current.

Therefore the authors in this paper introduce schemes for incremental cost-based energy pricing model to deal with congestion including losses and transmission usage tariff, but simplify the method and have acceptable transparency so that it may correctly generate economic signal to the market participants. In this manuscript, a new scheme is presented to briefly review the main idea behind the LMP calculation, and further discuss the techniques used to incorporate transmission usage tariff into the model. This would be a comprehensive approach in which pricing of transmission service is implemented together with short-term nodal pricing or LMP, which represents energy price, network losses cost, and transmission congestion cost. Findings of this research are expected to be useful to support developing standard market design in transmission networks, which promotes economic efficiency, lowers delivered energy costs, maintains power system reliability and mitigates exercising market power.

2. Dispatch methodology

The rules of dispatch methodology must be robust, fair and transparent (Christie et al., 2000). It should also encourage load elasticity and mitigate the application of market power (Niimura & Niu, 2002). This is because congestion will influence all market participants and may allow suppliers or generators to exercise market power. This action usually occurs during the congestion period or peak load hours to gain more profits, which in turn results in an expensive price at the customer node. Furthermore, economic signals have to be generated in the dispatch process to ensure the sustainability and security of the electricity market. Transmission pricing as the output of dispatch should not only be transparent and stable, but also promote optimal transmission system development and be able to avoid being overinvested (Farmer et al., 1995; Yamin, et al., 2004; Kaymaz et al., 2007). For that reason, economic optimality should be conducted in the dispatch mechanisms. This means transmission pricing associated with network constraints is required to send the correct cost signal of service to generators, suppliers and customers to avoid cross subsidy among different nodes at different times of usage.

Shift factor (SF) methodology is employed in order to perform congestion-based nodal price model through optimal power flow approach. It is used with the intention to maintain the linearity and superposition features of the LMP model while still able to account for both congestion and losses cost (California-ISO, 2005). The shift factor helps to determine the power flow over a given transmission line from the source node (generation) to the sink node (load). It is characterized by four attributes, namely; a reference node, a particular node, a particular line with reference direction, and the value of the shift factor.

Shift factor values depend on network topology and line impedance. Once these two variables change, the value of shift factor will change as well. Basically, the shift factor can be formulated through three stages based on dc load flow network model approach:

- *Stage 1:* Making sensitivity equation of phase angles as the function of node injections.
- *Stage 2:* Making sensitivity equation of branch flows as a function of phase angles.
- *Stage 3:* Substitution the result of stage 1 into stage 2.

3. A new *LMP-TUT* model for optimal energy pricing

In the author's previous proposed dispatch model (Nappu et al., 2008), two schemes were introduced to formulate energy pricing for both neglecting and considering network losses. The first scheme ignores the losses, called *LMP-lossless*, while the second scheme which takes network losses into account is named as *LMP-loss*.

$$\text{LMP}_{\text{lossless}} = \text{EP} + \text{CR} \quad (1)$$

$$\text{LMP}_{\text{loss}} = \text{EP} + \text{CR} + \text{LC} \quad (2)$$

Dispatch model discussed in this paper encompasses energy price (EP), transmission congestion revenue (CR), and transmission losses cost (LC). Embedded cost in terms of transmission usage tariff is also added into this formulation. Basically, the model in this scheme is equal to *LMP-loss* model, namely it encompasses three components: energy price, transmission congestion revenue and transmission losses cost. However, an embedded cost, transmission usage tariff (TUT) is added in to this formula. In fact, market operators use different approaches to account for this tariff, such as: postage stamp rate method, contract path method, MW-mile method, unused transmission capacity method or counter-flow method (Perez-Arriaga et al., 1995; Shahidehpour et al., 2002; Shu & Gross, 2002).

So far, pricing for transmission services using such methods above are still separately accounted for from the energy market price calculation. With the intention of having efficient, transparent and effective pricing due to transmission network usage services, LMPs' model in this scheme is formulated to take into account a tariff for transmission usage and is referred to as *LMP-TUT* model. By incorporating this component, the scheme is expected to simplify the method and have acceptable transparency so that it may send an economic signal correctly to the market participants (Luonan et al., 2002; Fonseka & Shrestha, 2006).

Accordingly, the formula for this model will be:

$$\text{LMP}_{\text{TUT}} = \text{EP} + \text{CR} + \text{LC} + \text{TUT} \quad (3)$$

3.1 Objective function

Total transmission usage tariff is written as:

$$T_m(P_{Gi}) = \alpha_m \text{flow}_m \quad (4)$$

In this scheme, the objective function is to minimize the total social cost and transmission usage tariff to decide the power supply and required demand.

$$\text{Min} \sum_{m=1}^M T_m(P_{Gi}) + \sum_{i=1}^{n_G} C_i(P_{Gi}) - \sum_{j=1}^{n_D} B_j(P_{Dj}) \quad (5)$$

where:

- T_m : total transmission usage tariff (\$/h)
- α_m : transmission charge rate for line m (\$/MWh)
- flow_m : power flow on line m (MW)
- C_i : production cost function (\$/h)
- B_j : customer benefit function (\$/h)

Constraints

- Bus power balance with network power losses

$$\sum_i P_{Gi} - P_L(P_{Gi}) = \sum_j P_{Dj}$$

- Generator power output

$$P_{Gi}^{\min} \leq P_{Gi} \leq P_{Gi}^{\max}$$

- Active power demand

$$P_{Dj}^{\min} \leq P_{Dj} \leq P_{Dj}^{\max}$$

- Power transfer capability

$$flow_m^{\min} \leq flow_m \leq flow_m^{\max}$$

Thus, the Lagrange function may be formulated as:

$$\begin{aligned} L(P_{Dj}, P_{Gi}, \lambda_i, \mu_i) &= \sum_{m=1}^M T_m(P_{Gi}) + \sum_{i=1}^{n_G} C_i(P_{Gi}) - \sum_{j=1}^{n_D} B_j(P_{Dj}) + \lambda_i \left(\sum_j P_{Dj} - \sum_i P_{Gi} - P_L(P_{Gi}) \right) \\ &\quad - \sum_j \mu_{\min, Dj} (P_{Dj} - P_{Dj}^{\min}) + \sum_j \mu_{\max, Dj} (P_{Dj} - P_{Dj}^{\max}) \\ &\quad - \sum_i \mu_{\min, Gi} (P_{Gi} - P_{Gi}^{\min}) + \sum_i \mu_{\max, Gi} (P_{Gi} - P_{Gi}^{\max}) \\ &\quad - \sum_m \mu_{\min, flow, m} (flow_m - flow_m^{\min}) + \sum_m \mu_{\max, flow, m} (flow_m - flow_m^{\max}) \end{aligned} \tag{6}$$

After obtaining the first order optimal condition of Karush-Kuhn-Tucker, Locational Marginal Prices or LMPs for both suppliers and customers can be formulated as follows:

LMPs for suppliers

$$\begin{aligned} \rho_i &= \frac{\partial T_m(P_{Gi})}{\partial (P_{Gi})} + \frac{\partial C_i(P_{Gi})}{\partial (P_{Gi})} - \mu_{\min, Gi} + \mu_{\max, Gi} \\ &= \lambda \left\{ 1 - \sum_{i'=1}^I G_{Ln-i'} \left(\sum_{i \in I(i')} P_{Gi} - \sum_{j \in J(j')} P_{Dj} \right) \right\} + \sum_m \mu_{\min, flow, m} \cdot S_{m,n} \\ &\quad - \sum_m \mu_{\max, flow, m} \cdot S_{m,n} - \sum_m \alpha_m \frac{flow_m(P_{Gi})}{|flow_m(P_{Gi})|} \cdot S_{m,n} \end{aligned} \tag{7}$$

LMPs for customers

$$\begin{aligned} \rho_i &= \frac{\partial B_j(P_{Dj})}{\partial (P_{Dj})} - \mu_{\min, Dj} + \mu_{\max, Dj} \\ &= \lambda \left\{ 1 - \sum_{i'=1}^I G_{Ln-n'} \left(\sum_{i \in 1(i')} P_{Gi} - \sum_{j \in 1(j')} P_{Dj} \right) \right\} + \sum_m \mu_{\min, flow, m} \cdot S_{m, n} \\ &\quad - \sum_m \mu_{\max, flow, m} \cdot S_{m, n} - \sum_m \alpha_m \frac{flow_m(P_{Gi})}{|flow_m(P_{Gi})|} \cdot S_{m, n} \end{aligned} \quad (8)$$

Merchandizing surplus which contains congestion revenue, cost of losses and the transmission usage tariff will be:

$$MS = \lambda P_L(P_{Gi}) + \sum_m \mu_{\max, flow, m} \cdot flow_m - \sum_m \mu_{\min, flow, m} \cdot flow_m + \sum_m \alpha_m |flow_m(P_{Gi})| \quad (9)$$

3.2 Basic tasks of the improved method

The methodology of this research comprises several basic objectives and is divided into 5 tasks.

1. Identification of primary data
2. Assessment of branch power flow and branch loss
3. Modeling of LMP Schemes
4. Developing optimization tools
5. Examining the most efficient reference node

In order for the proposed method to obtain appropriate reference node and to perform the lowest overall cost, the following iteration process needs to be taken:

1. select any arbitrary node as reference prior to running simulation
2. choose particular node which performs the lowest nodal price, and
3. re-run the simulation after fixing that node as the reference node.

3.3 Conceptual flowchart of the schemes

In a brief snapshot, problem identification represents the basic tasks is illustrated in Figure 2, which figures out all the basic objectives described in this section.

4. Results and analysis

4.1 Implementation of the proposed methodology

The LMP models formulated in Section 3 are implemented in software. An optimization tool has been successfully developed through MATLAB technical programming. The tool for assessing LMP using optimal power flow based on *shift factor* methodology, SF-OPF, covers all the schemes. In addition, another optimization tool using conventional DC optimal power flow methodology is also created.

Since the perspective of employing this approach was originally only appropriate to the *LMP-lossless*, then it should be modified in such a way so that it suits with the *LMP-loss* and *LMP-TUT* schemes as well. The main intention of making this second tool is to validate the

results of the proposed method, the SF-OPF. By running the tools, their outputs are evaluated and compared to each other with the aim of finding the best results.

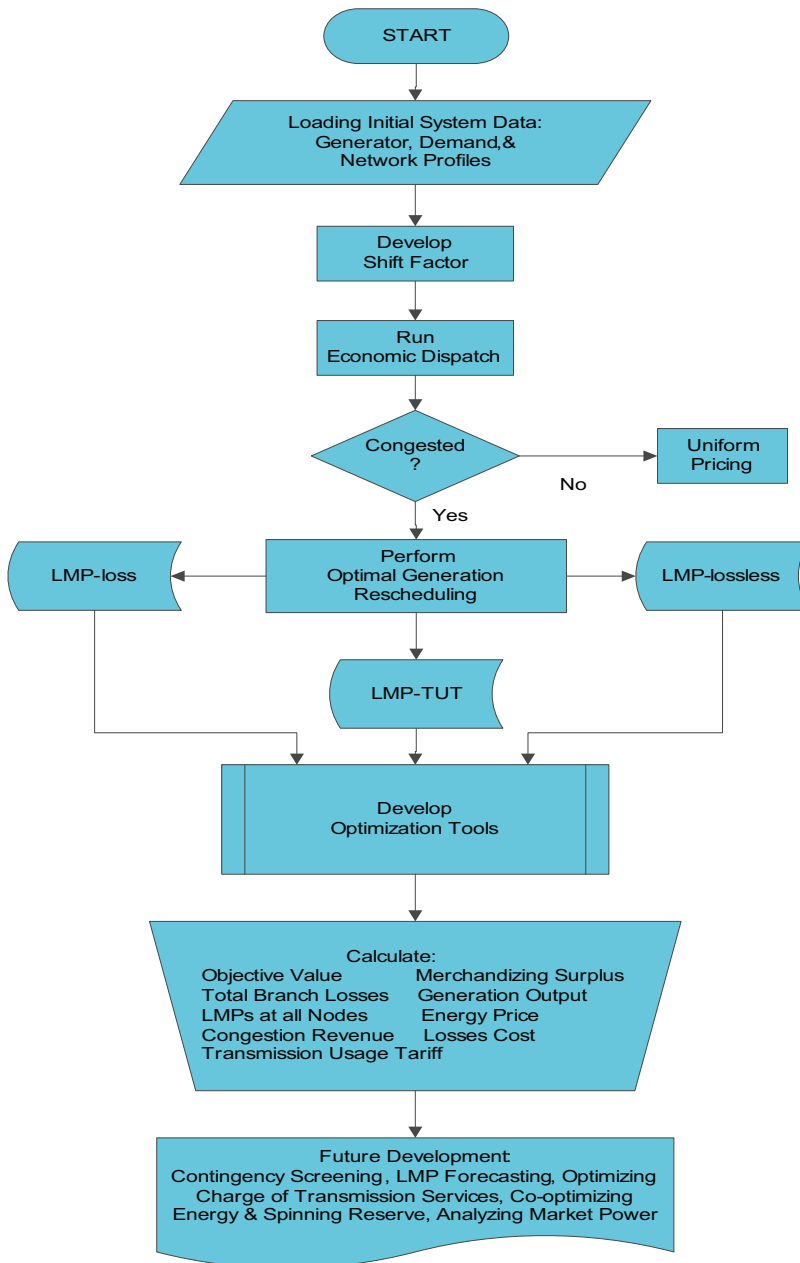


Fig. 2. Flowchart of the LMP schemes improvement

4.2 Illustrative example of simple 3-Bus system

The proposed method is implemented with a simple 3-bus system. Some important characteristics are evaluated to describe benefit features of the method. System details consisting of generation and branch profiles are given in Table 1.

Generator Profile						
	b_i (\$/MWh)	m_i (\$/MW ² h)	$\min G_i$ (MW)	$\max G_i$ (MW)		
G_1	20	0.015	150	600		
G_2	18	0.015	50	400		
Branch Profile						
	n'	n''	r p.u.	x p.u.	cap (MW)	α_m (\$/MWh)
L1	1	2	0.0134	0.1335	200	2
L2	1	3	0.0067	0.0665	550	1
L3	2	3	0.0084	0.1002	350	1.25

Table 1. 3-bus system generator and branch details

Results obtained are recapitulated and shown in Table II. From the table, it can be observed that the minimum cost is achieved when node-2 is selected as the reference node. This option causes minimum power supply for network losses at 24 MW, compared to the other option; 24.06 MW and 25.53 MW for node-1 and node-3, respectively. Although node-1 and node-2 tending to have the same network losses supply, selecting node-2 as reference node gives a minimum objective value as well. This is comparable to the results of model without adding embedded cost, *LMP-loss*.

However, LMPs obtained under this *LMP-TUT* model are diverse because the component of the LMP now has additional cost that is transmission usage tariff. As a result, notwithstanding all generators output and the total of branch loss in *LMP-loss* and *LMP-TUT* models are the same, yet objective value, cost of losses and merchandizing surplus are dissimilar. The relationship between objective value and merchandizing surplus relative to the selection of reference nodes is given in Figures 3 and 4.

Illustration about the change of branch flow for different reference node can be found in Figures 6(a)-6(d). It is apparent that branch flow over transmission line 2-3 decreases when node 2 is selected as the reference node. This means transmission congestion may be avoided since power flowing on this line is only 344.42 MW, which is lower than 350 MW as the maximum loadability of the line 2-3. In addition, by selecting node 2 as the reference node, it allows the network power loss to be supplied from node 2 which has the lowest nodal price. Meanwhile in DC-OPF method, compensation for network losses must be distributed to all generators in such a way to ensure the power flow in the line does not exceed network thermal limit. This fact causes adding up of the total cost compared to the proposed SF-OPF method, which needs a specific bus as injection point for the network power loss compensation.

SF-OPF (Proposed Method)												
Ref. Node	Obj. Cost1 (\$/h)	Loss (MW)	G-1 (MW)	G-2 (MW)	$\rho 1$ (\$/MWh)	$\rho 2$ (\$/MWh)	$\rho 3$ (\$/MWh)	λ (\$/MWh)	TUT (\$/h)	LC (\$/h)	CR (\$/h)	MS (\$/h)
1	19223	24.06	435.52	388.54	26.53	25.04	28.74	26.53	964.58	638.29	1061.29	2664.16
2	19177	24.00	424.00	400.00	25.15	25.06	26.62	25.06	949.25	601.45	0.00	1550.70
3	19299	25.53	449.71	375.82	27.35	25.45	30.11	30.11	964.67	768.78	1445.55	3179.00
DC-OPF (Conventional Method)												
Ref. Node	Obj. Cost2 (\$/h)	Loss (MW)	G-1 (MW)	G-2 (MW)	$\rho 1$ (\$/MWh)	$\rho 2$ (\$/MWh)	$\rho 3$ (\$/MWh)		TUT (\$/h)	LC (\$/h)	CR (\$/h)	MS (\$/h)
1	19238	24.53	436.88	387.64	26.55	23.81	29.53		964.62	673.41	1155.64	2793.68
2	19238	24.53	436.88	387.64	26.55	23.81	29.53		964.62	673.41	1155.64	2793.68
3	19238	24.53	436.88	387.64	26.55	23.81	29.53		964.62	673.41	1155.64	2793.68

Table 2. 3-bus system results

In view of that, there is no congestion revenue, and merchandizing surplus only contains the cost of network losses, which is the lowest cost of losses for this scheme. Therefore merchandizing surplus and objective value in this option are about half the value of other selected reference nodes, as shown in Figures 3-4. Normally, merchandizing surplus comes with congestion revenue component as the major element.

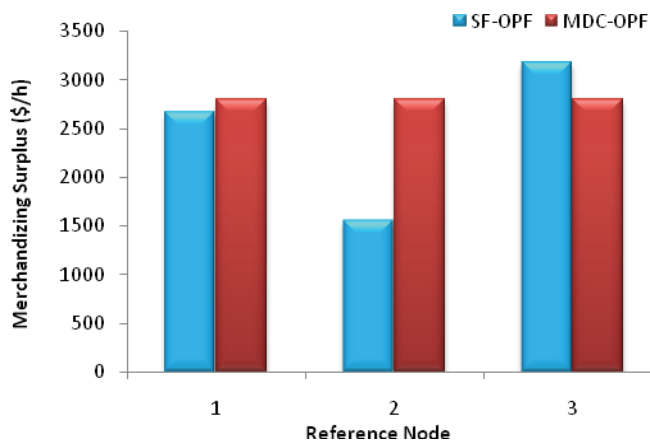


Fig. 3. Output of the optimization tools: Merchandizing Surplus vs. Reference Node

The behavior of the transmission usage charge formulated over this scheme can be analyzed in Figures 7(a)-7(b), in particular when demand is increased to 850 MW. Figure 7(a)

describes how the composition of the transmission revenue component changes as the network charge rates are raised. As shown by Figure 11(b), employing the SF-OPF method is able to save costs of about \$1000/h compared to the modified DC-OPF results.

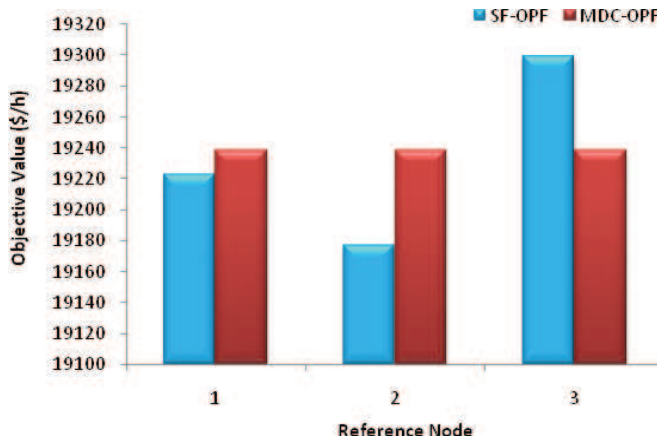


Fig. 4. Output of the optimization tools: *Objective Value vs. Reference Node*

The transmission usage tariff has a converse correlation with the transmission congestion revenue. As the network charge rate increases, it causes the transmission usage tariff to increase in value. Transmission congestion revenue then decreases while the total transmission cost, in this case merchandizing surplus remains constant. Thus, the total amount of transmission revenue is kept constant to the entire time subject to network charge rate. This condition will keep away market participants from the possible monopolistic price raised by transmission owners during peak load hours when the lines are more likely to be congested or exceeding the thermal limit. This is the main feature of the *LMP-TUT* scheme that can be useful to protect both generators and customers as the network users.

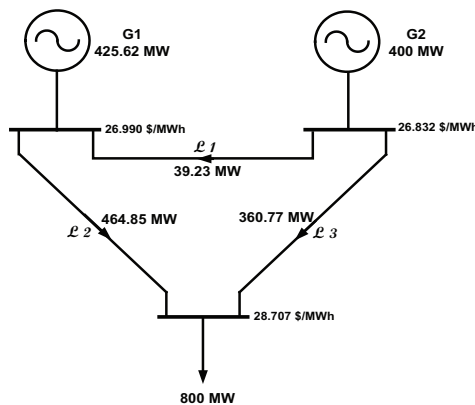


Fig. 5. Un-constrained branch flow of the 3-bus system

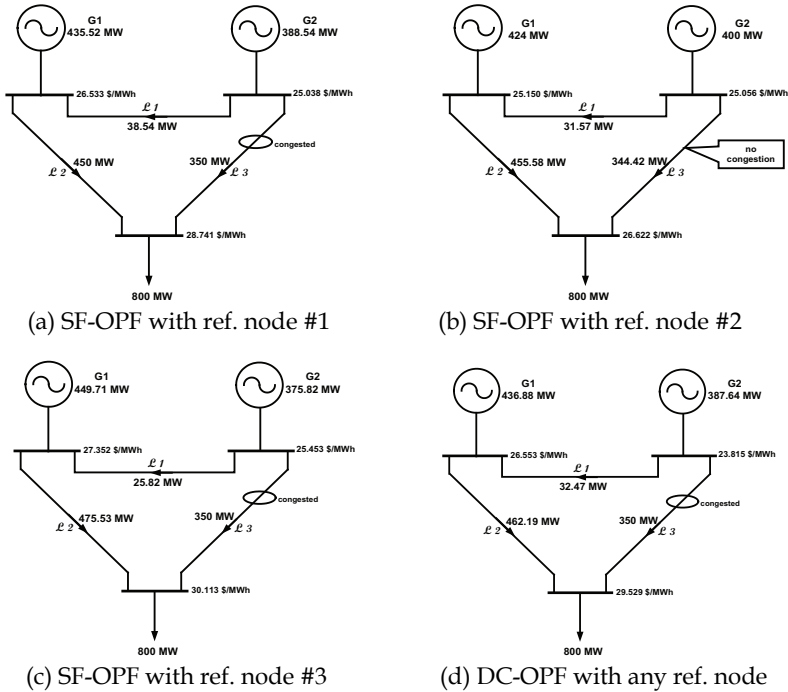


Fig. 6. The comparison of constrained branch flow with different reference node

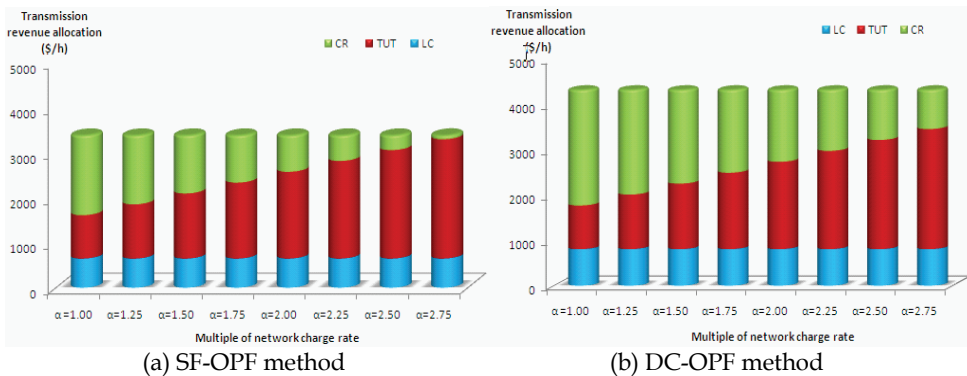


Fig. 7. Transmission revenue component vs. multiple of network charge rate with different approach

5. Conclusions

An effective congestion-based nodal price modeling is the key factor in determining optimal pricing, which could generate economic signal especially as congestion happens. Therefore a comprehensive tool for congestion-based nodal pricing has been developed to encourage

transparent and competitive price but still be able to address the issues surrounding transmission management.

Locational marginal prices formulated under the *LMP-TUT* model have an additional cost called transmission usage tariff. The SF-OPF and modified DC-OPF methods are used to simulate this third scheme of the author's proposed schemes. Market efficiency obtained by the SF-OPF method proves that this approach is much better than the conventional DC-OPF method.

In addition the results show that there is a reverse relationship between transmission usage tariff and transmission congestion charge. As the network charge rate increases, usage tariff also increases but congestion revenue decreases automatically. This particular scheme advantages market participants because it incorporates the usage tariff while keep the amount of total transmission charges to be constant.

By applying this scheme for managing transmission congestion, accordingly, it would be able to avoid network users from the drawback of potential monopolistic network charge rates increased arbitrarily by transmission owners, especially during the peak load period in which the lines are most probably exceeding their thermal limits.

6. Future research

From the study conducted in this project, there are a number of future research issues for further development as illustrated in Figure 2. Some of them are as follows:

6.1 The effect of transmission congestion on market power

The main concern of non-competitive participants in the deregulated power market, particularly the generation companies is when market power is exercised, since it may impede competition in power production, service quality and technological innovation (Shahidehpour et al., 2002). Furthermore, market power in electricity markets are more complicated than those in other markets because of the characteristic of the electricity (Peng et al., 2004). Market power can be exercised intentionally or unintentionally. When a generation company offers large amounts of generation to the market, by committing more expensive generating units to maintain system reliability while cheaper units could have been committed, this is called an intentional practice of market power. Nonetheless, market power can be the cause of transmission congestion that limits the transfer capability in a certain area, this is unintentional market power. Congestion phenomenon can prevent particular generating units that could be cheap from supplying power. On the other hand, transmission congestion can permit certain units to escalate market prices by offering expensive units.

The impact of transmission congestion on market power can be explored with long term dynamic simulation (Allen & Ilic, 2000). The research should be focused on the effect of transmission congestion on a generator's settlement prices, incomes and benefits. Simulation is continued by examining the charge of transmission services to discover the optimal pricing, which could meet revenue requirements of the assets and may stimulate third parties (investor) to build new transmission lines and generating capacity in optimal locations, in order to enhance efficiencies in the power market.

6.2 Co-optimization of energy and spinning reserve

Another area for research to be conducted is to analyze co-optimization of energy and spinning reserve. The spinning reserve is one of the most important ancillary services that

must have full attention paid to it in a markets management and operation. Thus, establishing an efficient market structure for spinning reserve services has become crucial (Allen & Ilic 2000; Bautista et al., 2006; Wong & Fuller, 2007). In addition, spinning reserve can be used to manage system contingencies (Jie et al., 2003). In this way, the research should focus on proposed scheduling and pricing algorithms, which provides LMP as a possible market signal tool of reserve supply. To analyze system security, simulation can be done in the presence of a network outage due to contingency screening. A co-optimization is performed in terms of minimizing the expected costs of energy and reserves while meeting system load and transmission constraints and maintaining certain grid security (Marwali & Shahidehpour, 2000; Shangyou & Shirmohammadi, 2002). This determines the optimum patterns of energy dispatch and reserves.

6.3 LMP forecasting

Since the introduction of restructuring and competition into the power system, the electricity price has become the center of all activities in the power market. Therefore short-term price forecasting is vital for market players to manage their price risk (Mandal et al., 2009). Nowadays, electricity has been considered as a commodity in various markets. Nevertheless, electricity has distinct characteristics that distinguish it from other commodities. Its characteristics are that electricity cannot be stored economically for long periods of time and transmission congestion in a power system may prohibit exchange among control areas. As a result, electricity price movement can demonstrate major volatility. Hence the price forecasting methods prevalent in other commodity markets cannot be applied to forecast the electricity price.

Research that could be conducted in a technical aspect of transmission congestion management is to investigate a framework for short-term LMP forecasting. Transmission congestion that occurs when power flow in a transmission line exceeds its thermal limit can cause different LMP or bus prices. Even though LMP is very volatile, they are not random. Thus certain patterns and rules concerning market volatility can be recognized. Because a high volatility of LMP is resultant during the congestion period, LMP forecasting is now holding a significant part in establishing proper economical operation (Valenzuela & Mazumdar, 2005; Li et al., 2007). Therefore it is crucial to predict the congestion rigorously for LMP forecasting. The effect of line flow and line limit will be calculated on price to find out the relationship between congestion and the LMP.

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The world's reliance on existing sources of energy and their associated detrimental impacts on the environment- whether related to poor air or water quality or scarcity, impacts on sensitive ecosystems and forests and land use - have been well documented and articulated over the last three decades. What is needed by the world is a set of credible energy solutions that would lead us to a balance between economic growth and a sustainable environment. This book provides an open platform to establish and share knowledge developed by scholars, scientists and engineers from all over the world about various viable paths to a future of sustainable energy. It has collected a number of intellectually stimulating articles that address issues ranging from public policy formulation to technological innovations for enhancing the development of sustainable energy systems. It will appeal to stakeholders seeking guidance to pursue the paths to sustainable energy.

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