NETWORK LOSS INCORPORATED LOCATIONAL MARGINAL PRICE BY USING DC-OPF

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ABSTRACT

Since simplified network model is used in real-time market operation, dispatching engine would not calculate the price component of transmission loss. Thus a separate procedure is required to calculate transmission loss factor (TLF). Then, TLF is used as scaling factor to determine network loss incorporated locational marginal price in the commercialised electricity industry. A methodological procedure for calculating network loss incorporated locational marginal price is reviewed by using DC-OPF in this paper. IEEE 30-bus system model is used for numerical simulation.

I. INTRODUCTION

It has been observed that the intrinsic physical property such as network connectivity for delivering electric energy between source and load has been playing important role to achieve the economic efficiency of commercialised electricity industry. Accordingly, regulatory body that is responsible to efficient industry operation tends to rely on locational pricing scheme by spatially distributing energy resources.

As discussed in previous work [1], locational marginal price of electric energy mainly consists of price components such as energy, transmission loss, and transmission congestion. Taking into account that transmission congestion might be occurred by special physical circumstance such as the shortage of transmission delivery capability, transmission network loss could be important financial issue to market participants in the normal market operation.

Meanwhile, according to the operation experience of energy management (EMS) or market management system (MMS), simplified mathematical model for transmission network is used to dispatch generation supplier in the dispatch engine of real-time market operation. However, dispatch engine based on simplified network model would not account the transmission losses in its mathematic model. Accordingly, the physical reality of transmission losses called as transmission loss factor (TLF) is externally calculated by means of more complicated network model, and then transmission loss factor is used as scaling factor to determine network loss incorporated locational marginal price in commercialised electricity industries [2]-[4].

A generic methodological procedure for calculating transmission loss factor as well as network loss incorporated locational marginal price is reviewed by means of DC-based optimal power flow in this paper. IEEE 30-bus system model is used for numerical simulation.

II. REAL-TIME NETWORK CONSTRAINED DISPATCH

A generic mathematic form of network constrained economic dispatch (NCD) based on DC-based network model is formulated, and then its optimality condition is discussed in this subsection.

Network constrained economic dispatch based on DC network model includes generation cost minimisation as objective function, and constraints such as active power supply and demand balance, transmission flow capacity lower and upper limit, and generator active power output lower and upper limit as shown in (1).

$$
\begin{aligned}
& min \quad \sum_{k\in G} C_k(P_{gk}) \\
& s.t \\
& \sum_{j\in N} B_{kj}(\theta_k - \theta_j) + P_{dk} = P_{gk} && \forall k \in N \\
& P_{kj}^{min} \le B_{kj}(\theta_k - \theta_j) \le P_{kj}^{max} && \forall k \in N, k \ne j \\
& P_{gk}^{min} \le P_{gk} \le P_{gk}^{max} && \forall k \in G
\end{aligned} \tag{1}
$$

where

N : set of all buses in the system

G : set of set of all buses having generating capacity

B_{kj} : line susceptance from bus k to j

θ_k , θ_j : phase angle at bus k and j

C_k	: production cost of generator at bus k
P_{gk}	: active power generation at bus k
P_{dk}	: active power demand at bus k
P_{gk}^{min}	: minimum generation limit of at bus k
P_{gk}^{max}	: maximum generation limit at bus k
P_{kj}	: active power flow from bus k and j
P_{kj}^{min}	: minimum transmission limit from bus k to j
P_{kj}^{max}	: maximum transmission limit from bus k to j

Given that generator capacity and transmission line capacity is not binding and thus equality constraint is only considered, the Lagrange function of (1) is formulated by introducing Lagrange multipliers to change constrained optimisation into unconstrained optimisation problem as shown in (2).

$$L(P_g,\theta,\lambda) = \sum_{k\in G} C_k(P_{gk}) + \sum_{k\in N}[\lambda_k \cdot \sum_{\substack{k\neq j\\ j\in N}} B_{kj}(\theta_k-\theta_j) + P_{dk} - P_{gk}] \tag{2}$$

where, λ_k is Lagrange multiplier on the active power balance at bus k.

Optimality condition for economic dispatch is obtained by differentiating the Lagrange function with respect to P_{gk}.

$$\frac{\partial L(\bullet)}{\partial P_{gk}} = \frac{\partial C_k}{\partial P_{gk}} - \lambda_k = 0 \quad \forall\, k \in G \tag{3}$$

Since transmission loss is not function of power flow in the DC-based network constrained dispatch, Lagrange multipliers of all buses is same as that of slack bus. This implies that the locational price obtained from DC-based network constrained dispatch could not include the price component of transmission losses.

III. LMP INCLUDING TRANSMISSION LOSSES

Since the simplicity of DC-based network constrained economic dispatch could not include the price component of transmission loss, a separated arrangement is required to incorporate transmission loss into locational price. The proved and conventional approach to incorporate transmission loss is to adopt inverse penalty factor (PF), which is determined by transmission loss factor (TLF).

A. LMP with Transmission Loss

Given that transmission losses are regarded as the function of network flow, transmission losses could be affected by the change of power flow injection in the systems. Thus economic dispatch without violation of transmission capacity limit and generation output limit is given by (4).

$$\begin{aligned} & min \quad \sum_{k\in G} C_k(P_{gk}) \\ & s.t \\ & P_D + P_L = \sum_{k\in G} P_{gk} \end{aligned} \tag{4}$$

Lagrange function of economic dispatch with Lagrange multiplier is given by (5).

$$L(P,\lambda) = \sum_{k\in G} C_k(P_{gk}) + \lambda[P_D + P_L - \sum_{k\in G} P_{gk}] \tag{5}$$

By using the optimality condition of Lagrange function with respect to the change of power flow injection as well as slack bus locational price (λ) obtained by DC-based network constrained dispatch, the locational marginal price at specific bus location (k) includes transmission loss price as shown in (6) [5].

$$\frac{\partial C_k}{\partial P_k} = \lambda_k = \lambda \cdot [(1 - \frac{\partial P_L}{\partial P_k})] \quad \forall k \in N \tag{6}$$

where, λ_k is locational marginal price at bus k, and $\partial P_L/\partial P_k$ is transmission loss factor at bus k, respectively.

B. Transmission Loss Factor (TLF) Calculation

As discussed above, transmission loss factor is essentially required to calculate transmission marginal price including transmission losses. The TLF calculation and LMP including network losses is discussed in this subsection.

Then, given that the net power injection (P_{ref}) at slack bus is function of phase angle and voltage magnitude, when P_k is changed, all bus angle and voltage magnitude in the system will be changed. Meanwhile, if reference bus penalty factor is given by using full Jacobian (**J**) and unit vector (**U**), transmission loss factor could be obtained by (7) [6].

$$\left[\frac{\partial P_L}{\partial \boldsymbol{P}}\right] = \mathbf{U} + [\boldsymbol{J}^T]^{-1} \cdot \left[\frac{\partial P_{ref}}{\partial \boldsymbol{\theta}}\right] \tag{7}$$

However, since it is very complex to calculate the inverse of Jacobian matrix, transmission loss factor could be more easily calculated by using decoupled Jacobian. Thus when the left-upper part of Jacobian (**H**) is used, the calculation of transmission loss factor could be less complex and given by (8).

$$\left[\frac{\partial P_L}{\partial \boldsymbol{P}}\right] = \mathbf{U} + [\boldsymbol{H}^T]^{-1} \cdot \left[\frac{\partial P_{ref}}{\partial \boldsymbol{\theta}}\right] \qquad (8)$$

IV. NUMERICAL TESTS

IEEE 30-bus system model is used to illustrated transmission losses incorporated locational price in this paper. MATLAB optimisation tool is used as optimisation engine, and numerical coding for DC-based OPF and power flow computation is based on MATPOWER 3.0 [7].

A. Test Design and Simulation Cases

Four cases are simulated to illustrate TLF pattern and its locational price by changing the location of slack bus among generators. Generator 1, 3, 22 and 27 are used as slack bus for Case 1, Case 2, Case 3 and Case 4, respectively. The modified DC-OPF, which is incorporated by transmission loss factor (TLF), is used to calculate the locational marginal price.

The brief description of computational process is as follow; firstly transmission loss factor is obtained by solving AC power flow, and secondly locational price at the selected slack bus is calculated through DC-OPF, and then finally the locational marginal price is calculated by incorporating TLF into system price as shown in (6).

Table 1. Generator Cost Model in IEEE-30 Bus Model

Gen	Capacity		Generator Fuel Cost [$/MW]		
	P_{min}	P_{max}	$a*P^2$	$b*P$	c
G1	0	80	0.0200	2.00	0
G2	0	80	0.0175	1.75	0
G13	0	40	0.0250	3.00	0
G22	0	50	0.0625	1.00	0
G23	0	30	0.0250	3.00	0
G27	0	55	0.0083	3.25	0

B. Test Results

Firstly, the transmission loss factors of generators for 4 test cases are illustrated by using full Jacobian and decoupled Jacobian as shown in Table 2 and Table 3.

Table 2. Transmission Loss Factor [Case 1 & Case 2]

Bus	Case 1		Case 2	
	Full	Decoupled	Full	Decoupled
1	0.0000	0.0000	0.0124	0.0104
2	-0.0040	-0.0041	0.0091	0.0070
13	-0.0146	-0.0127	0.0000	0.0000
22	-0.0372	-0.0381	-0.0235	-0.0265
23	-0.0107	-0.0113	0.0034	0.0008
27	-0.0134	-0.0120	-0.0001	-0.0007

Table 3. Transmission Loss Factor [Case 3 & Case 4]

Bus	Case 3		Case 4	
	Full	Decoupled	Full	Decoupled
1	0.0336	0.0336	0.0091	0.0077
2	0.0304	0.0303	0.0058	0.0043
13	0.0200	0.0222	-0.0048	-0.0042
22	0.0000	0.0000	-0.0270	-0.0292
23	0.0243	0.0243	-0.0003	-0.0022
27	0.0214	0.0229	0.0000	0.0000

The TLF pattern between full Jacobian and Decoupled method has a very similarity, and thus decoupled method might be useful when computational speed is highly required.

We observe that transmission loss factor at bus 22 is relatively large other than generator bus in all Case studies except Case 3. This implies that Gen 22 is the most sensitive with respect to transmission loss, and thus transmission loss could be reduced as possible as if Gen 22 would account the power mismatch.

With the result of transmission loss factor, locational marginal price for all buses are shown in Figure 1.

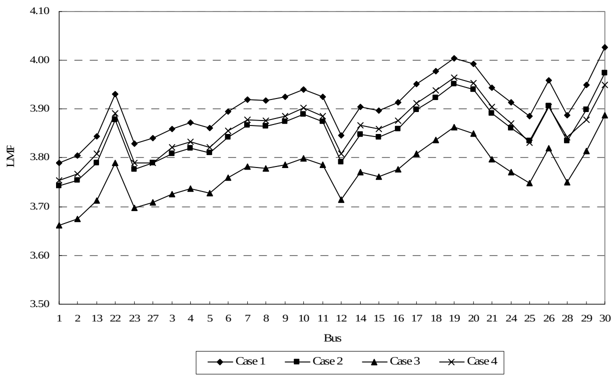

Figure 1. Locational marginal price profiles of cases

We observe that locational marginal price including transmission losses could be well calculated with DC-based network constrained dispatch by incorporating transmission loss factor. In addition, the price pattern could justify our discussion and expectation. That is, Gen 22 has the largest transmission loss factor, and thus Gen 22 is regarded as the most efficient to account the power mismatch in the test system. As a result, the profile of locational marginal price in Case 3 is lower than other Cases.

V. CONCLUSION

It is theoretically discussed and numerically illustrated to calculate network loss incorporated locational marginal price by using DC-based optimal power flow. For this purpose, transmission loss factor is incorporated into DC-based network constrained dispatch to account the network loss effects on locational price. It is also shown that that slack bus location could affect the locational marginal price. The test results show that slack bus location could play an important impact on the locational marginal price profile of power system, resulting into the great change of industry benefit. Thus, even though it requires huge computational difficulties to calculate transmission loss factor, it is necessary that the needs of slack bus dynamics have to be considered to evaluate more physically justified locational marginal price in electricity market.

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