Power Tracing and Prediction Of Losses For Deragulated Transmission System

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Abstract-- In a fully deregulated energy market a number of Transmission System Operators (TSOs) may be involved in a transaction. Losses related to a transaction need to be evaluated in real time, to facilitate the Gencos to supply the losses. This will also enable a TSO to plan the network operation in order to minimize the losses. Evaluation of extent of use of a transmission path by a transaction will enable determination of available transmission capacity (ATC) to accommodate other transactions, and together with its associated losses as the base data, will also address the congestion management issue.

Index Term-- Deregulation, congestion management, available transmission capacity, transaction.

1. INTRODUCTION

Electricity in contrast with other economic commodities or services must be delivered to an integrated grid for reasonable efficiency and reliability. The production must closely match the consumption instantaneously, not only in a system as a whole, but at each of the electrically distinct but interacting points on the network. To ensure this, an electricity system needs to be operated by some single entity viz. an independent system operator (ISO), or a system of closely cooperating entities, monitoring and controlling real time physical operations of virtually the entire system.

In economic terms, the market must determine the prices that equate demand to supply instantaneously at each of the network locations. If the spatial distribution of production and consumption does not meet well-defined constraints, prices in a pure market system must change to compensate the adjustments in production and consumption, necessary for reliable and secure system operations [1].

In a deregulated operation, consumers get their physical electricity through the meter connected to the low-voltage distribution system, and pay some retailing entity for this electricity. The retailing entity in turn pays for the electricity to generators (GENCOS) through some combination of contract arrangements and spot transactions, through a dispatch/trading entity. The dispatch/spot trading entity, a system operator or the ISO, coordinates real-time operations in a competitive system, using some sort of market process to induce and compensate responses to its instructions. The physical electricity is distributed from generators to consumers through the high-voltage transmission network of one or more transmission system operators (TSO) and the low-voltage distribution system of a distribution service provider (DISTCO) or a retailer. A quantum of power agreed to be supplied by a generation provider to a retailer is termed a transaction. The energy market can be based either on bilateral contracts or on spot trading. The combination of contract and spot transactions bring in the critical separation of real-time physical operations from longer-term bilateral commercial relationships. Different market models viz. the wheeling, the bilateral contracting, and the Poolco models are possible. Wheeling model handles incremental trades by third-party users, hence spot trading does not usually occur under the traditional wheeling model. Bilateral contracts define physical operations in case of integrated utilities with their own generation portfolios and internal dispatch processes. The wheeling utility can schedule the incremental third party contract flows, adjust its own generation incrementally if necessary, to accommodate contract mismatches and transmission constraints, and charge wheeling rates reflecting the resulting costs.

Since the electricity supply and demand conditions change quickly and unpredictably, system security and efficiency require that actual physical operations be based on actual system conditions and not on the contract positions negotiated beforehand. System operator takes over the adjustments in generation and load to maintain secure and efficient operations, without regard to the complex and ever-changing web of bilateral contracts among the system users. In emerging energy markets the products and services may be unbundled and re-bundled in different ways than the ones provided by the existing electric utility industry, and the fundamental form of unbundling may be the provision of open transmission services. Wherein, the transmission services can be hired by different transactions. The unique feature of emerging electric energy market structures is their transmission system, where the path of commodity or the energy flow is governed by the Kirchhoff’s law. ISO has to be responsible for coordinating the transmission system operation and providing open access to all transactions. Transmission pricing is made up of components such as access fee, congestion management, and losses. Pre-evaluation of a transaction involving assessment of security, cost and losses related to it, is an important process before a transaction is scheduled and then dispatched, which might involve rescheduling and curtailment management as well. Losses related to a transaction need to be evaluated in real time, to facilitate the Gencos to supply the losses. This will also enable a TSO to plan the network operation in order to minimize the
losses. Evaluation of extent of use of a transmission path by a transaction will enable determination of available transmission capacity to accommodate other transactions, and together with its associated losses as the base data, will also address the congestion management issue.

In a fully deregulated energy market a number of TSOs may be involved in a transaction. A transaction may involve one delivery point and a number of receipt points at the retailer’s end. This makes it important to be able to trace power flows as well as the associated losses related to a transaction in each transmission service used by a specific transaction, for its current and oncoming operating scenarios as well. As mentioned earlier, the transmission pricing based on actual transaction is preferred over the one based on the maximum flow in a transaction [2] to have the proper economic signal. Proportional sharing based power tracing method using linear equations proposed in [3-9] determine the different transactions needed to supply a specific retailer’s demand and losses related to each transaction. In [10], based on power flow solutions, the system impedance matrix is modified using load impedances and then using obtained current injections at the generation points, the power required in a transaction and share of generations in a line are determined. However, how a transaction shares a line with other transactions and its associated loss in a line is not indicated. This paper extends the method of proportional sharing [3-9] to compute losses associated with each transaction sharing a transmission path and proposes a real time implementable procedure to (i) determine extent of use each transaction makes of a transmission path and (ii) quantify the associated losses. The flows at both ends of a line for the current scenario are assumed to be available from state estimation computations validated through the measurements available from phase measurement units (PMUs). The prediction procedure proposed, uses a generalized quadratic relationship to learn the relationships between a retailer’s demand and: (i) the generation’s contributions to it at the receiving end, (ii) the associated losses in a transaction, (iii) the share of transactions in a line at a point of receipt and (iv) the line losses in each line used by a transaction, by generating learning coefficients. The current operating scenario and at least past two operating scenarios related to a specific transaction are used for this purpose. Using the generated learning coefficients, the paper then proceeds to determine for an oncoming operating scenario, a generator’s contribution to a retailer’s demand at the receiving end, power loss for a transaction, share of transactions in a line at the retailers end, and share of the line losses of each transaction in a transmission circuit for a retailer’s demand. With the developments coming up in the area of grid computing, it is feasible to implement the proposed procedure in real time.

2. POWER FLOW TRACING

Network structure of the transmission grid provides a number of alternative routes through which power can flow from a generator to a load. Transmission loss in a line depends on power flow through it, and power flow in any line is additive over supplies from generators connected to the line. Thus, portion of the transmission loss attributed to a generator depends on the way its power flow shares the lines in the network with the supplies from the other generators [6]. It is important to determine the power, a load receives at the point of receipt, from a specific generator and its transmission route. For determining the losses associated with a transaction sharing a transmission link with other transactions, it is also required to determine, how much power a generation has to supply at the sending end, to meet a portion of the load through a specific transmission route.

2.1 Flow Tracing from a Generator to a Load (down stream trace)

The \(i^{th}\) generator output supplying the \(k^{th}\) load demand at the generation end is given by [3]

\[
P_{zi} = \left( \frac{P_{zi}}{P_{zi} + \sum_{k=i}^{n} [A_{ik}^j] P_{zi}} \right) [A_{ik}^j] P_{zi} \quad i = 1, \ldots, n
\]  

\(P_{zi}\) is the nodal generation at the \(i^{th}\) bus and \(P_{zi}\) is the \(i^{th}\) nodal power. Equation (1) shows, where the power of a generator goes to. The downstream distribution matrix elements are

\[
[A_{ik}^j] = \begin{cases} 1 & \text{for } i = j \\ -c_{ij} & \text{for } j \in \mu \\ 0 & \text{otherwise} \end{cases}
\]

Where \(\mu\) is the set of nodes directly supplied from node \(i\). \(c_{ij} = \frac{P_{zi}}{P_{zi}^j}\) expresses relationship between flow in the line between \(i^{th}\) bus and the \(\ell^{th}\) bus and the nodal flow at the \(\ell^{th}\) node.

2.2 Flow Tracing from a Load to a Generator (upstream trace)

Participation of the \(k^{th}\) generation in the retailer’s demand at the \(i^{th}\) bus at the point of receipt \(i^{th}\) bus is given by [3]
\[ P_{Li} = \left( \frac{P_{L} \sum_{k=1}^{n} [A_{i,k}]_{k}}{P_{j}} \right) P_{G} \quad i = 1,...,n \]  

(2)

\[ P_{P_{Gp}} = \frac{P_{L_{m}}}{\sum_{q=1}^{m} P_{L_{q}}} \]  

(5)

\[ p \text{ is an index for a generation } P_{G}, \text{ and } q \text{ is an index for a load } P_{L} \text{ using the line } \ell, m \text{ is one of the } n \text{ loads and } r \text{ is one of the } s \text{ generations using the line } \ell. \]  

\[ \text{P}_{G_{p}} \text{ is available from equation (3) and } P_{L_{q}} \text{ is available from equation (4). The losses associated with a transaction } d \text{ sharing a line with the other transactions is given by} \]

\[ \text{Loss}_{id} = \left( \sum_{i=1}^{n} P_{G_{i}} - \sum_{j=1}^{m} \sum_{q=1}^{m} P_{L_{q}} \right) \sum_{q=1}^{m} P_{L_{q}} \]

(6)

3. LEARNING RELATIONSHIPS IN ONGOING SCENARIO FOR ONCOMING TRANSACTIONS

Six sets of information from equations (1) through (6) become available from the flow tracing procedure for each of the retailer nodes. They are: (i) share of the output of the \( i^{th} \) generator in the \( k^{th} \) load demand at the supply end, (ii) contribution of the \( k^{th} \) generator to the \( i^{th} \) load demand at the point of receipt, (iii) share of the \( k^{th} \) generation in the flow in line \( i - \ell \), (iv) portion of the \( k^{th} \) load demand that flows in line \( i - j \), (v) extent of use of a line \( \ell \) by a transaction between a \( p^{th} \) generation and the \( m^{th} \) load, and (vi) power loss due to a transaction in line \( \ell \). Information (i) & (ii) together, determine the overall losses associated with a transaction.

Generalized quadratic relationships between a retailer's demand and: (i) share of generations meeting this demand, (ii) the power loss in this transaction, (iii) the share of the each part transactions in a line, (iv) the losses related to each transactions in a line proposed in equations (7) to (10) facilitate the generation of learning coefficients describing these relationships. Four sets of learning coefficients \((\alpha_{1}, \beta_{1}, \gamma_{1}), (\alpha_{2}, \beta_{2}, \gamma_{2}), (\alpha_{3}, \beta_{3}, \gamma_{3}) \) and \((\alpha_{4}, \beta_{4}, \gamma_{4}) \) are generated at each retail node of the network. There will be \((ng \times npq) \) of \((\alpha_{1}, \beta_{1}, \gamma_{1}), (ng \times npq) \) of \((\alpha_{2}, \beta_{2}, \gamma_{2}), (ng \times npq \times n\ell) \) of \((\alpha_{3}, \beta_{3}, \gamma_{3}) \) and \((ng \times npq \times n\ell) \) numbers of \((\alpha_{4}, \beta_{4}, \gamma_{4}) \) learning coefficient sets generated using real time operating scenarios, during learning phase. ‘\( ng \)’ represents number of generations, ‘\( npq \)’ represents number of retail or demand points and ‘\( n\ell \)’ represents number of active links in the network. For the purpose of generating
the learning coefficients, values of the left and right hand variables viz. $P_g$, $P_{gd}$, Loss, $P_{td}$ and $\text{Loss}_{td}$ in equations (7) to (10) are derived from the power flow tracing for the ongoing and past two operating scenarios, with similar network configuration and similar voltages obtained through the transformer tap and the generation AVR setting adjustments.

3.1 a generator’s contribution to the retailer’s demand at the receiving end

$$\frac{\alpha_1}{P_d} + \beta_1 + \gamma_1 P_d = P_{gd}$$

(7)

Where $P_d$ is total demand at a retailer’s point of receipt in p.u., $P_{gd}$ is a generator’s contribution to a retailer’s demand at the point of receipt in p.u.

3.2 a retailer’s demand to the associated loss with a transaction

$$\frac{\alpha_2}{P_d} + \beta_2 + \gamma_2 P_d = \text{Loss}_{t}$$

(8)

Where $\text{Loss}_{t}$ is loss associated with a transaction in p.u. (The difference between a generation’s contribution to a demand at the supply end and a generation’s contribution to a demand at the load bus)

3.3 a retailer’s demand to the line’s extent of use by the associated transaction at the point of receipt

$$\frac{\alpha_3}{P_d} + \beta_3 + \gamma_3 P_d = P_{td}$$

(9)

Where $P_{td}$ is share of the transaction in a line at the point of receipt in p.u.

3.4 a retailer’s demand to the loss in a line used by a transaction

$$\frac{\alpha_4}{P_d} + \beta_4 + \gamma_4 P_d = \text{Loss}_{td}$$

(10)

Where $\text{Loss}_{td}$ is loss associated with the transaction in a line in p.u.

The use of ongoing and past two scenarios results in an invertible square matrix. To have better learning coefficients, a higher number of past operating scenarios may be used. In that case, the learning coefficients may have to be determined by using either regression or the pseudo inversion methods viz. $x = (A^T A)^{-1} A^T b$, for an over defined system as used in state estimation procedure. Where in $Ax = b$, $A$ is a rectangular matrix. For initialization purpose, power flow results corresponding to similar operating condition and validated through PMU measurements may be used.

4. Prediction for Oncoming Transactions

4.1 Predicting a generator’s contribution to a retailer’s demand at the point of receipt

$(ng \times npq)$ times use of equation (7) together with the available relevant learning coefficient sets $(\alpha_1, \beta_1, \gamma_1)$ and the retailer’s proposed demand for the oncoming operating scenario, yields the likely contribution of each generation to a retailer’s proposed demand at a point of receipt.

4.2 Predicting power loss for a transaction

$(ng \times npq \times n^d)$ times use of equation (8) together with the relevant learning coefficient sets $(\alpha_2, \beta_2, \gamma_2)$ and the retailer’s proposed demand for the oncoming operating scenario, yields the power loss for each transaction.

4.3 Predicting share of transactions in a line at the retailers end

$(ng \times npq \times n^l)$ times use of equation (9) together with the relevant learning coefficient sets $(\alpha_3, \beta_3, \gamma_3)$ and the retailer’s proposed demand for the oncoming operating scenario, yields the share of transactions in each line at each of the point of receipt.

4.4 predicting share of line loss for a retailer’s demand

$(ng \times npq \times n^l)$ times use of equation (10) together with the relevant learning coefficient sets $(\alpha_4, \beta_4, \gamma_4)$ and the retailer’s proposed demand for the oncoming operating scenario, yields the losses associated with each of the transactions sharing a line.

5. Validation of the Proposed Procedure

A six-bus system shown in Fig.1 is used to validate the proposed procedure.

9 transactions viz. G1-L4, G1-L5, G1-L6, G2-L4, G2-L5, G3-L4, G3-L5, and G3-L6 are possible, having 3 generation providers (G1 to G3) and 3 retailers’ (L4 to L6). Table I shows 3 possible transactions and
their associated losses for 3 different values of the retailer’s demand at bus-6. Equations (1) & (2) are used to compute supply and retail end powers respectively for a transaction. Predicted values of upstream trace and the loss associated with a transaction for an oncoming operating scenario related to bus-6 are shown in Table I. Set of learning coefficients are generated by substituting $P_{gd}$ & $\text{Loss}_{t}$ for the past scenarios in equations (7) & (8) respectively and using $x = (A^T A)^{-1} A^T b$ for multi scenario case.

Table II shows extent of use of the transmission paths by each transaction, calculated using equation (5). The loads at buses 4 & 5 have their base case values as (0.9+j0.6) and (1.0+j0.7) p.u., respectively, and the load at Bus-6 is (1.0+j0.66) p.u. Extent of use of a transmission circuit by a transaction and its associated loss are required inputs to frame a transmission service hiring contract and for determination of ATC and subsequent congestion management. These inputs are also determined at Bus-6 for real power loads 0.81 and 0.72 p.u. with the load power factor retained as in base case, while keeping the loads at bus-4 & Bus-5 at their base case values. This amounts to assuming that demands are not changed on all the retail ends simultaneously. The three sets of extent of use & loss inputs corresponding to loads 0.9, 0.81, 0.72 p.u., at Bus-6 determine set of learning coefficients ($\alpha, \beta, \gamma$) and ($\alpha', \beta', \gamma'$) respectively, used to predict extent of use of the lines, when oncoming demand at Bus-6 is 1.0 p.u. shown in Table IIA. Table II & IIA demonstrate the effectiveness of the proposed learning coefficients. Table III & IIIA shows the losses related to the above transaction and the predicted losses.
TABLE III
LOSES FOR TRANSACTION

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Table IIIA
PREDICTED LOSSES [MULTI-SCENARIOS CASE] ONCOMING DEMAND AT BUS 6 IS 1.0 P.U.

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CONCLUSION
The proposed real time implementable learning coefficients based prediction procedure implemented in a six bus system shows that the predicted values obtained by this method is within acceptable range of the actual value, thus facilitating the framing of transaction bids and transmission hiring contracts. It also addresses the determination of available transfer capacity and congestion management.

REFERENCES