A Latest Approach for Pricing of Reactive Power in Modern Power System

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Abstract— pricing of reactive power become a big issue now a days. In this paper a new technique for pricing of reactive power is presented which involve all the equality and inequality constraints. In this paper reactive power is decoupled from active power so that calculation of reactive power becomes much easier and convenient. A study on CIGRE 32 Bus systems carried out in which both stressed and unstressed cases are consider. This study also involves some benefits to the society.

This method of pricing intake by the selected generators by creating a bid between all the reactive power generator and select the generator into a stated zone as per requirement and calculated the reactive power by divide the whole bus system into the different zones.

Keywords—deregulated market, independent system operator, service provider, system security, pricing of reactive power.

I. INTRODUCTION

Reactive power plays an important role in supporting the real power transfer. This support becomes especially important when an increasing number of transactions are utilizing the transmission system and voltages become an uncontrollable in preventing additional power transfer[3]. Establishing an appropriate price structure for reactive support is important both operationally and financially [4]. Analyzing the costs involved is an indispensable part of determining the price. However, previous cost analysis only includes part of the real cost. FERC’s suggests a fixed tariff for reactive power support [1], which is not sufficient to provide a correct price signal. A recent approach, as proposed uses the node marginal cost. This marginal cost is the sensitivity of the generation production cost to the reactive power demand [5]. It represents a small portion of the true cost, as only the fuel costs of the generators are included. The purpose of reactive power dispatch is to determine the proper amount and location of reactive support in order to maintain a proper voltage profile [6].

Establishing a market for reactive power procurement services requires careful considerations of reactive power market characteristics and their effect on the system security [7]. All aspects of operating such a market and a conventional market for electric energy simultaneously must be analyzed carefully.

Offering remuneration for ancillary service provision such as reactive power support is sure to raise the price for electricity to consumers, however, in return for higher prices they get secured stable and continuous electricity supplied to them [8].

Reactive power supports the voltages that must be controlled for system reliability. If reactive power is transferred through lines, especially long lines, the real power losses in the line increase dramatically and the real power transfer capacity drops considerably. Because of their capacitive nature, power transmission cables allow even less transmission of reactive power than overhead transmission lines [16]. Reactive power has to be locally compensated so that it does not have to be supplied remotely and therefore causing large currents and voltage drops in the transmission lines. The system’s need for reactive power is composed of the system operator’s need to maintain system reliability and the reactive power consumption of loads, transmission equipment and generation.

II. REACTIVE POWER MARKET DESIGN

The main objective of this dissertation is identifying an appropriate market-approach for reactive power in light of the background discussion of reactive power markets in section 1.1.2 the goal here is to make a realistic market design. The reactive power responsible entity could act as the governor of the local market as a subsidy of the system operator by gathering bids. The system operator then controls the dispatch and awards the suppliers that contribute to local voltage control and keeping the reactive flows within the MVAr-bands. The proposed market structure here is to allow all available, local reactive power sources as market participants and compensating them in accordance with their contribution to the supply.

The proposed structure is as follows:

- All reactive power devices should be given a chance to participate in a market.
- Synchronous generators (or condensers) receive full payment in their market participation.
The local reactive power market is cleared by running a uniform bid auction to which generators (or synchronous condensers) submit bids for their support. The cost of reactive power support from generators is by far the highest of all the available sources. Therefore, only the generators submit bids and decide the market price. This is fair because if fixed shunt devices are present in the local market they get their reactive power dispatched first. The remaining reactive power requirements that exist in the system are supplied by the generators. The generator capability curve is limited in the under-excited operation by the end region heating limit. The associated costs regarding reduced real power sales are not as significant as they can be in the over-excited operation when generating reactive power. In the presented market design, generators submit their bids in a stepped structure and the local market clearing price is determined by the highest bid accepted by optimal dispatch. The system operator can choose to connect switched capacitors if their support is needed to maintain system integrity and reactive power flow limits. The balancing markets for both real and reactive power should also be as parallel as possible so that one does not restrict the other. The basic design of the reactive power market is as shown in fig 1.

The constraints for reactive power generation can be easily understood with the help of Fig. 2. In Figure 2, the armature heating limit is a circle with a radius \((V_I A)\), centered at the origin, and expressed by the following equation:

\[
P_g^2 + Q_g^2 \leq (V_I A)^2
\]

The field limit, on the other hand, is a circle with radius \((V_IE/X_s)\) at \((0, -V_t^2/X_s)\) and expressed by the following equation:

\[
P_g^2 + (Q_g + V_t^2/X_s)^2
\]

Following notations are as used:

- \(V_t\) = Voltage at generator terminal bus
- \(I_a\) =Armature Current
- \(E_f\) = Excitation Voltage
- \(X_s\) = Synchronous reactance
- \(P_g\), \(Q_g\) = Real and reactive power output
- \(P_{gr}\) = Real power rating
- \(P_{gA}\) = Real power output at point A
- \(P_{gB}\) = Real power output at point B

At an operating point A, with real power output \(P_{gA}\) such that \(P_{gA} < P_{gr}\) the limit on \(Q_g\) is imposed by the generator field heating limit and when \(P_{gA} > P_{gr}\) the limit on \(Q_g\) is imposed by the generator armature winding heating limit.

According to the capability curve in Figure 2, the generator can provide reactive power until it reaches its heating limits (point A in Figure 2) any further increase in reactive power provision from the generator will be at the expense of a reduction in its real power generation. Hence, the generator is expected to receive an opportunity cost payment for providing reactive power beyond \(Q_{gA}\), which accounts for the lost opportunity to sell its real power in the energy market and the associated revenue loss.

Following three region of reactive power generation can be identified in Fig 2:

In Region I \((Q_{gmin} \leq Q_g \leq 0)\)
The generator are required to provide a base leading reactive power support ($Q_{\text{blead}}$ to 0) any reactive power beyond $Q_{\text{blead}}$ is eligible for an under excitation payment component as an ancillary service.

In Region II ($0 \leq Q_g \leq Q_{gA}$)

The mandatory lagging reactive power requirement is from 0 to $Q_{\text{blag}}$ and any reactive power provision beyond $Q_{\text{blag}}$ is recognized as an ancillary services

In Region III ($Q_{gA} \leq Q_g \leq Q_{gB}$)

Any reactive power generation for a loss of opportunity cost payment

IV. SOCIETAL ADVANTAGE FUNCTION MAXIMIZATION

The Independent System Operator carries out a procurement market settlement where the objective is to maximize a societal advantage function The concept of social welfare from economic theory formulates a reactive power SAF which is based on the determination of aggregate system benefits occurred from reactive power services minus the expected payment by the Independent System Operator.

$$SAF_K = - \sum \rho_{KL} - \Sigma (C_{gL}) - \rho_{1K} (Q_{G1g} - Q_{\text{blead}}) + \Sigma \rho_{2K}(Q_{G2g} - Q_{\text{blag}}) + \Sigma \rho_{3K}(Q_{G3g} - Q_{\text{blead}} - 0.5p3K(Q_{G3g} - Q_{\text{blag}})$$

V. RESULTS & DISCUSSION

First of all the Reactive power at each bus in CIGRE 32 Bus Test System is calculated using load flow solution.

Load flow is carried out separately for each zone assuming the lines connected between the zones carry no P and Q

For Zone A

The $Y_{bus}$ for Zone A is calculated as under using direct inspection method through Matlab program

\[ TABLE \ I \]
\[ SOLUTION \ OF \ POWER \ FLOW \ MODEL \ FOR \ ZONE \ A \]

<table>
<thead>
<tr>
<th>Zone</th>
<th>Bus</th>
<th>$P_g$ (p.u.)</th>
<th>$V_i$ (p.u.)</th>
<th>$Q_g$ (p.u.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4072</td>
<td>13.910</td>
<td>1.025</td>
<td>2.383</td>
</tr>
<tr>
<td></td>
<td>4071</td>
<td>4.700</td>
<td>1.030</td>
<td>0.225</td>
</tr>
<tr>
<td></td>
<td>4011</td>
<td>4.610</td>
<td>1.050</td>
<td>3.106</td>
</tr>
<tr>
<td></td>
<td>4012</td>
<td>6.264</td>
<td>1.044</td>
<td>-0.600</td>
</tr>
<tr>
<td></td>
<td>1012</td>
<td>4.920</td>
<td>0.926</td>
<td>0.893</td>
</tr>
<tr>
<td></td>
<td>1014</td>
<td>7.520</td>
<td>0.857</td>
<td>-0.800</td>
</tr>
<tr>
<td></td>
<td>1013</td>
<td>4.000</td>
<td>0.931</td>
<td>0.124</td>
</tr>
</tbody>
</table>

Total $Q_g$ Demand of Zone A 4.331

For Zone B

The $Y_{bus}$ for Zone B is calculated as under using direct inspection method through Matlab program
The $Q_i$ for Zone C is calculated as under with the help of Matlab program.

**TABLE III**

<table>
<thead>
<tr>
<th>Zone</th>
<th>Bus</th>
<th>After solution of Power Flow Model we get $Q_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$P_{gi}$ (p.u.)</td>
</tr>
<tr>
<td>B</td>
<td>4021</td>
<td>2.820</td>
</tr>
<tr>
<td></td>
<td>4031</td>
<td>3.290</td>
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<tr>
<td></td>
<td>2032</td>
<td>7.990</td>
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<tr>
<td></td>
<td>1022</td>
<td>2.350</td>
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<tr>
<td></td>
<td>1021</td>
<td>4.788</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total $Q_i$ Demand of Zone B</td>
</tr>
</tbody>
</table>

**TABLE IV**

**FINAL SOLUTION FOR UNSTRESSED CONDITIONS**

- Total Expected Payment Calculated: $2804.756/h
- Total Marginal Benefits within System Security: $5119.2/h
- SAF Calculation (TMB-TEP) to ISO: $1944.15/h

**TABLE V**

**FINAL SOLUTION FOR STRESSED CONDITIONS**

- Total Expected Payment Calculated: $2121.859/h
- Total Marginal Benefits within System Security: $58879.00/h
- SAF Calculation (TMB-TEP) to ISO: $56757.141/h
REFERENCES