Derivation of Operating Point for Reactive Power Pricing

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Abstract— Many electrical power utilities, worldwide, have been forced to change their way of operation and business, from vertical integrated to unbundled open market structured. The main aim of the restructuring is to bring some form of deregulation or re-regulation in certain part of electricity business sector in order to allow competition in wholesale and retail level. In addition, it is expected to provide choice and social benefit to customers. In any interconnected system, if the change in reactive power at any single bus is happened it affects all the other buses connected to that bus. So if the point has been found at which the reactive power is changed, the right allocation of the price can be done.

I. INTRODUCTION

Voltage quality is an important indicator for good conduction of healthy power system operation. Due to the difference in load demand or equipment failure, it should be carefully monitored and maintained within acceptable limits. On the reorganization of the existing power systems and global deregulated with increasing demand for electric power, voltage control has become more problematic and difficult to handle. Voltage control and reactive power transmission are related to each other.

II. REACTIVE POWER AS AN ANCILLARY SERVICE

Ancillary services are defined as those services that are necessary to support the trans-mission energy from resources to loads while maintaining reliable operation of the Trans-mission Provider's Transmission System in accordance with good utility practices [2]

All available sources are not providing reactive power as an ancillary service, but only the reactive power provided by the generator is consider as an ancillary services and for that have to pay the cost.

Voltage and reactive power are related to each other and that's why by absorbing or injecting the reactive power voltage can be controlled. By controlling the voltage, situations like system fault, loss of generation, or transmission line outage can be avoided.[1]

III. REACTIVE POWER PRICING USING IEEE 14 BUS SYSTEM

For Reactive power pricing at any system first of all we have to find the operating point.

Now, getting the operating point we will apply the Neton – Raphson method to the IEEE 14 bus system.

A. *SYSTEM CONTAINS*

- There are mainly 14 bus in the system
- 5 bus are PV bus
- 9 bus are PQ bus
- No. of generator are 2
- No. of compensator are 3

Here IEEE 14 bus system is considered and simulation is done on IEEE 14 bus system Program, We can see subjective Diagram of IEEE 14 Bus System as follows. In which 5 generating buses are there and 9 load buses are considered. Where in generating buses 2 generators are considered and 3 compensators are included.

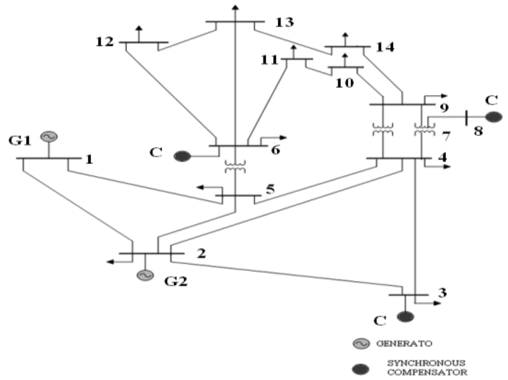

Fig. 1: IEEE 14 BUS SYSTEM

Now, when our main aim is pricing reactive power we have to know that which generator is producing how much active and reactive power producing at a bus, how much reactive power is needed to inject the bus and how much reactive power is consumed by the load.

It can be derived all these values by appling the Neton – Raphson method to the IEEE 14 bus test system with standard datas which are given below table.

Source Bus	Sink Bus	Resistance	Reactance
1	2	0.0194	0.0592
1	5	0.0540	0.2230
2	3	0.0470	0.1980
2	4	0.0581	0.1763
2	5	0.0570	0.1739
3	4	0.0670	0.1710
4	5	0.0134	0.0421
4	7	0	0.2091
4	9	0	0.5562

5	6	0	0.2520
6	11	0.0950	0.1989
6	12	0.1229	0.2558
6	13	0.0662	0.1303
6	8	0	0.1762
6	9	0	0.1100
9	10	0.0318	0.0845
9	14	0.1271	0.2704
10	11	0.0820	0.1921
12	13	0.2209	0.1999
13	14	0.1709	0.3480

Table.1: Line Data of IEEE 14 Bus

To measure the reactive power use the N-R method,

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j$$

Expressing in polar form;

$$I_i = \sum_{j=1}^{n} |Y_{ij}||V_j| \angle \theta_{ij} + \delta_j$$

From the equation of apperant power

$$P_i - jQ_i = |V_i| \angle - \delta_i \sum_{j=1}^{n} |V_{ij}||V_{ij}| \angle \theta_{ij} + \delta_j$$

Separating the real and imaginary parts,

$$P_i = \sum_{j=1}^{n} |V_i|\,|V_j||V_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j)$$

$$Q_i = -\sum_{j=1}^{n} |V_i|\,|V_j||V_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j)$$

Expanding Eqns. in Taylor's series about the initial estimate. We get

$$\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix} = \left[\begin{array}{c|c} \begin{pmatrix} \frac{\partial P_2^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial P_2^{(k)}}{\partial \delta_n^{(k)}} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial P_n^{(k)}}{\partial \delta_n^{(k)}} \end{pmatrix} & \begin{pmatrix} \frac{\partial P_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_n^{(k)}}{\partial |V_n|} \end{pmatrix} \\ \hline \begin{pmatrix} \frac{\partial Q_2^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_n^{(k)}} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_n^{(k)}} \end{pmatrix} & \begin{pmatrix} \frac{\partial Q_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_n^{(k)}}{\partial |V_n|} \end{pmatrix} \end{array}\right] \begin{bmatrix} \Delta \delta_2^{(k)} \\ \vdots \\ \Delta \delta_n^{(k)} \\ \Delta |V_2^{(k)}| \\ \vdots \\ \Delta |V_n^{(k)}| \end{bmatrix}$$

The Jacobean matrix gives the linearized relationship between small changes in $\Delta\delta i(k)$ and voltage magnitude $\Delta[Vik]$ with the small changes in real and reactive power $\Delta Pi(k)$ and $\Delta Qi(k)$

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix}$$

From the above equations we can derive the results for injecting, generating and consuming active and reactive power.[3]

That means, for the particular bus how much reactive power will be change and how much reactive power need to be compensate, that information can be derived from the given table which can be derived from Neton – Raphson method.

From the table No. 2 values of voltage, angle, active power and reactive power will be known and with the help of those values the operating point of the given system can be derived. And if it will be known that which bus supply how much active and reactive power, and which bus consume how much active and reactive power. So it will be convenient to pricing the active power and reactive power which will be beneficial to every consumer also.

Negative sign in the above table indicates the consumption of quantity and positive sigh indicates the injection of power in the buses. For consumption of the power consumer has to pay and for injection of the power consumer has to reward for the power.

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Table 2 Newton Raphson Load flow Analysis

Bus	Voltage	Angle	Injection		Generation		Load	
No.	V	δ	MW	MVar	MW	MVar	MW	MVar
1	1.0600	0.0000	232.593	-15.233	232.593	-15.233	0.000	0.000
2	1.0450	-4.9891	18.300	35.228	40.000	47.928	21.700	12.700
3	1.0100	-12.7492	-94.200	8.758	0.000	27.758	94.200	19.000
4	1.0132	-10.2420	-47.800	3.900	0.000	0.000	47.800.	-3.900
5	1.0166	-8.7601	-7.600	-1.600	0.000	0.000	7.600	1.600
6	1.0700	-14.4469	-11.200	15.526	0.000	23.026	11.200	7.500
7	1.0457	-13.2368	0.000	0.000	0.000	0.000	0.000	0.000
8	1.0800	-13.2368	0.000	21.030	0.0000	21.030	0.000	0.000
9	1.0305	-14.8201	-29.500	16.600	0.000	0.000	29.500	16.600
10	1.0299	-15.0360	-9.000	-5.800	0.000	0.000	29.500	16.600
11	1.0461	-14.8581	-3.500	-1.800	0.000	0.000	3.500	1.800
12	1.0533	-15.2973	-6.100	-1.600	0.000	0.000	6.100	1.6000
13	1.0466	15.3313	-13.500	-5.800	0.000	0.000	13.500	5.800
14	1.0193	-16.0717	-14.900	-5.000	0.000	0.000	14.900	5.000
Total			13.593	31.009	272.509	104.509	259.000	73.500

Table. 2: Newton Raphson Load flow Analysis

From Table 1

(1) Reactive power generation at pv bus 1 is negative means it has to absorb reactive power while other pv buses are supplying reactive power.

(2) Reactive power injections at some buses is positive so reactive power cost at that bus will be charged while on other buses is negative so reactive power consumers may be given incentives for this operating point.

IV. CONCLUSIONS

In this work, Reactive power support from Generators is distributed to each load fairly and from that distribution can derive the proper pricing for reactive power compensation. This work presents a Reactive Power tracing scheme, which allocates reactive power of generators to the bidding loads on the real-time operating point basis. The Reactive power delivery revenue of generator i to load j is directly obtained from its technical Value and also gives the information for Reactive Power injections and consumption to maintain voltage at various buses. In this work, a method is presented to allocate Voltage Control Costs of use of Reactive Power supply. The results obtained show that the methodology guarantees the total recovery cost for given services fairly based on the location of PQ bus. The revenue derived from sales of reactive power is sufficient to provide incentives for private investment in reactive-power capacity.

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