ISSN NO: - 2456 – 2165

Impact of Slack Bus Inclusion in Newton Raphson Load Flow Studies : A Review

Tanmay Shukla , Prof. Rajesh Sahu,
Oriental Institute of Science and Technology, Bhopal

Abstract : Load Flow is an important tool in the power system network to obtain its solution under incremental loading conditions at present and in future. This analysis is continuously made on the existing power system to establish equilibrium at present condition and load flow analysis is also helpful in undertaking proper system planning work for future. Among the various load flow methods Newton Raphson and its derivatives are most popular ones. In Newton Raphson method one of the buses (generally a generator bus) is treated as slack bus and is kept out of iterations. And when we conclude the result through iterations then we look for the losses and we say that losses are being fed by slack bus in this way we get the total power supplied by slack bus at the end when the iteration converges. The exclusion of slack bus from load flow iteration restricts us to make many other analysis. This paper is a review to what has been done so far to overcome this problem.

I. INTRODUCTION

Buses are divided into three categories in load flow studies namely load(P-Q) bus, generator(P-V) bus, slack (V-δ) bus[1,3]. Slack bus is generally that generator bus whose generation capacity is very high. Slack bus is a reference bus with respect to which voltages and phase angle of other busses are calculated. In load flow calculations, slack bus is not included in iterations and its power is not known to us at the time of iteration but it is known when the iteration converges to some result which restricts us to make other analysis. But some researchers have been made to include the slack bus into iteration so that the total burden of losses is not only on slack bus but distributed among all the busses. In this paper a review is being done to see what have been done so far in this field. Now a days with the increase in demand for power it is our necessity to move for distributed power generation. There are many ways of generating powers using different types of energies such as solar energy ,wind energy etc. but these all distributed generators have small capacity and also comparable sizes because of this distributed power generation it is not possible to select one reference bus i.e. slack bus of infinite capacity[4].so it is our necessity to move for distributed slack bus system. Mohapatra [5] given a method of decreasing burden of slack bus while maintaining the equal incremental loss criteria for optimum generation scheduling. Again, because of special characteristics of distribution systems, such as high R/X ratios and network imbalance, consideration of distributed slack bus is more realistic than single slack bus [6, 7]. And even the exclusion of slack bus from the iteration restricts us from carrying many analysis and conclusions. For this system loss equation is being analyzed which is found to be a function of magnitude of voltages and phase angles. Since Jacobian matrix in Newton Raphson have its elements to be the function of derivatives if real power and reactive power with respect to phase angle and voltage magnitudes but as the distributed slack bus system is considered so we need to modify the conventional Newton Raphson load flow equation.

II. MATHEMATICAL FORMULATION

In order to modify the conventional power flow equations it is required to understand what the conventional Newton Raphson method is. The power calculation in order to start the iteration by this method is done by having an initial guess. The guess is not just the guess but it decides the time of convergence of the result. At the time of start we have the loads at all the busses except slack bus which will be available to us at the end, when the result converges. So , we take initial loss as zero. After each iteration the losses are calculated and included with the scheduled power of the slack bus[9]. Simultaneously the rate of change of losses are also included into the jacobian.

A. Power Equations

In the power system we deals with three types of powers[1,2] :

1) Apperant power : it is the total power which is vector sum of other two powers. It is denoted by S. its unit is Kilo-Volt-Ampere. Now the total apperant power injected at bus I is given by

$$S_i = P_i + jQ_i = V_i I_i^* = V_i \sum_{i=0}^{n} V_k^* Y_{ik}^* \qquad .....(1)$$

2) Active power : It is the power which actually participates in the work done.Denoted by P. its unit is Kilo-Watt (KW). Actually it is the real part of the Apperant power. So, the total active or real power at the bus I is given by

$$P_i = Re[V_i \sum_{i=0}^{n} V_k^* Y_{ik}^*] \quad .....(2)$$

3) Reactive power : It is the power which is responsible for the magnetization of the circuit.it is denoted by Q and measured in Kilo-Volt-Ampere-reactive (KVAR) and the total reactive power at bus I is

$$Q_i = -Im[V_i \sum_{i=0}^{n} V_k^* Y_{ik}^*] \quad ......(3)$$

Now in order to get original scheduled real power in distributed slack bus system we need to subtract the losses out of actual injected power then our modified equation becomes

$$P_1' = P_1 - \quad Loss \quad .....(4)$$

By combining equation (2) and(4) we get,

$$P_1' = Re[V_i \sum_{i=0}^{n} V_k^* Y_{ik}^*] – Loss \quad ......(5)$$

B. Loss Equation

The loss is given by

$$\text{Loss} = I^2 R$$

And,

$$\text{I} = \text{VY}$$

Then, total loss can be expressed as,

$$\text{Loss} = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} |(V_i - V_k)^2 Y_{ik}^2 \, Re\left[\frac{-1}{Y_{ik}}\right]|$$

$$= \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} |(V_i - V_k)^2 C_{ik}| \quad ....(6)$$

Where ,

$$C_{ik} = Y_{ik}^2 \, Re\left[\frac{-1}{Y_{ik}}\right] \quad .....(7)$$

C. Jacobian And Its Modification

The matrix equation of the Newton raphson load flow studies is given as :

$$\begin{bmatrix} \Delta P_1 \\ \Delta Q_1 \end{bmatrix} = \begin{bmatrix} \frac{\partial P_1}{\partial \delta_1} & \frac{\partial P_1}{\partial |V_1|_1} \\ \frac{\partial Q_1}{\partial \delta_1} & \frac{\partial Q_1}{\partial |V_1|} \end{bmatrix} \begin{bmatrix} \Delta \delta_1 \\ \Delta |V_1| \end{bmatrix} \quad .....(8)$$

Now from this matrix in equation form corresponding to ΔP_1 is given by,

$$\Delta P_1 = \frac{\partial P_1}{\partial \delta_1} \Delta \delta_1 + \frac{\partial P_1}{\partial \delta_1} \Delta |V_1| \quad .....(9)$$

Now from this equation the elements of the jacobian corresponding to ΔP_1 is given by $\frac{\partial P_1}{\partial \delta_1}$ *and* $\frac{\partial P_1}{\partial |V_1|}$ and they are modified as

$$\frac{\partial P_1}{\partial \delta_1} = \frac{\partial \{Re[V_1^* \sum_{k=1}^{n} V_k Y_{ik}]\}}{\partial \delta_1} - \frac{\partial \{Loss\}}{\partial \delta_1} \quad ....(10)$$

$$\frac{\partial P_1}{\partial |V_1|} = \frac{\partial \{Re[V_1^* \sum_{k=1}^{n} V_k Y_{ik}]\}}{\partial |V_1|} - \frac{\partial \{Loss\}}{\partial |V_1|} \quad ....(11)$$

Where,

$\frac{\partial \{Re[V_1^* \sum_{k=1}^{n} V_k Y_{ik}]\}}{\partial \delta_1}$ and $\frac{\partial \{Re[V_1^* \sum_{k=1}^{n} V_k Y_{ik}]\}}{\partial |V_1|}$ are conventional terms and $\frac{\partial \{Loss\}}{\partial \delta_1}$ *and* $\frac{\partial \{Loss\}}{\partial |V_1|}$ are new terms.

Now, the new term in the equation (10) and (11) can be obtained by differentiating equation (6) with respect to δ_1 and $|V_1|$ respectively they are,

$$\frac{\partial \{Loss\}}{\partial \delta_1} = 2 \sum_{\substack{k=1 \\ k \neq i}}^{n} C_{ik} (V_1 - V_k) j V_1 \quad ..... (12)$$

$$\frac{\partial \{Loss\}}{\partial |V_1|} = 2 \sum_{\substack{k=1 \\ k \neq i}}^{n} C_{ik} (V_1 - V_k) e^{j\delta_1} \quad ..... (13)$$

In this way the jacobian elements are modified

D. Reference Angle Shifting

Due to involvement of all the busses in iteration and absence of a reference bus we need to shift the phase angle of all the busses after each iteration in opposite direction with an angle equal to greater power generating bus load angle say δ_1. This thing is achieved by multiplying each voltage vector by$e^{-j\delta_1}$[9].

III. RESULTS

Load flow analysis is carried out im MATPOWER[8] in IEEE 14 bus ,30 bus system using conventional load flow studies and our load newly developed procedure we found that the voltages and the load angles do not changes at all but regarding losses we get following results[10].

Case study	**Losses in MW (Conventional method)**	**Losses in MW (Developed method)**	**Loss reduction (%)**
IEEE Case-14	13.393	13.281	0.84
IEEE Case-30	2.435	2.417	0.74

From the above result we can see that the losses are reduced.

IV. CONCLUSION

From the results we can conclude that the voltage magnitude and angle is same in both type of load flows but the losses are minimized in distributed slack bus system.

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