Power Losses Estimation in Distribution Network (IEEE-69bus) with Distributed Generation Using Second Order Power Flow Sensitivity Method

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Abstract – *The demand for electricity is increasing day by day and the generation of power is not meeting the demand and also the losses experienced in transmission and distribution are the main causes of load shedding in India. We can reduce or counteract the losses by generating more power in conventional generating stations which needs huge investment, or by incorporating Distributed generators in the Distribution Network with very less investment which generates power of few Mega Watts . Distribution network which is the last stage of delivery of electricity to consumers experiences losses which can be minimized by local Distributed generators (DG). Distributed Generation also called as decentralized generation, on site generation are incorporated in the Distribution Network to eliminate the interdependencies on the utility and also for the continuous supply of power which boosts the efficiency in the delivery of power to the consumers. The Distributed Generators incorporated are time varying where repetitive power flow simulations are done to calculate the power losses which is time consuming and makes the calculation complex. Optimal placement of DG plays a significant role in minimizing power losses in Distribution systems. In this paper the total power losses of the distribution network (IEEE-69 bus) for any new DG condition is estimated by a single power flow method called Second order power flow sensitivities which helps in modeling the non linear nature of power losses. Therefore this method speeds up the solution of power losses reduction, DG allocation problems where several DG configurations are taken into consideration.*

Key Words: *Distributed Generation (DG), Decentralized generation, on site generation, Distribution Network (DN), second order power flow sensitivities, non linear losses*

1. Introduction

The first order sensitivity method such as Newton Raphson when used yields results only for operating conditions around base case DG. The error between the first order sensitivities and the power losses grow exponentially for large excursions of DG power output this is due to quadratic behavior of losses whose first order sensitivities may change significantly for large DG variation. To solve this issue this paper presents the method to estimate the total power losses of DNs for any DG condition.

Second order sensitivity method is Taylor series expansion up to second degree which includes second order sensitivities based on power flow Hessian matrix. The Taylor series expansion till second order is as given below:

$f^{1}(x)*\Delta x$ **is the active or reactive power losses deviation** due to the first order derivative of $f(x) = P_{loss}$ or Q_{loss} relative to x

$\frac{1}{2}*f^{11}(x)*\Delta x^2$ is ΔP^{11}_{loss} or ΔQ^{11}_{loss}

The total active and reactive power losses are estimated **by considering lumped π circuit model of distribution** network as shown in fig (1)

$$P_{loss} = \sum_{km \, \epsilon \, \Omega_r}[g_{km}(V_k^2 + V_m^2 - 2V_k V_m \cos\theta_{km})]$$
....(1)

$$Q_{loss} = \sum_{km \in \Omega_r}[-b^{sh}_{km}(V_k^2 + V_m^2) - b_{km}(V_k^2 + V_m^2 - 2V_kV_m \cos\theta_{km})]$$
................................(2)

θ_{km} is the difference between phase angles of buses k and m

Vk and Vm are the nodal voltage of bus k and bus m respectively

g_{km} and b_{km} are the conductance and the susceptance of the line k-m respectively.

The second order partial derivatives of the real power losses are as shown below from (3) to (9) obtained from (1)

$$\frac{\partial P_{loss}^2}{\partial \theta_k^2} = \sum_{m\in\Omega_k} 2\,g_{km}\,V_k\,V_m\cos\theta_{km} \quad \forall k \in \Omega_n \quad\text{................. (3)}$$

$$\frac{\partial P_{loss}^2}{\partial \theta_m \partial \theta_k} = -2\,g_{km}\,V_k\,V_m\cos\theta_{km} \quad \forall k \in \Omega_n \wedge \forall_m \in \Omega_k \text{......... (4)}$$

$$\frac{\partial P_{loss}^2}{\partial v_k \partial \theta_k} = \frac{\partial P_{loss}^2}{\partial \theta_k \partial v_k} = \sum_{m \in \Omega_k} 2\,g_{km}\,V_m \sin\theta_m \quad \forall k \in \Omega_n \text{......... (5)}$$

$$\frac{\partial P_{loss}^2}{\partial v_m \partial \theta_k} = 2\,g_{km}\,V_k \sin\theta_{km} \quad \forall k \in \Omega_k \wedge \forall m \in \Omega_k \text{............... (6)}$$

$$\frac{\partial P_{loss}^2}{\partial v_k^2} = \sum_{m \in \Omega_k} 2\,g_{km} \quad \forall k \in \Omega_k \text{.................................. (7)}$$

$$\frac{\partial P_{loss}^2}{\partial v_m \partial v_k} = -2g_{km}\cos\theta_{km} \quad \forall k \in \Omega_n \wedge \forall m \in \Omega_k \text{.................... (8)}$$

$$\frac{\partial P_{loss}^2}{\partial \theta_m \partial v_k} = -2\,g_{km}\,V_m \sin\theta_{km} \quad \forall k \in \Omega_n \wedge \forall m \in \Omega_k \text{............... (9)}$$
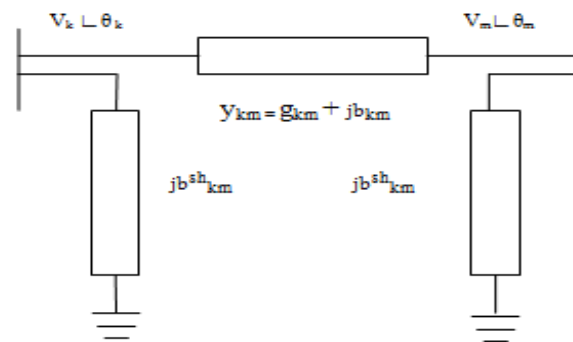
Where Ω_k is the set of buses connected to bus k and Ω_n is the total number of buses of the distribution network

The reactive power losses are also derived in the same manner as shown for the active power losses

The second order active power loss sensitivities for a system with n buses can be calculated from (10) to (13) they are called as Hessian matrix.

1.1 Hessian Matrix 1

It is a square matrix which contains second order partial derivatives as shown above. We are using the Hessian matrix in the calculation of active and reactive loss sensitivities.

$$H_P^{\theta\theta} = \frac{\partial P_{loss}^2}{\partial \theta^2} = \begin{bmatrix} \frac{\partial P_{loss}^2}{\partial \theta_1^2} & \cdots & \frac{\partial P_{loss}^2}{\partial \theta_1 \partial \theta_{n-1}} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_{loss}^2}{\partial \theta_{n-1} \partial \theta_1} & \cdots & \frac{\partial P_{loss}^2}{\partial \theta_{n-1}^2} \end{bmatrix}$$
................................(10)

Fig 1: **Distribution network represented by π circuit model**

$$H_P^{\theta V} = \frac{\partial P_{loss}^2}{\partial \theta \partial v} = \begin{bmatrix} \frac{\partial P_{loss}^2}{\partial \theta_1 \partial v_1} & \cdots & \frac{\partial P_{loss}^2}{\partial \theta_1 \partial v_{n-1}} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_{loss}^2}{\partial \theta_{n-1} \partial v_1} & \cdots & \frac{\partial P_{loss}^2}{\partial \theta_{n-1} \partial v_{n-1}} \end{bmatrix}$$
.... (11)

$$H_P^{V\theta} = \frac{\partial P_{loss}^2}{\partial v \partial \theta} = \begin{bmatrix} \frac{\partial P_{loss}^2}{\partial V_1 \partial \theta_1} & \cdots & \frac{\partial P_{loss}^2}{\partial V_n \partial \theta_{n-1}} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_{loss}^2}{\partial V_{n-1} \partial \theta_1} & \cdots & \frac{\partial P_{loss}^2}{\partial V_{n-1} \partial \theta_{n-1}} \end{bmatrix} \quad\quad (12)$$

$$H_P^{VV} = \frac{\partial P_{loss}^2}{\partial v^2} = \begin{bmatrix} \frac{\partial P_{loss}^2}{\partial V_1^2} & \cdots & \frac{\partial P_{loss}^2}{\partial V_1 \partial V_{n-1}} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_{loss}^2}{\partial V_{n-1} \partial V_1} & \cdots & \frac{\partial P_{loss}^2}{\partial V_{n-1}^2} \end{bmatrix} \quad\quad (13)$$

The order of all the matrices is n-1 * n-1 which means there is one power loss sensitivity for each bus of the system except for the substation bus, where voltage magnitude and phase angle are assumed to be fixed. The reactive power loss sensitivities ($H_Q^{\theta\theta}, H_Q^{\theta V}\ H_Q^{\theta V} H_Q^{VV}$) are similar to (10) to (13) with P_{loss} replaced by Q_{loss}. The elements of these four sensitivity matrices are obtained by differentiating (2) twice with respect to voltage magnitude (V) and phase angle (θ) .

The second order sensitivity power flow is applied to IEEE-69 bus Distribution network and the power losses are estimated in the same.
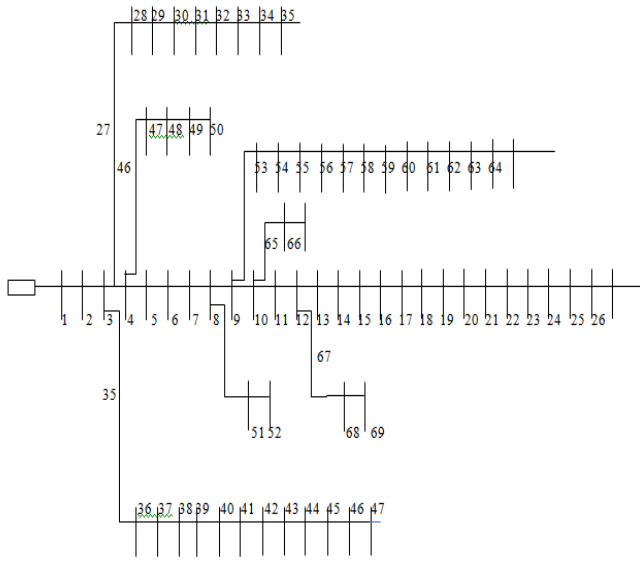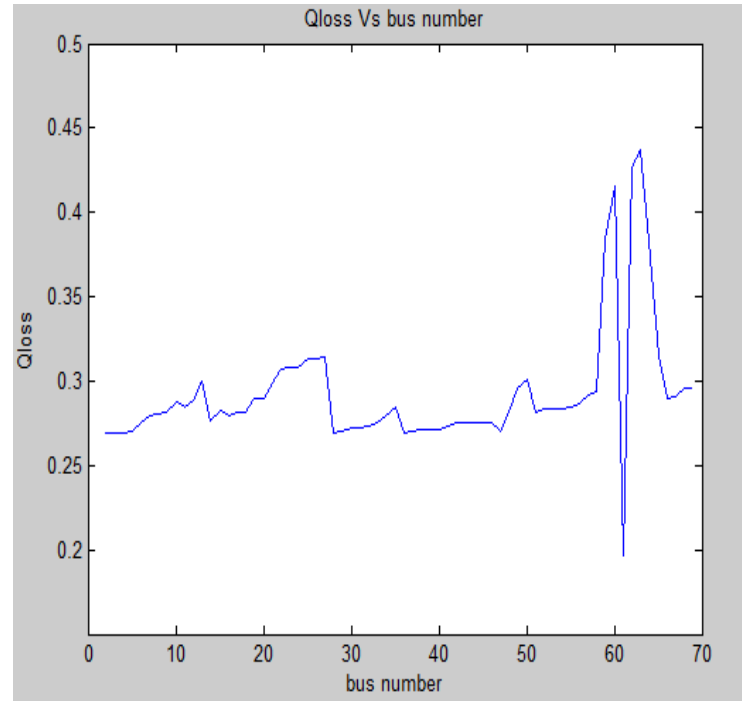
2. Flow Chart 2
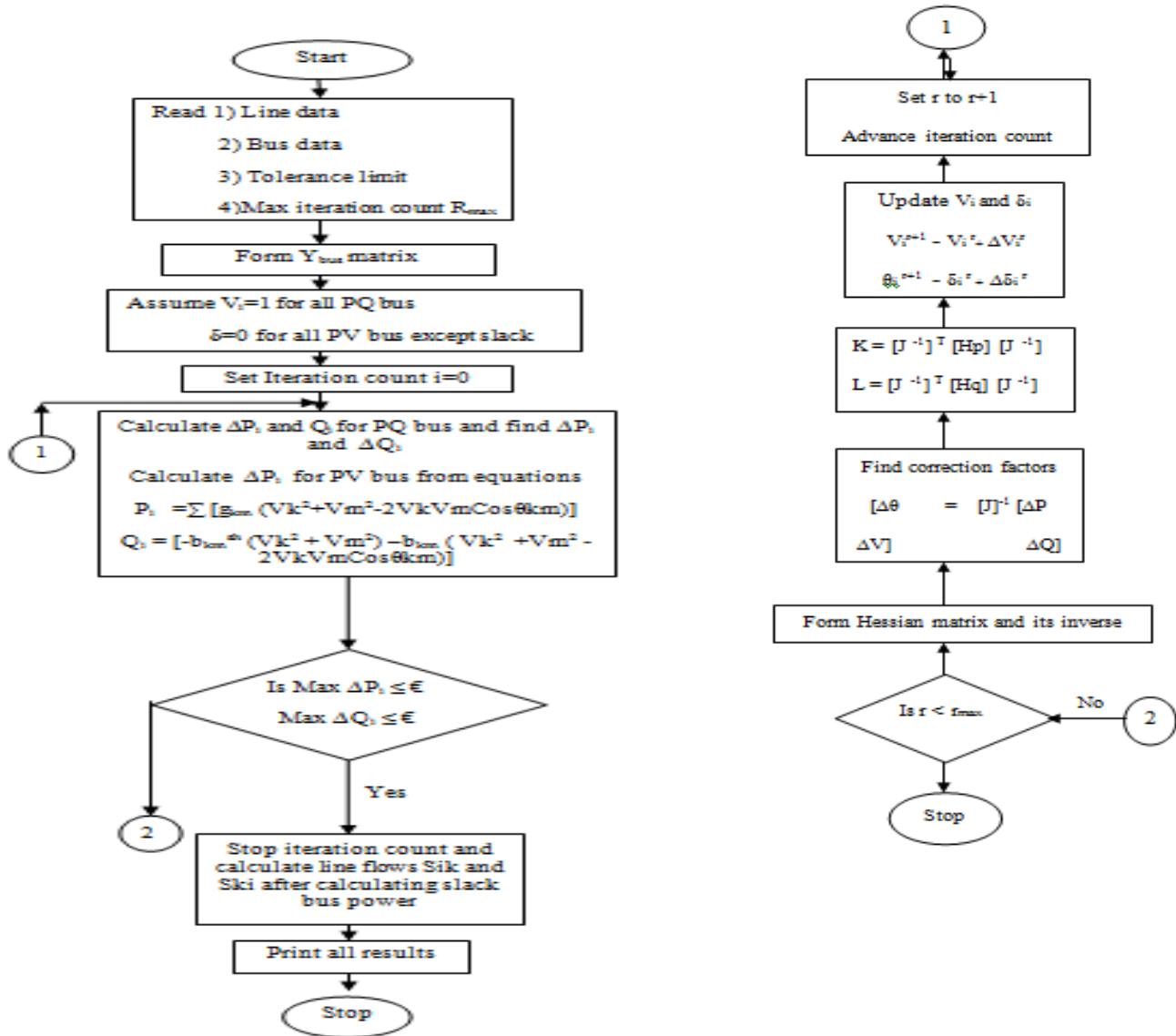
Fig 3: Total active power losses under maximum demand

of 500kW.

Fig 2: IEEE 69 bus Distribution Network

3. RESULTS

3.1 Location of DG 1

The active and reactive power losses when the DG is placed at different buses are as shown in figure (1) and (2) respectively. The graph tells us clearly the power losses totally depend on the DG placement. When the DG is placed at bus 62 it supplies the demand of downstream buses 63-66 which in turn reduces the power flow passing through the buses upstream of bus 63 (e.g., buses 1-9). As a result total power losses are decreases.
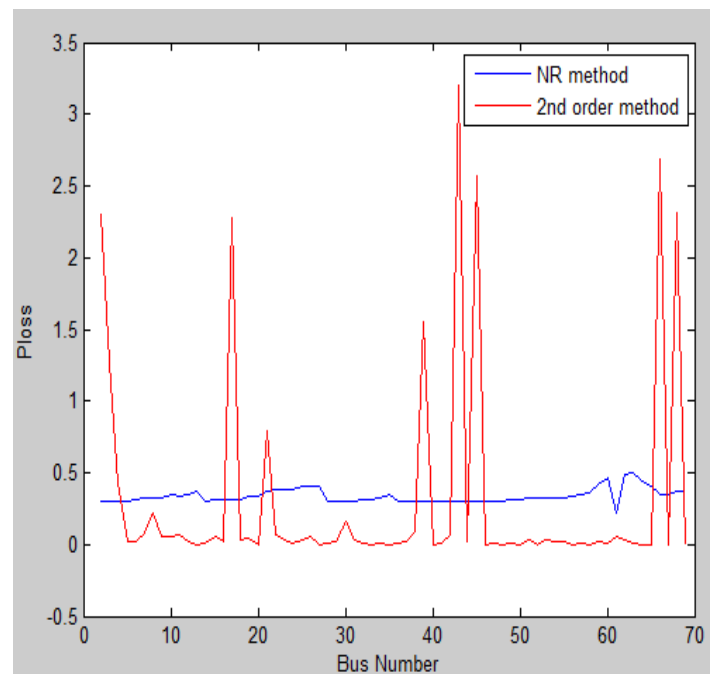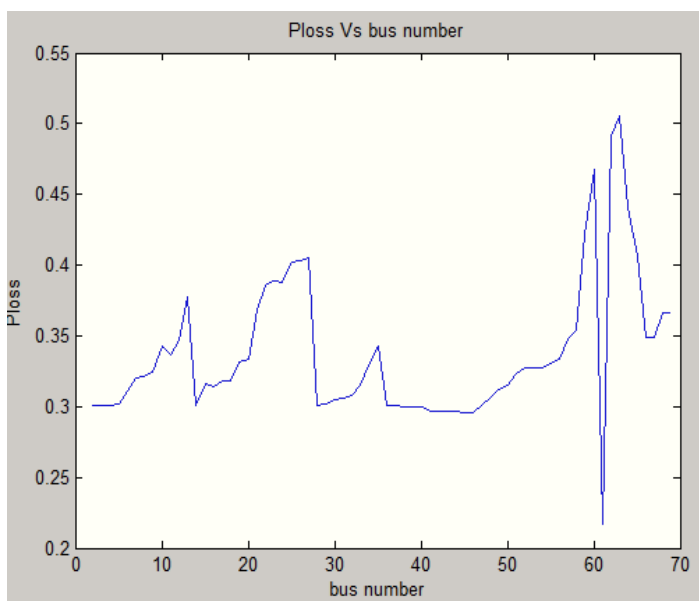

Fig 4: Total reactive power losses under maximum demand of 500kW.

Fig 5: Comparision of first order and second order sensitivities method.

Table-1: Comparision of real power losses in IEEE-69 bus test system without placement of DG.

Sl.no	First order Sensitivity Method(MW)	Second Order Sensitivity Method(MW)
1.	22.9345	23.2842

Table-2: Comparison of real power losses in IEEE-69 bus test system with placement of DG at 62nd bus.

| Sl.no	Rating of DG(MW)	First order Sensitivity Method(kW)	Second Order Sensitivity Method(kW)
1.	0.5	16.9664	23.3039
2.	0.75	14.8584	23.3127

The exact power losses are obtained by Second order power flow method. With and without DG placement as we can see from Table (1) and (2) .

3.2 DG unit's contribution to power losses reduction 2

Power losses impact when the DG is placed at different buses with fixed and varied generation is explained in this section. The Distribution network as shown in figure (2) is supplied by two DG units. One DG is placed at 18th bus with fixed generation of 500kW and another DG is placed at 66th bus with varied generation from 0 to 500kW through steps of 50kW.

We can observe that as DG unit placed at 66th bus is varied in steps i.e., as the generation level is increased the impact of DG_{66} is increased. When both the DG's are operating at 500kW we find out that it is advantageous to install a DG
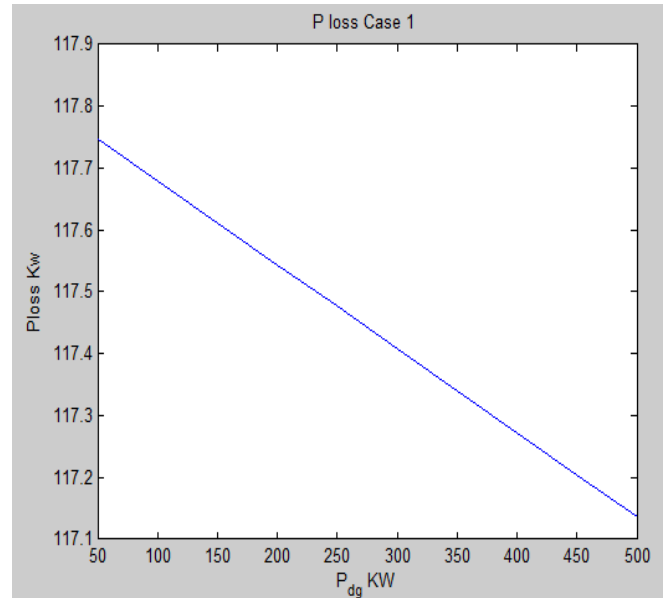
unit at 66th bus than at 18th bus.

The real and reactive power losses with the placement of DG are as shown in figure (6) and (7) .

Fig 6: Real power losses when DG is placed at 18th bus with fixed generation of 500kW and variable generation in steps of 50kW at 66th bus
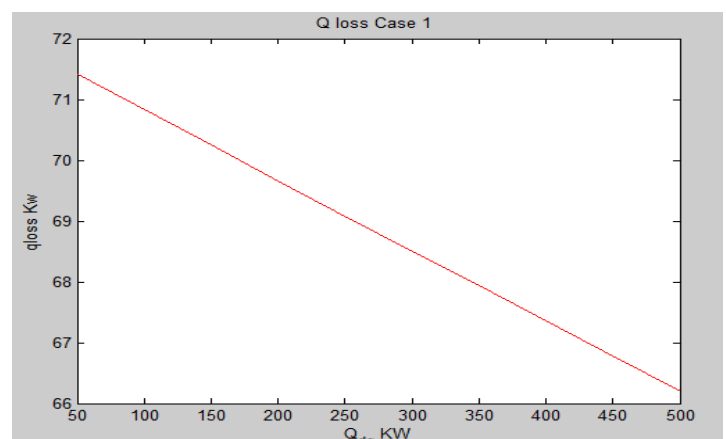

Fig 7: Reactive power losses when DG is placed at 18th bus with fixed generation of 500kW and variable generation in steps of 50kW at 66th bus

4. CONCLUSIONS

The second order method is effectively tested on IEEE-69 bus distribution network and gives the exact active and reactive power losses with all the DG conditions when compared to first order method. Here we are using loss sensitivities where non linear nature of power losses is modeled.

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