Voltage Profile improvement and power loss reduction for Constant Power type of Loads

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Abstract

The load flow calculation mainly involves for calculating the voltages at each load points and real and reactive power losses across each branch. The classical constant power load model is typically used in power flow studies of transmission or distribution Systems; however, the actual load of a distribution system cannot just be modeled using constant power models, requiring the use of constant current, constant impedance, exponential or a mixture of all these load models to accurately represent the load. This paper presents a study of voltage profile improvement and power loss reduction for constant power type of load model.

Keywords: Distribution systems, Load flow, static load models, voltage profile, and power loss.

1. Introduction

In the distribution system, the power quality supply not only depends on the frequency but also depends on the voltage at which consumer utilisation. The allowable range of frequency is +5% to -5%.however a low steady-state voltage leads to low illumination levels, shirking of television pictures, slow heating of heating devices, motor starting problems, and overheating in motors. The permissible voltage level is +6% to -13% for satisfactory operation of various devices. The loads connected to the distribution system are certainly voltage dependent; thus, these types of load characteristics should considered in load flow studies to get accurate results and to avoid costly errors in the analysis of the system. For example, in voltage regulation improvement studies, possible under- or over-compensation can be avoided if more accurate results of load flow solutions are available, as demonstrated in this paper. However, most conventional load flows use a constant power load model, which assumes that active and reactive powers are independent of voltage changes.

2. Static Load Models

Load models are traditionally classified into two broad categories: static models and dynamic models. Dynamic load models are not important in load flow studies. Static load models, on the other hand, are relevant to load flow studies as these express active and reactive steady state powers as functions of the bus voltages (at a given fixed frequency). These are typically categorized as follows:

Constant power load model (constant P): A static load model where the power does not vary with changes in voltage magnitude. It is also known as constant MVA load model

Constant current load model (constant I): A static load model where the power varies directly with voltage magnitude.

$$P \propto V$$

Constant impedance load model (constant Z): A static load model where the power varies with the square of the voltage magnitude. It is also referred to as constant admittance load model.

$$P \propto V^2$$

Exponential load model: A static load model that represents the power relationship to voltage as an exponential equation in the following way:

$$P \propto \left(\frac{V}{V_0}\right)^{\alpha}$$

3. Proposed Load Flow method

The load flow of distribution system is different from that of transmission system because it is radial in nature and has high R/X ratio. Convergence of load flow is utmost important. Literature survey shows that the following works had been carried out on load flow studies of electric power distribution systems.

In this method of load flow analysis the main aim is to reduce the data preparation and to assure computation for any type of numbering scheme for node and branch. If the nodes and branch numbers are sequential, the proposed method needs only the starting node of feeder, lateral(s) and sub lateral(s) only. The proposed method needs only the set of nodes and branch numbers of each feeder, lateral(s) and sub-lateral(s) only when node and branch numbers are not sequential. The proposed method computes branch power flow most efficiently and does not need to store nodes beyond each branch. The voltage of each node is calculated by using a simple algebraic equation. Although the present method is based on forward sweep, it computes load flow of any complicated radial distribution networks very efficiently even when branch and node numbering scheme are not sequential. A 33-node radial distribution networks with constant power (CP) modeling is considered.

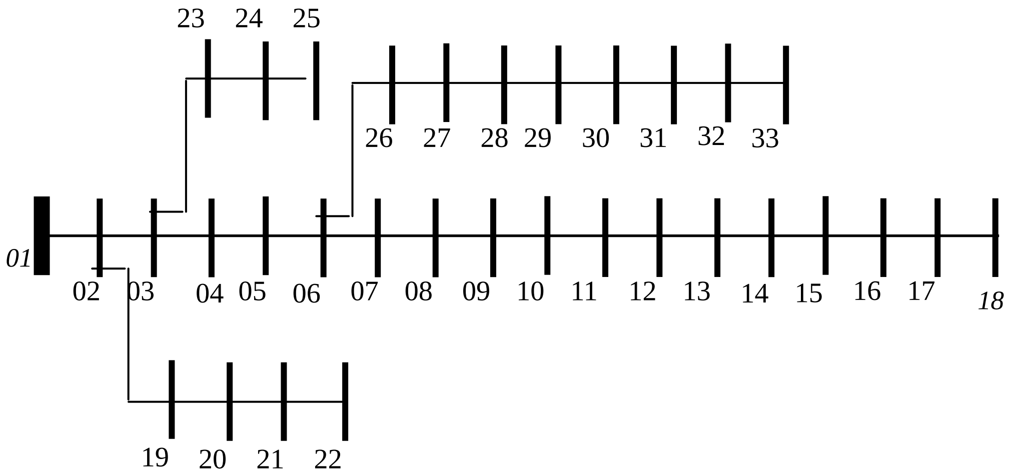

Fig1: Diagram of 33 Bus Distribution Systems

4. Solution methodology

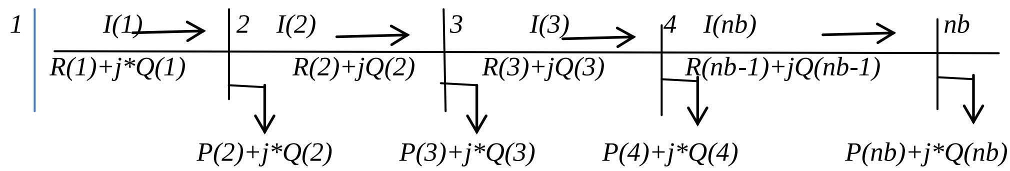

Fig 2. Radial main feeder

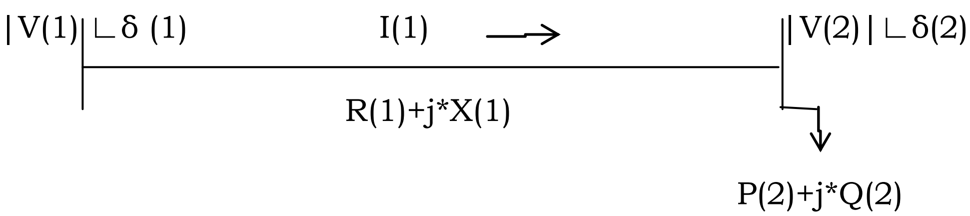

Fig. 3 Electrical equivalent of fig 1.

Consider a distribution system consisting of a radial main feeder only. The one line diagram of such a feeder comprising n nodes and n-1 branches is shown in Fig.2. Fig.3 shows the electrical equivalent of Fig.2. From Fig.3, the following equations can be written

$$I(1) = \frac{|V(1)|\angle\delta(1) - |V(2)|\angle\delta(2)}{(R(1)+j*X(1))} \qquad (1)$$

$$P(2)-j*Q(2)=V^*(2)I(1) \qquad (2)$$

From eqns. 1 and 2 we have

$$|V(2)|=[\{P(2)R(1)+Q(2)X(1)-0.5|V(1)|^2)^2 - (R^2(1)+X^2(1))(P^2(2)+Q^2(2))\}^{1/2} -(P(2)R(1)+Q(2)X(1)-0.5|V(1)|^2)]^{1/2} \qquad (3)$$

Eqn. 3 can be written in generalized form

$$|V(i+1)|=[\{P(i+1)R(i)+Q(i+1)X(i)-0.5|V(i)|^2)^2 - (R^2(i)+X^2(i))(P^2(i+1)+Q^2(i+1))\}^{1/2} -(P(i+1)R(i)+Q(i+1)X(i)-0.5|V(i)|^2)]^{1/2} \qquad (4)$$

Eqn. 4 is a recursive relation of voltage magnitude. Since the substation voltage magnitude |V(1)| is known, it is possible to find out voltage magnitude of all other nodes. From Fig.3 the total real and reactive power load fed through node 2 are given by

$$P(2)=\sum_{i=2}^{nb} PL(i)+ \sum_{i=2}^{nb-1} LP(i) \qquad (5)$$

$$Q(2)=\sum_{i=2}^{nb} QL(i)+ \sum_{i=2}^{nb-1} LQ(i)$$

It is clear that total load fed through node 2 itself plus the load of all other nodes plus the losses of all branches except branch 1.

$$LP(1)=(R(1)*[P^2(2)+Q^2(2)])/(|V(2)|^2) \qquad (6)$$

$$LQ(1)=(X(1)*[P^2(2)+Q^2(2)])/(|V(2)|^2)$$

Eqn. 5 can be written in generalized form

$$P(i+1)= \sum_{i=2}^{nb} PL(i)+ \sum_{i=2}^{nb-1} LP(i) \quad \text{for } i=1, 2,\ldots\ldots, NB-1 \qquad (7)$$

$$Q(i+1)= \sum_{i=2}^{nb} QL(i)+ \sum_{i=2}^{nb-1} LQ(i) \quad \text{for } i=1, 2,\ldots\ldots, NB-1$$

Eqn. 6 can also be written in generalized form

$$LP(i)=(R(i)*[P^2(i+1)+Q^2(i+1)])/(|V(i+1)|^2) \qquad (8)$$

$$LQ(1)=(X(i)*[P^2(i+1)+Q^2(i+1)])/(|V(i+1)|^2)$$

Initially, if LP(i+1) and LQ(i+1) are set to zero for all I, then the initial estimates of P(i+1) and Q(i+1) will be

$$P(i+1)= \sum_{i=2}^{nb} PL(i) \quad \text{for } i=1, 2,\ldots\ldots, NB-1 \qquad (9)$$

$$Q(i+1)= \sum_{i=2}^{nb} QL(i) \quad \text{for } i=1, 2,\ldots\ldots, NB-1$$

Eqn. 9 is a very good initial estimate for obtaining the load flow solution of the proposed method.

The convergence criteria of this method is that if the difference of real and reactive power losses in successive iterations in each branch is less than 1 watt and 1 var, respectively, the solution has converged.

5 Algorithm for load flow computation

The complete algorithm for load flow calculation of radial distribution network is shown in below.

Step1 : Read the system voltage magnitude |v(i)|, line parameters and load data.

Step2 : Read base KV and base MVA.

Step3 : Read total number of nodes nb,

Step4 : compute per unit values of load powers at each node i.e. pl(i) And ql(i) for i=1, 2, 3,…nb, as well as resistance and reactance of each branch i.e. r(j) and x(j) for j=1, 2,3,……..nb-1.

Step5 : By examine the radial feeder network note down the lateral number l, source node sn(l), node just ahead of source node lb()l, end node eb(l).

Step6 : Read the nonzero integer value f(i), i.e. whether node consists of lateral or not. If yes f(i)=1, otherwise f(i)=0, for i=1, 2, 3,…nb

Step7 : Initialize the branch losses lp(i)=0.0, lq(i)=0.0 for i=1, 2, 3,.nb-1

Step8 : set iteration count IT=1, ε(0.0001).

Step9 : compute TP(l) and TQ(l) by using eqn. 10

Step10 : compute TP(1)=sum(TP), TQ(1)=sum(TQ).

Step11 : set the losses ploss(i)=lp(i), qloss(i)=lq(i) for i=1, 2, 3,…..nb-1

Step12 : l=1, p2=1

Step13 : for i=1

Step14 : set k=0, p1=1

Step15 : initialize spl(l)=0.0, sql(l)=0.0, ps(l)=0.0, qs(l)=0.0

Step16 : k=k+f(i)

Step17 : If f(i) is greater than zero go to next step otherwise go to step20

Step18 : compute ps(l) and qs(l) by using the formulae are
ps(l)=ps(l)+TP(l+i3), qs(l)=qs(l)+TQ(l+i3).

Step19 : p1=p1+f(i)

Step20 : compute node real power and reactive powers by using eqn. 7

Step21 : solve the eqn. 4 for |v(i+1)|

Step22 : i is incremented by i+1

Step23 : If i is not equal to eb(l) go to next step otherwise go to step26

Step24 : compute spl(l), sql(l) by using eqns.
SPL(l)=SPL(l)+PL(i)+LP(i)
SQL(l)=SQL(l)+QL(i)+LQ(i)

Step25 : Then go to step 16

Step26 : |v1(j)|=|v(j)| for j=p2 to eb(l).

Step27 : If i is not equal to nb then go to next step otherwise go to step32

Step28 : set k1=eb(l), p2=eb(l+1)

Step29 : l is incremented by l+1.

Step30 : set k2=sn(l)

Step31 : set |v(k1)|=|v(k2)| then go to step step5.

Step32 : compute lp(i), lq(i) by using eqn.8 for i=1, 2, 3,…nb-1

Step33 : compute dp(i) and dq(i) by using eqns
dp(i)=lp(i)-ploss(i)
dq(i)=lq(i)-qloss(i) for i=1, 2, 3,…nb-1

Step34 : If (max |(dp(i))| & max|(dq(i))|) is less than not equal ε go to next step otherwise go to step36

Step35 : write voltage magnitudes and feeder losses.

Step36 : stop.

6 Sensitivity Analysis and Loss Sensitivity Factors

A Sensitivity Analysis is used to determine the candidate nodes for the placement of capacitors using Loss Sensitivity Factors. The estimation of these candidate nodes basically helps in reduction of the search space for the optimization procedure. The sensitivity analysis is a systematic procedure to select those locations which have maximum impact on the system real power losses, with respect to the nodal reactive power.

Loss Sensitivity Factors can be obtained as

$$\left[\frac{dP_{LINELOSS}}{dQ_{eff}}\right] = \left(\frac{2*Q(q)*R(k)}{V(q)^2}\right)$$

Where

Qeff [q] = Total effective reactive power supplied beyond the node ‘q’.

Plineloss=Active Power loss of the kth line.

R[k] =Resistance of the kth line.

V[q] =Voltage at node’q’.

∂ Ploss/ ∂ Q = Loss Sensitivity Factor.

7. Test results

Table 1 voltage profile improvement before and after capacitor placement for CP load

Node No.	Voltage Before Compensation (CP LOAD)	Voltage After Compensation (CP LOAD)
1	1.0000	1.0000
2	0.9970	0.9976
3	0.9829	0.9868
4	0.9755	0.9817
5	0.9681	0.9768
6	0.9497	0.9673
7	0.9458	0.9669
8	0.9413	0.9636
9	0.9351	0.9608
10	0.9293	0.9576
11	0.9284	0.9569
12	0.9269	0.9556
13	0.9208	0.9510
14	0.9180	0.9490
15	0.9171	0.9482
16	0.9157	0.9469
17	0.9137	0.9449
18	**0.9132**	**0.9440**
19	0.9965	0.9971
20	0.9929	0.9935
21	0.9919	0.9925
22	0.9916	0.9922
23	0.9794	0.9832
24	0.9727	0.9765
25	0.9694	0.9732
26	0.9477	0.9661
27	0.9452	0.9646
28	0.9334	0.9584
29	0.9255	0.9539
30	0.9220	0.9513
31	0.9178	0.9494
32	0.9169	0.9489
33	0.9166	0.9487

Base voltage=11kv Base MVA=1MVA

By loss sensitivity factor analysis, the optimal capacitor location is determined. It gives the sequence order for placing the capacitors location. By choosing a capacitor size of 1200 kvar at 6th node and 600 kvar at 28th node is selected for capacitor size in the constant power load model.

Table 2 Real and Reactive power loss for before and after compensation for CP load

S.NO	WITHOUT COMPENSATION	WITH COMPENSATION
REAL POWER LOSS(p.u)	0.200	0.145
REACTIVE POWER LOSS(p.u)	0.055	0.025

For constant power load model , by using conventional load flow method, the total real and reactive power losses are determined. Without compensation for constant power load model, the real power losses are 0.200 (p.u) and reactive power losses are 0.055 (p.u).by compensation the real and reactive power losses are respectively 0.160 (p.u) and 0.025 (p.u).similarly the voltage profile is also improved by placing the shunt capacitors across the nodes by selecting the location by loss sensitivity factor analysis.the minimum node voltage occurs at 18th node which is equal to 0.9132 9p.u) and voltage regulation is 9.50%.by compensation the minimum node voltage is 0.9440(p.u) and voltage regulation is reduces to 5.94%.

Table 3 voltage regulation CP load model with and without compensation

S.NO	WITHOUT COMPENSATION	WITH COMPENSATION
MINIMUM NODE VOL(p.u) (At 18th node)	0.9132	0.9440
VOLTAGE REGULATION	9.50%	5.94%

5. Conclusion

In this paper a method of load flow analysis has been proposed for radial distribution networks based on the forward sweeping method to identify the set of branches for every feeder, lateral and sub-lateral without any repetitive search computation of each branch current. Effectiveness of the proposed method has been tested by an example 33-node radial distribution network with constant power load. The power convergence has assured the satisfactory convergence in all these cases. The proposed method consumes less amount of memory compared to the other due to reduction of data preparation. A sensitivity factor analysis method is used for optimal capacitor location and by shunt compensation method, a capacitor of total size 1800kvar is placed across the 6th and 28th node for voltage profile improvement and power loss reduction.

References

M. H. Haque(1996), “Load flow solution of distribution systems with voltage dependent load models’’,
Int. J. Electric Power System Res., 36, 151–156.

D. Das, H. S. Nagi, and D. P. Kothari(1994)., ‘Novel methods for solving radial distribution networks’, IEE Proc. Generation T ransmission and Distribution, 141(4) .

M. A. Salama and A. Y. Chikhani(1993),, ‘A simplified network approach to the var control problem for radial distribution systems', IEEE Trans. Power Delivery, 8(3) , 1529–1535.

J. D. Glover and M. Sarma(1993), Power System Analysis and Design, 2nd edn (PWS Publishing Company, Boston,).

C. G. Renato(1990), "New method for the analysis of distribution networks", IEEE Trans. Power Delivery, 5(1), 391–396.

M. E. El-Hawary and L. G. Dias(1987), 'Incorporation of load models in load-flow studies: form of models effects', IEE Proc. C, 134(1) , 27–30.

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