배전자동화 시스템에서 분포부하를 고려한 새로운 조류계산 알고리즘

양하, 최면송, 임일형, 이승재
명지대학교 차세대전력기술연구센터

A New Load Flow Algorithm based on DAS with Considering Distributed Load

Xia Yang, Myeon-Song Choi, Il-Hyung Lim, Seung-Jae Lee
Myongji-university Next-generation Power Technology Center

Abstract - In this paper, A new algorithm for load flow calculation is proposed for radial distribution network. Feeder Remote Terminal Unit (FRTU) is utilized to collect data such as current magnitude and angle of power factor at each node. Proposed algorithm is based on the model of distributed load in distribution system. Load flow calculation is using four terminal constants method.

1. Introduction

Power flows are categorized into transmission power flow and distribution power flow. The conventional load flow methods developed for solving transmission networks may encounter convergence problems when applied to distribution networks. Moreover, the loads in distribution networks are distributed and always varying with a series of change when it is in the different conditions.

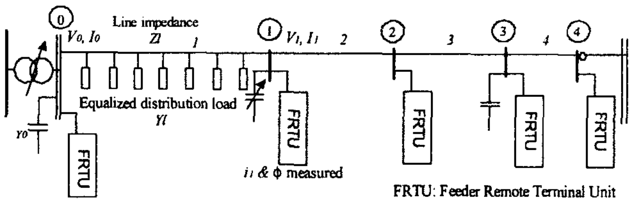
Some work has been carried out on load flow analysis in distribution networks. Forward sweeping method has been proposed for solving radial distribution networks by evaluating the total real and reactive power fed through any node [1]. Reference [2] proposes another method for power flow solution in the forward and backward sweep. A simple method for solving radial distribution networks is by evaluation only a simple algebraic expression of receiving-end voltage [3].

Proposed algorithm is using a new modeling which considers the load is equalized to distribute in each line in distribution system. And it is based on distribution automation system (DAS), in which remote terminal units (RTUs) collect data automatically to provide for load flow calculation.

2. Proposed Algorithm

2.1 Overview of Proposed Algorithm

Figure 1 shows a diagram of a simple distribution system consisting of 5 nodes with FRTU respectively. Given the magnitude and phase angle of the voltage and current at node 0, then those data at node 1 is calculated through the proposed algorithm, then it would be moved to the next section between node 1 and 2. In the second section, the magnitude and phase angle of the voltage and current at node 2 is calculated in the same way. Then moving the section one by one, those data at the last node of the system would be achieved.



<Fig.1> A simple distribution system

2.2 Load Flow Solution in distributed Modeling System

The one-section modeling between nodes p and q is shown in Fig. 2. Line impedance zk and equalized load admittance yk are distributed at every dx in the line. The basic equations of voltage drop and current drop are illustrated as follows.

$$dV(x) = -I(x)zdx \quad (1) \qquad dI(x) = -V(x)ydx \quad (2)$$

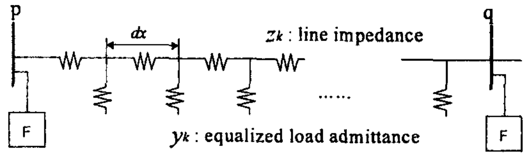
where, zdx is line impedance in the unit length, ydx is load admittance in the unit length.

Through a series of differential calculations, the aforementioned equations can be solved. The solutions of the voltage and current are calculated in (3) and (4).

$$V(x) = C_1 \cosh \gamma_k x + C_2 \sinh \gamma_k x \quad (3)$$

$$I(x) = C_3 \sinh \gamma_k x + C_4 \cosh \gamma_k x \quad (4)$$

where, $\gamma_k = \sqrt{z_k y_k}$ is the characteristic constant of the line.



<Fig.2> Distribution system modeling

Assuming Lk is the length of one section, the data of the voltage and current at the load side would be achieved in the case of x=Lk. The expressions of the equations are shown in (5) and (6).

$$V_q = V_p \cosh \beta_k - Z_k I_p \sinh \beta_k \quad (5)$$

$$I_q = -\frac{V_p}{Z_k} \sinh \beta_k + I_p \cosh \beta_k \quad (6)$$

where, $Z_k = \sqrt{z_k / y_k}$, $\beta_k = \gamma_k L_k$

To get load admittance yk, some information at the load-side node is needed: (i) the magnitude of current is measured by FRTU; (ii) the phase angle difference between the voltage and the current is acquired by FRTU, and it is same as the angle of power factor.

There are two cases in the distribution line. One is the line in a special section which is connected with a feeder end; The other is the line in a normal section which is not connected with a feeder end.

For the former, the current at the end of the feeder is zero.

$$I_q = -\frac{V_p}{Z_k} \sinh \beta_k + I_p \cosh \beta_k = 0 \quad (7)$$

Substituting (5) and (6) into (7), it is able to achieve yk through Newton-Raphson iteration method.

Then for the second case, two equations are found out:

$$i_q^2 = I_q \cdot I_q^* \quad (8)$$

$$(V_q I_q^*)^2 = v_q^2 i_q^2 \cos^2 \varphi_q \quad (9)$$

Substituting (5) and (6) into (8) and (9), they are expressed as follows:

$$i_q^2 = (I_p \cosh \beta_k - \frac{V_p}{Z_k} \sinh \beta_k)(I_p \cosh \beta_k - \frac{V_p}{Z_k} \sinh \beta_k)^* \quad (10)$$

$$\left((V_p \cosh\beta_k - Z_k I_p \sinh\beta_k) \cdot (I_p \cosh\beta_k - \frac{V_p}{Z_k} \sinh\beta_k) \right)^2 = i_q^2 (\cos\varphi_q)^2 (V_p \cosh\beta_k - Z_k I_p \sinh\beta_k)(V_p \cosh\beta_k - Z_k I_p \sinh\beta_k)^* \quad (11)$$

where, i_q is the magnitude of current at load-side node q φ_q is the angle of power factor at load-side node q. As mentioned above, both of them are measured by FRTU.

In terms of (10) and (11), yk can be solved through Newton-Raphson method, which is same as done in the first case.

2.3 Four Terminal Constants

But for a complicated radial system, itis very hard to get the solution of load flow for each node in this way. So the method of four terminal constants has been used to simplify the process of load flow calculation. Actually, (5) and (6) can be expressed as shown in (12) and (13) in matrix form.

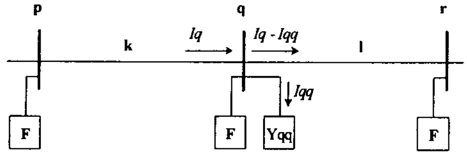
$$\begin{pmatrix} V_q \\ I_q \end{pmatrix} = \begin{pmatrix} A_k & B_k \\ C_k & D_k \end{pmatrix} \begin{pmatrix} V_p \\ I_p \end{pmatrix} \tag{12}$$

And compared with (5) and (6), it is easy to achieve the coefficient matrix as follows:

$$\begin{pmatrix} A_k & B_k \\ C_k & D_k \end{pmatrix} = \begin{pmatrix} \cosh\beta_k & -Z_k \sinh\beta_k \\ -\frac{1}{Z_k}\sinh\beta_k & \cosh\beta_k \end{pmatrix} \tag{13}$$

The coefficient matrix (13) is called four terminal constants. And it is a basal form of four terminal constants. Since radial distribution networks have many different cases at different node, so the extension forms of four terminal constants are analyzed as follows.

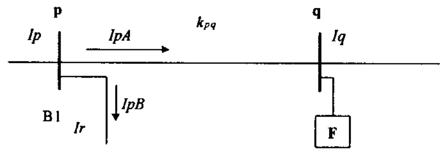
(1) Node with out-flowing current



<Fig.3> Node with out-flowing current case

$$\begin{pmatrix} A_l & B_l \\ C_l & D_l \end{pmatrix} = \begin{pmatrix} \cosh\beta_l + Y_{qq} Z_l \sinh\beta_l & -Z_k \sinh\beta_l \\ -\frac{1}{Z_l}\sinh\beta_l - Y_{qq}\cosh\beta_l & \cosh\beta_l \end{pmatrix} \tag{17}$$

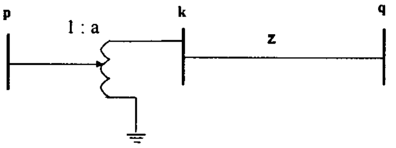
(2) Node with lateral



<Fig.4> Node with lateral case

$$\begin{pmatrix} A_k & B_k \\ C_k & D_k \end{pmatrix} = \begin{pmatrix} \cosh\beta_k & -K_{pq} Z_k \sinh\beta_k \\ -\frac{1}{Z_k}\sinh\beta_k & K_{pq}\cosh\beta_k \end{pmatrix} \tag{24}$$

(3) Node with Transformer



<Fig.5> Node with transformer

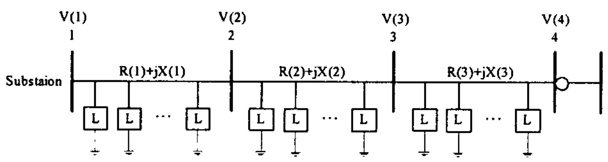
$$\begin{pmatrix} A_k & B_k \\ C_k & D_k \end{pmatrix} = \begin{pmatrix} a & -z/a \\ 0 & 1/a \end{pmatrix} \tag{25}$$

Where, z is the impedance of the transformer. The ratio of the transformer is 1:a.

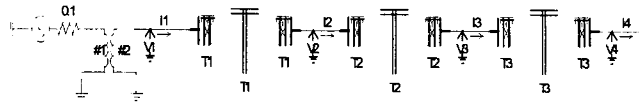
3. Case Study

3.1 Case Study 1

The comparison results between the proposed algorithm and a conventional algorithm [1] are demonstrated. The conventional algorithm regards that the load is concentrative at the end of each section. Fig.6 shows a single line diagram of a main feeder in distribution system. There are three sections in it, the length of each section is 5 [km]. Fig.7 is the simulation model in EMTDC. The comparison results between the simulation and both algorithms are tabulated in Table 1.



<Fig.6> Single line diagram of a main feeder



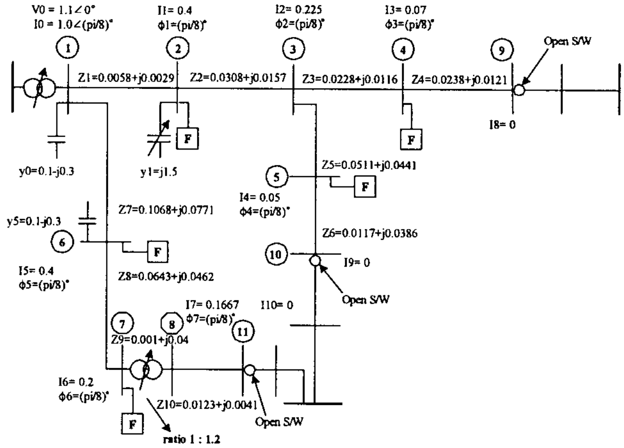
<Fig.7> The simulation model

<TABLE 1> Comparison Results

Types V [p.u]	Simulation Results	Proposed Algorithm	Conventional Algorithm
V(1)	1.0000	1.0000	1.0000
V(2)	0.9102	0.9103	0.8815
V(3)	0.8647	0.8647	0.8115
V(4)	0.8510	0.8510	0.7795

3.2 Case Study 2

Proposed algorithm is testified in a simple radial distribution system with 11 nodes. All line impedances and the transformer impedance have been marked in Fig.8. In addition, the ratio of the transformer is 1:1.2. The angle of power factor is pi/8; and the compensation factor of the capacitances is 0.03. The results are shown in Table 2.



<Fig.8> A simple radial distribution system

<TABLE 2> Results for the System

Node	V	V_θ	I	I_θ
1	1.0000	0.0000	1.0000	-0.5236
2	0.9971	-0.0001	0.4000	-0.3050
3	0.9749	0.0215	0.2250	-0.2834
4	0.9726	0.0210	0.0750	-0.2838
5	0.9698	0.0194	0.0500	-0.3733
6	0.9417	-0.0097	0.4000	-0.4024
7	0.9186	-0.0156	0.2000	-0.4083
8	1.0996	-0.0211	0.1667	-0.4083
9	0.9716	0.0209	0.0000	-0.1604
10	0.9692	0.0186	0.0000	0.5045
11	1.0985	-0.0211	0.0000	-0.4636

4. Conclusion

A new algorithm of load flow analysis has been proposed for radial distribution system based on DAS. And it is using distributed load modeling of distribution networks. Meanwhile, the method of four terminal constants is utilized to simplify the load flow calculation.

5. Acknowledgment

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