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분산전원의 특성을 고려한 조류계산의 새로운 알고리즘 고찰

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The algorithm of the load flow problem for integrated distributed generation network

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Abstract - The aim of this paper is to present a new algorithm for the load flow problem using modified Newton-Raphson (NR) iteration method and a approach to derive a simple formula to compensate the reactive power at some heavy load bus. The reactive power source used in this research is the DG which is adjacent to the heavy load.

Phenomena of low voltages may cause the load flow calculation process to diverge. In modified NR method, low voltages will be detected and corrected before the next iteration. Therefore, the results of load flow calculation process satisfy the voltage constraint i.e. higher than the lower voltage limit or higher than the critical voltage in case the conventional load flow diverges.

Linearizing the power network using PTDFs is a simple method with accepted errors. A new value of voltage at the DG terminal is computed in terms of the voltage deviation of load buses. In this approach, solving the entire system is unnecessary.

1. INTRODUCTION

In power system networks, if there are some heavy loads, voltage drop along transmission line is significant. This leads to a low voltage at the load and several undesirable consequences to the system. One of the most popular remedies for this problem is using compensation devices such as capacitor banks. However, these devices have some disadvantages. Therefore, using DGs as continuous reactive sources is proposed. A simple formula is needed to calculate the extra amount of the reactive power produced by DGs as well as the new voltage at the DGs terminal.

In this paper, modified NR method is introduced to guarantee the outcome of iteration within limits or to ensure convergence in case the conventional load flow problem diverges.

2. LOAD FLOW AND VOLTAGE CONTROL PROBLEM

2.1 Steady state voltage control

2.1.1 MIT method for steady state voltage monitoring and control

Reference [1] describes recent work on the theoretical and algorithmic enhancements of the MIT method for steady state voltage monitoring and control. The approach in the proposed method is to attempt to maintain a given "optimal" voltage profile as the load demand, generation availability and network topology vary. In mathematical terms, the problem is to minimize $\|\Delta V_L\|_2$, a vector of load voltage deviation only.

2.1.2 A matrix $[\alpha]$ based on PTDFs

The concept of PTDFs is useful to linearize the network then some simple relationships can be derived from the linear model. The desired results are the matrix $[\alpha]$ and matrix [p] satisfies:

$$\Delta V_{DG} = [\alpha][\Delta V_L] \quad (1)$$

$$\Delta Q_{DG} = [p][\Delta Q_L] \quad (2)$$

The approximation error depends on how to compute PTDFs. Therefore, accuracy of PTDFs is the key of the proposal method.

2.1.2.1 Computing PTDFs

The reactive power flows through the line (lij) between bus i and bus j can be computed as:

$$Q_{l(ij)} = -V_i^2 \cdot B_l - V_i \cdot V_j \cdot [G_l \cdot \sin(\delta_i - \delta_j) - B_l \cdot \cos(\delta_i - \delta_j)] \quad (3)$$

Since G_l and $(\delta_i - \delta_j)$ is neglected, PTDFs can be obtained:

$$p_{ij-k} = \frac{dQ_{l(ij)}}{dQ_{Lk}} = -B_{ij} \cdot \frac{d}{dQ_{Lk}}(V_i^2 - V_iV_j \cos\delta_{ij})$$

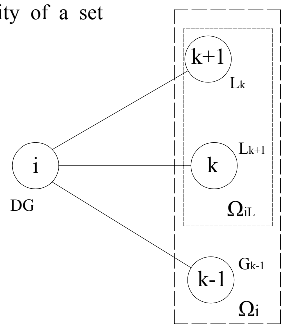
$$= -B_{ij}.V_i\left(\frac{2}{\frac{dQ_{Lk}}{dV_i}} - \frac{\cos\delta_{ij}}{\frac{dQ_{Lk}}{dV_j}}\right) \quad (4)$$

The DG resides at bus i and we define Ω_i and Ω_{iL} as:

Ω_i = {j | Bij>0}, $\aleph(\Omega_i) = g$

Ω_{iL} ={j | Bij>0 & bus j is a load bus} $\subset \Omega_i$, $\aleph(\Omega_{iL}) = h$ (h<g)

$\aleph$ is the cardinality of a set



<Fig 1> Illustration of Ω_i and Ω_{iL}

2.1.2.2 Computing [p] matrix

$$\Delta Q_{l(ij)} \approx \sum_{j\in\Omega_i, k\in\Omega_{iL}} \frac{dQ_{l(ij)}}{dQ_{Lk}} \Delta Q_{Lk} \quad (5)$$

The DG reactive power mismatch is represented in terms of lines reactive power deviation:

$$\Delta Q_{DG} = \sum_{j\in\Omega_i} \Delta Q_{l(ij)} \quad (6)$$

In matrix form it becomes:

$$\Delta Q_{DG} = [p][\Delta Q_{Lk}] \quad (7)$$

$$p_k = \sum_{j\in\Omega_i, k\in\Omega_{iL}} p_{ij-k}$$

2.1.2.3 Computing $[\alpha]$ matrix

The fast decoupled power flow equations [3] can be rewritten as:

$$\begin{bmatrix} B_{ii} & B_{ik} \\ B_{ki} & B_{kk} \end{bmatrix} \begin{bmatrix} \Delta V_i \\ \Delta V_{Lk} \end{bmatrix} = -\begin{bmatrix} \Delta Q_{DG} \\ \Delta Q_{Lk} \end{bmatrix} \quad (8)$$

Where: k$\in$ Ω_{iL}, $B_{ik} \subset \mathbb{R}^{1xh}$, $[B_{k'k}] \subset \mathbb{R}^{hx1}$

$\Delta V_{Lk}, \Delta Q_{Lk}, B_{ki} \subset \mathbb{R}^{hx1}$, $B_{kk} \subset \mathbb{R}^{hxh}$

From equation (7) and (8), we yield:

$$\Delta V_i = [\alpha][\Delta V_{Lk}] \quad (9)$$

$$\alpha_k = \frac{B_{ki} - [p][B_{kk}]}{[p][B_{ki}] - B_{ii}}$$

In steady state control problem, after defining $[\Delta V_{Lk}]$ as the difference between the desired voltage profile and the present one, by using equation (1), the new value of voltage at the DG terminal can be obtained.

2.1.2.4 Optimal solution

Whether controlling the DG voltage to regulate the voltage at the heavy load bus is a optimal choice. Since the DG is adjacent to the heavy load, the DG significantly affects the voltage of the load. In mathematical representation, since susceptance of the bridging element from the DG bus to the heavy load bus is much larger than the others i.e. $B_{ik} >> B_{il}$, then

$$\left|\frac{dQ_{DG}}{dV_k}\right| >> \left|\frac{dQ_{DG}}{dV_l}\right|; \quad \left|\frac{dQ_{DG}}{dV_k}\right| >> \left|\frac{dQ_G}{dV_k}\right|$$

Where: V_k: voltage at the heavy load

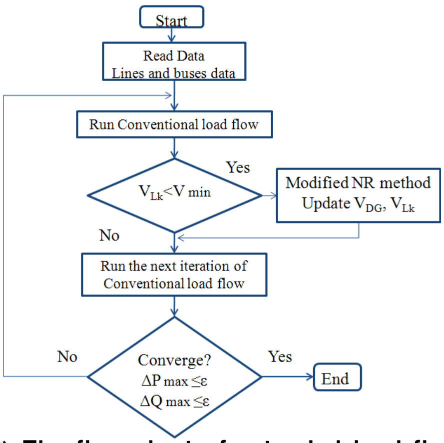
V_l: voltage at load bus $l \neq k$

Q_G: reactive power injected by the others generators

2.2 Extended load flow problem with modified NR method

2.2.1 General idea

The idea of this method is to raise the voltage at the heavy load bus when the voltage violates the voltage constraints by controlling DG voltage along iteration process. In Newton-Raphson iteration process, after updating the voltage at the heavy load, if the new voltage value is lower than the limit, the voltage will be set equal to V_{min} and the DG increases its terminal voltage as in equation (1).



<Fig 2> The flow chart of extended load flow problem with modified NR method.

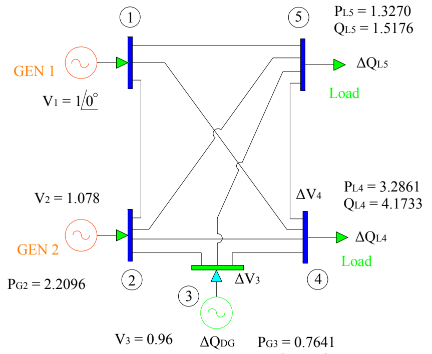
2.2.2 Ensuring convergence

The load flow problem diverges when the voltages is lower than the critical voltage (V*) [4]. Therefore, if the voltage is raised higher than V^*, convergence property will be guaranteed. In that case, modified NR method can be applied. At the υ^{th} iteration, the process begins to diverse i.e. the reactive power mismatch at the heavy load is larger than that at the $(\upsilon\text{-}1)^{th}$ iteration, this means the voltage is lower than V^*. To treat this problem, the voltage at υ^{th} iteration will be set equal to its value at the $(\upsilon\text{-}1)^{th}$ iteration, which is higher than V^*. In order to mitigate effects of correction action on the reactive power mismatch, the mismatch check must be skip at the $(\upsilon+1)^{th}$ iteration and continued at the next iteration.

As long as the DG is capable to raise the voltage at the heavy load higher than V^*, after finite corrections, the iteration process will terminate.

3. CASE STUDY

The proposal algorithm has been tested for a 5-bus system to demonstrate its effect. The test was conducted twice to examine the two results.



<Fig 3> The one-line diagram of a five-bus power system

3.1 Conventional load flow problem

Bus 1 is chosen as slack bus and the DG resides at bus 3. With the tolerance of 0.005 (ε=0.005), the calculating process stops after five iterations.

<Table 1> Results of the conventional problem.

Iteration number	V_4	V_5	ΔQ_4	Max ΔQ
0	1	1	-6.7733	-1.0976
1	0.9458	0.9585	-0.4347	-6.7733
2	0.9417	0.9549	0.0085	-0.4347
3	0.9418	0.9551	-0.0013	0.0124
4	0.9418	0.9550	-0.0018	0.0096

The results show that the voltage at load bus 4 is lower than voltage limit (V_{min} = 0.95).

3.2 Extended load flow problem and modified NR method

With the same tolerance, the computing process converges after five iterations.

<Table 2> Results of the extended load flow problem with modified NR method

Iteration number	V_3		V_4		V_5		ΔQ_4	Max ΔQ
	Ex	An	Ex	An	Ex	An	An	
0	0.960		1		1			-6.7733
1	0.9600	0.9645	0.9458	0.9500	0.9585	0.9606	-0.5106	-0.5106
2	0.9645	0.9696	0.9453	0.9500	0.9570	0.9594	-0.0698	-0.0698
3	0.9696	0.9702	0.9495	0.9500	0.9596	0.9598	-0.0107	-0.0107
4	0.9702	0.9703	0.9499	0.9500	0.9598	0.9599	-0.0006	-0.0006

Ex: Before correction; An: After correction

From the results shown in the above table, the new voltage at DG bus 3 is 0.9703 and the voltage at the heavy load bus 4 is improved and equal to V_{min} = 0.95.

4. CONCLUSION

The definition of Ω_i and Ω_{iL} is useful to localize the power system network. Only a small portion of system where voltage problem exists can be achieved. With such simple $[\alpha]$ matrix, remedial actions will be determined rapidly.

The extended load flow and modified Newton Raphson method shows a nice convergence property. This approach is a candidate to treat the divergence problem of the network where some low voltages exist.

[REFERENCES]

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