A Selecting Method of Optimal Load on Time Varying Distribution System for Network Reconfiguration considering DG

Bohyeon Cho*, Kihwan Ryu*, Jinhyun Park*, Wonsik Moon*, Sungmin Cho* and Jaechul Kim†

Abstract – This Paper presents about selecting the most suitable load used for distribution optimization considering time-varying load demand and generation of DG. The objective of this paper is to find optimal load which obtain best network reconfiguration result according to time-varying load demand and DG generation. Many researches about distribution reconfiguration for optimization have been studied for ages and they have used constant loads only for reconfiguration. To get the best result, however, at least for 24 hours time-varying load demand and generation of DG should be considered. Four daily load curves and one PV generation curve have been decomposed into sequential levels. But, the optimal distribution reconfiguration considering time-varying load demand and PV generation should not to be the only scheme. Because, the reconfiguration result may demand hourly switching operation of electric devices and it might cause deterioration of switches lifespan. Therefore, the method of how to select the most optimal load considering not only time-varying loads demand and DGs generation but also the number of switching for maximizing income is researched. The method of selecting optimal load is proved by adapting to a simple model system and the more efficient result is also confirmed in this paper.

Keywords: Time-varying, Reconfiguration, Distribution, Load curve, DG

1. Introduction

In real distribution system, network reconfiguration is important network control means aside from ULTC(Under Load Tap Changer) and capacitor switching. By changing open/close status of sectionalizers and tie-switches, network reconfiguration is achieved. Network reconfiguration generally has three purposes: (1) to reduce power losses and decrease the operation cost; (2) to relieve overloads in the distribution system; (3) to restore power to all customers. In normal operation conditions, (1) and (2) are used and (3) is only used for a planned outage or a fault. In this paper, only loss minimization is considered for reconfiguration. Merlin and Back presented one of the first optimization methods to improve distribution system [1]. The discrete branch and bound optimization method was implemented in mesh distribution system. However, the discrete branch and bound optimization require significant computation effort so that is not very proper method to be realized in real system. Cinvanlar proposed an efficient distribution reconfiguration algorithm called ‘branch exchange’ for loss minimization [2]. A simple formula with simplified assumptions can estimate the loss changes for a particular switching selection between two feeders. Baran and Wu [3] improved the solution approach of Ref. [2] by introducing two approximated formulas for power flow. More methods proposing optimization are GA applied reconfiguration first by Nara [4], simulated annealing to obtain global or near global optimal solutions by Jeon [5] and fuzzy multi-objective method based evolution programming by Hsiao [6]. In this paper, DISTOP(Distribution Network Optimization) method which is finding the switch carrying the least current is used for the network reconfiguration [7].

Distribution system reconfiguration founded on loss minimization carries improved operational conditions. Most of the optimization methods are only focused on snapshot reconfiguration for maximizing or minimizing its object functions. Due to the time varying loads demand and generation of DGs, however, reconfiguration with only one single snapshot of distribution system condition cannot be the best optimization result. In other words, to obtain the optimization result from reconfiguration, time varying system condition for the given time interval should be considered. In the real distribution system, reconfiguration...
for every time is not proper because hourly switching operations by reconfiguration lead to switching loss and deteriorations of switches lifespan. Accordingly, in this paper, a selecting method of optimal loads considering varying-time system and the number of switching for maximizing income is suggested.

2. System Modeling & Proposed Technique

2.1 System Modeling

In this paper, a hypothetical 23 kV radial distribution test system with 33 buses [3] is used for network reconfiguration and to find optimal loads in time-varying system, 4 different type of daily loads demand and 1 PV(Photo Voltaic) daily generation are used. The loads consist of commercial, house, industry and school and all the different type of loads are dispersed to each bus. A high proportion of DG capacity will bring down the power quality. Hence, the total capacity of PV does not over 25% of the total system capacity in the test system. Fig. 1 shows the 33 bus test system with 5 PV generators. Each of buses has different type of load and the capacity is also different.

The load and PV generation curves are shown in Fig. 2. In Fig. 2 (a), each daily load has different peak demand time. To compare the load curves with each other, the average values of each time-varying load are set to 1000. PV generation curve is shown in Fig. 2 (b) and the average of PV generation is also set to 1000. All the loads are assumed to have power factor of 0.95 and all the power factor PV generators are assumed unity.

2.2 Reconfiguration Algorithm

DISTOP is an efficient and robust heuristic method in a real network system. It finds the optimal or almost near-optimal solution and the final solution is totally independence from the initial status of the switches. Therefore, unlike other method such as branch and bound or branch exchange, DISTOP is not dependent on the initial status of the switches so it does not need to escape from local solution. The optimal solution can be expressed following equation (1).

$$\min \sum_{i=1}^{n} R_i |I_i|^2$$

Subject to : $V_{\text{min}} \leq V_p \leq V_{\text{max}}$

$I_i \leq I_{i,max}$

$N_{\text{loop}} = 0$

$N_{\text{bus_isolation}} = 0$

Where,

$n$ - total number of branches;

$R_i$ - resistance of branch $i$;

$I_i$ - current of branch $i$;

$V_p$ - voltage of node $p$;

$V_{\text{min}}$ and $V_{\text{max}}$ - minimum and maximum voltage band of network nodes;

$I_{i,max}$ - maximum allowable current of branch $i$;

$N_{\text{loop}}$ - number of loops in distribution system;

$N_{\text{bus_isolation}}$ - the number of isolated buses in distribution system.
Fig. 3 shows the flowchart for the DISTOP algorithm. In proposed method, firstly, close all the switches to create a complete meshed distribution system. After running power flow study for the meshed distribution system, all the voltage of buses and branches current are obtained. Under these meshed system, resistive line losses is reached to minimum. To find optimal point among the available switches and to keep radial structure in the system, it is necessary to open one switch carrying the lowest current in each fundamental loop. By opening the switch, one branch is selected so resistive loss of the consequent radial network is almost equal to loop network. Hence to keep the radial network with minimum resistive line loss, one branch should be opened in each loop that causes minimum loss change of loop network. If the distribution system does not violate above constraints and it keeps complete radial structure with no isolated bus, reconfiguration process would be ended.

According to proposed algorithm, it needs only one AC load flow to find nodal currents injections in meshed network and the other simple mathematical calculations are executed. This DISTOP method is very fast and no negative effect on time of calculations exists even for very large scale of distribution system.

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2.3 Proposed Selecting Technique of Optimal Load

Conventionally, peak or average snapshot load demand was used to operate reconfiguration. However, due to time-varying load demand, reconfiguration with peak or average load demand might not be the optimal solution. However, excessive or hourly reconfiguration also can cause switch deterioration. Hence, proposed load selecting technique considers both loss minimization and switching numbers.

To select optimal load, the case results of hourly reconfiguration with daily load curves is necessary. A daily load curve has 24 different load demands so 24 reconfiguration results can be obtain after hourly reconfiguration. The reconfiguration results, however, are not exactly 24 different results. Because the load curves do not change abruptly, some of results are overlapped and only several cases might be resulted in. Once the cases are obtained, the power flow for 24 hours is executed for each case and one day loss can be calculated from the power flow. After this computation process, the optimal load can be selected by equation (2) considering reconfiguration loss reduction and switching loss for specified period [8]. From the equation (2), the case which is maximizing income is the optimal load.

\[
\max f = c \int_{t_0}^{t_1} [P_{l0}(t) - P_l(t)] dt - N_s C_s
\]

where,
- \( f \) – income for the time period \( t_0 \sim t_1 \) (₩);
- \( c \) – cost of energy (₩/kWh);
- \( P_{l0}(t) \) – initial total power losses (kW) at time \( t \);
- \( P_l(t) \) – total power losses (kW) at time \( t \) after network reconfiguration;
- \( t_0 \) – starting point of the time period (hour);
- \( t_1 \) – end of the time period (hour);
- \( N_s \) – the number of switching operation during the time period \( t_0 \) to \( t_1 \);
- \( C_s \) – operating cost of single switching operation (₩);

3. Test System Result

The distribution system with 33 buses is used to verify the proposed technique. The average loads of total test system for 24 hours are 22.7153 MW and 1.358 MVAr. The total test system power loss for initial configuration is 2.324 MW (10.23%). Table 1 shows the reconfiguration case results of each time period. After reconfiguration process with 24 different time-varying loads, the reconfiguration results are divided into four cases. Although load demand curves are changed every hour and different from each other, sum of total loads demand converges into one patterned curve. Hence, the status of normally open switches of each case does not completely different.
Table 1. Reconfiguration results of each case for test distribution system

<table>
<thead>
<tr>
<th>Time</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Average Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normally open switch</td>
<td>1,19,20,21,22,24</td>
<td>2,3,4,5,6,7,23</td>
<td>8</td>
<td>9,10,11,12,13,14,15,16,17,18</td>
<td>-</td>
</tr>
<tr>
<td>33→33</td>
<td>33→33</td>
<td>33→33</td>
<td>33→33</td>
<td>33→33</td>
<td>33→33</td>
</tr>
<tr>
<td>34→14</td>
<td>34→34</td>
<td>34→14</td>
<td>34→34</td>
<td>34→34</td>
<td>34→34</td>
</tr>
<tr>
<td>35→11</td>
<td>35→11</td>
<td>35→11</td>
<td>35→11</td>
<td>35→11</td>
<td>35→11</td>
</tr>
<tr>
<td>36→16</td>
<td>36→17</td>
<td>36→17</td>
<td>36→17</td>
<td>36→16</td>
<td>36→16</td>
</tr>
<tr>
<td>37→28</td>
<td>37→28</td>
<td>37→28</td>
<td>37→28</td>
<td>37→28</td>
<td>37→28</td>
</tr>
<tr>
<td>20 times (a day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2 shows the changes of one day loss caused by reconfiguration results of each case. One day loss decreases in comparison with initial state for all the case 1, 2, 3, and 4. Especially, the tie-line no.33 is fixed at all time and tie-line no.35 and no.37 were relocated to line no.11 and no.28 for all the case. From these results, we can analyze that tie-line no.33, line no.11 and no.28 is the most influence line section over the resistive loss reduction. From the one day loss in table 2, we can find that hourly reconfiguration has the minimum one day loss through changing 20 times of switches status. Case 1 (when the time period 1, 19, 20, 21, 22, 24) is the next best solution having minimum resistive loss. When the time at 21 belonging to the case 1, the transmitted total power, the total sum of loads demand and PV generation, is the biggest power among the other time and the total power at 5, belonging to the case 2, has the smallest power among other cases. From this result, we can notice that the case which has the biggest total transmitted power is the best case when only loss is considered.

Table 2. One day loss of each case

<table>
<thead>
<tr>
<th>Initial state</th>
<th>One day loss [MWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly reconfiguration</td>
<td>2.024</td>
</tr>
<tr>
<td>Case 1</td>
<td>2.035</td>
</tr>
<tr>
<td>Case 2</td>
<td>2.088</td>
</tr>
<tr>
<td>Case 3</td>
<td>2.048</td>
</tr>
<tr>
<td>Case 4</td>
<td>2.04</td>
</tr>
</tbody>
</table>

To find optimal case, total income which is considering not only loss but also switching cost is calculated and the result is shown in table 3. The energy cost is 86.12 [₩/kWh] and switching for one operation is 25,000 [₩]. The energy cost adhere to standard of KEPCO[8] and the switching cost[9] is calculated arithmetically allowing for the cost of switch, installation cost and potential cut off number of load current. Table 3 shows that by considering switching loss, hourly reconfiguration and case 1 which have minimum one day loss were not the optimal case no further. Case 4 is selected as an optimal case which maximizes total income. From here, the reason of considering switching cost is elucidated.

Table 3. Total income for each case

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hourly reconfiguration</td>
<td>16,680</td>
<td>45,200</td>
<td>-25,520</td>
</tr>
<tr>
<td>Case 1</td>
<td>16,594</td>
<td>200</td>
<td>16,394</td>
</tr>
<tr>
<td>Case 2</td>
<td>16,184</td>
<td>150</td>
<td>16,034</td>
</tr>
<tr>
<td>Case 3</td>
<td>16,494</td>
<td>200</td>
<td>16,294</td>
</tr>
<tr>
<td>Case 4</td>
<td>16,556</td>
<td>150</td>
<td>16,406</td>
</tr>
</tbody>
</table>

4. Conclusion

Many of reconfiguration algorithms for loss minimization have been developed and applied to real distribution network. In comparison with reconfiguration algorithms, selecting optimal load for reconfiguration seldom has been studied. Proposed method does not provide an optimal reconfiguration solution, however, it helps reduce the resistive loss. The function of proposed technique is finding one single snapshot of distribution system condition in time-varying system to obtain optimal solution considering not only loss minimization but also switching loss. Ultimately, the purpose of proposed technique is maximizing income for specific period.

In this paper, simulation with test system has been executed for one day to find optimal loads. Although the load curves are different from weekdays and weekend or different from each season, the simulation shows that proposed technique can maximize income with representing load curves for a specified term.

Acknowledgements

This work was supported by the Power Generation & Electricity Delivery of the Korea Institute of Energy Technology Evaluation and Planning(KETEP) grant funded by the Korea government Ministry of Knowledge Economy. (No. 2009T100200067)

References


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