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A Study on the Effect of Distributed Generation of the Reconfiguration of Distribution Networks

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Abstract – Distributed generation (DG) in the future will play an important role in the electricity supply systems, in wich can provide DG capacity from a few hundred kW to tens of MW. However, it is connected to the local power grid, DG will have certain influence on the power quality of the power grid. One of the most significant effects is that they will change the configuration of the local power grid as well as affecting the operation mode of the grid. This paper presents a method of finding the optimal open loop, analyzing and selecting the appropriate mode of operation to reduce power losses of power distribution networks that includes DG.

Keywords: Medium voltage network, Distribution network, Power loss reduction, Reconfiguration

1. Introduction

Medium voltage networks (MVN), also known as distribution networks are usually designed in the closed form, but required to operate in the radial form to reduce short circuit current and increase simplicity of operation [1, 2]. Besides, in real distribution system, network reconfiguration is important network control means aside from ULTC (Under Load Tap Changer) and capacitor switching [3]. By changing open/close status of section-alizers 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 [4, 5, 6]

When DGs is integrated to the MVN, the power flow on the branch lines will be changed and affects the optimal configuration of MVN, it therefore requires to find a new optimal configuration of MVN with integrated DGs. The new configuration must satisfy with multiple objectives: Improve the quality of bus voltages on MVN, reduce power loss, enhance reliability of power supply and prevent line overload. This article only focuses on reconfiguring MVN with DGs to reduce power loss (ΔP). There are many methods to perform reconfiguration problem of power distribution networks with DG reduce ΔP. These methods are based on two algorithms such as:

- The algorithm of A.Merlin & Back [1] (cut loop technique) represents the heuristic method combined with optimization techniques;
- Civanlar algorithm [3] (technical branch exchange) represents the pure heuristic methods.

In algorithm of [1], methods which are subsequently developed based on the idea of opening the branches with the smallest current, the process ending when the network obtains the opening operational status. The advantage of [1] is simple, after examining all the search space, reducing ΔP configuration will be found. However, the algorithm still has the disadvantage of waste of time in calculations because there are 2^n configurations occurring if there are n branches with switches. In [3], Civanlar algorithm is based on heuristic rules to reconfigure the MVN. This algorithm is a good one because of defining rules to reduce the number of power switches considered and building empirical function that describes the decrease of ΔP when there is a change in the status of a pair of electric switches in the process of reconfiguration. Reconfiguration technique of distribution networks in this algorithm is shown in the process of replacing 1 opening switch with 1 closing switch in the same loop to reduce ΔP. The loop wich is chosen to change branches has a pair of switches on/off with the largest decrease of ΔP. The process is repeated until ΔP cannot be reduced any more. The algorithm has the advantages of: quickly identifying the reconfiguration plan with smaller ΔP by heuristic rules and using empirical formulas. However, the weakness of this algorithm is that in each calculating step, only a pair of power switches in a loop is considered, and it does not solve the global minimum ΔP problem in the network [6, 8, 9, 10] completely.

To overcome the limitations mentioned above, this paper will develop an algorithm based on ideas of [1], that is, instead of reducing directly ΔP = I2R (which takes a lot of calculating time), we build the objective function to reduce increasing rate of ΔP, say function G, that contains

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information about the MVN and DG. Consequently, since the biggest reduction of function G found, it will mean that an optimal configuration with the smallest ΔP is found.

Despite belonging the same application of the heuristic search algorithm, in the process of calculating, the reduced function G only needs to solve the problem on the power distribution in distribution network having DG closed with a single return. This reduces the volume and increases calculating speed, which are suitable for online operation on the distribution network

The function G, we built fully described the relationship between power and current courses in the branch distribution grid so it can examine all the independent round at the same time, which means that it takes less time and goes directly to DP minimum configuration. Compared to some previous studies, the results of the proposed algorithm which are rated for one grid pattern have shown a very high efficiency of this method.

2. The Problem of Reconfiguration of Distribution Networks

2.1. Power loss function for MVN with DG.

In a simple medium voltage network without DG (Fig. 1), if branch current i is I_{Pi} and I_{Qi} (i = 1 ... n) and is constant at considered time, the ΔP before the MVN configuration is [6]:

$$\Delta P^{before} = \sum_{i=1}^{n} R_i (I_{Pi}^2 + I_{Qi}^2) \qquad (1)$$

When redistributing the additional load, that means transferring an amount of current I_{Qj} and I_{Pj} (j = 1 ... k, if MVN with loop k) from the old configuration to the new one, can be done generally by: withdrawing/injecting an amount of current I_{Qj} and I_{Pj} at the open–switch MN_j on all loops of the network, respectively [2].

A_{ij} is called as the correlation index between the current direction of loop j and power flow direction in the opening-branch *i* in the radial network:

A_{ij} = 1: The direction of $I_{Pj} + jI_{Qj}$ is the same as I_{Pi} and I_{Qi};

Aij = -1: The direction of $I_{Pj} + jI_{Qj}$ opposite to the I_{Pi} and I_{Qi};

A_{ij} = 0 if branch *i* does not belong to the loop j.

With a complex MVN consists of multiple loops connects several DGs shown in Fig. 1. ΣI_{Pl}^{DG} and ΣI_{Ql}^{DG} is known as the total current of the DG behind the *i* th branch with the direction from the electric source to open–switch MN_j (j = 1...k), the action of redistributing the additional load is equivalent to the injecting/withdrawing the same amount of electric current I_{Pj}, I_{Qj} in open–switch. ΔP on the branches are:

$$\begin{aligned}\Delta P^{after} = & \sum_{i=1}^{n}\left(I_{Pi} - \sum_{l=1}^{L} B_{il} I_{Pl}^{DG} + A_{ij}\sum_{j=1}^{K} I_{Pj}^{MN}\right)^2 R_i + \sum_{j=1}^{K}\left(I_{Pj}^{MN}\right)^2 R_j^{MN} \\ & + \sum_{i=1}^{n}\left(I_{Qi} - \sum_{l=1}^{L} B_{il} I_{Ql}^{DG} + A_{ij}\sum_{j=1}^{K} I_{Qj}^{MN}\right)^2 R_i + \sum_{j=1}^{K}\left(I_{Qj}^{MN}\right)^2 R_j^{MN}\end{aligned} \qquad (2)$$

Where:

I_{Pi}, I_{Qi}: The current of the branch *i* in the network with n branches I_{Pj}^{MN};

I_{Qj}^{MN}: The injected/ withdrew current in the branch with open–switch MN_j in the network with k loops.

R_j^{MN} : The resistance of the branch with open–switch MN on the first loop j

I_{Ql}^{MN}: The l[th] reactive current in the network with L DGs (l = 1…L);

B_{il} : The coefficient of relationship between DG 1 and branch i, value (in which, 0 is not relative and +1 is DG 1 behind from the source to the branch *i*, respectively).

2.2. Conditioner for minimizing power loss.

The necessary condition for (2) is minimized by the following variables I_{Pj}^{MN} and I_{Qj}^{MN}, which is represented in

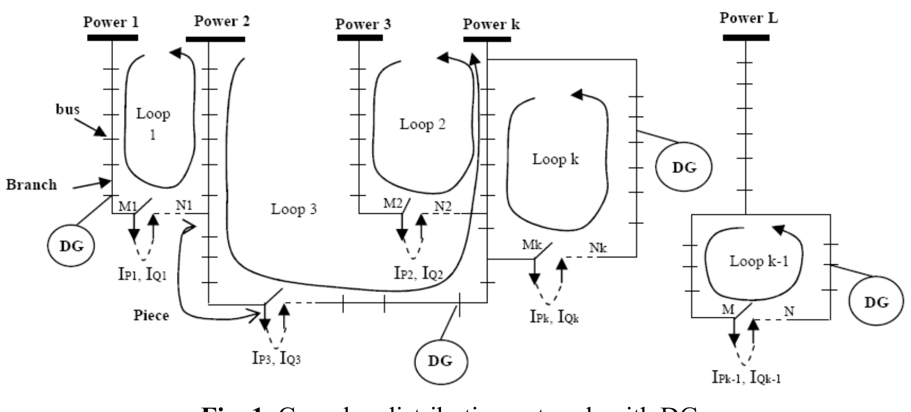

Fig. 1. Complex distribution network with DGs

two expressions (3) and (4):

$$\frac{\partial \Delta P^{after}}{\partial I_{Pj}^{MN}} = I_{Pj}^{MN}.R_j^{MN} + A_{ij}\sum_{i=1}^{n}\left(I_{Pi} - \sum_{l=1}^{L} B_{il} I_{Pl}^{DG} + A_{ij}\sum_{j=1}^{K} I_{Pj}^{MN} \right) R_i = 0 \quad (3)$$

$$\frac{\partial \Delta P^{after}}{\partial I_{Qj}^{MN}} = I_{Qj}^{MN}.R_j^{MN} + A_{ij}\sum_{i=1}^{n}\left(I_{Qi} - \sum_{l=1}^{L} B_{il} I_{Ql}^{DG} + A_{ij}\sum_{j=1}^{K} I_{Qj}^{MN} \right) R_i = 0 \quad (4)$$

According to Eq. (2), there is always $\forall$ j ≠ h (h = 1 ... K and i = 1 ... n), where the second derivative by the current variable are always greater than 0, to reach the minimum of the objective function. Hence it always satisfies the sufficient condition in order that Eq. (3) and Eq. (4) reached minimum wwith the variables I_{Pj}^{MN}; I_{Qj}^{MN}. The values of I_{Pj}^{MN}; I_{Qj}^{MN} are calculated from expression (3) and (4) as follows:

$$I_{Pj}^{MN} = \frac{-A_{ij}\sum_{i=1}^{n} I_{Pi}R_i + A_{ij}\sum_{i=1}^{L} B_{il} I_{Pi}^{DG} R_i}{R_j^{MN} + A_{ij}\sum_{j=1}^{K} R_j} = \frac{-A_{ij}\sum_{i=1}^{n} I_{Pi}R_i}{R_j^{LoopMN}} + \frac{A_{ij}\sum_{i=1}^{L} B_{il} I_{Pi}^{DG} R_i}{R_j^{LoopMN}} \quad (5)$$

$$I_{Qj}^{MN} = \frac{-A_{ij}\sum_{i=1}^{n} I_{Qi}R_i + A_{ij}\sum_{i=1}^{L} B_{il} I_{Qi}^{DG} R_i}{R_j^{MN} + A_{ij}\sum_{j=1}^{K} R_j} = \frac{-A_{ij}\sum_{i=1}^{n} I_{Qi}R_i}{R_j^{LoopMN}} + \frac{A_{ij}\sum_{i=1}^{L} B_{il} I_{Qi}^{DG} R_i}{R_j^{LoopMN}} \quad (6)$$

Expression (7) can be obtained when carry out a summation of expressions (5) and (6) after multiply two sides of the (6) by j.

$$\frac{\partial \Delta P}{\partial I_{Pj}^{MN}} + j\frac{\partial \Delta P}{\partial I_{Qj}^{MN}} = \left(I_{Pj}^{MN} + jI_{Qj}^{MN}\right) R_j^{MN}$$
$$-A_{ij}\sum_{i=1}^{n}\left[\left(I_{Pi} + jI_{Qi}\right) - j\sum_{l=1}^{L} B_{il}\left(I_{Pl}^{DG} + jI_{Ql}^{DG}\right) + A_{ij}\sum_{j=1}^{K}\left(I_{Pj}^{DG} + jI_{Qj}^{DG}\right)\right] R_i = 0 \quad (7)$$

From the above analysis, we can carry out some important issues as below:

a. In initial MVN configuration, if a current is injected/withdrew at open switches as Eq. (5) and Eq. (6), it will create a loop current through the branches. Then, power loss function ΔP at Eq. (2) will minimum and equal ΔP_{loop}.
b. The values of $I_{Pj} + jI_{Qj}$ depend on the position of the switch chosen in loop j. In theory, the switch which has injecting/withdrawing equal zero is an optimal open switch. However, in fact that it can be only found the switch which has the most minimum loop current to open.
c. Eq. (7) describes the total voltage drop across the independent loop j in the pure resistance network. This equation shows that the optimal values of current calculated in Eq. (5) and Eq. (6) is the current in the mesh network. Then $\Delta P_{after} \geq \Delta P_{loop}$.
d. The second part in Eq. (5) and Eq. (6) describes the impact of DGs into MVN. This value shows that the optimal configuration of MVN with DG will be different compared with its MVN without DG. In addition, DGs usually depend on many objective factors, so the operating conditions which need to calculate for distribution network reconfiguration, will be more increase.

3. Proposed Algorithm of Minimizing Power Loss.

Rewriting Eq. (5) and Eq. (6) in the loop j as follows:

$$\begin{aligned} I_{Pj}^{MN}.R_j^{LoopMN} &= \left[-A_{ij}\sum_{i=1}^{n} I_{Pi}R_i + A_{ij}\sum_{\substack{i=1 \\ i\neq j}}^{L} B_{il} I_{Pi}^{DG} R_i\right] = \alpha_{Pj} \\ I_{Qj}^{MN}.R_j^{LoopMN} &= \left[-A_{ij}\sum_{i=1}^{n} I_{Qi}R_i + A_{ij}\sum_{\substack{i=1 \\ i\neq j}}^{L} B_{il} I_{Qi}^{DG} R_i\right] = \beta_{Qj} \end{aligned} \quad (8)$$

Eq. (8) includes two components: The current of the additional load on the MVN without DG and the DG current impacting on MVN. I_P^{MN} and I_Q^{MN} defined by Eq. (5) and Eq (6) is the condition of minimizing ΔP. When reduce this value that will make the objective function value decrease. However, the reduction of G from Eq. (2) will face some difficulties due to the interaction between branch current and DG impacting the MVN, moreover we also notice that when I_P^{MN} and I_Q^{MN} are the smallest the better, ΔP will be the best. Starting from the idea of putting $G = \Sigma[\alpha_{Pj}^2 + \beta_{Qj}^2]$ with j = 1 ... K, then:

$$G = \sum_{j=1}^{K}\left[\left(I_{Pj}^{MN}.R_j^{LoopMN}\right)^2 + \left(I_{Qj}^{MN}.R_j^{LoopMN}\right)^2\right] = \sum_{j=1}^{K}\left(I_j^{MN} R_j^{LoopMN}\right)^2 \rightarrow \min \quad (9)$$

The objective function in Eq. (9) is a rate rise function ΔP, abbreviated as a function G. From comments 2.2. Show that MVN operators at the opening status with ΔP that is the smallest if the function G is indicated in the MVN decreasing the most. So in the process of calculating of decreasing the function G, we just solve the power distribution on the MVN operators with DG one time only. This reduces the volume and increase speed of calculation. However, minimizing the function G is a difficult problem, this section will present a search algorithm to reduce the function G as follows:

In an independent loop, if we can find a branch with the current that is less than I_j^{MN} (assuming that the current branch I_j^{NH}), if we open the branch MH we will have ΔP that is smaller than that we open branch MN. Therefore, in order to minimize the objective function G in (9) we can replace the values I_{Pj}^{MN} and I_{Qj}^{MH} by I_{Pj}^{NH} and I_{Qj}^{NH}, respectively, with smaller value and in the same loop j, value is R_j^{Loop} by the Eq. (10). Here:

$$\Delta G_j^{MN-NH} = \left(R_j^{LoopMN}\right)^2\left[\left(\left(I_{Pj}^{MN}\right)^2+\left(I_{Qj}^{MN}\right)^2\right)-\left(\left(I_{Pj}^{NH}\right)^2+\left(I_{Qj}^{NH}\right)^2\right)\right]$$
$$= \left(R_j^{LoopMN}\right)^2\left[\left(I_j^{MN}\right)^2-\left(I_j^{NH}\right)^2\right] \qquad (10)$$

Because the MVN has many independent loops, reducing the function G should be carried out step by step. The dependent loop chosen for first opening is the loop with the greatest decreasing level ΔG compared to all remaining independent loops in MVN with DG. In the independent circuit, the power switch opened is with the smallest current in the independent loop.

A iterative process is done to reduce the function G until we neither can find the pair of switches/open–switches MNj and NH_j nor can reduce the function G more.

Flowchart decrease function G is shown in Fig. 2 on the basis of additional block of decrease G in the algorithm of [1], then test ΔP levels decrease to achieve optimal configuration with the smallest ΔP. In essence, stage 1 of the proposed algorithm is based on the algorithm [1], but has added the function G on blocks in the algorithm, hence, the branch is open at this stage is the smallest electric current running through. At the end of stage 1, distribution networks have become completely radial, but also could not confirm the MVN has the smallest ΔP (such as weakness of the algorithm stated in [1]).

Stage 2 is a stage of checking the optimization by: turning each switch power on, solving power distribution branch to check if the selected switch to open has the smallest current or not. If it is the smallest current, the results will be accepted, if it is not, choose the branch with smaller current to open. This work was conducted for each loop independently (turn each switch in sequence on).

In stage 1, determining speed of MVN configuration is done very rapidly, the power loss decrease ΔP in each redistribution load is very high, but do not consider interaction of independent loops of MVN at this stage as it is not really the least. However, by the flash speed and reduction of the function G at the impact of each pair of switch, it can be used to build online operation algorithms of MVN.

In stage 2, the radial network in stage 1 will be check the values of G function for every independent loop to continuous reduce ΔP. In this stage, ΔP reduction is not high after every redistribution load should only be worth pointing out that the structure of MVN with the smallest ΔP, but it means when operating MVN in a very long time. After each closing/opening a switch pair, power distribution problem is calculated on the remaining closed MVN with consideration for DGs. Because of this difference the current composition of the I_p and I_q of DG effects consideration on I_P^{MN} and I_Q^{MN} components during the remaining iterations decrease G.

The comments above will be verified by examples of MVN 16 nodes as below.

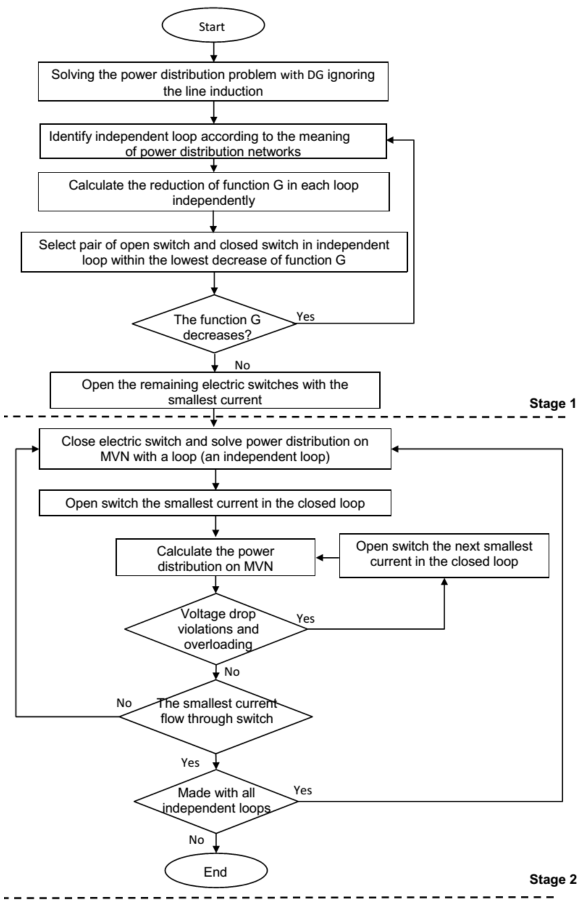

Fig. 2. Flowchart of proposed algorithm

4. Evaluation Scenarios and Result Discussion.

The 16 nodes MVN with a nominal voltage of 6 kV has 21 branches, 6 opening switches and 2 DG by G. Celli in [4], is described in Fig. 3. The data for the branches and nodes are shown in [4].

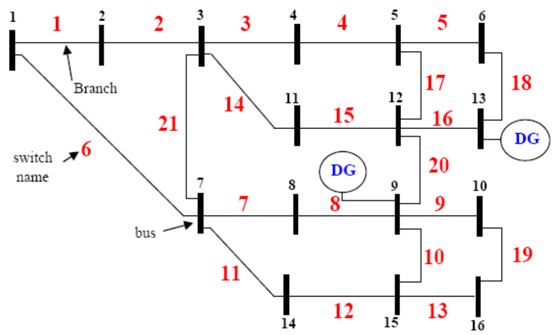

Fig. 3. MVN 16 nodes has two DGs

Table 1. The survey results on 16 nodes distribution networks.

No	Open switch	ΔP kW	Methods	DG1-bus 9, kW	DG2 – bus 13, kW	Note
1	2;8;9;15;16;20	144.17	G Celli[4]	0	0	No DG
2	2;16;17;10;20;19	92.3	TOPO	0	0	
3	2;16;17;10;20;19	92.3	Proposed algorithm	0	0	
4	2;8;10;15;18;20	81.93	G Celli[4]	450	630	Have 2 DG
5	2;17;18;20;10;19	66.3	TOPO	450	630	
6	2;17;18;20;10;19	66.3	Proposed algorithm	450	630	
7	2;8;10;15;16;20	84.74	G Celli[4]	450	0	DG1 working and DG2 stopping
8	2;17;16;20;10;19	83.7	TOPO	450	0	
9	2;17;16;20;10;19	83.7	Proposed algorithm	450	0	
10	2;9;10;15;18;20	99.04	G Celli[4]	0	630	DG1 stopping and DG2 working
11	2;17;18;20;10;19	74.3	TOPO	0	630	
12	2;17;18;20;10;19	74.4	Proposed algorithm	0	630	

In power distribution networks, the additions of power are 2 DGs of 450kW installed at node 9 and 630KW installed at node 13, respectively. The process of finding the operation configuration in order to reduce power loss is investigated in two cases, that is, with DGs and without DGs. Results of finding the optimal configuration are compared with the results of [4] and compared them with TOPO in the PSS/ADEPT 5.0 [7] to verify the advantages of the proposed algorithm. The synthesis results shown in Table 1.

TOPO (Tie Open Point Optimization) tool is a module of PSS/ADEPT software. This tool has the analysis function to identify the optimal tie open point in the power grid to find the configuration with minimal power loss. TOPO's searching method is based on Civanlar's branch exchange type heuristic algorithm [3]. This is considered the most powerful tool nowadays which power companies can use to search for the optimal power configuration. However, one of its advantages is long calculation time.

4.1 Searching process of network configuration without DGs.

The radial distribution networks initially [4] have the open-switches K_{21}, K_{17}, K_{18}, K_{20}, K_{10} and K_{19}. Power loss is first calculated by PSS/ADEPT: $\Delta P_{old} = 171.6$kW.

Solving the power flow calculation on close MVN. Conduct to decrease G function at stage 1 by the proposed algorithm. The G function decreases ($\Delta G_1 = 18342$) when considering independent loop L_1 (close K_{21} and open K_2). The other independent loops do not reduce the G function. Power loss at the moment is $\Delta P_{stage1} = 94.6$kW

Carry out stage 2, this configuration of distribution networks has open–switches as: K2, K17, K18, K20, K10 and K19. Solve the problem of power distribution when closing each open switch then opening the switch with the smallest current flowing through it. The result is:

Close K_2 : Independent loop 1 has the smallest current I_2 (41.1A)
Close K_{17}: Independent loop 2 has current I_{17} (30.9A)
Close K_{18}: Independent loop 3 has the smallest current I_{16} (8.1A) $\Rightarrow$ close K_{16} open K_{18}
Close K_{20}: Independent loop 4 has the smallest current I_{20} (30.5A)
Close K_{10}: Independent loop 5 has the smallest current I_{10} (9.6A)
Close K_{19}: Independent loop 6 has the smallest current I_{19} (11.1A)

So after stage 2, the switch to open the MVN will be: K_2, K_{17}, K_{16}, K_{20}, K_{10} and K_{19}, so the power loss from $\Delta P_{stage1} = 97.1$kW reduced to $\Delta P_{stage2} = 92.3$kW

4.2 Searching process of network configuration with 2 DG at node 9 and node 13.

The radial power distribution network initially [4] has the opening switches K_{21}, K_{17}, K_{18}, K_{20}, K_{10} and K_{19}. Power loss is first calculated by PSS/ADEPT 5.0: $\Delta P_{old} = 120.5$kW.

Solving the power flow calculation on closed distribution networks. Conduct stage 1 function G decrease by the proposed algorithm. After iteration 1 reduce G function ($\Delta G1 = 13437$) when considered independent loop L_1 (closed K_{21} and open K_2: $\Delta P_1 = 67.5$kW) and iteration 2 ($\Delta G2 = 20$) when considering independent loop L3 (closed K_{18} and K_5 open: $\Delta P_2 = 68.4$kW). Power loss in the second iteration G function increased but decreased as the power loss decreases as expression (4) and (5) simultaneously equal to 0

Carry out stage 2, this configuration of distribution networks is the switches to open: K_2, K_{17}, K_5, K_{20}, K_{10} and K_{19}. Solve the power distribution when close every switches and open switch with the smallest current flowing through it. That results:

Close K_2 : Independent loop 1 has the smallest current I_2 (33.6A)
Close K_{17}: Independent loop 2 has current I_{17} (21.7A)
Close K_5 : Independent loop 3 has the smallest current I_{18} (11.5A) $\Rightarrow$ close K_5 and open K_{18}, $\Delta P_3 = 67.5$kW
Close K_{20}: Independent loop 4 has the smallest current I15 (28.2A) $\Rightarrow$ close K_{20} and open K_{15}, $\Delta P_4 = 66.4$kW
Close K_{10}: Independent loop 5 has the smallest current I_{10} (6.7A)
Close K_{19}: Independent loop 6 has the smallest current I_9 (1.3A) $\Rightarrow$ close K_{19} and open K_9, $\Delta P_5 = 66.3$kW

So after stage 2, the open-switches of MVN will be: K_2, K_{17}, K_{18}, K_{15}, K_{10} and K_9, so the power loss from $\Delta P_{stage1} = 68.4$kW reduced to $\Delta P_{stage2} = 66.3$kW.

4.3 Search network configuration when there is a DG at node 9

The radial distribution networks initially [4] had the open-switches as: K_{21}, K_{17}, K_{18}, K_{20}, K_{10} and K_{19}. Power loss is first calculated by PSS/ADEPT is ΔP_{old} = 166.9kW

Solving the power flow calculation on closed distribution networks. Perform the process of decreasing the function G (stage 1) following the proposed algorithm. After iteration 1 reduce G function ($\Delta G1 = 13006$) when considering independent loop L_1(close K_{21} and open K_2, $\Delta P_1 = 89.8$ kW).

Carry out stage 2, this configuration of distribution networks have open–switches: K_2, K_{17}, K_{18}, K_{20}, K_{10} and K_{19}. We solve the problem of power distribution when closing each open switch then opening the switch with the smallest current flowing through it. The result is:

Close K_2: Independent loop 1 has the smallest current I_2 (33.6A)
Close K_{17}: Independent loop 2 has current I_{17} (30.9A)
Close K_{18}: Independent loop 3 has the smallest current I_{16} (8.1A) $\Rightarrow$ close K_{18} and open K_{16}, ΔP_3 = 85.8kW
Close K_{20}: Independent loop 4 has the smallest current I_{15} (28.2A) $\Rightarrow$ close K_{20} and open K_{15}, ΔP_4 = 84.0kW
Close K_{10}: Independent loop 5 has the smallest current I_{10} (12.1A)
Close K_{19}: Independent loop 6 has the smallest current I_9 (1.3A) $\Rightarrow$ close K_{19} and open K_9, ΔP_5 = 83.7kW

So, after stage 2, the open switch of the MVN will be: K_2, K_{17}, K_{16}, K_{15}, K_{10} and K_9, so the power loss from ΔP_{stage1} = 89.8kW reduced to P_{stage2} = 83.7kW

4.4 Searching process of network configuration with a DG at node 13.

The radial distribution networks initially [4] had the switches to open K_{21}, K_{17}, K_{18}, K_{20}, K_{10} and K_{19}. Power loss is first calculated by PSS/ADEPT is ΔP_{first} = 125.2kW.

Solving the power flow calculation on closed distribution networks. Carry out process of decreasing the G function (stage 1) following the proposed algorithm. After iteration 1 reduce G function ($\Delta G1$=14405) when considering independent loop L_1 (close K_{21} and open K_2: $\Delta P_1 = 74.3$ kW) and iteration 2($\Delta G2 = 4$) when considering independent loop L3 (closed K_{18} and K_5 open: $\Delta P_2 = 75.2$ kW). Power loss in the second iteration increases but function G decreases because the power loss decreases as expression (3) and (4) simultaneously equal to 0.

Carry out stage 2, this configuration of distribution networks has open-switches as: K_2, K_{17}, K_5, K_{20}, K_{10} and K_{19}. We solve the problem of power distribution when closing each open switch then opening the switch with the smallest current flowing through it. The result is:

Close K_2: Independent loop 1 has the smallest current I_2 (35.5A)
Close K_{17}: Independent loop 2 has current I_{17} (21.7A)

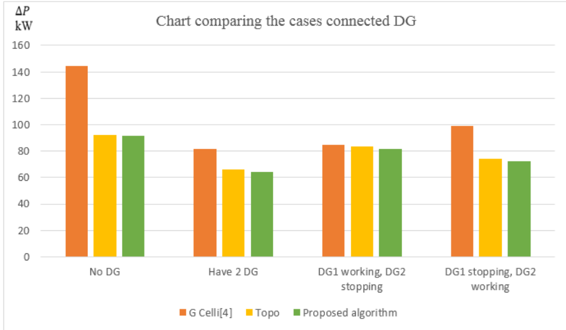

Fig. 4. Chart comparing the cases connected DG

Close K_5: Independent loop 3 has the smallest current I_{18} (11.3A) $\Rightarrow$ close K_5 and open K_{18}, ΔP_3 = 74.3kW
Close K_{20}: Independent loop 4 has the smallest current I_{20} (23.5A)
Close K_{10}: Independent loop 5 has the smallest current I_{10} (9.6A)
Close K_{19}: Independent loop 6 has the smallest current I_{19} (11.1A)

So, after stage 2, the opening of switches of the MVN would be: K_2, K_{17}, K_{18}, K_{20}, K_{10} and K_9, so the power loss from ΔP_{stage1} = 75.2kW reduced to P_{stage2} = 74.4kW.

In summary, the survey results on distribution networks for 16 nodes in the Table 1.

The calculation results in Table 1 and 4 show that, the application of the proposed algorithms for the power loss value in plans has positive results. The configuration that we found has smaller power loss than the recommendations in [4]. Despite giving similar results as [7], our proposed algorithm uses a much shorter calculation time than that of [7], because calculation is repeated once only and not depending on the initial configuration. This is very different from the calculation method of [7], in which for each calculation, only 1 pair of electrical switches in an independent round is considered, the selected configuration in [7] depends a great deal on the initial configuration.

5. Conclusion

DG resource has great impact on the electric current distribution across the whole MVN. After connecting DGs, the reconfiguration of distribution networks is very important in order to ensure that MVN with DGs operated with the smallest ΔP. The DGs changing strongly seasonally (such as small hydropower) as clearly shown in expressions (5) to (6). Therefore MVN configuration that essentially needs to change to obtain the smallest reduction ΔP after having DG.

The proposed algorithm has described impact of DG and reconfiguration to reduce ΔP in MVN. The calculation of G function is simple and quickly than the calculation of ΔP.

In addition, application of G function allows to find the final configuration which has the smallest ΔP dual to the comparison the value of G function between independent loops in MVN. Because the value of G function decrease in each step, so G function can be developed to solve the reconfiguration problems considering DG such as decreasing operating cost, restoring the power, preventing overload.

The proposed algorithm appropriates to the online mode of operation of distribution networks with DGs on the basis of comparing the deviation c.ΔA with switching costs. When moderators have information on additional load forecast, DGs, the percentages of additional industrial load ratio and switching time, they will help operators to have decision for configuration of power distribution networks.

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