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Fuzzy Coordination of Distributed Generation Sources

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Abstract. In the recent years the power system technology like other technologies is going to face great changes. One of the important issues of this restructure is employment of distributed generation (DG). The common aim of using distributed generation is generation of active power. But the most recent researches on use of DGs are reactive power control by distributed generation in distribution systems. Existing methods use the classic optimization algorithms such as Genetic to optimize power losses at distribution system. But in this paper a novel method using fuzzy rules has presented to online control of Distributed Generation Outputs in distribution system in order to reduce power losses and improve voltage profile which is more accurate and faster than other methods. This method uses many bus voltages as inputs and according to fuzzy rules, sets DGs outputs. Use of this method on a standard distribution network reveals great improvement in mentioned parameters.

Keywords: reactive power, distributed generation, fuzzy rules, voltage profile, power losses

1. Introduction

Nowadays, the power systems are going to face great changes. These changes involve both of technologies and control methods. Also many of nonelectrical parameters like environment health and economics effect these changes [1],[9],[10]. Generating of reactive power is one of the most important necessities of power system that there are many ways to generating of it [2],[3]. So there are many researches on this subject, too. One of the latest sources of this type of power is distributed generation that has a lot of other effects on power system such as increasing of reliability and power factor correction. According to this subject, in this paper we have presented an online method based on fuzzy systems to control DGs. The result of this method is reduction of power losses and improvement of voltage profile in distribution network [12]. In the next part of this paper the common methods of DGs coordination have been reviewed. In the third part the main steps of our method will be described. In the fourth part the final method will be presented and finally the results of use of this method for a standard distribution network will be presented and many recommendations to improve of this method will be introduced.

2. The Most Common Coordination Methods of DG Sources

The current coordination methods of DG sources for generation of reactive power use classic optimization algorithms to get the final results. Therefore they need a goal function and this function also needs some conditions. Some of these methods are ANTS COLONI, LINEAR PROGRAMING, GENETIC ALGORITHM [4],[7] and etc. As discussed, in these algorithms we try to improve the parameters of system such as voltage profile and power losses. So the goal function will be based on these variables [5]. You can see one sample of these functions in equation (1). As you can see, the main function is based on power losses while the independent variable is the voltage of system. Of course, other limiting subjects such as maximum number of switching for capacitor banks can be used as condition, if it is necessary.

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$$F = \min(P_{LOSS}(v(i))) \tag{1}$$

In the current methods and researches all the network loads considered as a unit load that changes along a day between three or four levels [6],[7]. Then according to these limited levels, the goal function will be determined and will be optimized by suitable algorithm. The result of this matter is a time based table for amount of DGs outputs.

Although these methods have many benefits but they have some problems that will be mentioned in the follow.

a) Load Simultaneous Factor: The supposition of these methods is that all loads of the network, in any parts of it, have simultaneous increasing and decreasing. This supposition doesn't adopt with the reality, because there are different kinds of loads in a network and while some of them are increasing the others may decrease or be constant. And it's clear that the results of load flow in the network will be different at these two conditions.

b) Non-continuous Load Changing: In real networks there are continuous load changes while in current methods it has considered discontinuous [11]. So the load levels will be limited. The result of this supposition is reduction of accuracy.

3. The Method , Illustrated in This Paper

In this part we will introduce the new method that has cleared most problems of other methods. This plan has many steps that will be mentioned.

i. At the first step the distribution feeder must be divided to many independent areas. This division is based on some parameters such as network structure or location and amount of loads of the feeder. The quality of loads centralization at different branches and loads nearness to the main busbar, one or three phase loads, capacitor banks and finally the main parameter for this plan, the location of DG sources are the most important basics to determine areas of the feeder. A sample feeder division is shown in Fig.1 . Of course the experience of planner and his information about the feeder is important for a nice division.

ii. At this part the loads of each area is supposed as a unit load with many levels. It's clear that the load levels of each area must be adopted to real daily loads changing. So we have many combinations of load levels at a feeder by combining of all areas load levels. The great advantage of this method is that, we can get a specified percentage of full-load of the feeder by different combination of areas load. For example, we can get to %60 of feeder load by combining of %50 of load "A" and %80 of load "B", or %65 of load "A" and %45 of load "B", or any other combination of these two areas loads.
On the other hand, by combining of these levels the load of network has been divided into smaller steps than other methods. So the error of calculations will decrease.

iii. At this stage we use many combinations of areas loads as inputs of the network and calculate the outputs. According to aims of this method, the magnitude of busbars voltages is taken as outputs and next decisions will be based on them. Of course it must be mentioned that discontinuity of loads levels has not been solved yet.

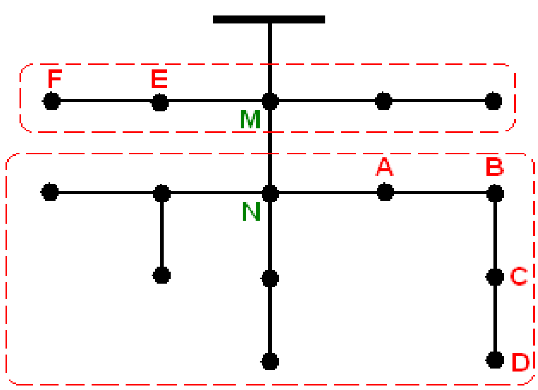

Fig. 1: selection of areas and main bus of each area

iv. After calculation of busbars voltages, it's necessary to find busbars with similar changes. It's clear that the busbars of each branch of the feeder depend together completely. But voltage changing in each branch is not suitable to guess the voltage changing of other branches. So we need to use voltage changing of each branch independently. As a result, at first we need to select one busbar voltage from each area as the main bus of that area or branch. For this selection it must be considered that the selected bus is not allowed to get same voltages in different loads levels combinations. In Fig. 1 the buses called "M" and "N", have all notified points.
v. Now, according to existing experiences the amount of capacitor banks and DGs must be set in order to reach specified variables to the suitable ranges. So it's necessary to make many test samples by a professional planner. Finally many pairs of inputs and outputs will be created which inputs are the loads of areas and the outputs are the amount of DGs and capacitor banks.
vi. At the next step of this method we will fuzzificate the output and input variables. It will solve the problem of discontinuity of variables, because the middle real values that don't belong to any specified levels will be defined by existing levels of variables. So every case of input and output pairs can be studied. For example, in Fig. 2, %87 of load can be defined based on %80 and %100 membership functions.

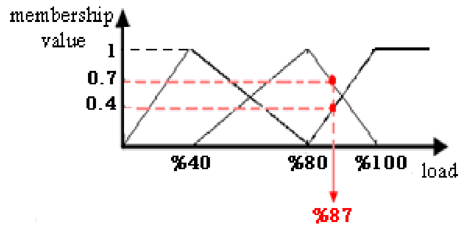

Fig. 2: fuzzification of loads

vii. After mentioned steps a daily program for setting of capacitor banks and DGs can be provided and the generated reactive power can be set in order to have suitable voltage profile.

4. The Final Control Method

As discussed before, this method results a specified plan of daily power generation. Now if we want to achieve an online control system, we must make some changes at illustrated steps.

a. It was illustrated that there are many combination of areas loads and therefore many related generation outputs to keep voltages in range. In other word, for each load combination there is one appropriate generation combination. But according to load changing, it may change from for example case 'A' to 'B' while the sources have been set for case 'A' which is not proper now! So the outputs must change, too. To design the controller we must simulate all possible combinations of load and generation, and save the resulted voltages for next decisions. For example, if there are 9 load situation, there will be 9 proper generation too, while all combinations are 81 pairs. As a result, as load changes, the controller must change DGs and capacitor outputs from an improper state to new proper state immediately.
b. At the next step, according to achieved combinations, DGs outputs must be inverted to fuzzy variables.
c. Now the most important step of suggested method will be done and it is generation of fuzzy rules for controller. We know from last steps that each combination of main buses voltages is result of a specified areas load. And this load has a proper generation combination to improve voltage profile. So we can make suitable fuzzy rules to change generation outputs from an improper state to a proper one. Of course it's not necessary to use all possible combination of inputs and outputs, but some of important combinations are enough, which selecting of them needs professional users. These selected pairs of inputs and outputs must show all behaviors of the system.

5. Employing of Suggested Method To a Sample Network

As it was mentioned before, the network that has been used in this project is IEEE 13 buses network which is used as one of the standard networks for studying of distribution systems [13]. In Fig. 3, the feeder has been

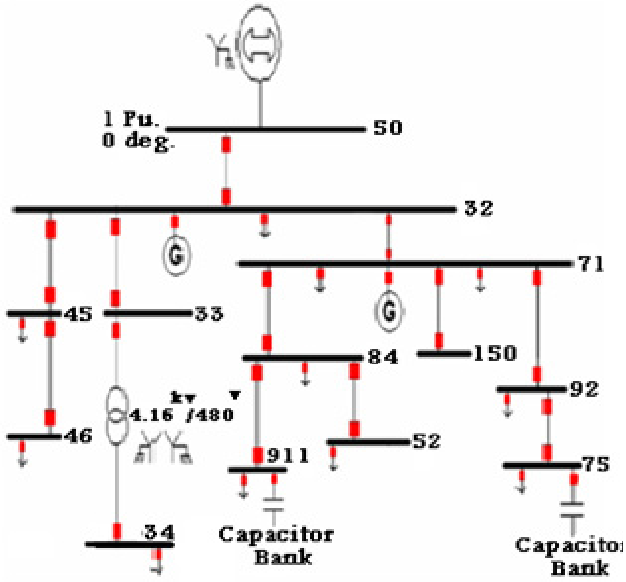

Fig. 3: IEEE Standard 13 Buses Network

Table 1. Selected Values Of Voltages and DGs Outputs

BUS 32 (volts)				
2376.1	2383.1	2384.7	2385.6	2390.4
2391.6	2392.7	2393.4	2397.2	2398.2
2401.6	2404.9	2405.7	2414.9	
BUS 71 (volts)				
2353.9	2363.5	2367.3	2370.1	2374.6
2379.4	2381	2382.4	2383.2	2391.8
2393.9	2394.3	2394.9	2397.9	2398.1
2407.7	2413.1	2422.2		
G1 (%)	23.1	30	80	100
G2 (%)	30	55	70	100

divided to two areas and voltages of buses number 32 and 71 have been chosen as input variables of the controller. Also three levels (%40, %70, %100) have been considered for load of each area that create 9 different global load combinations for the feeder and there will be 9 appropriate generation combinations, too. By simulating the network in these 9*9 = 81 combination of load and generation, 81 voltage values for buses number 32 and 71 will be generated. Of course, thirteen points out of the whole possible values of bus 32 and seventeen points out of all the possible values of bus 71 were assigned as input variables (Table 1). The fuzzy illustration of inputs and outputs can be observed in the Fig. 4 and 5, respectively.

To obtain the result, twenty rules have been used but based on the table of load and generation combination it is likely that the number of rules used by another designer be different. We have used fuzzy toolbox of MATLAB software to generate fuzzy rules employed its results for power flow program [14]. As pointed out previously, in this method heavy emphasis is placed on the experience and knowledge of the designer and a change in the rules or the key points might lead to obtaining more appropriate results. The following are some of the used rules. Now, the controller has been designed. Finally, for testing the controller, many combinations of loads and primary values of generations have been applied to it which results are given in table 2. And a comparison has been made with the state in which the DG sources are not used.

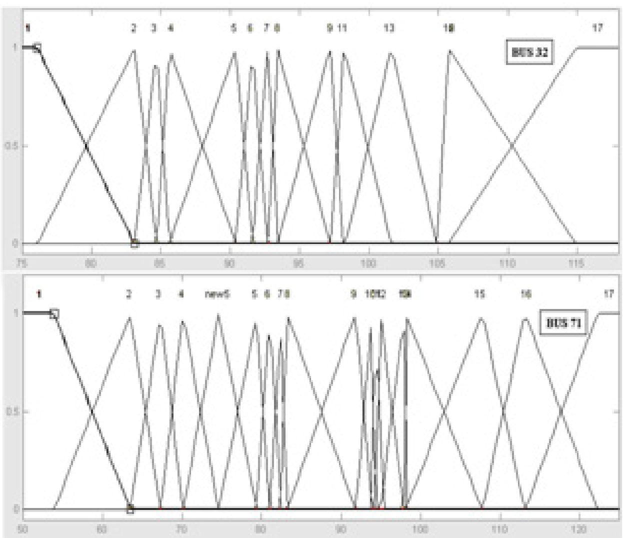

Fig. 4: Fuzzification of Voltages (Inputs)

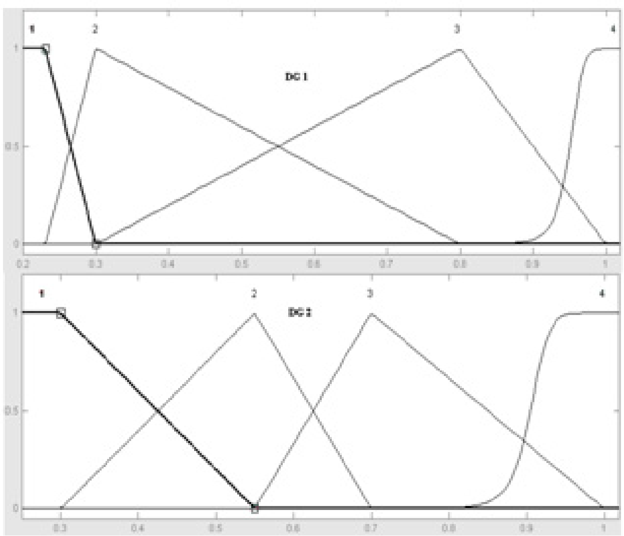

Fig. 5: Fuzzification of DGs Outputs

Table 2. The Results Of Applying Many Inputs

Iteration	Power Losses (kW)	New setting of DGs (%)		Primary setting of DGs (%)		Load (%)	
		DG 2	DG 1	DG 2	DG 1	Area 2	Area 1
5	29.838	38.54	66.51	70	30	80	50
3	14.508	91.55	66.97	50	50		
2	14.508	91.56	66.97	35	85		
-	64.991	Without DGs					
2	9.526	36.41	97.84	40	20	60	25
3	9.526	36.41	97.84	30	45		
4	6.661	63.50	61.00	90	75		
-	31.797	Without DGs					
3	17.551	36.52	46.09	25	20	30	85
2	17.551	36.52	46.09	40	55		
3	17.550	36.53	46.10	70	95		
-	32.216	Without DGs					

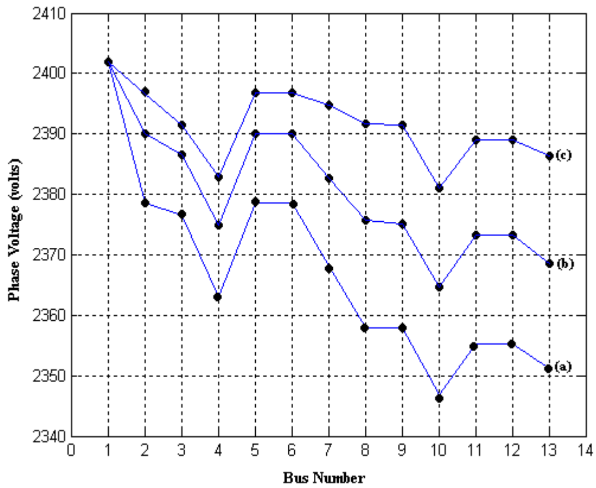

Fig. 6: voltage Profile of Network

(a) Without DGs

(b) With 30% and 70% primary values Of DGs

(c) With 50% and 50% primary values Of DGs

For example, in the first state the load of area "1" is %50, the load of area "2" is %80 and DGs outputs supposed at three different primary states. These states for sources "1" and "2" are (30,70), (50,50), (85,35) percents, respectively. Then by making the control program it's observed that in all states, the output (DGs productions) follow the input (voltages of buses 32 and 71) until reaches to new proper value, based on defined fuzzy rules. As you can see these new values are (66.51,38.54), (66.97,91.55), (66.97,91.56) respectively. Also you can see in table 2, the number of main loop iterations of the used power flow program to reach the voltages in the acceptable range.

It is obtained from the results that second and third states have converged together while the final state is different from them. Of course this matter depends to designer knowledge and ability and fuzzy rules he made. The results of this algorithm employing have been shown for two other random combinations of load and generation. Also power losses before using DGs can be seen in this table. Fig. 6, shows the voltage profile of the system. As you can see, after using this method the voltage profile has been improved. As a sample, the voltage of bus No. 10 has changed from 2347 to 2381 volts. Referring to other researches on this case [6],[15],[16] shows a reduction in power losses about two times while by good selection of fuzzy rules we can reduce power losses in this method even to five times. Of course the other important advantage of this method, compared to others is its speed to follow the load which prevents large errors in settings of outputs.

6. Conclusion

This paper has illustrated a novel and different method from common methods for DGs coordination in distribution networks. Employing of this method offered an online control of DGs according to load changes. Of course it must be reminded that results accuracy of this method depends on accuracy of primary loads levels selection, proper generation outputs selection and suitable fuzzy rules defined.

Also according to introduced algorithm many suggestions offered.

1) Exact selection of fuzzy membership functions has an important impact on accuracy outputs and fuzzy rules. Hence, we can use GA to find the must proper fuzzy membership function.

2) In this paper load changes have been considered in many fuzzy levels. But if we want to get closer to reality we can add a new variable as input that is "time". In the other word the rate of loads changing can be considered as a new variable, too.
3) Some points of last methods that have enough accuracy can be used in this method as leader points of "SUGENO" algorithm.

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