Load Distribution using Fuzzy Logic

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Abstract— **The distribution system problems, such as planning, loss minimization, and energy restoration, usually involve the phase balancing. The faulty distribution can lead some areas overloaded and some areas with less loaded. So to avoid these conditions, controlling of power and hence controlling of load is required in those areas. It leads to the load balancing technique. Load balancing is the process to prevent the system from overloading situation. In this paper, the design and implementation of Power Load Balancing will be done using Fuzzy logic toolbox of MATLAB. Fuzzy logic provides easy way using graphical user interface to implement fuzzy system.**

Keywords— **Load balancing, Fuzzy logic, Matlab, Feeder**

I. INTRODUCTION

The steps for the power system are generation of power, transmission of power and distribution of power. Once power transmission to the subsystem is done, the next thing is to distribute the power among all the consumers. The faulty distribution can lead some areas overloaded and some areas with less loaded. So to avoid these conditions, controlling of power and hence controlling of load is required in those areas. It leads to the load balancing technique. Load balancing is the process to prevent the system from overloading situation. This project explains the details of load balancing and steps for how to design and implement a load balancing in power distribution. Consumption of the power at consumer side is highly unpredictable. Consumption varies at each time of the day and each day of a year. Now as we know that it is hard to save large amount of electricity using buffers, to avoid such problems, power controlling is desirable. Automatic generation control (AGC) is the one way to control power. It is implemented at the power station side and it controls the generation of power as requirement or load changes. If the power usage is very small, it is costly to implement such a system. So load balancing is the easy way to control power.

Load balancing is implemented at the power distribution side. The basic action the system will take during overloading situation is to balance the load from over loaded area to the less loaded areas. The transfer is done through open/closed switches. In this paper, designed and explained load balancing using fuzzy logic toolbox. Fuzzy logic has advantages of simple to understand and cheaper to implement.

II. LITERATURE REVIEW

To improve the system efficiency in the modern power distribution systems, sectionalizing switches and tie switches for feeder reconfiguration are used extensively. Baran and Kelly used the state estimation technique for feeder reconfiguration [1]. Siti and Jordaan [2], Siti et al. [3] presented the way to control the tie switches using heuristic combinatorial optimization based methods. The only disadvantage with the tie-switch control is that, in most of the cases, it makes the current and the voltage unbalances worse [4]. There have been different studies concerning the loss minimization of distribution feeders cited in [5-6]. With the advent of artificial intelligence, telecommunication and power electronics equipments in power systems, it is getting easier to envisage automation of the phase and load balancing problem. The automation implementation will be technically advantageous as well as economical for the utilities and the customers, in terms of the variable costs reduction and better service quality, respectively. Walters and Schele [7], Chen and Cherng [8] presented the use of genetic algorithms for improving system unbalance and loss minimization. On the basis of these results, other networks identify the radial topology satisfying the optimal condition. Kashem, Jasmon and Ganapathy presented the three phase load balancing in distribution system using index measurement techniques in [9]. It was improved by the reconfiguration system using the fuzzy multi-objective approach [10].

Therefore, we wanted to explore fuzzy logic for phase balancing. Another reason is that if fuzzy logic-based approach is successful this could be easily implemented using FPGA architecture.

III. REPRESENTATION OF THE FEEDER

The distribution feeder is usually a three –phase, four wire system with a radial or open loop structure. To improve the system phase voltage and current unbalances, the connection between the specific feeder and the distribution transformer should be suitably arranged, The loads are connected, as in most cases, in a single-phase. For the problem in this paper, we assume that each feeder contains 50 loads or connections to it, So, the total load to the three feeders can be 150 connections as shown in Fig. 1. In Fig. 1, each load, through the tie-switches, can be connected only to the one of the three phases.

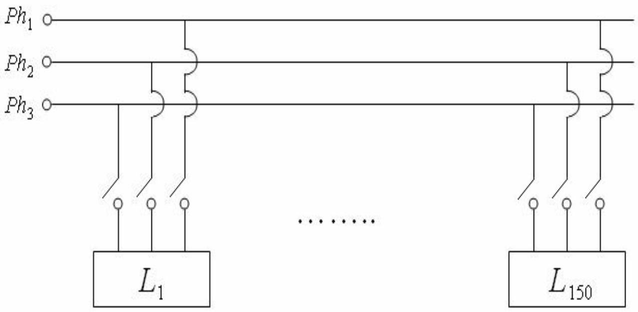

Fig. 1. Example distribution feeder

IV. PROPOSED TECHNIQUE

In this paper, a fuzzy logic-based load balancing technique along with combinatorial optimization oriented system for implementing the load change decision. The architecture of the proposed system is shown in Fig. 2.

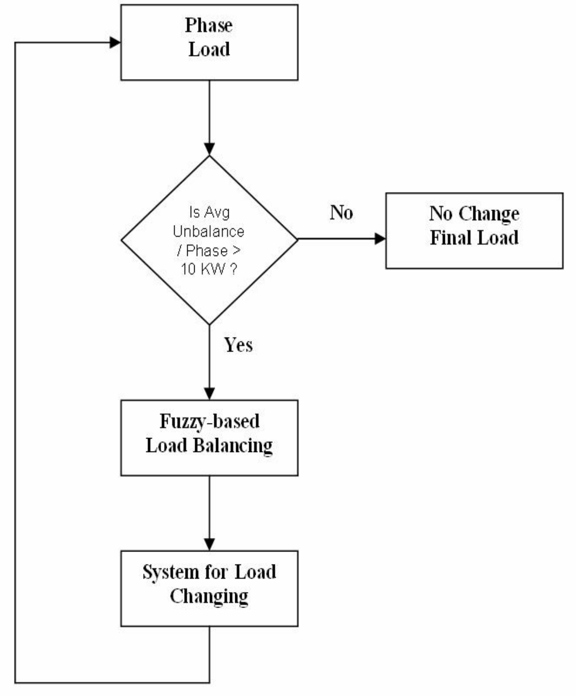

Fig. 2. Architecture for the proposed load balancing system

$$Average\ Unbalance/Phase = \frac{\left[\mathrm{Load}_{Ph1} - Load_{Ph2}\right] + \left[Load_{Ph2} - Load_{ph3}\right] + \left[Load_{ph3} - Load_{ph1}\right]}{3}$$

“Equation 1”

In Fig. 2, the input is the total phase load (for each of the three phases). The average unbalance per phase, calculated according to (1), is checked against a threshold of 10 kW. If the average unbalance per phase is below 10 kW, we can assume that the system is more or less balanced and discard any further load balancing. Otherwise, we go for the fuzzy logic-based load balancing. The output from the fuzzy-based load balancing step is the load change values for each phase. A *negative* value indicates that the specific phase has surplus load and should *release* that amount of load, while a *positive* value indicates that the specific phase is less loaded and should *receive* that amount of load. This load change configuration is the input to the implementation system which tries to optimally shift the specific number of load points.

However, sometimes the implementation system may not be able to execute the exact amount of load change as directed by the fuzzy step. This is because the actual load points for any phase might not result in an optimum combination which sums up to the exact change value indicated by the fuzzy step. So, we implement the best possible change from the implementation system and iteratively check the system unbalance until we achieve the average unbalance below 10 kW, if achievable.

V. FUZZY LOGIC BASED LOAD BALANCING

In this section, we describe the fuzzy logic-based load balancing technique in details. As described in section 3, we assume the average per phase capacity of the system to be 150 kW, with 50 load points connected to any specific phase. For designing the fuzzy controller, we further assume the maximum overload capacity of any phase to be 300 kW. Beyond 300 kW the fuzzy controller should not be used for load balancing. Because, in any case, when any phase reaches its 200% overload condition, it should be cut out from the service to prevent power breakdown and severe overloading of the transformer.

VI. FUZZY CONTROLLER: INPUT AND OUTPUT

To design the fuzzy controller, first we design the input and the output variables. We choose the input as ‘Load’, i.e., the total phase load (kW) for each of the three phases, and the output as ‘Change’, i.e., the change of load (kW, positive or negative) to be made for each phase. For the input variable, Table 1 shows the fuzzy nomenclature, and Fig. 3 the respective triangular fuzzy membership functions [11]. And for the output variable, Table 2 shows the fuzzy nomenclature, and Fig. 4 the corresponding triangular fuzzy membership functions [11].

TABLE I
FUZZY NOMENCLATURE FOR THE INPUT VARIABLE

S. No.	Input (Load) Description	Fuzzy Nomenclature	KW Range
1	Very Less Load	VLL	0 to 50
2	Less load	LL	35 to 85
3	Minimum Less Load	MLL	65 to 115
4	Perfectly Load	PL	100 to 150
5	Single Over Load	SOL	125 to 175
6	Medium Over Load	MOL	165 to 215
7	Over Load	OL	200 to 250
8	Heavily Over Load	HOL	235 to 300

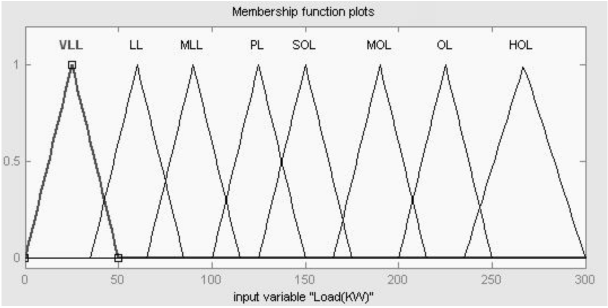

Fig. 3 Fuzzy membership functions for the input variable

TABLE III
FUZZY NOMENCLATURE FOR THE OUTPUT VARIABLE

S. No.	Input (Load) Description	Fuzzy Nomenclature	KW Range
1	High Subtraction	VLL	- 150 to – 85
2	Subtraction	LL	-100 to -50
3	Medium Subtraction	MLL	-65 to -15
4	Slight Subtraction	PL	-50 to 25
5	Perfect Addition	SOL	0 to 50
6	Medium Addition	MOL	35 to 85
7	Large Addition	OL	65 to 115
8	Very Large Addition	HOL	100 to 150

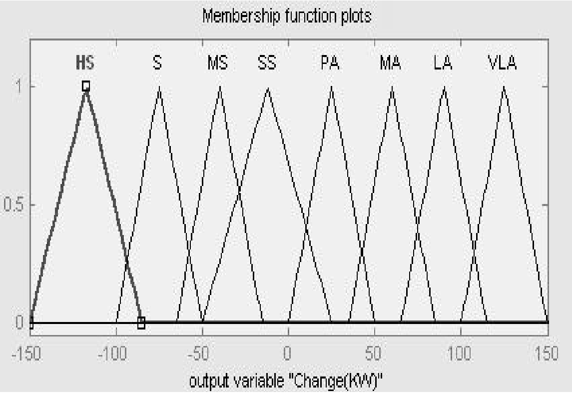

Fig. 4 Fuzzy membership functions for the output variable

VII. FUZZY RULES AND SURFACE

Next we determine the IF-THEN fuzzy rule set [11] governing the input and output variable as described in Table 3.

TABLE IIII
FUZZY RULES FOR THE INPUT AND OUTPUT VARIABLE

Rule No.	Rule Description
1	If Load is VLL then Change is VLA
2	If Load is LL then Change is LA
3	If Load is MLL then Change is MA
4	If Load is PL then Change is PA
5	If Load is SOL then Change is SS
6	If Load is MOL then Change is MS
7	If Load is OL then Change is S
8	If Load is HOL then Change is HS

Corresponding to the fuzzy input, output variables and the associated rule set, the fuzzy surface [12] is shown in Figure 5 depicting the nonlinear relationship between the input and the output variable.

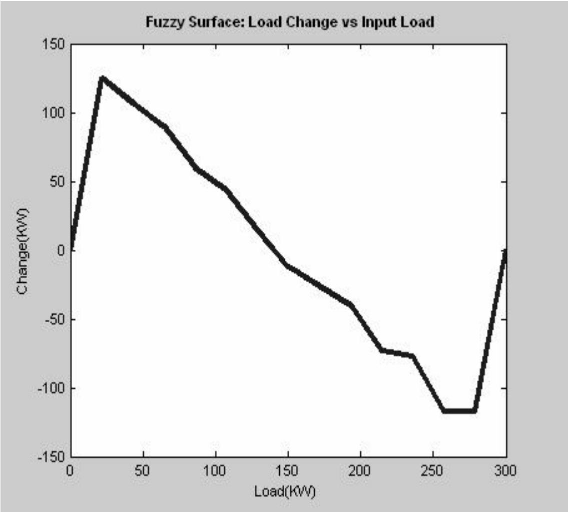

Fig. 5 Nonlinear relationships between the input and the output variable

VIII. APPLICATION RESULTS

In this section, we show the application results using the fuzzy logic-based load balancing technique. Matlab® fuzzy toolbox [12] was used for the simulation. We have utilized the Mamdani [12] fuzzy differencing technique.

We take an example input load configuration of [245120 82] kW for the three phases. We try to balance it using the fuzzy controller described above. The graphical determination of the output load change for the three phases corresponding to this input load and involving the eight fuzzy rules are shown in Figure 6 to.8.

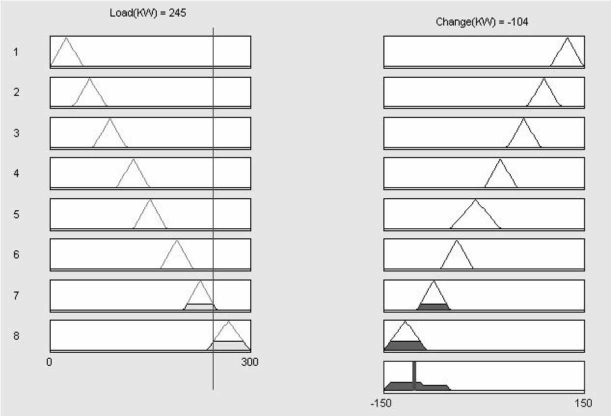

Fig. 6 Determination of the output load change for phase 1 of the input load

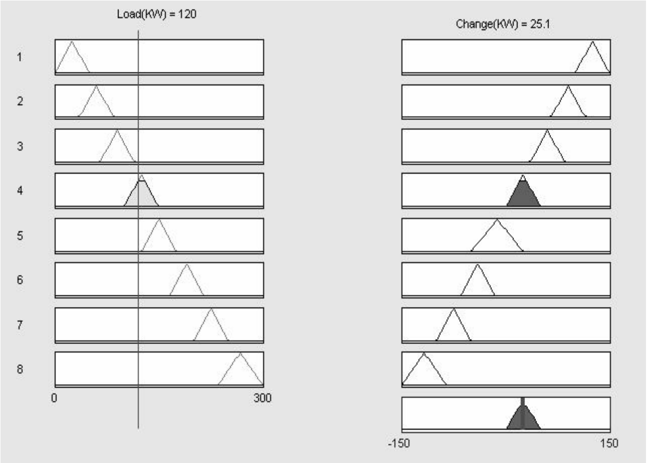

Fig. 7 Determination of the output load change for phase 2 of the input load

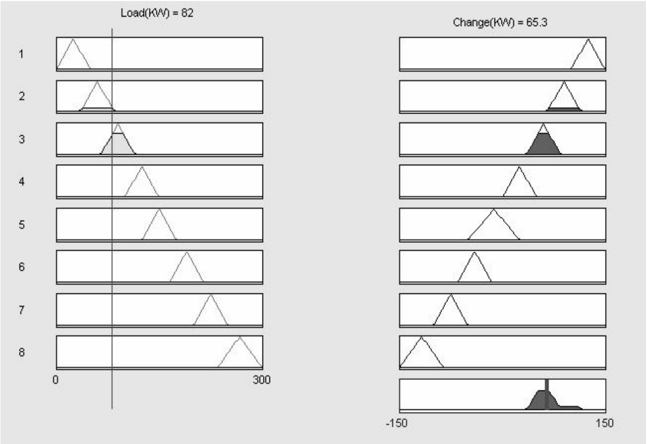

Fig. 8 Determination of the output load change for phase 3 of the input load

So, after rounding the output load change, for the input load $P_{in} = \begin{bmatrix} 245 \\ 120 \\ 82 \end{bmatrix}$ kW, the output load change configuration is $P_{Fuzzy} = \begin{bmatrix} -104 \\ 25 \\ 65 \end{bmatrix}$ kW. However, with this load change configuration, we will have error. Because the positive and the negative totals are not equal, i.e., $\sum \Delta P_{fuzzy} = -14 \neq 0$ kW. So, if we implement this load change configuration, this will result in reduction of -14 kW of total load. This is not possible, because, with the load balancing we can only interchange the load points amongst the three phases, keeping the total loads same, i.e., without increasing or decreasing the total load.So, we have to perform an error correction. The average error (AE) is given as

$$AE = round\left(\frac{\Delta P_{fuzzy}}{3} \right)$$

We use the average error to construct the error matrix ΔP_{error}, by distributing the AE evenly among the three phases.

$$\Delta P_{error} = \begin{bmatrix} AE \\ AE \\ \sum \Delta P_{fuzzy} - 2 * AE \end{bmatrix}$$

We get the final load change configuration ΔP, by subtracting the ΔP_{error} from the uncorrected fuzzy output ΔP_{fuzzy}.

$$\Delta P = \Delta P_{fuzzy} - \Delta P_{error} \quad \sum \Delta P = 0$$

Applying (3)-(5) in our example case, we get the following.

$$AE = -5kW$$

$$\Delta P_{error} = \begin{bmatrix} -5 \\ -5 \\ -4 \end{bmatrix} kW$$

$$\Delta P = \begin{bmatrix} -104 \\ 25 \\ 65 \end{bmatrix} - \begin{bmatrix} -5 \\ -5 \\ -4 \end{bmatrix} = \begin{bmatrix} -99 \\ 30 \\ 69 \end{bmatrix} kW$$

$$P_{final} = P_{in} + \Delta P = \begin{bmatrix} 245 \\ 120 \\ 82 \end{bmatrix} + \begin{bmatrix} 99 \\ 33 \\ 69 \end{bmatrix} = \begin{bmatrix} 146 \\ 150 \\ 151 \end{bmatrix} kW$$

Applying (2) on P_{in} and P_{final}, we get respectively

Initial Absolute Average Unbalance (IAUB) / Phase = 108.67 kW,

Final Absolute Average Unbalance (FAUB) / Phase = 3.33 kW

The reduction of unbalance indicates improvement of the phase balancing.

IX. CONCLUSION

Phase balancing is very important and usable operation to reduce distribution feeder losses and improve system security. In this paper, we have presented a fuzzy logic-based load balancing system along with a combinatorial optimization-based implementation system for implementing the load changes. The input to the fuzzy step is the total load (kW) per phase of the feeders. Output of the fuzzy step is the load change values, negative value for load releasing and positive value for load receiving. Sum of the positive and negative values is zero, i.e., the total load remains unchanged for the entire phase balancing. The output of the fuzzy step is the input to the load changing system. The implementation system uses combinatorial optimization techniques to translate the change values (kW) into the number of load points and then selects the specific load points. It also performs the optimal inter-changing of the load points between the releasing and the receiving phases. The load balancing system is tested at the three-phase, four-wire unbalanced feeders. Application of the proposed system is substantiated by detailed application example using Matlab® for the simulations. Further application results for different feeder loading configurations indicate substantial improvement of the unbalance conditions. The proposed phase balancing system using the fuzzy logic and the implementation system is practically effective for reducing the feeder unbalance. The phase balancing techniques and the systems presented in this paper could be generically extended further for other distribution systems and feeder load configurations than presented in this paper.

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