DYNAMIC FEEDER ROUTING IN SMART GRID DISTRIBUTION

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Received: March 14, 2016; Revised: June 07, 2016; Accepted: June 07, 2016

Abstract

The increment of reactive power is one of the most practical problems in power system. The increment of reactive power in distribution system causing low power factor or PF. The impacts of this problem are higher current in distribution line, higher power generation at the power plant, overloading current in devices, etc. Smart Grid can face the impact that found in the traditional grid. However, this problem of reactive power can be solved with the smart technology. This research proposed the dynamic feeder routing method to improve the maximum PF in the feeder of Smart Grid distribution. A modified version of Dijkstra's algorithm applied to this research in order to decide and select a power route for each load cluster. New parameters included with the factor of impedance (FoI), the angle between active load and apparent power created as major factors for using in the method. The results of the proposed methods effectively reduced the variance of load fluctuation (FoS Variance) of all feeders as much as 51.16%. Moreover, the PF was higher base on reactive power that measured by the totality index in PF correction (PFAI Totality) of all feeders could be reduced as much as 38.42% with no exceeding in power rating of each feeder.

Keywords: Smart grid distribution system, power factor, dijkstra's algorithm, feeder routing

Introduction

Electrical energy is the main crucial importance for supporting the business sectors operation including the appliance in the household. The effect of electrical power availability causes to the demand for electricity to rise steadily. Therefore, the power system is developed by integrated Information and Communications Technology (ICT) to the traditional grid. The integration of ICT supports the generation, transmission,

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distribution and consumption (Bichlien, 2013). Moreover, the Smart Grid feature able to support Distributed Generation (DG) penetration as well (James, 2012).

Improvement the PF, a key part of the Smart Grid distribution from the obligation to supply the power in transmission through consumption that operated by converting the medium voltage to low voltage (Paulo *et al.*, 2011). The aforementioned operation, the distribution loss in Smart Grid was a problem as the traditional grid. The distribution loss arose by the case of the reactive load that generated from the impedance of electric devices coupled with active power (Youjie *et al.*, 2014). The distribution loss, from the case of reactive load (Jame, 2012), occurred by the lagging voltage of electric current in magnetic flux devices (Eaton, 2014) such as electric devices that assembled with the coil part. The distribution loss led to increasing of supply power that affects improvement cost in distribution line and distribution transformer. Moreover, the mentioned problem has been increasing the cost of substation building for accommodating the electricity consumption (Xiang-min *et al.*, 2014). The consequence from distribution loss, the PF was reduced (Zhang *et al.*, 2014) in Smart Grid distribution.

The objective of research aimed to solve the problem in the scope of electric energy services organizations. The solution achieved by routing the power in each feeder both radial and loop distribution system. The objective of routing power was defined to improve the maximum PF under the terms of reactive load occurred (Glover, 2002).

In addition, the demand fluctuation depends on the consumption time. The fluctuation caused by the daily demand or seasonal demand changing on load types (Ozturk *et al.*, 2013), such as the factory production planning as the result of the potential demand led to exceeds supply ability. The process of research solved the problems by analyzing the variables to develop the feeder routing (William, 2002; Xiang-min *et al.*, 2014) in the Smart Grid distribution. The solution was defined by the routing algorithm from the source of supply power, in the constraint of the feeder supply capacity doesn't exceed ability in each feeder (Chiumarulo, 2015).

In related research, the radial distribution feeder was routed by Dijkstra's algorithm that could reduce the fixed cost, energy cost and interruption cost (Priya *et al.*, 2013). Moreover, a few work set the objective to determine the routing factors to measure the feeder routing performance about the power sufficiency and the PF improvement. The significant technique used the graph theory to search the shortest paths with Dijkstra's algorithm because of simple and lower complexity implementation (David *et al.*, 2011; Kocay *et al.*, 2004; Priya *et al.*, 2013). After finding the shortest path, the next step developed the routing algorithms for selected and adjusted the feeder routing with variables and routing factors (Raju *et al.*, 2014).

Meterials and Methods

In order to obtain this goal, the researchers determined the steps to carry out in three parts; input section, process section and output section, that show in Figure 1.

The first part was input section that analyzed relevant information on the statistics for process simulation data for experiments in Figure 1(i). The data were the key variables in Figure 1(ii) for mapping to graph theory in Figure 1(iii). The second part was the process section the defined the routing factors in Figure 1(iv) and development routing algorithms in Figure 1(v). The routing factors and routing algorithms conducted to routing experiments in any situation in Figure 1(vi). The last part was output section that involved the results of feeder routing from an experiment and comparison of results in Figure 1(vii).

Analyze and Simulate Data

The information of electricity consumption is daily load, both terms of active load and reactive load (PEA, 2015). The process of preparing the data shown in Figure 2.

In the analysis process, load pattern in each load type in Figure 2(i) are combined to the group of electricity demand that call load types that consist of 5 categories; department stores, factory, hotel, household and office. After the process defines the load curve in a

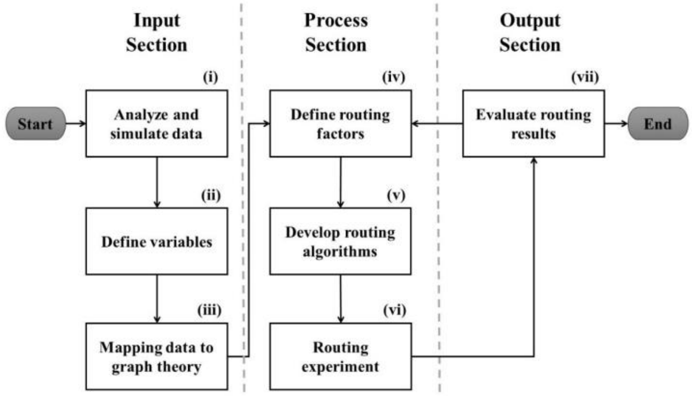

Figure 1. The section of the experiment

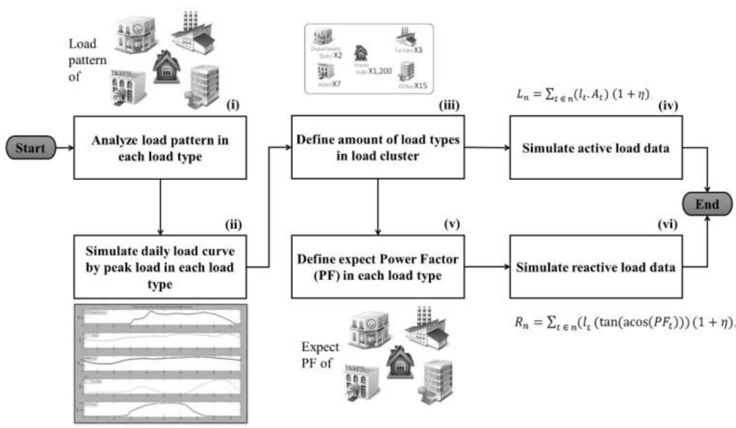

Figure 2. The process of analysis and simulation data

day. The daily load curve is calculated from load pattern with peak load in Figure 2(ii) (CEATI, 2010) and defines a number of load types in load clusters in Figure 2(iii), that groups load cluster from various load types.

The load clusters are determined by simulation data that could divide into 2 parts consisting of the active load and reactive load. The first part is the step of simulation active load data in Figure 2(iv) from the summation of the electricity consumption in each load type in half-hourly intervals of the day. After that, the result is multiplied by consumption in peak time and add the random variable with probability distribution function. The variables are compost of; L_t is active load (watt) and A_t is the number of consumption (unit) in load type t. The active load is defined as

$$L_n = \sum_{t \in n}(l_t . A_t)\,(1+\eta), \qquad (1)$$

where L_n is active load (watt) in load cluster n that computed from the summation of $l_t . A_t$ that t is the member of load cluster n and added with random variable with probability distribution function, in the term of $1+\eta$.

The second part is the reactive load (volt-ampere reactive) simulation by replicating data from the sum of the electricity consumption of each load type to calculation with expected PF in each load type in Figure 2(v). The load types comprise department stores, factory, hotel, household and office by expected PF are respectively by 0.85, 0.80, 0.85, 0.90 and 0.85 (Norman Disney & Young, 2002). After that, the next phase simulates reactive load data in Figure 2(vi). The random variable with probability distribution function by PF_t is expect PF in load type t and the reactive load define as

$$R_n = \sum_{t \in n}(l_t\,(\tan(\mathrm{acos}(PF_t)))\,(1+\eta), \quad (2)$$

where R_n is reactive load (volt-ampere reactive) in load cluster n that compute from the summation of l_t multiply by reactive in each load type t, in term of $\tan(\mathrm{acos}(PF_t))$, and add the random variable with probability distribution function.

The simulation data generated the matrix format of active load and reactive load. The matrix contained 48 rows by half- hourly periods of a day and the number of columns followed by load clusters. By the results, the simulation data of load clusters are grouped that each group comprising load types in Table 1.

The load clusters were set the load types amount and classified as 3 classes. The first class comprised the high consumption as the factory that conducted by the load clusters 1-4. The second class comprised the medium consumption that scheduled in working time as a department store, hotel, and office that the group of load clusters 10-14. The third class comprised the low consumption class that tentatively scheduled of use as the group of the household in load clusters 5-9. Notwithstanding in three class, load types were combined with the real characteristics of consumption. After simulation the data, daily load curve could find the power consumption activity varied and still highest power consumption at the peak time. Finally, in the terms of feeder supply from substations, the capable of supply power were equal 15 MW in each feeder.

Define Variables

The variables are determined by calculated the important variables. Let M is set of supply, N is the set of load cluster and f is number feeder. The supply variables are consist of;

$$S_{all} = \sum_{m \in M} S_m, \quad (3)$$
$$S_f = \sum_{m \in f} S_m, \quad (4)$$

where S_{all} is all supply (watt) that computed by the summation of S_m, supply (watt) number m which member of supply set M. The S_f is feeder supply (watt) that computed by summation of S_m in feeder f.

The active load and reactive load variables are consists of;

$$L_{all} = \sum_{n \in N} L_n, \quad (5)$$
$$L_f = \sum_{n \in f} L_n, \quad (6)$$

Table 1. The number of load types in load cluster

Load Cluster No. (L_n)	Load Type Units (L_t)				
	Department Store	Factory	Hotel	Household	Office
1	1	5	1	100	1
2	1	6	0	200	2
3	0	4	0	150	2
4	1	3	2	100	3
5	1	0	1	900	4
6	0	0	1	1,000	2
7	1	0	3	800	2
8	2	0	2	1,000	5
9	1	0	1	1,100	1
10	4	0	6	200	2
11	2	0	5	300	7
12	3	0	4	100	8
13	3	0	4	200	5
14	1	2	1	700	15

$$R_{all} = \sum_{n \in N} R_n, \quad (7)$$
$$R_f = \sum_{n \in f} R_n, \quad (8)$$

where L_{all} is all active load (watt) and R_{all} is all reactive load (volt-ampere reactive). Let L_n is active load (watt) and R_n is reactive load in load cluster number n. Both L_{all} and R_{all} are computed by summation of L_n and R_n in the set of N. In the scope of the feeder, L_f i.s feeder active load (watt) and R_f is feeder reactive load (volt-ampere reactive). Also, L_f and R_f are computed by summation of L_n and R_n is the member of f.

In the same notion, the capacity reserve variables are capable of supplying and computing by supply subtraction with the active load. The capacity reserve variables are consist of

$$C_{all} = \sum_{m \in \boldsymbol{M}} S_m - \sum_{n \in \boldsymbol{N}} L_n, \quad (9)$$
$$C_f = \sum_{m \in f} S_m - \sum_{n \in f} L_n, \quad (10)$$

where C_{all} is all capacity reserve (watt) and C_f is feeder capacity reserve(watt).

Mapping Data to Graph Theory

The experiment chose the distribution loop system topology. The features of the load clusters abled to connecting in any feeder. The path topology an association was the first feeder that connected with load cluster 1-4, the second feeder was connected with the load cluster 5-9 and the third feeder was connected to load cluster 10-14 as shown in Figure 3.

The one-line diagram transformed base on graph theory. The nodes assigned by the source of feeder and load clusters were connecting supply power with edges. Graph topology was directed graph in which direction from efficacy the power flow by edges and configuration from the data obtained in simulation. Each simulation data group consisting of active load and reactive load that was calculated the weights for use in experiments to the next step as shown in Figure 4.

From the graph topology, the nodes were assigned by the rectangle symbol presented the Source of Feeder Node (SN) and a symbol of the circle presented Load Cluster Node (LN). In the case of the edges were bi-directional that meant the connection between nodes had an alternative to change the flow as well. Graph topology implemented with MATLAB by import active load and reactive load inclusive feeder topology of each connected load clusters to the feeder (PEA, 2015), which shown in Figure 5.

Routing Factors

The routing factors defined under the conditions and circumstances (Vineetha *et al.*, 2014), the active load and reactive are designated consists of; Factor of Sufficiency (FoS), Factor of Prioritize (FoP), Factor of Impedance (FoI),

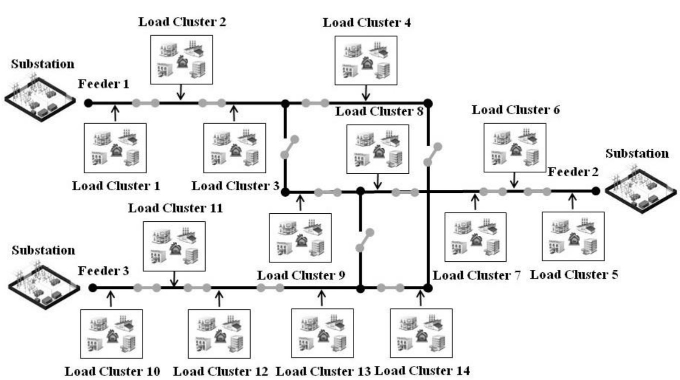

Figure 3. One-line diagram of the experiment