MURDOCH UNIVERSITY

Optimal generator placement in a distributed network

ENG470: Engineering Honours Thesis

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Abstract

Since the industrial and residential huge demand for electricity, as well as higher requirements for the electricity reliability and power quality. Meanwhile, the world has been in the energy crisis, the power shortage, and a large area often experienced blackouts accident. All exposed the deficiencies of 'centralized power'. Thus, the approaches of reducing active power loss in power systems have become increasingly important.

Among them, the method of the optimal location and size of distribution generators in a distributed network is one of the most prospective approaches in the future. And it can use into practice to achieve the purpose of low-carbonate, less cost and flexible power generation power systems because install DGs at the optimal location and with optimal size in distributed network can dramatically reduce active power loss in power systems. There are several models and methods have been suggested for solving the optimal DG placement problem. This paper presents models and methods applied to solve the optimal DG placement problem, and especially propose a new approach that based on an exact solution method using the enumerative method to reduce the number of the combination by request of constraints. In this case, the proposed method firstly will be applied to the simple 6 buses system, and then applied to 14 buses real size distribution network model which is based on the 126 buses real size distribution system. It can be evaluated for active power loss reduction features by DGs installation and choose optimal location and size of distribution generation in distributed network considering actual use.

Contents

1. Introduction

1.1 Objectives

There have been many methods put forward to solve the problem of optimal generator sizing and placement in a distribution network. However, the accuracy of these methods has generally been poor, as they cannot determine the location and size precisely due to the nonlinear discrete nature of the problem. So, an enumerative method that can give exact solutions has been found. Although enumerative methods have many advantages, such as simplicity and versatility, and are easy to use, they can suffer from the problem of combinatorial explosion. To overcome this problem, this thesis proposes a new approach to optimal generator sizing and placement that reduces the number of the combinations greatly by applying a number of constraints.

1.2 Background

In recent years, the integration of distributed generation (DG) into distribution networks has reached high penetration levels. The optimal allocation of dispersed generations (DGs) throughout the network is important because it can reduce active power loss, thereby reducing the amount of power that needs to be generated. The optimal allocation problem will also need to consider other network requirements, such as maintaining appropriate voltage levels throughout the network.

The more accepted distribution networks had been designed for high-voltage transmission of electric power, where the majority of electrical power was generated by just a few large scale generation plants, and transmission and distribution networks distributed this electricity in one-way power flows to customers [1]. Under these conditions voltages were relatively easy to regulate. With dispersed generation, maintaining voltage stability margins has become more significant issue. Optimization methods that are used for optimally location and sizing of the DG units in the system must also ensure that the solution has acceptable voltage stability margins.

2. Description of the technical aspects

2.1 Approaches and methods

An optimal allocation of Distributed Generations can increase electricity rapidly, reduce system energy loss, mitigate transmission congestion and improves voltage profile, enhances reliability and provides lower operating cost. So there are some approaches proposed for achieving the purpose of finding optimal allocation and sizing of distribution generation.

2.2 Fuzzy-GA method

The Fuzzy-GA method is very effective to reduce distribution system power losses for solving distribution generator placement in a distributed network system [3]. It can also determine the optimal location of DG installation as well as to minimize the power loss of the system in network systems by using analytical methods. Normally the proposed method is tested by simulations on 16-bus test distribution system [4].

As a good solving tool, the Genetic Algorithm (GA) method can resolve the problem for optimal location of generators to improve voltage profile and power loss reduction in the distribution network. And the load flow is required to apply for making a desirable decision due to need to consider the sensitivity of the fitness values in GA. In order to obtain the admissible result, the load flow algorithm is combined suitably with GA. The suggested method is programmed under MATLAB software and applied ETAP software for evaluating of results correctness [6], [7]. The study shows that the Khoda Bande Loo distribution test feeder in Tehran has been solved using the proposed algorithm, meanwhile make GA method simply and illuminated the improvement of voltage profile and loss reduction indexes. [Optimal Location and Sizing of Generator in Distributed Generation System, 2014].

2.2.1 Methodology

The principle of Genetic Algorithms (GAs) is to do a random global search and optimize the system based on the method of natural biological evolution. Combining the 'natural biological evolution' method, the GA method is similar to a population of solutions by applying the principle of 'survival of the fittest,' successive approximation produces better solutions. At each generation of a GA, there is a procedure to create a new set of approximations. Firstly, according to their fitness level in the problem field to select individuals and then using operators borrowed from natural genetics to reproduce it. This process leads to the evolution of populations, as in natural adaptation, the groups of individuals are better than individuals from which they were created and suited to their environment. Due to these advantages, GA has been applied in several problems and excellent texts [12-16].

In the initialization for GA parameters selection, the first step is to decide the coding structure. Coding for a solution called chromosome in the GA literature. And these components of the chromosome are then labeled as genes. The following figure 1 shows that the standard procedure of a canonical genetic algorithm.

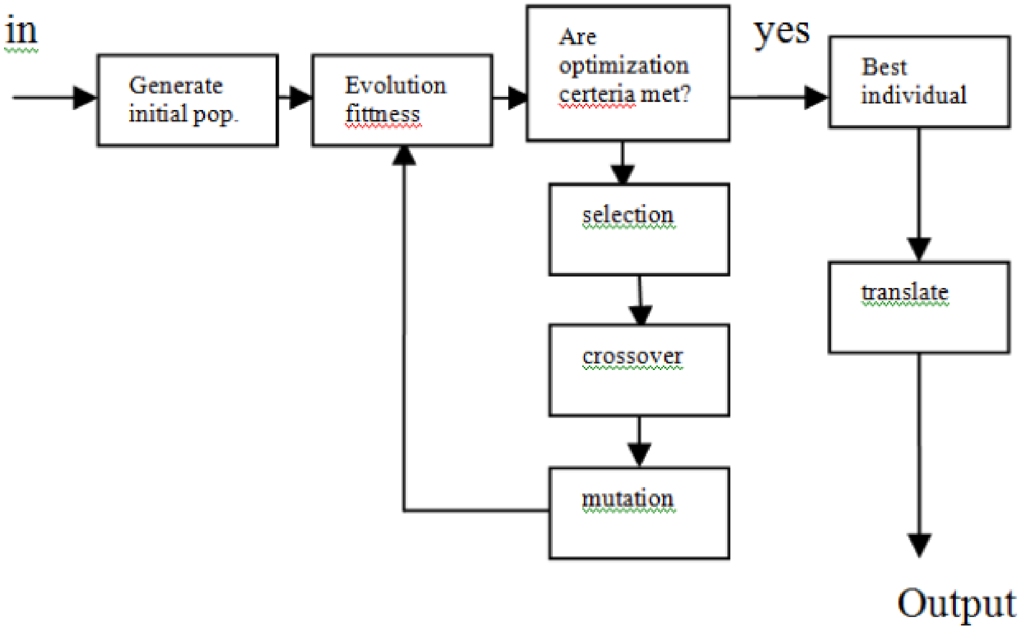

Fig1: standard procedure of a canonical genetic algorithm.

In the procedure, there are three operators that are proposed to allow the genetic algorithm to get good results in many practical problems as follows:

- Crossover: Crossover is a way that let the individual random organized pairs, and their space locations combined when they were paired. The result in such a way is that each former pair of individuals gives rise to a new pair.
- Mutation: Mutation is a way to reach other points of the search space by randomly modifying some individuals.
- Selection: After mutation and crossover, the individuals are evaluated. According to the probalistic rule, it can make a choice of selection for giving a greater probability to the “better” individuals.

2.2.2 Advantages and Disadvantages

The reason for using GA is it does not require any knowledge or information about response surface gradient [16], and effectively avoids falling into local optima, and the method can be applied to a wide variety of optimization problems. But, there is a problem of using GA in that it could require large amounts of fitness evaluation calculations to find the exact global optimization. That is mean it’s hard to achieve an analytic relationship between simulated power system sensitivity and the parameter values and to be optimized.

2.3 IA method and Harmony search algorithm

Nowadays, distributed generation technologies are divided into renewable and nonrenewable. Renewable energy technologies include solar, thermal or photovoltaic, wind, geothermal, ocean. Nonrenewable technologies include internal combustion engine, ice, combined cycle, combustion turbine, micro turbines and fuel cell. [23] And the energy sources of green energy are widely used in DGs, which is assumed pollution free [24].

From the study, the purpose of using the method is to avoid builds the new substations to energize with new transmission lines, and an available solution is to install DGs at the load centers. Because the installation of DG units can effectively avoid to increase the existing traditional generation capacity and build more power systems. Also, DG capital doesn't need to pay the substantial initial cost of installation DG because of the advantages of moderate electrical size, and modular behavior allows it is installed incrementally[24]. That is mean it doesn't require a large capital cost to set up the new distribution system, unlike installing new substations and feeders [25]. In addition, the optimal DG size and location is selected to apply to the system because the technical benefits, which include voltage improvement, mitigated transmission and distribution jamming, loss reduction, improved utility system reliability and power quality [24], increasing the endurance of equipment, improving the quality of power, voltage stability and total harmony distortion networks by making changes in the path through which power passes [26]. But it is worth to mention that there is a bad outcome that if DG does not choose the correct optimal size and position, it can lead to actual power loss increases and higher than DGs real power loss without DG and power flow reverse from larger DG units. The reason caused higher losses, and higher capacity of DG is that the distribution system was initially just designed to make power flows from the end of substation sending to the load, and the conductor sizes are gradually decreased from the substation to the consumer point. Thus the load size (MW) of the distribution system plays an important role in determining the DG size. And if using high capacity DG without the reinforcement of the system, it would lead to power flows overflowing through small sized conductors and results in higher losses. [27]

So, an approach, in order to minimize the annual energy losses in the distribution system, has been proposed for determining the optimal renewable DG units as follows:

- Determine the optimally distributed generator placement location by analytical expressions.
- Using IA method and harmony search algorithm to calculate the optimal DG size.
- To indicate the reliability of the method, these two methods are tested on two test systems 33-bus and 69-bus radial distribution systems [23]. The final results showed that the harmony search algorithm gives the same loss reduction and minimum voltage in the system with smaller size DGs than obtained using the IA method.

2.4 An optimization method

There is an optimization method have been proposed to determine the optimal location and size of DG in a distribution network. In the method, use the MATLAB program to compound the result that proposed in a different approach to repeated load flow for loss reduction [8], makes the analysis faster, more accurate and more efficient. The sensitivity factors are evaluated for each bus with identified maximum sensitivity.

2.4.1 HARMONY SEARCH ALGORITHM

The harmony search algorithm (HSA) belongs to a new meta-heuristic algorithm. The advantages of HSA are in concept simple, few parameters and easy implementation. HSA is a concept from natural musical performance processes [8]. Thus it can be described as ‘In music improvisation, with each musician playing possible pitches to make a harmony vector’. It means if all the pitches create a good harmony, then the musician would save them in memory and they will help to increase the harmony for next time. Similarly, in an engineering optimization field, first select the variable value within the possible range and formed a solution vector. If all variable values lead to a good solution, then save all variable experienced value in memory and it increases the possibility of good or better solutions for next time.

3. Improved enumeration method

Approaches for low-carbonization are global challenges to achieve sustainable development society, and activities have emerged as priorities around the world to address. The electric power industry has been utilized fossil fuels such as coal, petroleum, and natural gas for power generation for a long term and is one of a significant amount of CO2 emission industries. Thence, for the electric power industry, the implementation of low-carbon society activities in each business domain, and the establishment of low-carbon energy management system is to realize one of the main objectives of Smart Grids and Smart Cities is essential, which is receiving plenty of attention in the world. An optimal allocation of dispersed generations (DGs) is one approaches for engineering innovation shortly to realize low-carbonate power system because DG is one of the important methods to install renewable energy generation and also connect DGs with optimal location and sizing can dramatically reduce loss in power systems.

Against this background, various studies for optimal allocation of DG in distribution systems have been implemented recently, and these are the study of the problem solution to decide the optimal location and size of single or multiple DGs for minimizing power loss in the targeted distribution systems. The purpose of the optimal allocation of DG requires to solve a non-linearly discrete optimization problem and in order to solve this challenge, there especially propose a new approach that based on an exact solution method using the enumerative method to reduce the number of the combination by request of constraints, and the proposed method is evaluated by the simulations with multiple DGs installations using both simple pilot model and real size distribution system model.

This is the improved approach based on an exact enumerative solution to solve such difficult optimal DG placement in a distributed network. The advantages of the enumerative method is simplicity, versatility and easy of use, but it cannot avoid the combinational explosion occur. The approach is proposed to overcome the critical challenge of combinational explosion by constraining the application to reduce the number of combinations. Also the approach is applied to a real size distribution system model, and evaluated for active power loss reduction feature by DGs installation and calculation speed considering actual use. A six bus test system can exam for the convergence properties of the proposed algorithm [2].

In this paper, DG is used as a device for reducing active power loss in the targeted distribution systems and this means DG is just a device which can provide active and reactive power. The proposed solution method can be utilized with various power system control devices such as Automatic Voltage Regulator (AVR), Step Voltage Regulator (SVR) and Static Var Compensator (SVC) etc.

3.1 method assumption

In order to determine allocation and size of the DGs to minimize the distribution power loss and size of a fixed number of distributed power, and total specific capacities of distributed generation energy sources, the following assumptions were adopted in the formulation:

- Assume the maximum number of installable DGs is given.
- Assume the total installation capacity of the DGs is given.
- Assume for each feeder, the possible locations for the DG installation are given.
- Assume the upper and lower limits of node voltages are given.
- Assume the current capacities of the conductors are given.

3.2 Descriptions of the problem

In the problem to minimize power loss, it is required to a non-linear discrete optimization problem called "The Optimal Power Flow Problem". It should be operated under constraints such as power flow laws, voltage upper and lower limits, and upper limit of apparent current. However, 'Discrete OPF (Optimal Power Flow)' has individual intractability for the solution and thus approximate solutions such as analytical and metaheuristic methods have been adopted to decide optimal location and sizing of DG.

However, it is difficult to ensure that the solution of this approximation is optimal. In addition, this approximate method is difficult to understand as the minimum power loss of the overall characteristics by a variety of installation conditions DG, and cannot be applied to multi-DG installation problems [18].

3.3 Studies and approaches for power loss reduction in Distribution network

Many studies for power loss reduction in distribution networks have been implemented. Various metaheuristics approaches such as: Simulated Annealing (SA), Improved Tab Search (TS) and Genetic Algorithm (GA) had been applied to network reconfiguration for power loss reduction. According to the reference [19], it described that the impact on feeder losses of DG can be analysed with something akin to the 2/3 rule, and reference [20] proposed an analytical method for the optimal DG location and sizing to minimize power loss for 4 DG types–Injecting P (active power) only, Injecting Q (reactive power) only, Injecting P & Q and Injecting P and consuming Q. The proposed approach in [8] used the real power loss expression popularly known as “The exact loss” formula [21] as follows.

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j + P_iQ_j)] \tag{1}$$

$$\alpha_{ij} = \frac{r_{ij}}{U_iU_j}\cos(\delta_i - \delta_j),\ \beta_{ij} = \frac{r_{ij}}{U_iU_j}\sin(\delta_i - \delta_j)$$

Where

rij + jxij = Zij is (i,j)th entry of [Z bus] matrix;

Ui∠ δ i, U j∠ δ j is the complex voltage at the ith and jth buses;

Pi, Pj is the active power injections at the ith and jth buses;

Qi, Qj is the reactive power injection at the ith and jth buses;

N is the numbers of buses.

3.4 Formulation of Optimal DG Allocation Problem

In the formulation, allowable DG locations are buses in the targeted system model and y is utilized for showing whether DG is installed or not at the targeted bus. As constraints, power flow law and cardinalities which reduce combination numbers of DG location candidates are considered but voltage and apparent current constraints are not considered. If simulation results in the simple system and real size distribution system would excess these unconsidered limits, new constraints would be considered.

Based on these conditions, the problem for optimal allocation of DGs is formulated as follows:

Equation (2) is the objective function which represents overall active power loss minimization in the targeted system.

$$\min \sum_{i \in M} P_{\mathrm{loss}i} \tag{2}$$ [30]

Where

$P_{\mathrm{loss}i}$ is active power loss obtained by power flow at grid branch i, $Ploss i = Ri|\dot{\boldsymbol{I}}_i|^2$ (Ri is resistance, $\dot{\boldsymbol{I}}_i$ is line current, at grid branch i).

M= {1, 2… m} is set of grid branches;

The equation (3) — (7) are constraints. And equation (3) is the power flow constraint.

s.t.

$$\dot{S}_j + \dot{G}_j = \dot{U}_j \dot{I}_j^*, \quad j \in N$$ (3) [30]

Where

N= {1, 2… n} is set of grid buses: $\dot{S}_j$ is complex power Load at grid bus j (nonpositive value);

$\dot{G}j$ =complex power generation at grid bus j (nonnegative value), see Tab.1 how to specify j

$\dot{G}j$ at the bus corr. to the candidate DG location k (Assume that $\dot{G}j$ =0 at all load buses before placing the DGs);

$\dot{U}_j$ = complex voltage obtained by power flow at grid bus j;

$\dot{I}\,j$ = complex injected current obtained by power flow at grid bus j;

$\dot{I}\,j$ = $\dot{Y}\dot{U}_j$ (Y is admittance matrix)

Equation (4) is 0- 1 variable which represents the status of whether DG is installed or not at the targeted bus.

$$y_k \in \{0,1\}, \quad k \in K$$ (4) [30]

Where

K is set of candidate DG locations;

yk is 1 if candidate DG location k is selected, 0 otherwise ($k \in K$);

Equation (5) is the integer constraint for the discrete variable x which decides discrete capacity in DG in each location. Input data for DG location candidates, bus number, group number, DG type and the number of considered capacity and its discrete values are defined.

$$x_k \in \{0,1,\cdots n_k\}, \quad k \in K$$ (5) [31]

Where

K is set of candidate DG locations;

nk is number of allowable DG sizes at candidate DG location k ($k \in K$);

xk is decision variable for DG size at candidate DG location k ($k \in K$), 0 if yk=0;

Equation (6) is the total DGs capacity constraint in order to not exceed the value of S_{max}.

$$\sum_{k \in K} size[x_k] \le S_{\max}$$ (6) [31]

Where

K is set of candidate DG locations;
Size [] is allowable DG sizes for each candidate DG location (*P* or *Q* values);
*S*max is total allowable capacity of installed DG's ((*P* or *Q* values) ;

Equation (7) is the total number of DGs constraints

$$K_{\min} \leq \sum_{k \in K} y_k \leq K_{\max} \qquad (7)\ [31]$$

Where
K is set of candidate DG locations;
yk is 1 if candidate DG location *k* is selected, 0 otherwise (*k*∈*K*);
*K*min is minimum cardinality for the number of installed DG's;
*K*max is maximum cardinality for the number of installed DG's;

The DG type considered at each candidate location bus is PQ type–injecting both active and reactive power, and the capacity of each installed DG is defined. The reason using PQ type's DG is PQ control principle is to decouple P and Q so as to control the current, and using the PI controller to make the error under steady state is zero. Its aim is to use a way that controls inverter to ensure that the distributed power output of P and Q keep constant.

Table. 1 shows DG type and defined discrete capacity values for DGs.

DG type	Bus specification	Input values	Used in power flow
PQ type: both active and reactive power injecting DG	PQ bus	P_1~$P_{nk,}$: P/Q ratio or power factor	Re($\dot{G}$), Im($\dot{G}$)

Table1: Types and capacity of DGs.

3.5 Simulation of power loss reduction effects by DGs allocation for simple pilot system model

The formulated optimal allocation of DGs problem is applied to a simple pilot system model and the effects of power loss reduction by installation of multiple DGs are evaluated. In the evaluation, simulations using the exact solution method based on the enumerative method are implemented.

As the procedure of the simulation, firstly enumerates all possible combinations of optimal location candidates of DGs, and then calculates the active power loss for each combination by power flow calculation. Finally, select the combination to minimize the active power loss of the target system, as the optimal solution.

To reduce the number of combinations for optimal location candidates of DG, a simple pilot system which has only 6 buses and no branches is used as shown in Fig.

8. Bus1 is the slack bus and resistance *ri* and reactance *xi* (*i*=1, 2… 5) are considered in each branch.

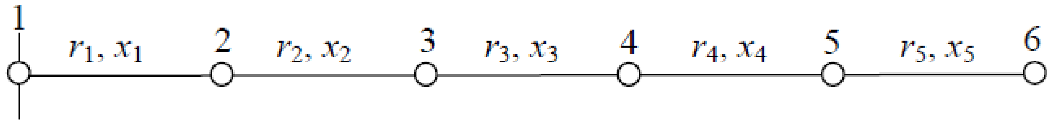

Fig8: Simple pilot system

3.5.1 Simulation Procedure

In the simulation, optimal allocation of DGs is considered for the simple pilot system. The load value of each bus is predefined and DGs are installed at two of the five buses in the pilot system except for Bus1. For each combination of DG installation buses, active power loss is calculated by changing injecting power of two DGs in incremental steps. The number of combinations for two DGs location is C (5, 2) =10. Table. 2 shows these combinations.

Case	DG1(Bus)	DG2(Bus)	Case	DG1(Bus)	DG2(Bus)
Case1	2	3	Case6	3	5
Case2	2	4	Case7	3	6
Case3	2	5	Case8	4	5
Case4	2	6	Case9	4	6
Case5	3	4	Case10	5	6

Table2: Combinations of two DGs location in the simple pilot system.

In this report, Backward and Forward (B/F) methods as used as power flow calculations. The reason is that the B/F method is an optimal power calculation method for the radial distribution systems, and it suits the situation that unity within the network of distributed power management and scheduling through the top layer energy management system to ensure the balance of grid transient, inhibition on the main network. And computation time is shorter, compared with the Newton-Raphson method which is commonly used for power flow calculation.

Table. 3 shows load (active and reactive power) and initial voltage *U*0 for each bus and resistance and reactance for each branch. Using these data, active power loss of the simple pilot system without DG can be calculated by the power flow calculation, and the value is 0.0147.

Bus	P/pu	Q/pu	U_0/pu
1	—	—	1.0
2	–0.1	–0.05	1.0
3	–0.1	–0.05	1.0
4	–0.1	–0.05	1.0
5	–0.1	–0.05	1.0
6	–0.1	–0.05	1.0
Branch	r/pu	x/pu	
1-2	0.02	0.01	
2-3	0.02	0.01	
3-4	0.02	0.01	
4-5	0.02	0.01	
5-6	0.02	0.01	

Table3: Power and voltage data of bus and impedance of branch.

With regard to DG type and capacity, PQ type DGs are used and active power P is set from 0.05 to 0.5 in 0.05 steps. Reactive power is set at $0.5P$ considering general power factor values.

3.5.2 Simulation details on the MATLAB

In this thesis, the model simulated in MATLAB, and the details shows in the following figures. (Fig.9 and fig.10)

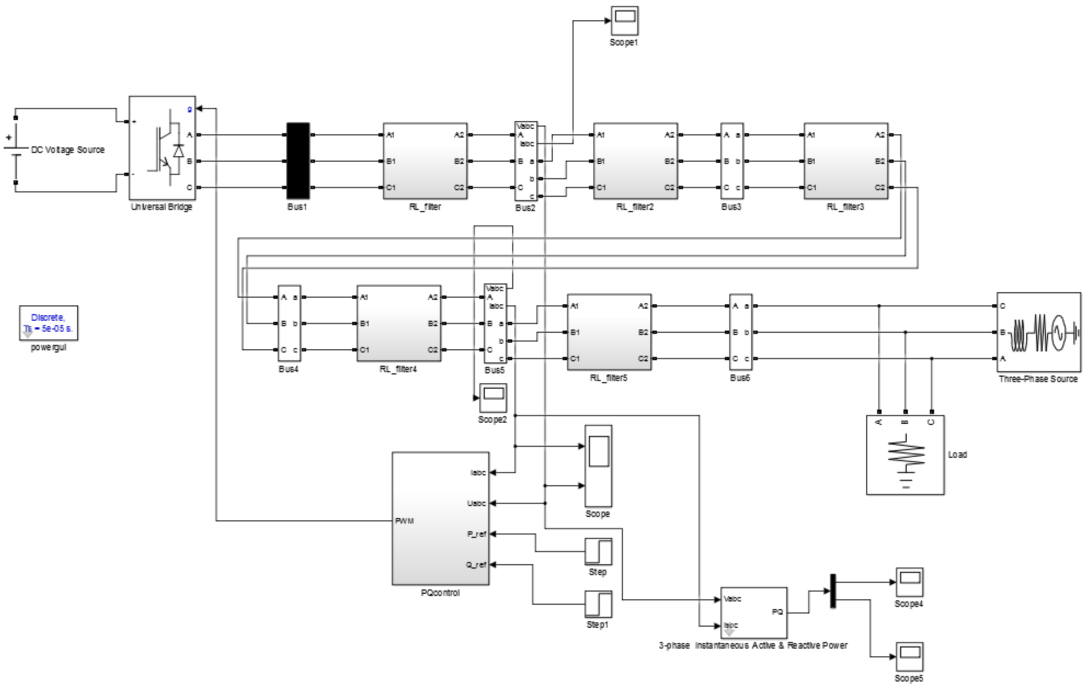

Fig9. The 6 bus system.

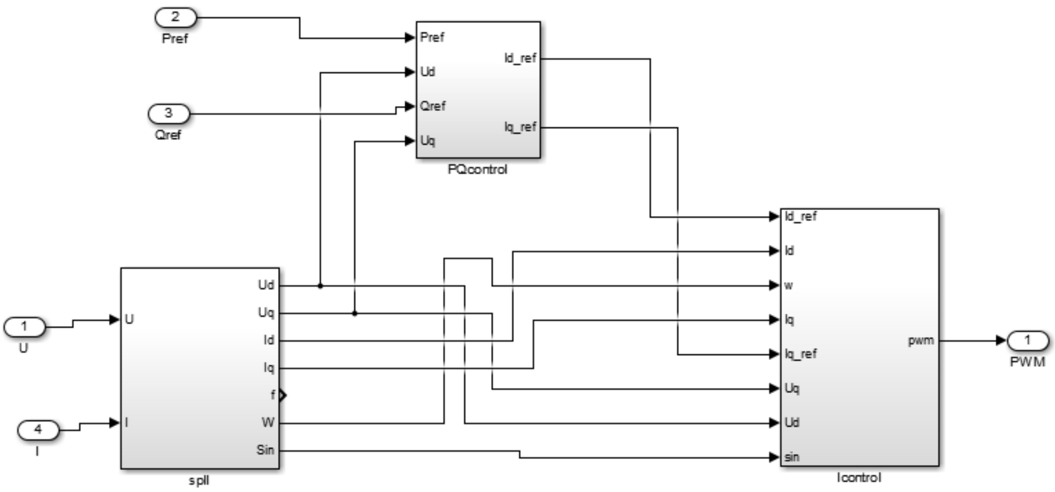

Fig10. The PQ type DGs.

3.5.3 Simulation Results and Evaluation

As the result of power flow calculations for all possible combinations regarding location and sizing of two DGs, power loss is minimized when DGs are located at Bus3 and Bus5. Fig. 11 shows the profile of power loss value (z axis) by active power capacity of installed two DGs at Bus3 and Bus5. Tab. 4 represents power flow calculation results in case that DGs are installed at Bus3 and Bus5.

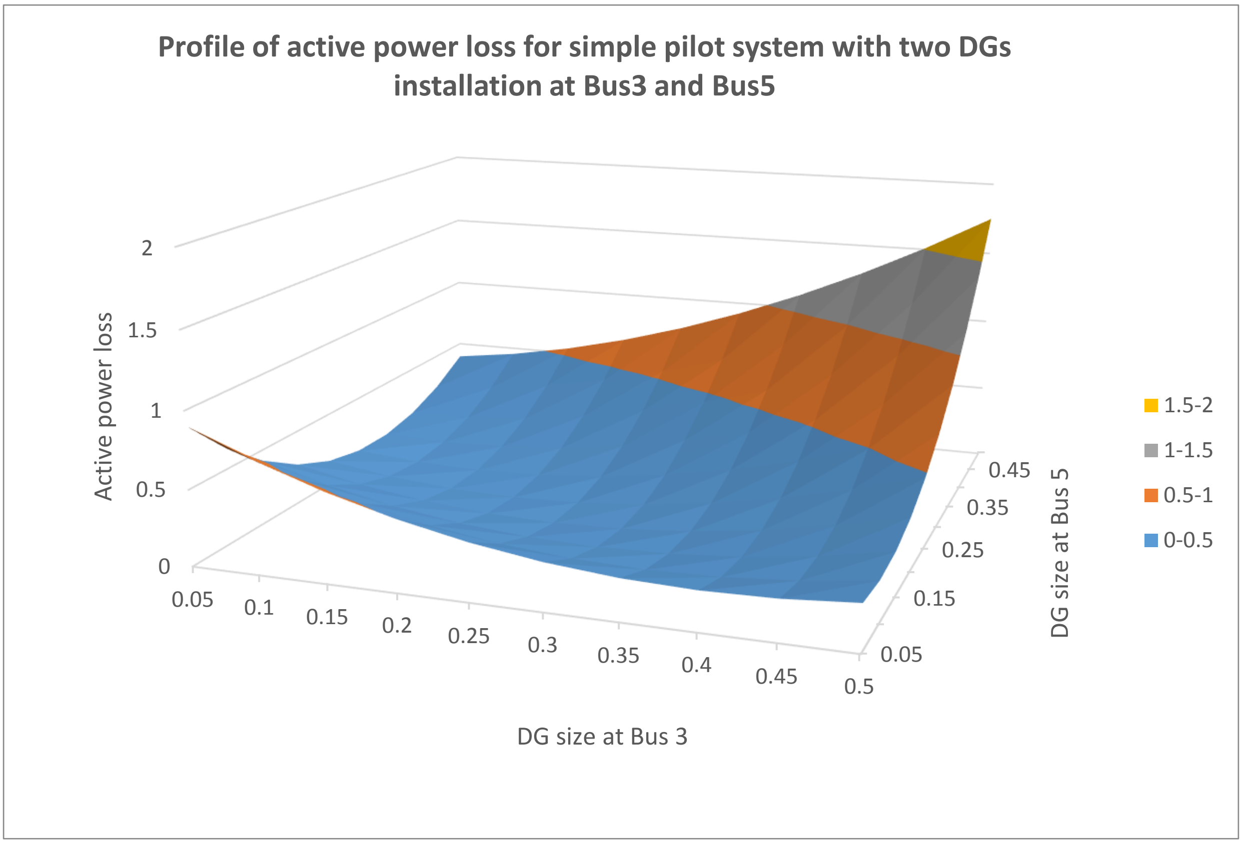

Fig11: Profile of active power loss for simple pilot system with two DGs installation at Bus3 and Bus5.

	DG size at Bus 3/pu									
DG size at Bus 5/pu										
	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
0.05	0.9072	0.734	0.5881	0.4692	0.3768	0.3107	0.2702	0.2552	0.2651	0.2996
0.1	0.6381	0.4933	0.3753	0.284	0.2188	0.1793	0.1651	0.1759	0.2114	0.271
0.15	0.426	0.3088	0.2181	0.1535	0.1147	0.1012	0.1127	0.1487	0.209	0.2932
0.2	0.269	0.1787	0.1146	0.0761	0.063	0.0749	0.1113	0.172	0.2565	0.3645
0.25	0.1655	0.1015	0.0632	0.0502	0.0622	0.0987	0.1595	0.2441	0.3523	0.4836
0.3	0.1138	0.0754	0.0623	0.0741	0.1106	0.1712	0.2558	0.3638	0.495	0.6492
0.35	0.1124	0.099	0.1105	0.1465	0.2069	0.297	0.3988	0.5297	0.6835	0.8598
0.4	0.1599	0.1708	0.2063	0.266	0.3496	0.4568	0.5872	0.7404	0.9162	1.1143
0.45	0.2548	0.2894	0.3484	0.4312	0.5376	0.6672	0.8197	0.9948	1.1922	1.4115
0.5	0.3957	0.4536	0.5355	0.6409	0.7696	0.9211	1.0953	1.2917	1.5101	1.7502

Table4: Power loss calculation result with two DGs installation at Bus3 and Bus5

By analysing the results, it shows that:

In Fig. 11, distribution of power loss values shows convex downward shape, and in all possible combinations of two DGs, distributions of power loss values also show convex downward shape. This means that combinations of optimal capacities for two DGs exist once combinations of location of two DGs are fixed.

In the case that DGs are installed at Bus3 and Bus5, active power loss would be minimized when the capacity of active power for Bus3 is 0.2 and Bus5 is 0.25, and the value of active power loss would be 0.000 502pu.

Because active power loss for the system without DG is 0.014 7pu, so, active power loss reduction rate compared with the system of DG at bus 3 and bus 5 would be dramatically improved value of 96.6%. The result shows that active power loss can be reduced dramatically by optimal location and sizing of DGs and the proposed approach using exact solution method based on the enumerative method can be utilized for the optimal DGs allocation problem for the simple pilot system.

3.6 Solution of Optimal Allocation of DGs problem for real size distribution system.

In fact, usefulness of the method would be applied to the real size radial distribution system. Because when the proposed approach using exact solution based on the enumerative method applied to real size distribution system, it would be very complex case, the case closer to real useful situation. Therefore, the proposed approach would be to apply to real – size radial distribution system.

3.6.1 Basically implementation procedure.

- Firstly, enumerate the combination of optimal location candidates for DGs.
- Then, implement calculating of active power loss by power flow calculation.
- Finally, select the best solution that minimizes active power loss.
- However, the targeted distribution system which the proposed approach is applied, would be very complex and it might easy cause combinatorial explosion. Therefore, some practical measures are considered to reduce the number of combinations for optimal allocation of DGs.

3.6.2 The definition of the real – size distribution system.

The following fig.12 is a real size distribution system model. It built based on the 126buses system (figure.13). It represents the wiring diagram of the distribution system. Bus1 is the slack bus in this distribution system, and other all parameters which are used for power flow calculations are also same values provided in [22].

Total load of the system is P=4.230 0 Q=2.887 0 respectively and from the power flow calculation result, the slack bus provides P=4.423 9 and Q= 3.105 3. Therefore, the total active and reactive power loss of the system would be 0.193 9, 0.218 3 respectively and power loss rate in the system would be 4.383% and 7.030% respectively.

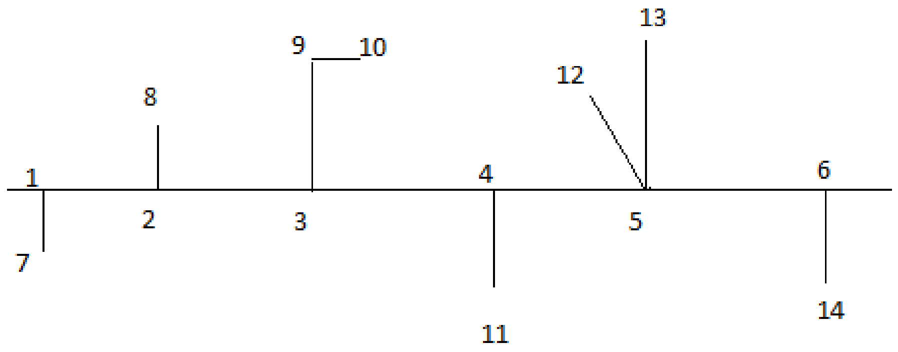

Fig12:14 wiring diagram of grid.

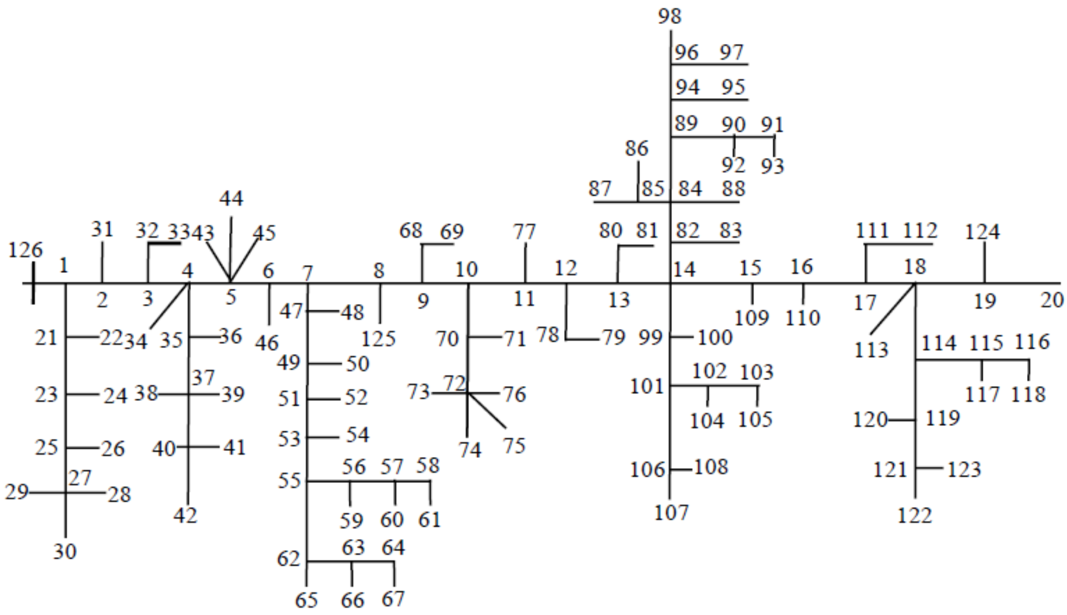

Fig13:126 wiring diagram of grid.

3.6.3 Combinatorial enumeration for calculation of optimal DGS allocation

Firstly, enumerate all possible combinations of optimal location candidates for DGs. As the enumerative method commonly used “The Backtracking method”, this method is also utilized in this thesis. The backtracking method is a typical method for enumeration of all solutions, and it has the search policy if the current step in a search process had no branch or no feasible solution on the enumeration tree, the search process would go back to the previous step and continue the search process. The Depth-First Search (DFS) for such enumeration tree is the algorithm which realizes this backtracking method [22].

In the proposed method, combinatorial enumeration by the backtracking method is applied to two separated stages - location and capacity of the DG, which are two major characteristics for optimal allocation of the DG problem. This method is called “2-Stage Backtracking method.” It means that as the first stage, the candidates for the location of DGs are enumerated and, as the second stage, combinations of DG capacity are listed for each combination of location candidate. In this 2-stage backtracking method, the characteristic which is clarified in the last simulation utilized. That is, optimal capacity of DG can be decided when the optimal location of DG is decided.

Let the number of location candidates be K, the average number of DG capacity be s, the number for combination of the 2-stage backtracking method would be $\sum_k s^k C\,(K, k)$ (k|Kmin~Kmax). Although this enumerated combination number does not depend on system size, it shows large amounts values of K, Kmin, Kmax or s might bring combinatorial explosion. (For example, combination number for 10 different capacity values, 20 location candidates and 3 DGs installation would be 103C(20,3)=1,140,000.)

Therefore, in the proposed 2-stage backtracking method, location candidates for DGs are grouped and the number of installation DGs is also limited to reduce the number of combinations. This constraint is based on the practical condition such that only one DG would be installed for a certain estimating load area.

3.6.4 Constraints of DG Allocation

In order to make the proposed method provide the real size of the distributed system, DGs location candidates are decided based on the following policies considering all practical installation constraints.

- Less than one DG is installed in one of some areas which have a certain amount of electricity demand.
- Although capacity values in a certain range are enumerated with constant increment value, combination number is reduced by focusing targeted scope considering the result of ref. [1] and well-known "2/3 rule"., and in order to inject power by DG efficiently, it is assumed that DGs installation locations should be on the main route and must not be at the end of buses or branch lines.

So as that, followings parameters are added to shows such constraint for the objective function.

- KG: Set of groups classifying the candidate DG locations;
- Kg: Maximum cardinality for the number of installed DG's in group g (g∈KG);
- Ngroupk: Group number to which candidate DG location k belongs (k∈K).

Based on the above policies, bus 1to bus 6 is defined as the main route and active power loss would be evaluated installing some DGs into the main route. Also, the main route is divided by the major branch point of bus 3 and bus 5, and the DGs would be installed each divided group.

The following table shows group data which were utilized in the simulation, and G1and G2 are bus groups belonging to the main route. G3 and G4 are groups created for complementary considerations. These group categories are used as constraints that DGs can be located only at one bus in categorized group. The reason why all buses are not location candidates for DG is to prevent combinatorial explosion.

Group		candiate bus number
G1		3, 5
G2		1, 2, 4, 6
G3		9
G4		12,13

Table5: DG location candidates group.

3.7 Input data and selection details

Based on the basic policy that DGs are located at buses in groups on the main route such as G1 and G2, the following three cases were simulated for the evaluation of optimal DG allocation.

Case1: One DG is located in group G1 and G2 respectively.

Case2: One DG is located in rest of these 2 groups (G3 and G4).

In all cases, the type of DG is PQ type which is suitable for reducing power loss, and capacity of active and reactive power data are showed in Tab. 6—8. Reactive power data are set as 0.5*P* considering.

Bus	Group	P value/pu	Q value/pu
3	G1	0.6-2.2 by step of 0.1	0.5P
5	G1	0.6-2.2 by step of 0.1	0.5P
1	G2	0.4-1.4 by step of 0.1	0.5P
2	G2	0.4-1.4 by step of 0.1	0.5P
4	G2	0.4-1.4 by step of 0.1	0.5P
6	G2	0.4-1.4 by step of 0.1	0.5P

Table6: DG location candidates and PQ capacity values for Case 1.

Bus	Group	P value/pu	Q value/pu
3	G1	0.6-1.6by step of 0.1	0.5P
5	G1	0.6-1.6by step of 0.1	0.5P
1	G2	0.5-1.0by step of 0.1	0.5P
2	G2	0.5-1.0by step of 0.1	0.5P
4	G2	0.5-1.0by step of 0.1	0.5P
6	G2	0.5-1.0by step of 0.1	0.5P
9	G3	0.1-0.4by step of 0.1	0.5P
12	G4	0.1-0.4by step of 0.1	0.5P
13	G4	0.1-0.4by step of 0.1	0.5P

Table7: DG location candidates and PQ capacity values for Case 2.

3.8 Simulation Result and Evaluation of Solution

Once DGs candidates of location and values of capacity are enumerated and selected by the proposed 2- stage backtracking method, power flow calculation for every selected combination is implemented, and the power loss is decided. In the power flow calculation, the customized program based on the B/F method is utilized, and the program adopts various high-speed technics considering actual use with a large number of combinations.

Using branch and bus parameters follows the study of 'IEEE International Conference on Power and Energy (PECon2008)' [10], enumeration of all combination of DGs locations and capacity values and selection of the optimal solution was implemented for the 14 bus distribution system.

From the simulation result, it can be summarized with the result showed in the following table (Table 8). Firstly, in every case that the optimal solution time is short. Then it easy to conclude that when the Case3 number of enumerations increased, with the number for Case1 and Case2 decreasing to several even to zero, and the computation times were less than 1 second. This means the number of combinations might be reaching the limit for using the enumerative method.

Case1, Case2 and Case3 were configured so that their optimal solutions would be better in that order, active power loss values represented in Tab. 9 shows that. The best value of active power loss is 0.008 4 in Case3, and the loss reduction rate compared with the base (without DG) case showed in extremely great improvement of 95.9%. The result shows almost zero or very low active power loss distribution systems can be established by the adequate allocation of DGs or equivalent voltage compensators, and it indicates that an efficient power supply and demand in local communities can be realized utilizing regional DGs and other related devices.

Case	Optimal active power loss value/pu	Avtive power loss reduction rate r%	slack bus power		computation time
			P/pu	Q/pu	
Base	0.1939=b	-	4.4335	3.1059	0.022
1	0.0186=a	92.3	0.7521	1.2115	0.071
2	0.0097=a	95.5	0.3585	0.9843	0.679
3	0.0084=a	95.9	0.3481	0.9782	30.955

Note: r=100(b-a)/b

Table8: Simulation result.

Although the simulation result shows possibilities for nearly zero loss distribution systems with the detailed installation of DGs, it is enough results of more than 90% of active power loss reduction. Therefore, even Case1 and Case2 can be magnificent designs for optimal DGs allocation.

The simulation result shows that the number of candidate combination for optimal allocation of DGs can be reduced drastically by adding practical constraints to location candidates and by narrowing down the scope of capacity values of DGs. In addition, the result that more than 90% active power loss reduction was attained shows that the proposed approach can obtain a good enough optimal solution even compared with the optimal solution selected from all enumeration solutions without any constraints.

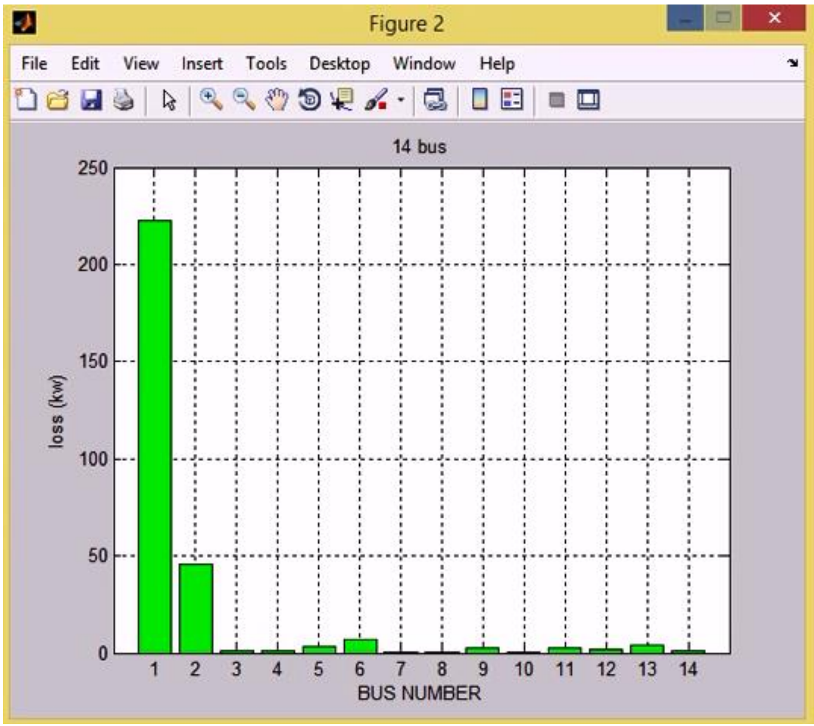

Fig14: power loss by DG placements in 14 bus distribution system.

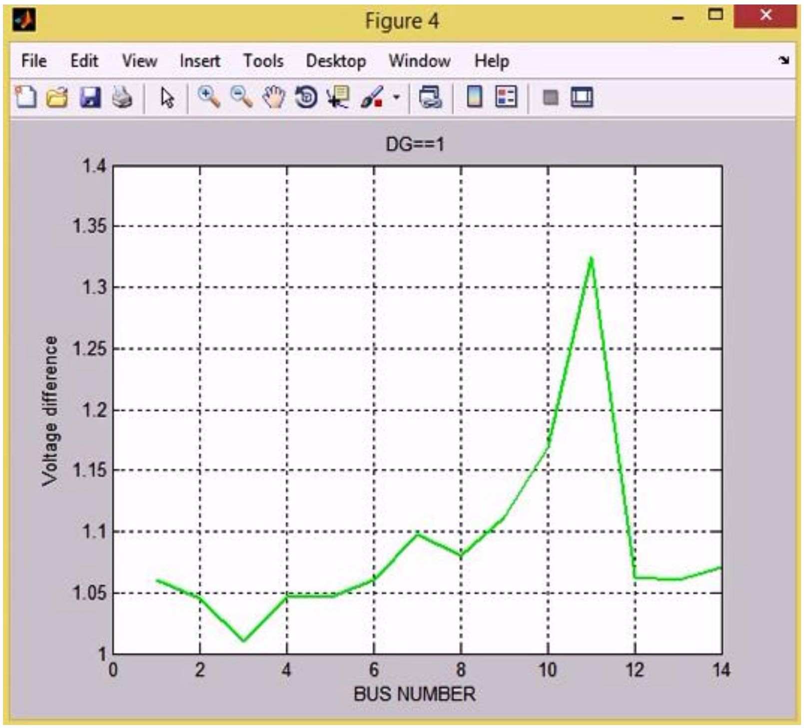

Fig15: Voltage magnitude improvement by DG1 placements in 14 bus distribution system.

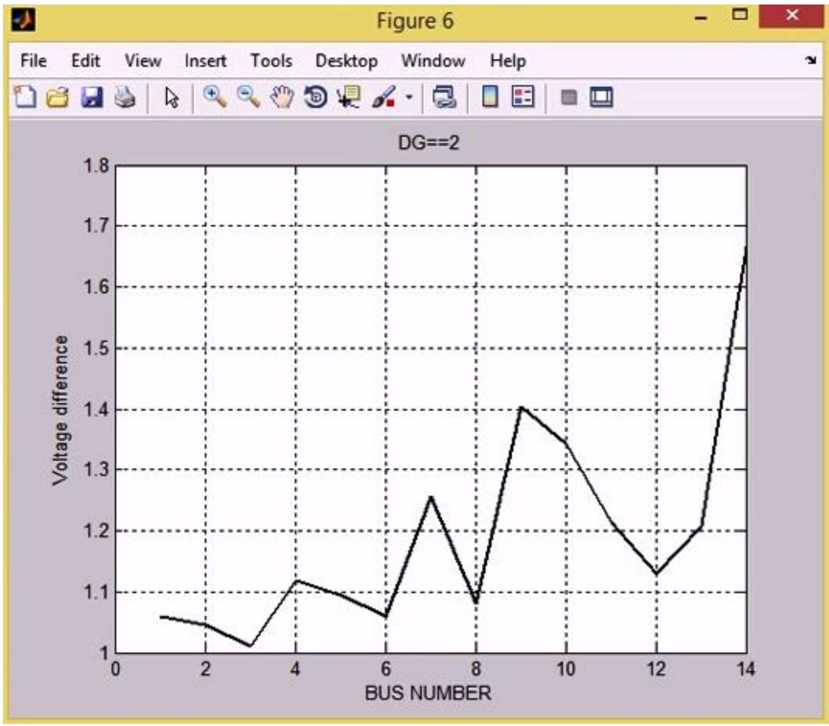

Fig16: Voltage magnitude improvement by DG2 placements in 14 bus distribution system.

Fig. 14, Fig. 15 and Fig. 16 represent the DGs power loss at each bus and the profile of voltage for Case2 with the optimal DG allocation respectively, and both figure 15 and figure 16 also show those of the base case for comparison.

4. Conclusions

According to the simulation result in this thesis, the primary purpose is that the proposed approach, use an exact solution based on the enumerate method for the optimal allocation of DGs problem, and through constrains drastically reduces the number of enumerated combinations was considered it.

Firstly, the improved enumeration method can analyse the distribution network effectiveness, and the combinations explosion challenges of the proposed approach for optimal allocation of DGs were considered by the simulation using the simple pilot system. The qualitative profile of the optimal allocation of DG problem was considered, and it was clarified that the proposed approach could apply to this kind of problems and provided very efficient results.

In addition, the proposed approach was applied to a real-sized 14 bus distribution system and the reduction of active power loss was evaluated. The simulation result shows optimal location and sizing of DGs which reduced active power loss more than 90% could be found in a short time. From these results, the effectiveness of the approach as a practical active power loss reduction method could be verified for migration to future low carbonate power systems from existing systems.

5. Future work

Firstly, applications of the proposed approach into multiple DGs installation problems and large scale distribution networks model should be considered.

Then, numerical simulation for larger distribution systems should be implemented. Because the number of enumerated combinations does not depend on the size of the distribution system, the approach can be applied to large-scale problems by narrowing down the scope of the DG allocation. In this case, computation time depends on power flow calculations which rely on the distribution system scale. Also, it is one of the interesting challenges in turn that this approach is for the static optimization problem not should be applied to a dynamic optimization problem considering fluctuating loads. This dynamic optimization is a more realistic challenge, and the solution method might be the useful tool for expansion from the loss minimization to cost minimization and benefit maximization.

6. Appendices A: Load data for 16 bus.

Table. 1. Load data for 16 bus taken form [17].

		Line Impedance in p.u.				Loads on to-node (p.u)		
F	T	R p.u.	X p.u.	L	S_L	P	Q	L_T
1	2	0.000574	0.000293	1	4.6	0.1	0.06	R
2	3	0.00307	0.001564	6	4.1	0.09	0.04	I
3	4	0.002279	0.001161	11	2.9	0.12	0.08	C
4	5	0.002373	0.001209	12	2.9	0.06	0.03	R
5	6	0.0051	0.004402	13	2.9	0.06	0.02	I
6	7	0.001166	0.003853	22	1.5	0.2	0.1	C
7	8	0.00443	0.001464	23	1.05	0.2	0.1	C
8	9	0.006413	0.004608	25	1.05	0.06	0.02	I
9	10	0.006501	0.004608	27	1.05	0.06	0.02	C
10	11	0.001224	0.000405	28	1.05	0.045	0.03	C
11	12	0.002331	0.000771	29	1.05	0.06	0.035	R
12	13	0.009141	0.007192	31	0.5	0.06	0.035	C
13	14	0.003372	0.004439	32	0.45	0.12	0.08	R
14	15	0.00368	0.003275	33	0.3	0.06	0.01	C
15	16	0.004647	0.003394	34	0.25	0.06	0.02	I
16	17	0.008026	0.010716	35	0.25	0.06	0.02	C

Where

F= From node, T=To node, L=Line number, S_L=Line MVA limit in p.u., P=Real MW load in p.u., LT=Load Type, R=Residential, I=Industrial, C=Commercial

Appendix B: The 126 bus model and result

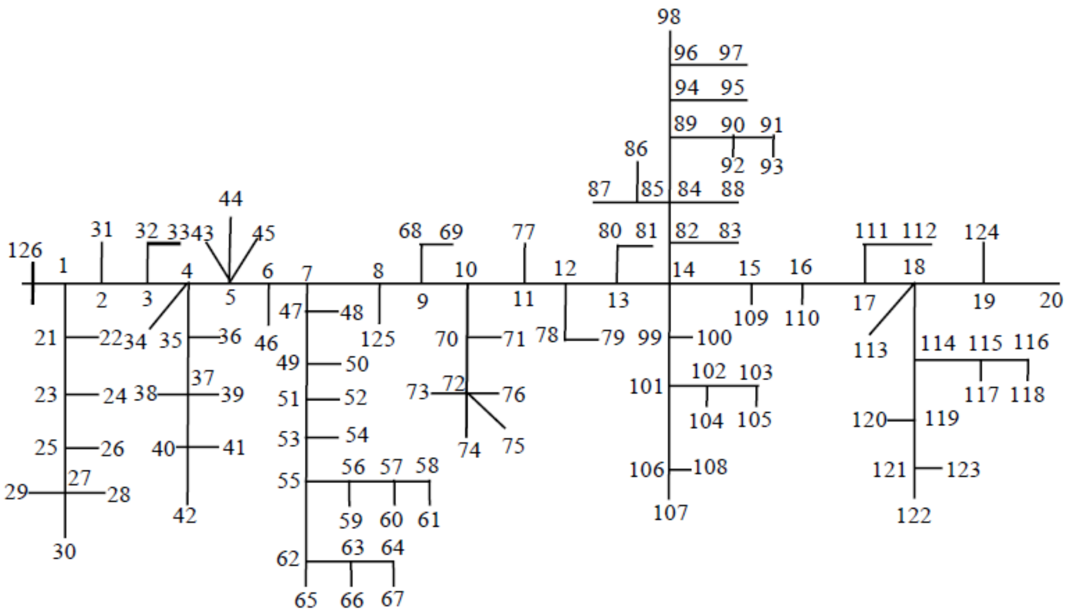

Fig13:126 wiring diagram of grid.

Group	Candidate bus number
G1	7, 9, 11, 13
G2	14,16, 18, 20
G3	1, 3, 5
G4	55, 72
G5	84, 89
G6	101, 114

Table 2. DG location candidates group

Bus	Group	P values/pu	Q values/pu	n_k
7	G1	0.6~2.2 @0.1	0.5P	17
9	G1	0.6~2.2 @0.1	0.5P	17
11	G1	0.6~2.2 @0.1	0.5P	17
13	G1	0.6~2.2 @0.1	0.5P	17
14	G2	0.4~1.4 @0.1	0.5P	11
16	G2	0.4~1.4 @0.1	0.5P	11
18	G2	0.4~1.4 @0.1	0.5P	11
20	G2	0.4~1.4 @0.1	0.5P	11

Table 3. DGlocation candidates and PQ capacity values for case 1

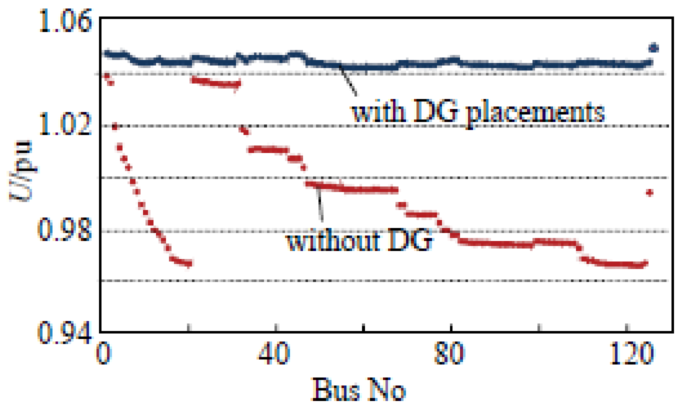

Fig 17. Voltage magnitude improvement by DG placement in 126 bus distribution system.

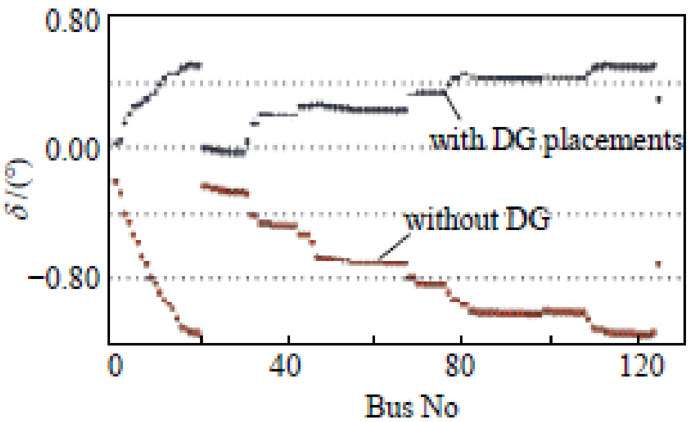

Fig 18. Voltage angle changes by DG placement in 126 bus distribution system.

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