ENHANCEMENT OF VOLTAGE STABILITY AND POWER LOSSES FOR DISTRIBUTION SYSTEM WITH DISTRIBUTED GENERATION USING GENETIC ALGORITHM

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All the praise to the Almighty Allah Subhanahu Wa Ta'ala for giving me his uncountable graces, guidance and blessings.

Then to my beloved parents for their unconditional love and support.

And to you, whom I do not know yet, going to fall for

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ABSTRACT

Distributed generation (DG) is in rising attention in power systems as a solution to environmental and economic challenges caused by conventional power plants. The optimal location and capacity of DGs in power systems is very important for obtaining their maximum potential benefits. A lot of research studies have been carried out to propose different methods in terms of optimal placement and capacity for the distribution generator units to minimize and improve costs and efforts. In this project, genetic algorithm (GA) optimization method along with Newton Raphson (NR) load flow calculation method are used to obtain the optimum size and optimum location of the DGs in the standard IEEE 34-bus radial distribution network. The developed GA-NR algorithm is based on minimizing the power losses and maximizing the voltage profile in the primary radial distribution network. The developed algorithm is applied to determine the optimal sizes and locations for four different cases where each case includes a specific number of DGs. Results indicated that, case 3 where three DG units were installed is the optimal solution to enhance both of the voltage stability and the power losses for the IEEE 34-bus radial distribution system. Furthermore, if the three DGs are located at their suggested optimal locations and have the suggested optimal sizes which are proposed by GA, the total power losses in the IEEE 34-bus radial distribution network will be reduced by nearly 55% and 65% for active and reactive power respectively. Besides, the voltage profile will be improved by nearly 26% if the same condition was applied. Finally, the results have been verified and demonstrated their robustness through comparing with other optimization methods, such as CPF and NLP optimization methods, and by observing the buses voltage profiles and the power losses when relocating the DGs randomly. The comparison results proved that GA placement and sizing is superior to CPF placement and NLP placement and sizing when both of voltage stability and power losses are considered.

ABSTRAK

Generasi diedarkan (DG) adalah dalam perhatian yang semakin meningkat dalam sistem kuasa sebagai penyelesaian kepada cabaran alam sekitar dan ekonomi yang disebabkan oleh loji janakuasa konvensional. Lokasi optimum dan kapasiti DGS dalam sistem kuasa adalah sangat penting untuk mendapatkan faedah potensi maksimum mereka. Dalam projek ini, algoritma genetik (GA) kaedah pengoptimuman bersama-sama dengan Newton Raphson (NR) kaedah pengiraan aliran beban digunakan untuk mendapatkan saiz yang optimum dan lokasi optimum DGS dalam IEEE 34-bas rangkaian pengagihan jejarian standard. Maju algoritma GA-NR adalah berdasarkan meminimumkan kerugian dan memaksimumkan kuasa profil voltan dalam rangkaian pengagihan jejarian utama. Algoritma dibangunkan digunakan untuk menentukan saiz dan lokasi yang optimum bagi empat kes yang berbeza di mana setiap kes termasuk beberapa tertentu DGS. Hasil kajian menunjukkan, kes 3 adalah penyelesaian optimum yang mencadangkan untuk memasang tiga unit DG. Tambahan pula, jika tiga DGS terletak di lokasi yang optimum yang disyorkan mereka dan mempunyai saiz yang optimum yang dicadangkan yang dicadangkan oleh GA, jumlah kehilangan kuasa dalam IEEE 34-bas rangkaian pengagihan jejarian akan dikurangkan sebanyak hampir 55% dan 65% untuk aktif dan kuasa reaktif masing-masing. Selain itu, profil voltan yang akan ditambah baik dengan hampir 26% jika keadaan yang sama telah digunakan. Akhirnya, keputusan telah disahkan dan menunjukkan keteguhan mereka melalui membandingkan dengan kaedah pengoptimuman lain, seperti CPF dan kaedah pengoptimuman NLP, dan dengan memerhatikan bas profil voltan dan kehilangan kuasa apabila menempatkan semula DGS secara rawak.

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LIST OF ABBREVIATIONS

AA	-	Analytical Algorithms
ACS	-	Ant Colony System
BCO	-	Bee Colony Optimization
CPF	-	Continual Power Flow
CSO	-	Cuckoo Search Optimization
DG	-	Distributed Generation
DGA	-	Distributed Generation Allocation
DGP	-	Distributed Generation Planning
DGs	-	Distributed Generators
EAs	-	Evolutionary Algorithms
ES	-	Exhaustive Search
FFM	-	Firefly Method
FS	-	Fuzzy Set
GA	-	Genetic Algorithms
GAOPF	-	Genetic-Optimal Power Flow
GAPSO	-	Genetic-Particle Swarm Optimization
GATS	-	Genetic-Tabu search
HIA	-	Hybrid Intelligent Algorithms
ICM	-	Imperialist Competitive Method
LCD	-	Line Drop Compensator
LP	-	Linear Programming
MINLP	-	Mixed Integer Nonlinear Programming
NLP	-	Nonlinear Programing
NR	-	Newton Raphson

NSGA	-	Non-Dominated Sorting Genetic Algorithm
OPF	-	Optimal Power Flow
PSO	-	Particle Swarm Optimization
PSOOPF	-	Particle Swarm Optimization-Optimal Power Flow
RDS	-	Radial Distribution System
SA	-	Simulated Annealing
SCIG	-	Squirrel Cage Induction Generator
TS	-	Tabu Search
VSI	-	Voltage Stability Index
VSM	-	Voltage Stability Margin

LIST OF SYMBOLS

FF	-	Fitness Function
I_{ij}	-	Current Between Bus i and Bus j
N	-	Number of Buses
P_{ij}	-	Active Power Between Bus i and Bus j
P_L	-	Total Real Power Losses
PL_{New}	-	Total Real Power Losses of Iteration i + 1
PL_{Old}	-	Total Real Power Losses of Iteration i
Q_{ij}	-	Reactive Power Between Bus i and Bus j
Q_L	-	Total Reactive Power Losses
QL_{New}	-	Total Reactive Power Losses of Iteration i + 1
QL_{Old}	-	Total Reactive Power Losses of Iteration i
S_{ij}	-	Apparent Power Between Bus i and Bus j
V_i	-	Voltage of Bus i
V_{ij}	-	Voltage Between Bus i and Bus j
V_{New}	-	Total Voltage Profile of Iteration i + 1
V_{Old}	-	Total Voltage Profile of Iteration i
V_t	-	Total Voltage Profile
W	-	Weighting Factor

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CHAPTER 1

INTRODUCTION

1.1 Introduction to Electrical Power System

The electric power system mainly consists of three parts which are generation, transmission and distribution subsystems. Conventionally the power at the generating units is transmitted to the loads via transmission system and then distributed between them by different distribution systems. Figure 1.1 demonstrates the conventional electrical power system.

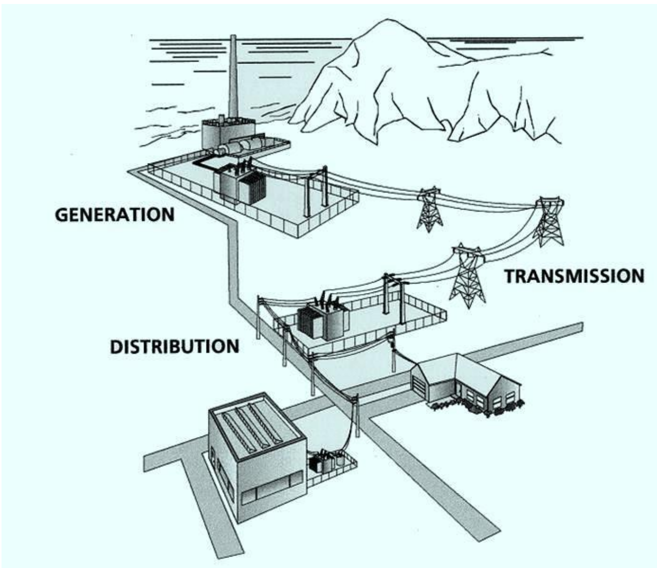

Figure 1.1 Traditional Electrical Power System [1]

Distribution systems are classified into two types, radial systems and network or mesh system [2]. Each system has advantages and disadvantages in terms of voltage stability, reliability and security. Figure 1.2 illustrates the types of electrical distribution systems.

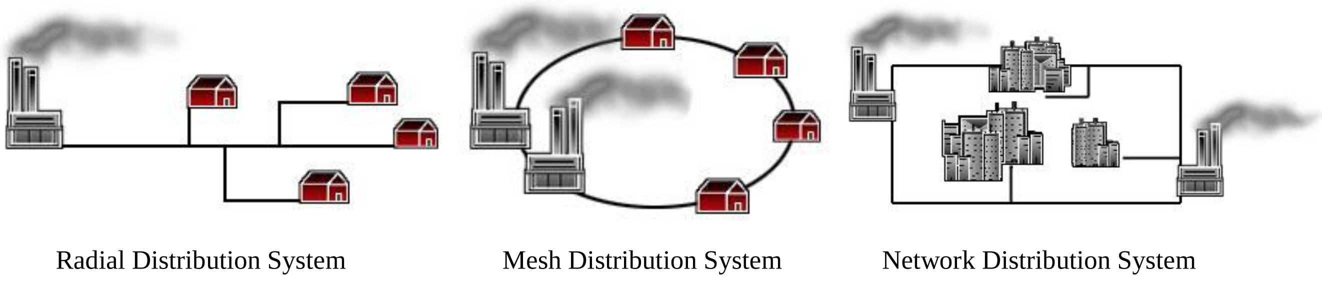

Figure 1.2 Electrical Distribution Systems [3]

Nowadays, the energy consumption is increasing and the power transmission networks need a major upgrades to feed the increasing demand. Upgrades to the power system is not easy and usually tend to encounter environmental, economic and political barriers. However, Power utilities still have the responsibility to provide safe and reliable power to the customer whatever obstacles or challenges they encounter. Typically, to accommodate the increment in energy consumption, power companies tend to build large centralized power plants. Nevertheless the security and stability of the power system are threatened if the power transported across an aging and congested networks. The number of generation resources need to be increased and well distributed around the network if the transmission system have little transmission capability [4].

Distributed generation (DG) is often used to compensate and supply the required electricity demand. DG attracts the power companies due to flexibility, economic and being a good alternative solution rather than building a new power system plant. DG is used to offset transmission costs or other costs associated with major improvements to the power network. When the timing and costs of establishing new lines are compared against the construction of distributed generation, DG tends to be more desired and attractive. Furthermore, there are another alternatives such as conductor upgrades, capacitor placement, and feeder reconfiguration can also be instrumental in optimizing the power system, but DG tends to be more attractive because of providing additional benefits when compared to some of these alternatives [4]. Figure 1.3 depicts the modern power system that interfaced with different type of DG.

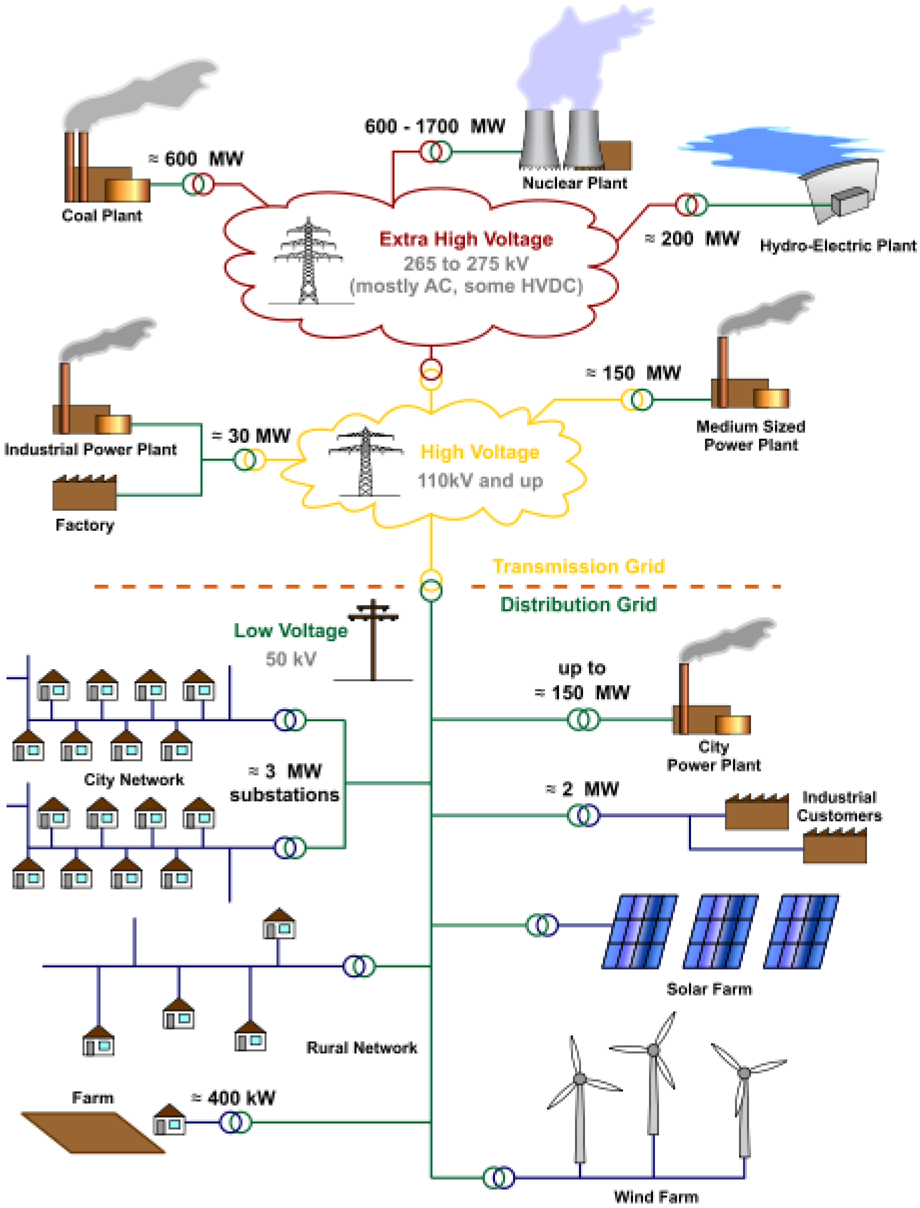

Figure 1.3 Modern Power System [4]

1.2 Introduction to Voltage Stability

To ensure the continuity of supply, the electric power system must be stable and secure. Voltage stability means maintaining steady acceptable voltage magnitudes at all buses in the system while voltage security can be defined as the absence of risk of system operation disruption. In practice, it is defined as the ability of the system to withstand the credible incidents without suffering from any serious consequences [5].

Recently, voltage instability has been given much attention by planners and researchers. It had been regarded as one of the major sources of power system insecurity. As stated, at any point of time, a power system operating condition should be stable, meeting various operational criteria, and it should also be secure in the event of any credible contingency.

Present day power systems are being operated closer to their stability limits due to economic and environmental constraints which rise the issue of voltage instability and voltage collapse and made them very important terms to be understood and well-known so their negative effect can be prevented or at least minimized.

Voltage instability phenomena can be defined as reduction in receiving end voltage to a rate below than its normal value and does not come back even after setting restoring devices or continues to oscillate for lack of damping against the disturbances. Voltage collapse can be defined as the process that drop the voltage to an unacceptable low value as a result of avalanche events accompanying voltage instability which usually lead to blackout [6].

Based on the time span of a disturbance in a power system, voltage instability problem can be classified into two terms which are long-term and short-term. The corresponding voltage stability dynamics is called long-term and short-term dynamics respectively. When the system is stable, short-term disturbance vanishes and the system enters a slow long-term dynamics. Typically, the long-term time frame is for a few minutes to tens of minutes and the voltage stability problem in this time frame is mainly because of the large electrical distance between the load and the generator, and thus depends on the detailed topology of the power system [5, 7, 8].

To analyze the voltage stability, it is often useful to categorize the problem into small-disturbance and large-disturbance voltage stability. Small disturbance or steady state voltage stability deals with the situation when the system is subjected to a small perturbation, such that the system can be analyzed by linearizing around the pre-disturbance operating point. Steady state stability analysis is helpful in getting a qualitative picture of the system. Large-disturbance stability deals with larger disturbances such as loss of generation, loss of line etc. To analyze the large-disturbance stability, one has to capture the system dynamics for the whole time frame of the disturbance [7, 8].

Different methods and tools have been developed by the specialists to analyze the steady state voltage stability. The conventional methods can be classified into P-V curve method, V-Q curve method, singularity of jacobian matrix at point of voltage collapse and continual power flow method.

To summarize, maintaining a stable and secure operation of a power system is a very important and challenging issue. Power systems are expected to become more heavily loaded in the future decade as the demand for electric power rises while economic and environmental concerns limit the construction of new transmission and generation capacity. As a result, many solutions have been proposed by the researchers and the experts such as distribution generation.

1.3 Introduction to Distributed Generation

Distributed generation (DG) is in rising attention in power systems as a solution to environmental and economic challenges caused by conventional power plants. DG is gaining widespread attraction due to several advantages that can benefit three parties which are supplier, consumer and national [9].Using DG technology at sensitive points is more economical and easier to enhance the voltage stability of a system than changing the power system parts or constructing a new one [10].

In general, distributed generation (DG) can be defined as electric power generation within distribution networks or on the customer side of the network. They range from a few kWs to a few MWs and span diverse types [11].

The distributed generators (DGs) have different categories and classifications, for example, distributed generators are classified based on delivered power as dispatchable DGs and non-dispatchable DGs. Dispatchable DGs are the ones that supply a constant continuous power to the system or their output can be adjusted, while the non-dispatchable DGs supply an intermittent power to the power system or their output is uncontrollable. For example; diesel, fuel cell and biomass DGs are classified as dispatchable while photovoltaic and wind DGs are categorized as non-dispatchable [4, 12].

Most of the recent work have been done on proposing a suitable method for determining the location and sizing of the DGs in distribution systems. The most appropriate location for distributed generators can provide the best enhancement in terms of voltage, security and losses minimization for all the system nodes and buses. Furthermore, the suitable capacity of distributed generators can provide the best enhancement performance as well and optimize the economic issue. A more explanation about DGs is held in the next chapter.

1.4 Problem Statement

A lot of proposed methods to allocate DGs in the radial distributed system have been presented in the recent work such as; continual power flow (CPF), voltage stability index method (VSI), Lagrange method, two degrees gradient method, genetic algorithms (GA), swarm optimization, Artificial Intelligence and sensitivity analysis method.

Every optimization technique uses single or number of objectives to form the objective function. The objective function is the tool that used to combine the objectives of project, or specific limitations, in the optimization technique. The objective function may consists of one objective or several objectives of a project. When the objective function is used to represent more than one objective, it is called multi-objective function. Fuzzification is a new invented technique and it can be used to bring the different objectives in the multi-objective function to a same scale and use it as single objective function.

Each method has its own strength and efficiency in computing some required parameters, but at the same time it has number of limitations that will be discovered when executing the techniques on different cases. Some of proposed methods require number of iteration, such as CPF, which make it computationally intensive for a large number of nodes. Voltage index method provide a comprehensive way to allocate the DGs but it require number of test cases similar to the number of buses in the system which will elongate the work for large system. Some of other methods are complicated and require complex software.

In this research, a genetic algorithm (GA) method is chosen as an optimization method to determine the size and location of the distributed generators in a specific distributed system that had been used in other researches and had been tested by other optimization techniques. Then, a comparison between the gained optimized results using GA and the other optimized results via CPF and nonlinear programing (NLP) is drawn which express the contribution of this study along with the NR-GA algorithm link.

1.5 Objectives of Study

The objectives of the research are as follows:

(i) To develop an algorithm for determination of optimal size and location of the DGs for radial distribution system (RDS) using genetic algorithm (GA).

(ii) To utilize the algorithm to reduce power losses and improve the voltage profile of RDS.

(iii) To validate the proposed method by comparing it with continual power flow (CPF) and multi-objective nonlinear programming (NLP) optimization methods.

1.6 Scope of Study

The motivation of the current thesis research is to investigate the optimal location and the best size of the DGs over a nominated Power Distribution Network. The Genetic algorithms have been used for optimizing and specifying the optimum size and location for the selected DGs. This optimization is applied with respect to the voltage profile, network power losses and DGs economic status of a specific system. The main scopes of this study are narrowed in the following points:

(i) Only radial distribution networks were examined by the GA and the IEEE 34-bus radial distributed system (RDS) was chosen as a specific test case.

(ii) Newton Raphson (NR) method as a load flow technique to determine the voltages and the angles of the system buses at the initial case.

(iii) Steady state dispatchable DGs units with real and reactive power support.

1.7 Report Organization

The current thesis is organized in five chapters. The study background, problem statement, thesis objectives and scope are represented in the current chapter which is the first chapter.

A wide literature review elaboration about the impact of DGs on the RDS, general concept of GA and overview about different optimization methods are illustrated in the second chapter.

The third chapter involves the methodology flow chart demonstration of the project. It includes a wide explanation about GA fitness functions, stopping criteria, settings and constrains as well.

The GA optimization results and their validation stages are sufficiently elaborated in chapter 4 while the conclusion and future work recommendations are discussed in chapter five.

REFERENCES

1. Electrical knowhow. *General overview of Generation, transmission & distribution stages of electricity*. Available at http://www.electrical-knowhow.com/2011/11/course-ee-1general-overview-of.html. 2011.

2. Sallam, Abdelhay A, & Malik, Om P. *Electric distribution systems*. Vol. 68. John Wiley & Sons. 2011.

3. Fandamentals of Electricity. *Radial, Loop, & Network Systems*. Available at http://epb.apogee.net/foe/ftdstr.asp.

4. Cherry, Derrick Dewayne. *Optimal placement of distributed generation on a power system using particle swarm optimization.* Ph.D. Thesis. Mississippi State University. 2012.

5. Van Cutsem, Thierry, & Vournas, Costas. *Voltage stability of electric power systems*. Vol. 441. Springer. 1998.

6. Taylor, Carson W. *Power system voltage stability*. McGraw-Hill. 1994.

7. Chakrabarti, S. Notes on power system voltage stability. *Dept. of EE, IIT, Kanpur*. 2010.

8. Kundur, Prabha, Balu, Neal J, & Lauby, Mark G. *Power system stability and control.* Vol. 7. New York. McGraw-hill. 1994.

9. Smallwood, C. Distributed generation in autonomous and nonautonomous micro grids. *Rural Electric Power Conference.* IEEE. 2002.

10. Esmaili, Masoud. Placement of minimum distributed generation units observing power losses and voltage stability with network constraints. *IET Generation, Transmission & Distribution,* 2013. *7*(8): 813-821.

11. Ackermann, Thomas, Andersson, Göran, & Söder, Lennart. Distributed generation: a definition. *Electric power systems research,* 2001. *57*(3): 195-204.

12. Hung, Duong Quoc, Mithulananthan, N, & Lee, Kwang Y. Optimal placement of dispatchable and nondispatchable renewable DG units in distribution networks for minimizing energy loss. *International Journal of Electrical Power & Energy Systems,* 2014. *55*: 179-186.

13. Borges, Carmen LT, & Falcao, Djalma M. Optimal distributed generation allocation for reliability, losses, and voltage improvement. *International Journal of Electrical Power & Energy Systems,* 2006. 28(6): 413-420.

14. Al Abri, RS, El-Saadany, Ehab F, & Atwa, Yasser M. Optimal placement and sizing method to improve the voltage stability margin in a distribution system using distributed generation. *Power Systems, IEEE Transactions on,* 2013. 28(1): 326-334.

15. Rao, RSrinivasa, Ravindra, K, Satish, K, & Narasimham, SVL. Power loss minimization in distribution system using network reconfiguration in the presence of distributed generation. *Power Systems, IEEE Transactions on,* 2013. 28(1): 317-325.

16. Hedayati, Hasan, Nabaviniaki, Sa, Akbarimajd, & Akbarimajd, Adel. A method for placement of DG units in distribution networks. *Power Delivery, IEEE Transactions on,* 2008. 23(3): 1620-1628.

17. Brown, Richard E, & Freeman, LAA. Analyzing the reliability impact of distributed generation. Power Engineering Society Summer Meeting, 2001.

18. Hajiabbas, Mahmoud Pesaran. *Distributed wind turbines optimal allocation using evolutionary algorithms in power systems.* Ph.D. Thesis. Universiti Teknologi Malaysia. 2014.

19. Goldberg, David E. *Genetic algorithms in search, optimization and machine learning*. E.(1989). Addison-Wesley. 1990.

20. El-Ela, AA Abou, Aly, GEM, & Shammah, AAE. Multi-objective optimal planning and operation of distribution systems using genetic algorithm. *International Energy Journal,* 2007. 8(4).

21. Shukla, T, Singh, S, & Naik, K. Allocation of optimal distributed generation using GA for minimum system losses in radial distribution networks. *International Journal of Engineering, Science and Technology,* 2010. 2(3): 94-106.

22. Eminoglu, Ulas, & Hocaoglu, M Hakan. A new power flow method for radial distribution systems including voltage dependent load models. *Electric power systems research,* 2005. 76(1): 106-114.

23. Abou El-Ela, AA, Allam, SM, & Shatla, MM. Maximal optimal benefits of distributed generation using genetic algorithms. *Electric Power Systems Research,* 2010. 80(7): 869-877.

24. Safari, A, Jahani, R, Shayanfar, HA, & Olamaei, J. Optimal DG allocation in distribution network. *Int. J. Electr. Electron. Eng,* 2010. 4(8): 550-553.

25. Khani, Davood, Sadeghi Yazdankhah, Ahmad, & Madadi Kojabadi, Hossein. Impacts of distributed generations on power system transient and voltage stability. *International Journal of Electrical Power & Energy Systems*, 2012. 43(1): 488-500.

26. Raja, Pitchaimuthu, Selvan, Manickavasagam Parvathy, & Kumaresan, Natarajan. Enhancement of voltage stability margin in radial distribution system with squirrel cage induction generator based distributed generators. *IET Generation, Transmission & Distribution,* 2013. 7(8): 898-906.

27. Sattianadan, Dasarathan, Sudhakaran, M, Dash, Subhransu Sekhar, Vijayakumar, K, & Ravindran, P. Optimal Placement of DG in Distribution System Using Genetic Algorithm. *Swarm, Evolutionary, and Memetic Computing.* Springer. (pp. 639-647); 2013.

28. Esmaili, Masoud, Firozjaee, Esmail Chaktan, & Shayanfar, Heidar Ali. Optimal placement of distributed generations considering voltage stability and power losses with observing voltage-related constraints. *Applied Energy,* 2014. *113*: 1252-1260.