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Research Article

Optimizing the Localization of Distributed PV Products in the Distribution Network with regard to Uncertainty of Sun Radiation

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Abstract

Since the widespread and complexity of traditional networks, this paper is attempted to reduce the uncertainty in sun radiation by appropriate and optimal location of distributed PV products, and the efficiency of electrical energy is increased. So, this work in term of type of method is an applied one in which fundamental research results are used to improve and perfect the patterns and methods. The data collection tool in this paper is done in a library method. Therefore, the information from books, dissertations, articles, previous practical databases and IEEE's library distribution network model has been extracted to complete the evaluation of the theoretical framework of the study. Also, optimization was performed with the aid of MATLAB software to increase the efficiency of solar cell production power in the output. By doing so, the best place for solar panels is achieved due to the uncertainty of sun radiation and finally, the power output using panels can be analyzed. In addition, it was found that the current and as a result, the power generated by a PV unit is depended on radiation and its intensity. After that, through comparing different points in power generation, a relative coefficient is obtained for placement of PV unit.

Keywords: *localization, distributed PV products, sun radiation*

Introduction

Excessive consumption of fossil fuels as energy sources and its impact on the environment has attracted global attention to the use of renewable energies. Over the last few decades, the consumption of these fuels has produced greenhouse gases, and in particular an increase of 30% atmospheric carbon dioxide, acid rain and the phenomenon of global warming and other harmful environmental phenomena. Also, the use of these fuels to provide energy for the ecosystem, climate and health of living beings, especially humans, has also had a negative impact. These issues have led the scientific community to think about the use of alternative energy sources (M. Dixit, 2016).

As explained, today, due to concerns about environmental issues and the reliability of energy resources, electricity production has become increasingly important through the use of renewable energy sources. Possibility of production near the place of load in the form of distributed products is desirable for us. IEEE defines power generation as a dispersed generation by devices that are smaller enough than central power plants and capable of being installed in place of use.

In recent years, distributed sources (DGs), turbine power plants and multi-megawatt solar farms have found a wide range of commercial applications around the world (D. Q. Hung, 2014).

Sun radiation is the largest renewable energy source on Earth, and if only one percent of the world's desert is used with solar thermal power plants, the same amount will be enough to produce world-wide annual demand for electricity. Photovoltaic cells, in fact, are silicon semi-circular crystals and their non-crystalline forms that are processed and operative on them. As a photon moves to the surface of a silicon cell, the electron is generated from the circuit and the electric current. When the light enters the crystal, the electrons are excited by light and are separated from their fields, and there is a potential difference between the high and low sides of the difference cell. If the orbits are completed, then this difference in potential creates a direct current called the photovoltaic mechanism (Sol. Energy, 2016).

Over the past decade, employment of solar power for electricity generation has grown dramatically due to its economic benefits. However, due to variable nature of PV generation, the integration of a large amount of PV in a close geographic region will have various negative effects on the operation of distribution feeders. Therefore, optimal allocation of PV generation is necessary to support grid voltage

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regulation and improve the performance of distribution networks.

For the PV distributed generation, there are different studies to examine the optimum allocation of the system. As it mentioned, the optimal site and size of DG show the maximum loss reduction and development in voltage profile of distribution system. Numerous methods have been proposed to show the optimum location of the DG. These methods are either based on analytical devices (S. Kucuksari, 2014).

Karimyan *et al* (2016) proposes a population-based method called particle swarm optimization (PSO) for optimal planning of the location and sizing of different types of DG units in the distribution network, considering different loading conditions. The objective of this application is power loss minimization. In order to find the optimal location and size of DG units, continuous and discrete forms of PSO are deployed, respectively. In addition, the optimal locations and sizes of the DG units are determined in the areas of significant feeder load growth. The presented method is tested on the standard IEEE 33-bus and IEEE 69-bus test systems. In order to show the effectiveness of the proposed methodology, the results are compared with another method of DG allocation and another loss minimization technique (Peyman Karimyan, 2016).

Electrical energy is continuously dissipated in power systems at the transmission and distribution levels. Power losses in the distribution network, due to lower voltage level, in comparison with transmission level, are more significant. Power losses are important due to the economic and environmental effects associated with them. Moreover, power losses have a noticeable impact on generation capacity and must be paid by consumers. With deregulation and liberalization, distribution network operators (DNOs) are responsible for operating, expanding, and maintaining distribution systems (Hadjsajd N, 2011).

Studies (Atwa YM, 2010) show that if DG units are improperly sited, the reverse power from larger DG units can lead to excessive losses and can overload the feeders. It is worthwhile noting that the current policy of DG installation, which focuses on association rather than integration, is perfectly illogical. As a result, DG will not have the expected benefits for the system and even it could better be replaced by the energy produced by centralized units (Sansawatt T, 2010).

In addition, in (Hung DQ, 2013), this approach has been developed for multiple DG allocation and achieved a higher power losses reduction.

In (Abu-Mouti, 2011), an ant bee colony algorithm has been proposed to determine optimal location, size, and power factor (PF) of DG units for power losses minimization.

In (Khatod DK, 2012), an evolutionary based approach has been presented for optimal allocation of the PV array and wind generator for energy losses minimization without constraints violation in the distribution network. In (Moravej Z, 2013), a cuckoo search algorithm (CSA) has been presented for DG allocation.

Kaur and Jain (2017) present the optimal placement of multiple Dispersed Generators using multi-objective optimization. The optimization is carried out with objectives namely active power loss, reactive power loss, voltage deviation and overall economy. The multi-objective optimization and accounting conflicting objectives are realized through Particle Swarm Optimization with fuzzy decision approach to find the optimal sizes and sites of Dispersed Generators for voltage dependent residential, commercial and industrial loads. The clusters of buses are formulated from base case load flow to limit the search space for finding the placement of the Dispersed Generators. The effectiveness of the proposed approach is tested on a 69-bus radial distribution. It is found that the optimal placement of the Dispersed Generators improves the overall performance of the system and the optimal allocation is affected by the type of load (Navdeep Kaur, 2017).

Elmitwally (2013) in a study, a systematic simple approach to allocate multiple DG units in radial/meshed distribution network is proposed. The concept of equivalent load is introduced and extended to identify the load centroid precisely with two methods. A performance index that combines the power system real power loss and average node voltage is defined. Based on load centroid and performance index, a straightforward algorithm for sizing and locating multiple DG units is developed. The proposed technique is applied to radial and meshed test systems. Results confirm stability, integrity and efficacy of the proposed approach (A.Elmitwally, 2013).

Vita *et al* (2015) examined the impact of three different types of distributed generation (diesel generator, wind turbine and photovoltaic (PV)) on distribution networks' voltage profile and power losses. EPLAN software and the extended Newton-Raphson method have been used in the analysis. The obtained results show that different types of DG influence differently the distribution network and that their precise location and size are vital in reducing power losses and improving the voltage stability (Vasiliki Vita, 2015).

Vasiliki (2017) presents a decision-making algorithm that has been developed for the optimum size and placement of distributed generation (DG) units in distribution networks. The algorithm that is very flexible to changes and modifications can define the optimal location for a DG unit (of any type) and can estimate the optimum DG size to be installed, based on the improvement of voltage profiles and the reduction of the network's total real and reactive power losses. The proposed algorithm has been tested on the IEEE 33-bus radial distribution system. The obtained results are compared with those of earlier studies, proving that the decision-making algorithm is working well with an acceptable accuracy. The algorithm can assist engineers, electric utilities, and distribution network operators with more efficient integration of new DG units in the current distribution networks (Vasiliki Vita, 2017).

Mosbah *et al* (2017) proposed the Optimal Power Flow (OPF) for power system in presence of DG-unit, considering the objective of minimal power losses using genetic algorithm method. This method determines the optimal DG-units location and size in a transmission system. The efficiency of the optimization method discussed in this work has been validated on standard test network IEEE 30_busand Algerian114_bus power system using MATLAB software (Mustafa Mosbah, 2017).

Nadeem Khan and Nadeem Malik (2017) in a paper, optimal allocation of photovoltaic (PV) based DG is carried out while considering probabilistic generation and time varying voltage dependent load models. First, a novel probabilistic generation model is proposed for solar irradiance uncertainty modeling to compute the hourly output power produced via PV units. Subsequently, the obtained power values are used to determine the optimum PV allocation in the distribution system through particle swarm optimization to minimize the multi-objective function. The proposed algorithm has been validated on 33-bus and 69-bus distribution test systems. The results demonstrate that the proposed model is suitable for solar irradiance modeling and can be employed in power system planning studies (Muhammad Faisal, 2017).

Mohammadi and Esmaeili (2012) in a study considered optimal placement of photovoltaic systems (PV) as a source of active and reactive power in radial distribution networks. The objective function of this problem is minimizing system losses and improving voltage profile. Genetic Algorithm (GA) implemented for this purpose. Photovoltaic solar systems can be used as STATCOM for voltage regulation and power factor correction during both nighttime and daytime. This novel PV solar system application, beside other useful applications, makes it very useful, so it can operate more effective by considering its reactive and active power generation in 24 hours. In this study backward-forward power flow method is applied on standard IEEE 33-bus system (E. Mohammadi, 2012).

Gómez *et al* (2010) introduces a Binary Particle Swarm Optimization based method to accomplish optimal location and size of a Photovoltaics Grid-Connected System (PVGCS) for distributed power generation. The main technical constraint is the maximum installed peak power, which is limited for utilities Power Distributor Company. The fitness function to be optimized is the profitability index. A fair comparison between the proposed algorithm and other methods is performed. For such goal, convergence curves of the average profitability index versus number of iterations are computed. The proposed algorithm reaches a better solution than genetic algorithms when considering similar computational cost (M. Gómez, 2010).

Kirmani *et al* (2011) presented a methodology for determining the optimum size and location for installing the solar photovoltaic (SPV) based DG system for supplying the active power at the node in a radial distribution system for loss reduction. The objective of this paper is to apply heuristic search strategies to determine the node for the appropriate placement of DG. In heuristic approach, a critical node, called sensitive node is selected based upon maximum power losses caused for installing DG system. This method ensures that voltage constraints are met. This heuristic approach is useful for large distribution system and can be useful for online implementation. Test results have been tested on IEEE-33 bus system and presented (Sheeraz Kirmani, 2011).

Bagheri Tolabi *et al* (2014) presented a methodology for determining the optimum size and location for installing the solar photovoltaic (SPV) based DG system for supplying the active power at the node in a radial distribution system for loss reduction. The objective of this paper is to apply heuristic search strategies to determine the node for the appropriate placement of DG. In heuristic approach, a critical node, called sensitive node is selected based upon maximum power losses caused for installing DG system. This method ensures that voltage constraints are met. This heuristic approach is useful for large distribution system and can be useful for online implementation. Test results have been tested on IEEE-33 bus system and presented (Hajar Bagheri, 2014).

Al-Sabounchi *et al* (2014) has been developed a suitable procedure for optimal sizing and location of single PVDGs on radial distribution feeders. It goes along with the current trend of interfacing renewable energy generators with the grid due to global warming concern. The procedure applies single PVDG unit at points on the feeder while allowing reverse power flow (RPF) within the feeder line sections. The optimization objective is to minimize the accumulated line power loss over the day (line energy loss) along the feeder, while keeping the voltage profile along the feeder within permissible limits. A method has been applied to rate the line energy loss considering one time interval, namely feasible optimization interval. The procedure has been applied to an actual 11 kV feeder in Abu Dhabi city. The application showed obvious benefits in terms of line loss reduction and improvement of the voltage profile. The procedures also resulted in alternative feasible solutions in case the optimal solution cannot be applied for any reason - like inconvenience/limitation of land or investment (Al-Sabounchi, 2014).

Hence, this paper is attempted to reduce the uncertainty in sun radiation by appropriate and optimal location of distributed PV products, and the efficiency of electrical energy is increased.

Research Method

The research method is descriptive. In fact, in fundamental research, we examine the nature of objects, phenomena, and relationships between variables, principles, rules, and the making or testing of theories. Also, this type of research can be either empirical or theoretical. This research in term of method is applied in which fundamental research results are used to improve and perfect the patterns and methods. The purpose of this applied research is the development of applied knowledge in a specific field, which is here increasing the amount of energy generated by solar cells.

One of the necessities of any study is the availability of reliable information and the speed and ease of access to it. Given this information, it provides an opportunity for the researcher to follow the process of studying and analyzing the data to evaluate the research objectives and hypotheses.

The researcher will also be able to achieve the desired goals by spending time and money. The data collection in this research was conducted in a library method. Therefore, the information from books, dissertations, articles and databases has been extracted to complete the evaluation of the theoretical framework of the research. Also used for collecting information about the subject is the available documents and documentation.

The basic information contained in this study includes data from articles in this area and information that IEEE has put into the distribution network model in its library. In this research, the optimization was performed with the help of MATLAB software to increase the efficiency of the solar cell's output power, and thus the best place for solar panels with respect to the uncertainty of sunlight was obtained. And finally, the power output can be analyzed using panels. The TLBO algorithm was written by MATLAB software for this research and implemented on a power distribution system and calculated bus voltages and the flow of transmission line and tried to get the best place to put solar cells to generate power by considering uncertainty in sun radiation.

The criteria for determining the location and capacity of photovoltaic power plants

One of the criteria for selecting the location and optimal capacity of photovoltaic power plants is the cost of delivering electrical energy to distribution network subscribers.

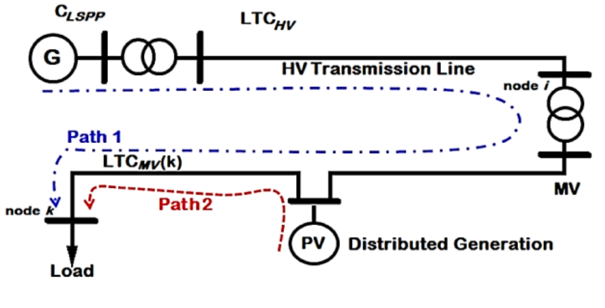

Figure 1: Single-line diagram of a power system in the presence of a PV

This amount of energy can be supplied by using thermal power plants or distributed generation units. In this case, the goal is to determine the economic points for the installation of diffuse generation units of a photovoltaic type (Nouri, Fatemeh, 2014).

According to the above figure, the price of electrical energy supplied by the thermal power plant is equal to LP^{psth1} and passes through Path 1 to reach the joint. This cost is commensurate with the following equation:

$$LP_{path1} = C_{LSPP} + LTC_{HV} + LTC_{MV}(K) \quad (1)$$

where in:

C_{LSPP}: The price of electricity purchased from the thermal power plant

LTC_{HV}: The cost of electricity transmission from the transmission network

LTCMV (K): The cost of energy transfer in the medium pressure grid from the super-distributed post to the load location (K node).

LP_{path2}. The price of electricity purchased from photovoltaic units, which passes through the Path2 pathway. The following amount of cost can be deduced from the following equation:

$$LP_{path2} = C_{PV} + LTC'_{MV}(K) \quad (2)$$

where in:

CPV: The price of electricity purchased from photovoltaic units

LTC'MV (K): The cost of electricity transmission in the medium voltage network from the photovoltaic unit to the load location (K node).

In these circumstances, photovoltaic power plants can compete with large power plants at points in the distribution network where the following points can be used. To achieve this, first, the cost of transmission of power and electrical energy from the medium to low load distribution network (LTC'MV, LTCMV) is calculated and then for all the nodes of the medium pressure distribution network, costs are calculated on the basis of relations (1) and (2) and evaluation is based on the relationship (3) (Nouri, Fatemeh, 2014).

$$LP_{path2} \Leftarrow LP_{path1} \quad (3)$$

Optimal Solutions

The connection of the PV generator to the radial distribution feeder injects a certain amount of power in the coupling (CP). The production curve of the PV generator is guided throughout the day with SI units. Looking at Fig. 2, we can say that this process ends with the collision of two functional curves that vary independently in the hours of sun radiation. These curves are the feed load curve driven by frequencies, and the curve of PV generator generates with the intensity of the sun's radiation. As mentioned above, it should be noted that peak formation in both curves is likely to occur at different times. Therefore, the concept of solving the optimization problem for maximizing ΔPPL with a PV generator is not considered to be effective. An alternative method for solving the ΔEL maximization problem is suitable as this method explores the benefits of daily energy savings over the course of a day, regardless of the peak of the mismatch. However, energy quantities need to repeat computations on a daily basis. Therefore, the proper concept for the ΔEL is defined only on the basis of an interval. Figure. 2 represents the interval 'A' in which the PV arrangement reaches its peak (PV (FOI)). As a result, the highest possible decrease in line capacity between the substation and the CP occurs during 'A'. Accordingly, 'A' in this study is called FOI (Nouri, Fatemeh, 2014).

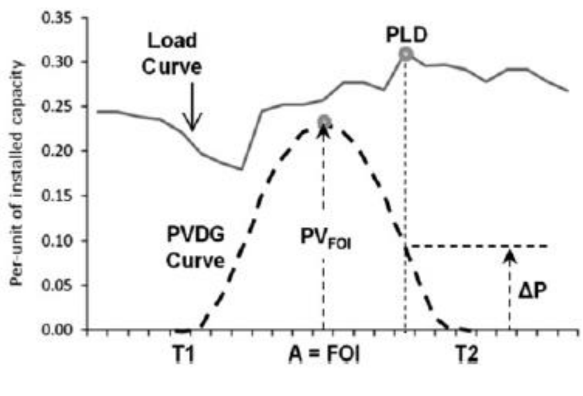

Figure 2 The peak point of the PV

This section is devoted to the reduction of energy loss (ΔEL) by decreasing power loss in (ΔPL_{FOI}) without the need for energy calculations. Derivative results show that optimal solution results in ΔPL_{FOI} maximization, which ultimately maximizes ΔEL. Based on the above, Section A of this chapter is dedicated to determining the optimal size and location of the unit of photovoltaic generators and minimizes power flow in FOI, thereby maximizing ΔPL_{FOI}. In the same sense, Section B is dedicated to proving that this solution is similar to the solution to minimize energy flux throughout the day, which results in maximization of ΔEL. According to the above description, it can be said simply that the photovoltaic generator unit is used for power generation unit in this study.

Photovoltaic (PVS) modeling and simulation

In this study, optimization is done using MATLAB software to increase efficiency of the power generated by solar cells in outputs. Through this, the best location is gained for solar panels due to uncertainty of sunlight radiation and finally, the amount of power generated using panels is analyzed. Using the governing equations of PV model, the behavior of system is simulated. The desired circuit for PV system is presented as follows (D.Petreus, 2008).

$$I = I_{SC} - I_{O1}\left[e^{q\left(\frac{V+IR_S}{N_1KT}\right)} - 1\right] - I_{O2}\left[e^{q\left(\frac{V+IR_S}{N_2KT}\right)} - 1\right] - \left[\frac{V+IR_S}{R_p}\right] \quad (4)$$

Where;
I= output current of cell
I_{sc}= the current generated by photons (short circuit)
I_{o1}= Diode reverse saturation current 1
I_{o2}= Diode reverse saturation current
q= charge per electron ($(1.602 \times 10^{-19} C)$)
Rs= secret resistance
Rp= parallel resistance
N1= diode quality coefficient 1 (diode diffusion coefficient 1)
N2= diode quality coefficient 2 (diode diffusion coefficient 2)
K= Boltzmann's constant $\mathbf{1.381 \times 10^{-19}}\ {}^{J}/_{K}$
T = cell temperature

Simulation for optimal localization of PV unit

Despite to old distributed generation units, power generation by PV units is uncontrollable and non-programmable and is highly depended on sunlight radiation on solar panels. In this chapter, this study tends to introduce a method for optimization of location and size of PV generation unit, so that the losses are reduced in addition to improve quality of power. Load flow calculation is one of the key calculations to determine static behavior of distribution system. In presence of distributed generation, common approaches of distribution load flow are not efficient anymore and some changes should be created in these approaches. Distributed generation units are modeled as or *PV* buses in load flow calculations. *PQ* buses are usually considered as a negative load in load flow assessments. However, to model PV buses, additional processes in load flow solution are needed. With the increase in influence of distributed generation, distribution network is changed from a passive grid (to which just loads are connected) into an active grid (containing loads and generators). This process is depended on making some changes in distribution analysis strategy. One of the most important and fundamental tools for analysis of every power system, whether in designing step or programming step, is load flow section.

One of the recent challenges in load flow calculations is the distribution of penetration of distributed generation in the distribution network. The issue of load flow could be considered as one of the most important issues in field of designing and utilizing power systems. While designing step, in order to ensure of quality of voltage in different parts of the network, standards related to its limitations in short-term and long-term future are evaluated and while utilization and implementation of the working process, load flow is used to ensure of authorized limit of voltage profile. The aim by designing and utilizing a power system is providing the loads needed by the network. Load flow calculation takes measure to calculate electric quantities of power system in static mode per certain loads. The quantities include bus voltage, active and reactive powers generated by generators and active and reactive powers flown in distribution lines. In fact, design and development of system in future due to load growth and necessity of adding generators, transformers and new lines in system is impossible without load flow calculation. Load flow calculation is one of the most fundamental issues in electricity industry. In the load flow calculation, repetitive response of big set of linear equations is one of the time consuming parts of power system simulation. The main defect of all advanced methods is high rate of required calculations. This is because of analysis, combination and calculation operations of Jacobian matrix. Proper implementation of these methods in networks with wide and inefficient dimensions can lead to additional calculation time and memory. In addition to the said items, in many systemic issues, the load flow calculation as a sub-problem helps solving the problem; for example, in this study, the load flow problem as a sub-problem helps solving the main problem that is local optimization of PV panel.

Implementation of simulation

The following results are for the case that PV unit is not added to system yet and only resource consumed by loads is the central power distribution network. For voltage, power of loads, current and power loss of lines, following figures have been respectively obtained from the software output:

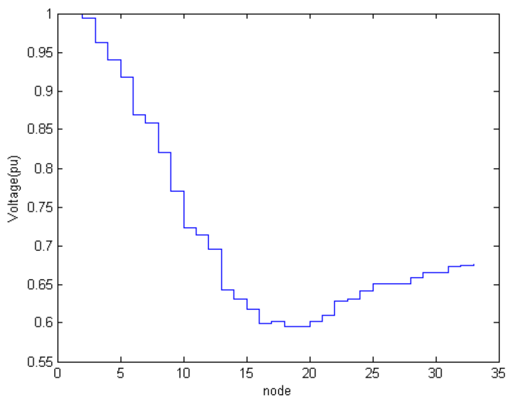

Figure 2: Voltage of line nodes without solar panel

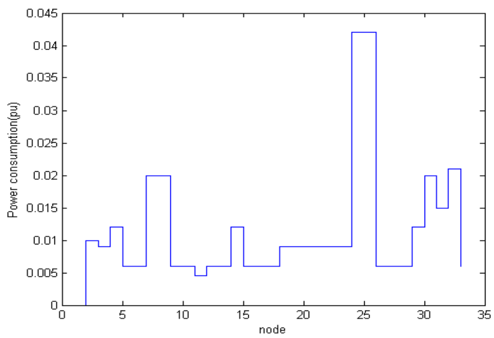

Figure 3: Consumed power by each node

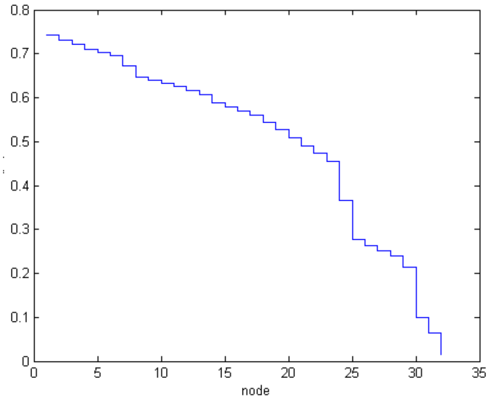

Figure 4: The current flow in spaces between nodes

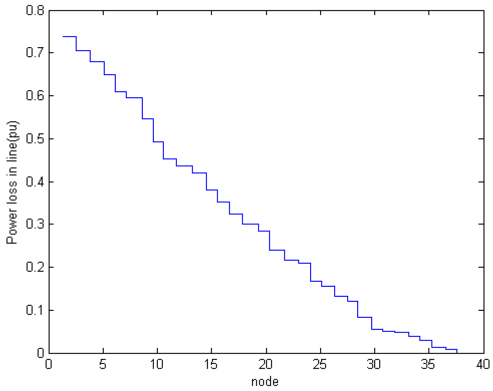

Figure 5: The power loss of lines between nodes

Now, same graphs in the state that PV generation units are placed respectively from end node to 5th node near the slack and load flow is implemented for every state. In figure 6, it could be observed that with the displacement of PV unit and load flow after each displacement, quality of voltage has been significantly increased at the end of 33-bus feeder and the range related to voltage has reached to the limit of 1 per unit. As it is clear in figure 7, in is found that in nodes 18 and 19, through placing PV unit, the maximum possible losses could be created for 33-bus line. Figure 8 illustrates mid node location for each placement location of solar panel.

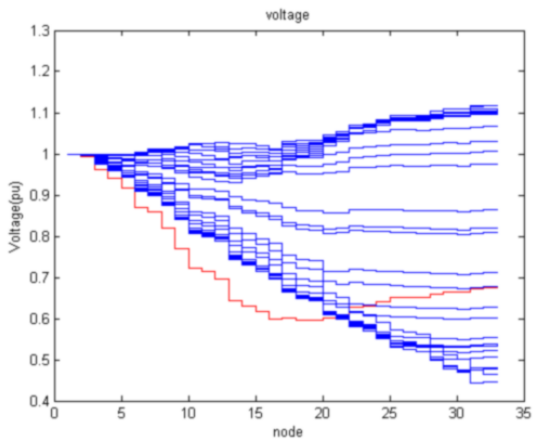

Figure 6: Change in voltage of nodes along with displacement of generation unit

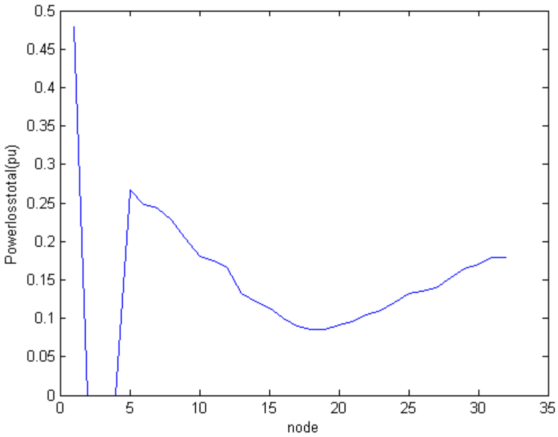

Figure 7: Total power loss due to location of generation unit

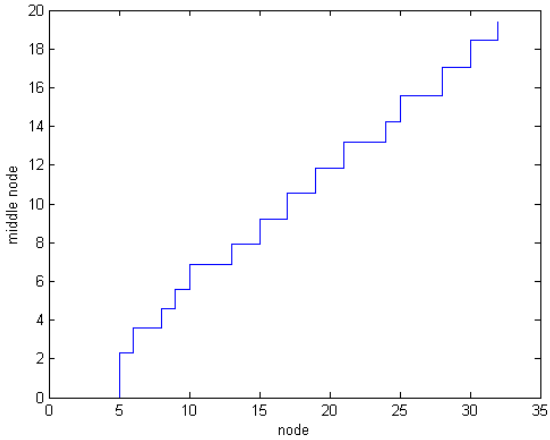

Figure 8: The mid node selected to determine capacity of generated power in generation unit

Conclusion

In this study, due to the process observed in chapter 4, for optimal localization of PV unit along a feeder about 35km, new method is used. This method was explainable due to possibility of creating recursive current by PV unit in all 33 nodes existed in the feeder. In this method, through placing the PV unit from the end of line to the 5th node and obtaining regarding uncertainty in sunlight radiation, location and suitable size of PV unit along a feeder is evaluated. In this way, uncertainty in sun radiation is introduced as amount of radiation in different nodes and it has been found that the current and the generation power of PV unit are depended on radiation angle and its intensity. After that, through comparing different points in the generation of power, relative coefficient is achieved for placement of PV unit in each group. In next step, every time that PV unit is replaced in each node, the mid node related to the replaced node is identified by obtaining values of A1 and A2. Then, number of cells or size of PV unit is determined based on the power consumed between two nodes with multiplying it in relative coefficient obtained in previous section.

Figure 9 shows that to what extent use of this method for localization of PV unit can lead to reduction of losses caused by electric energy.

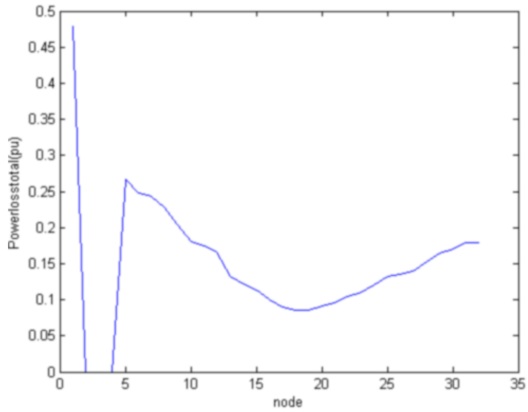

Figure 9: Total power loss due to location of generation unit

As it is obvious, through placing PV unit from bus 33 to bus 19, power loss caused by transmission is decreased and in bus 19, it is in lowest level. Power loss is about 0.475 per unit at the beginning of the process that no PV unit is existed in the system and this value reaches below 0.1 through placing generation unit in bus 19. This shows that optimal use of PV unit in a microgrid can decrease power loss to more than 1 fourth.

Here, the study has tried to illustrate the power loss distribution in figure 10 between two groups, so that exact illustration of reduction of losses could be formed with the existence of PV panel in mind of readers.

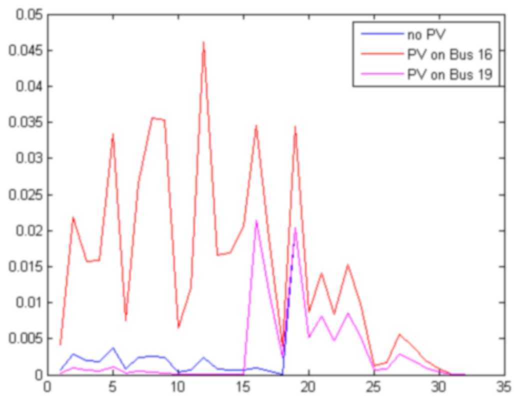

Figure 10: Power loss between lines in feeder

In figure 10, the red graph is for the time that no PV unit is used in microgrid and it is observed that to what extent losses of transmission lines is high. Through localization and change the location of PV unit, the amount of losses is decreased significantly.

In figure 11, voltage drop in different modes of existence and lack of existence of PV unit is observed. It could be observed from the previous diagrams that through placing generation unit in bus 19, least losses are created.

However, reduction of losses is not the only way to achieve an appropriate power system. Another goal is drop of voltage caused by transmission along the line.

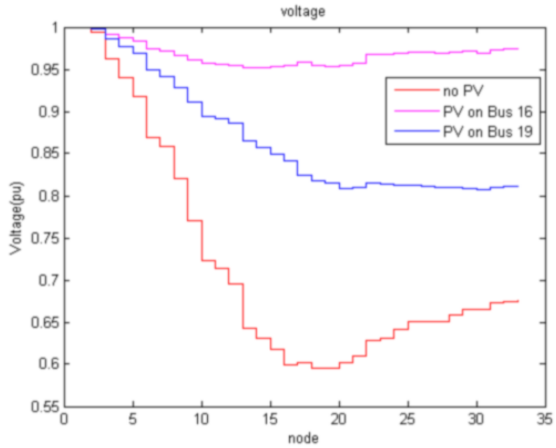

Figure 11: Voltage drop along the line

Blue graph shows that voltage drop at the end of line is equal to 0.2 per unit through placing generation unit in bus 19 and this value seems high. Purple graph shows that placing the unit on bus 16 has less voltage drop; although losses in lines are in high level. As a result, bus 16 is better than bus 19 to place PV unit.

In figure 12, the curve related to sun radiation in different points during 11 hours of on mode is observed.

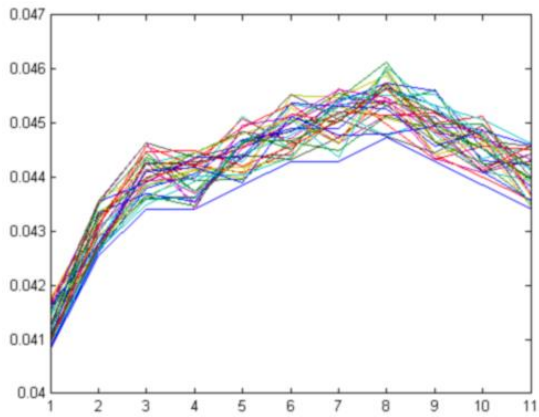

Figure 12: Relative radiation coefficient for different blades during 11hrs

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