KKU ENGINEERING JOURNAL 2016;43(S2):307-310 Research Article

KKU Engineering Journal

https://www.tci-thaijo.org/index.php/kkuenj/index

Improvement of reliability in distribution systems by optimal location and size of solar PV systems

Noppadol Kranjanaudom and Uthane Supatti*

Faculty of Engineering at Sri Racha, Kasetsart University, Sri Racha Chonburi, Thailand.

Received April 2016
Accepted June 2016

Abstract

This paper presents the methodology to improve reliability of distribution systems by using solar PV systems. The system's reliability is evaluated by using the future performance prediction and loss of load probability for optimal location and size of the PV systems. The optimal condition is evaluated through two distribution reliability indices which are SAIFI and SAIDI. Moreover, the economic value is calculated and compared to differences of size and location of the PV systems. In this paper, the PV systems are assumed to be connected to distribution networks at all buses of the IEEE 13 bus testing systems. Then, the implementation is conducted with comprehensive technical considerations, including solar radiation data, patterns of load demand, possible failures of PV units and PV output power. The results are shown that the PV system can improve reliability of the distribution systems. With economic consideration, the optimal size and location of the PV systems are determined and ultimately, these suitable parameters lead to improvement of the reliability of the distribution systems.

Keywords: Future performance prediction, Loss of load probability, SAIDI, SAIFI, Solar PV systems

1. Introduction

At present, the demand for electric power in Thailand is continually increasing. Therefore, the ministry of energy has proposed "Thailand Power Development Plan 2015 (PDP2015)" for supporting and boosting the economic growth in Thailand. The power demand forecasted, that during the years 2014-2036 the electricity demand would increase by 2.67 percent per year. In 2015 only, the total electricity capacity is 30,218 MW and will be increased up to 49,655 MW in 2036. Hence, the power consumption will go up to 64% within 20 years [1].

In addition to the sources of energy needed to produce electric power, it is necessary to give priority to the stability and reliability of the electric system. Power outage occurred in the electrical system can affect all customers including business and industry group of customers. There are many solutions to improve reliability of systems such as using higher quality equipment, increasing number of additional recloses on a feeder, adding interconnections between multiple feeders fed by several sources. Improving of reliability in distribution systems has been studied in various solution and several topics. In [2], a method for optimal placement of transformers in LV distribution networks was proposed by using an MINLP. A novel sub-islanding approach to identify the fault location and improving reliability of power distribution has been presented in [3]. In [4], a comparison of reliability indices with the effect of protection failure on an electrical to hydrogen distribution system was introduced.

The analytical methods discussed above have focused on the development of the equipment or the use of suitable equipment for improving reliability of systems. At present, solar panels have been increasingly installed in different areas around the world and still expensive due to the fact that the technology for the development. Therefore, a new methodology to improve reliability of systems with economic consideration needs to be developed.

The goal of this research is to propose the procedure to improve reliability of distribution systems by using PV systems. The optimal location and size of PV are also determined to achieve the reliability target.

2. Materials and methods

2.1 The power of photovoltaic systems

New generation of power plants with concentrating solar power systems uses the sun as an energy source. Solar panels used to power homes and businesses are typically made from solar cells .The electrical power of solar panel is up to area of one panel. The output power can be calculated in equations (1).

$$E = A \times r \times H \times PR \quad (1)$$

Where E is energy (kWh), A is total solar panel area (m^2), r is solar panel yield (%), H is annual average solar radiation on tilted panels (shadings not included), PR is

*Corresponding author. Tel.: +6685 929 4336
Email address: uthane@eng.src.ku.ac.th
doi: 10.14456/kkuenj.2016.116

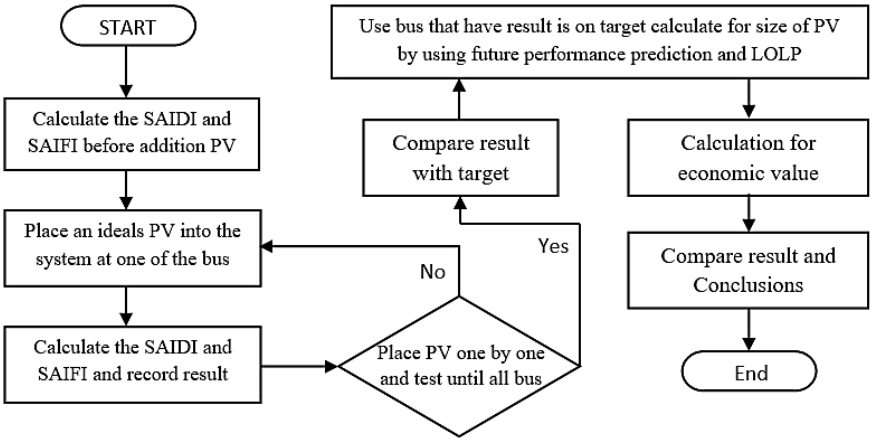

Figure 1 Simulation procedure

performance ratio, coefficient for losses (default value = 0.75).

2.2 Reliability assessment

There are several reliability indices used in the power systems [5-6]. By considering the reliability indices of distribution systems used in the Provincial Electricity Authority (PEA), Thailand, there are 1) System Average Interruption Frequency Index (SAIFI) and 2) System Average Interruption Duration Index (SAIDI). The SAIFY is the average number of interruptions that a customer would experience and the SAIDI is the average duration of interruptions that a customer would experience.

2.2.1 Future performance prediction

To predict the system reliability in the future, data collection of each device is required for calculation. In the case of SAIFI and SAIDI, failure rate and repair rate of each device need to be calculated and they are used to calculate the system reliability. The future performance prediction is used for planning of increasing power distribution systems or adding power stations. The equations to calculate the SAIFI and SAIDI in the future are as following [5].

$$SAIFI = \frac{\sum \lambda i \times Ni}{\sum Ni} \quad (2)$$

$$SAIDI = \frac{\sum Ui \times Ni}{\sum Ni} \quad (3)$$

Where λ_i is failure rate of each load point i, U_i is annual outage time of each load point i, and N_i is the number of customers of each load point i.

2.3 Calculation of loss of load expectation

The electricity from solar energy is uncertain throughout the day. It is available only daytime. If the power outage during the night, the PV system which is integrated into the system, could not increase the reliability.

The index used for reliability evaluation is based on the "loss of load or energy" approach. The expected number of days (or hours) is Loss of Load Expectation (LOLE) [6-7]. That is the time in which load is more than the available generation capacity [8].

Reliability of a system is good if LOLE is low. With the increasing of demand, if the generation of the system is not increased then LOLE will be further increased which indicate the overall system instability. The probability can be obtained from these equations.

$$LOLE = \sum_{i=1}^{n} t_i \, P_i \, (H/y) \; ; (L_{max} > C) \quad (4)$$

Where L_{max} is maximum load on day *i*, *C* is capacity of power on day *i*, P_i is the probability of this outage (from COPT table), and t_i is the number of time units for which this outage cause loss of load.

2.4 Simulation procedure

Steps to improve the reliability of the system by using future performance prediction and loss of load probability are shown in Figure 1. The target of SAIDI and SAIFI is defined first. Then assessing of the reliability before and after improvements is performed. The target of SAIDI and SAIFI will reduce the number of cycles to calculate optimal location and size of PV. The calculation procedure is detailed as following.

1) Calculate the SAIDI and SAIFI of the systems before integrating PV system by using (2) and (3).

2) Place an ideal PV system into the system at one of the bus system. Assuming that the added PV unit can provide power throughout the time during the power outage.

3) Calculate the SAIDI and SAIFI of systems after adding PV systems by using (2) and (3).

4) Repeat steps 2 to 3 for the rest of all buses and keep SAIDI and SAIFI value of each bus.

5) Use target values of SAIFI and SAIDI to compare with SAIDI and SAIFI obtained by adding the ideal PV units.

6) If the SAIDI and SAIFI obtained by adding the ideal PV unit at any bus is less than SAIDI and SAIFI of targeted value, use that bus as the location to calculate the size of the PV unit by using future performance prediction and loss of load probability.

7) Compare the SAIDI and SAIFI values obtained from step 6 in order to define the sizing of the PV unit. The optimal size of the PV system is achieved by considering the minimum SAIDI and SAIFI which meet the target.

8) Calculate the installation cost of the PV system in each location and size of the PV system that make reliability on target and compare to confirm the result.

2.5 Case study

This section discusses reliability evaluation techniques applied in IEEE 13 Node Test Feeder as shown in Figure 2, and reliability data for components in system is shown in Table 1.

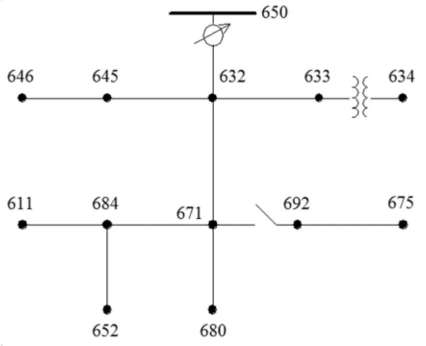

Figure 2 IEEE 13 Node Test Feeder [9]

Table 1 Reliability data for system components

Components	Sustained Failure Rate (failures/year)	Repair Time (in hours)
Substation	0.0071	108
Feeder line section	0.0025	11
Fuses	0.006	4
Recloser	0.006	4
Regulator	0.015	10
Transformers	0.015	10

The PV system will be added into the distribution network for reliability evaluation. The characteristics of the PV system are shown in Table 2.

Table 2 Reliability data for PV unit

Solar PV units	
MTTF (Hour)	4380
MTTR (Hour)	90
FOR	4%
Max power	100W/Unit

For the solar PV systems, the generated power is depending on the value of the solar radiation which is changing all the time throughout the day. To get the attributes of the solar radiation close to reality, this paper use the actual data measured by the Meteorological Department, Bangna, Bangkok, Thailand. The solar radiation value is shown in Figure3.

Load demand used in this paper is from load pattern of one area in Thailand and all bus is residence. The data of load demand is shown in Figure 4.

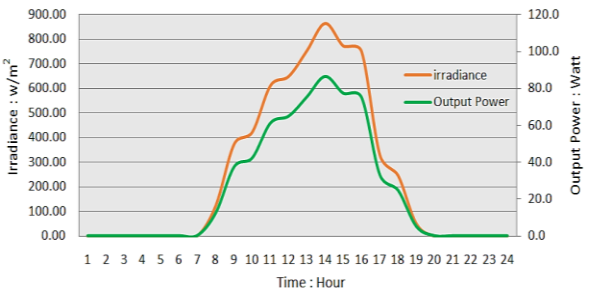

Figure 3 Solar radiation measured at the Meteorological Department, Bangkok, Thailand

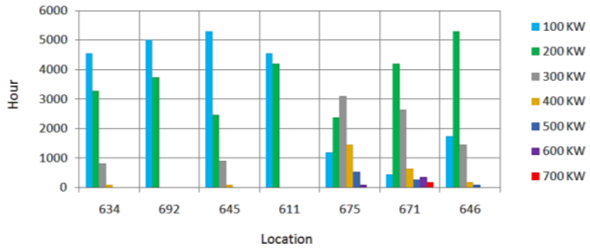

Figure 4 Load demand of each bus

3. Results and discussion

From the test system, the reliability of the system before improving was 0.01808 interruption/costumer/years for SAIFI. The reliability targets in this paper is assumed to reduce the SAIFI down to at least 5%.Therefore, the targeted SAIFI of the system should be equal or less than 0.01718 interruption/costumer/years.

To determine the appropriate size of the PV system, an ideal PV system is added into each bus with difference of PV's size depending on the connecting load on that bus. The PV's size is assumed to be equal to the maximum load on the connecting bus. The simulation results are shown in Table 3.

Table 3 Results of simulation by adding ideal PV systems

Location	Size of the PV system	SAIFI
634	400 KW	0.01195
645	400 KW	0.01751
646	500 KW	0.01723
611	200 KW	0.01750
652	200 KW	0.01763
671	700 KW	0.01442
692	200 KW	0.01730
675	600 KW	0.01306

The value in the Table 3 is the best SAIFI as the PV system is integrated into each bus. There are several nodes which obtained reliability values are still higher than the target value (0.01718). Therefore, it should be considered only node that value less than or equal the targeted SAIFI. Therefore, by considering Figure5, installation of the PV system on the bus number either 634, 675 or 671 will provide reliability levels that meet the target.

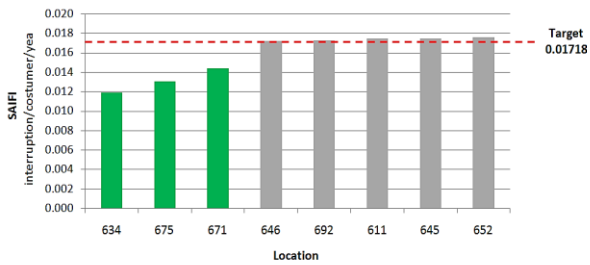

Figure 5 Comparison of the SAIFI for each bus

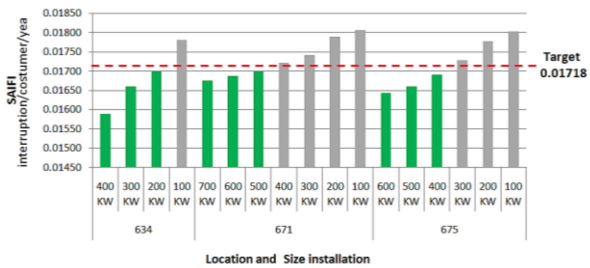

Figure 6 Comparison of the SAIFI for each bus with different sizes of the PV system

Table 4 The comparison of installation cost in different sizes of the PV systems

Location	Size installation	SAIFI	Percent of improvement	Cost of installation	ICPPOI
634	400 KW	0.01589	12.11%	$1,760,000	$145,300
634	200 KW	0.01700	5.97%	$880,000	$147,319
634	300 KW	0.01661	8.13%	$1,320,000	$162,351
675	500 KW	0.01660	8.19%	$2,200,000	$268,757
675	400 KW	0.01691	6.47%	$1,760,000	$271,973
675	600 KW	0.01644	9.07%	$2,640,000	$291,044
671	500 KW	0.01699	6.03%	$2,200,000	$364,917

The PV systems is integrated into the network in different sizes subject to its connecting bus. Figure 6 shows the simulation results of the comparison of the SAIFY with different locations and sizes of the PV systems. These comparison results are used to determine all sizes and locations of PV systems that make reliability being on the target.

For economic analysis in this paper, the installation cost of utility-interactive PV systems used for calculation is $4.4/W [10]. Table 4 shows comparison of the PV installation cost that use to improve the reliability of the tested system. The buses that are considered for the comparison consist of the bus 634, 675 and 671 integrating with different sizes of installed PV systems. The Installation Cost Per Percentage Of Improvement (ICPPOI) is used to ultimately determine the optimal required values. In this case, the lowest ICPPOI is $145,300USD. Therefore, the optimal location and size of the PV system to be installed in 13 Bus test feeder with 5% reliability improvement is the bus 634 and 400kW of the PV system, respectively. The cost of installation is about $1,760,000 USD.

4. Conclusions

This paper presents a method to improve reliability of distribution systems by using solar PV systems. The Future Performance Prediction with LOLE is utilized as tools for testing. Reliability of systems is evaluated through the SAIDI and SAIFI that make reliability meeting the target and also economic calculation is finally used to find the optimal size and location of the PV system.

With standard system, IEEE 13 node test feeder, and the assumption of 5% reliability improving, the PV system can improve reliability to meet the designed target. There are many options on size and location selection for installing PV systems. Hence the economic analysis was used to determine size and location. The proposed method is used to select the size and node that introduces the lowest installation cost per percentage of reliability improvement.

Although, the PV systems can improve the reliability of the distribution systems, the reliability is still depending on other factors such as transmission environment, lifetime of equipment, maintenance, etc. Therefore, to improve the reliability of the system, the other factors should be also considered in order to get the best reliability.

5. Acknowledgements

Authors would like to thank the Faculty of Engineering, Kasetsart University, Sri Racha campus, for its support throughout the study.

6. References

[1] Ministry of energy. Thailand Power Development Plan 2015. PDP 2015 – 2036. Bangkok: Ministry of energy; 2015.

[2] Haghifam MR, Esmaeeli M, Kazemi A, Shayanfar H. Optimal Placement of the Distribution Substations to Improve Reliability Under Load Growth. 2015 IEEE Power & Energy Society General Meeting; 2015 Jul 26-30; Denver, USA. New Jersey: IEEE; 2015. p. 1-5.

[3] Heidari A, Agelidis VG, Zayandehroodi H, Mills G. Sub-Islanding Approach to Improve the Reliability of Power Distribution Systems Considering Distributed Generation. 2013 4th IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG); 2013 Jul 8-11; Rogers, USA. New Jersey: IEEE; 2013. p. 1-8.

[4] Johnston DL, Johnson BK. Comparison of Reliability Indices with the Effect of Protection Failure for an Electrical to Hydrogen Distribution System. 2009 North American Power Symposium (NAPS); 2009 Oct 4-6; Mississippi, USA. New Jersey: IEEE; 2009. p. 1-5.

[5] Kai Zou, Agalgaonkar AP, Muttaqi KM, Perera S. An Analytical approach for reliability evaluation of distribution system containing dispatchable and nondispatchable renewable DG unit. IEEE Transactions on Smart Grid 2014;5(6):2657-2665.

[6] Billinton R, Billinton JE. Distribution System Reliability Indices. IEEE Transactions on Power Delivery 1989;4(1):561-568.

[7] Kranjanaudom N, Supatti U. An analytical approach for reliability evaluation of distribution systems for optimal siting, sizing and types of renewable distributed generators. 2015 IEEE Innovative Innovative Smart Grid Technologies - Asia (ISGT ASIA); 2015 Nov 3-6; Bangkok, Thailand. New Jersey: IEEE; 2015. p. 1-6.

[8] IEEE power engineering society. Distribution System Analysis Subcommittee IEEE 13 Node Test Feeder. USA: The Institute of Electrical and Electronics Engineers; 2000.

[9] Hamoud G, Billinton R. Uncertainty Aspects in LOLE Calculations for Two Interconnected Systems. IEEE Power Engineering Review 1981;PER-1(5):32.

[10] Al-Sabounchi A, Gow J, Al-Akaidi M. Simple procedure for optimal sizing and location of a single photovoltaic generator on radial distribution feeder. IET Renewable Power Generation 2014;8(2):160-170.