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Reliability Assessment of Distribution Network Considering Photovoltaic Array (P.V)

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Abstract: Using photovoltaic arrays as energy sources change the reliability of distribution power systems. This paper studies the effects of photovoltaic arrays on the reliability of a distribution power system. The method is based on the value-based method for a PV farms located in Iran. The obtained results show that when the photovoltaic arrays number changes, then the reliability of the power system varies non-linear. Therefore, the optimal number of the photovoltaic arrays for maximum reliability can be obtained by using value-based method.

Key words: photovoltaic arrays, Reliability, Distributed Power Generation, Distribution Power System.

INTRODUCTION

Solar (photovoltaic) energy is a major renewable energy source at the forefront of stand-alone and distributed power systems.

In general, photovoltaic arrays (PVs) are used in distribution power systems as alternative energy sources beside existing fossil power plants. The positive impacts of PVs such as reduction of greenhouse gases increase the attention on the development of using PVs in distribution networks. In last decay, the use of PVs around the world increased by 30%. Despite their rapid growth, PVs output power varies when the wind speed varies, therefore a reliable output power cannot be produced only by PVs. In this case, the reliability of the power system changes and it is necessary to use some techniques for investigating the reliability of the power system. The value-based method is one of the popular techniques for dealing with the power systems reliability. There have been proposed many studies associated with the value-based techniques, but most of them deal with radial topologies. When PVs are connected to a radial distribution power system, then the network changes to non-radial system. Because, in this case, the distribution power systems are fed from two sides, on one side there are PVs and on the other side there are conventional generation (CG) sources. In this paper the value-based technique based on the cost/worth concept is used for evaluating the effects of adding PVs on the reliability of power systems. The indices such as EENS (Expected Energy Not Supplied), Ecost (Expected Interruption Cost), SGIEB (Solar Generation Interrupted Energy Benefit), SGICB (Solar Generation Interrupted Cost Benefit), ENCG (Equivalent Number of Generators) and ECGC (Equivalent Conventional Generation Cost) are used. In addition, the optimal number of PVs based on the value of SGIEB will be obtained. The method will be applied for a PV.

Hybrid Power System:

Fig.1 shows the block diagram of the hybrid power system proposed in this study that connected to main grid in Point Common Coupling (PCC).

The considered structure for HRES in this study is a kind of renewable energy sources, includes PV and battery bank. In Figures 2 the structure of proposed HRES is shown.

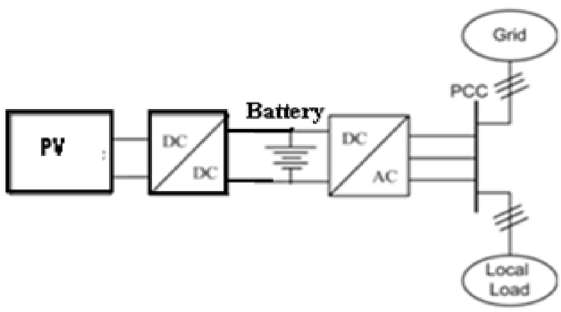

Fig. 1: The block diagram of the hybrid power system considering PV

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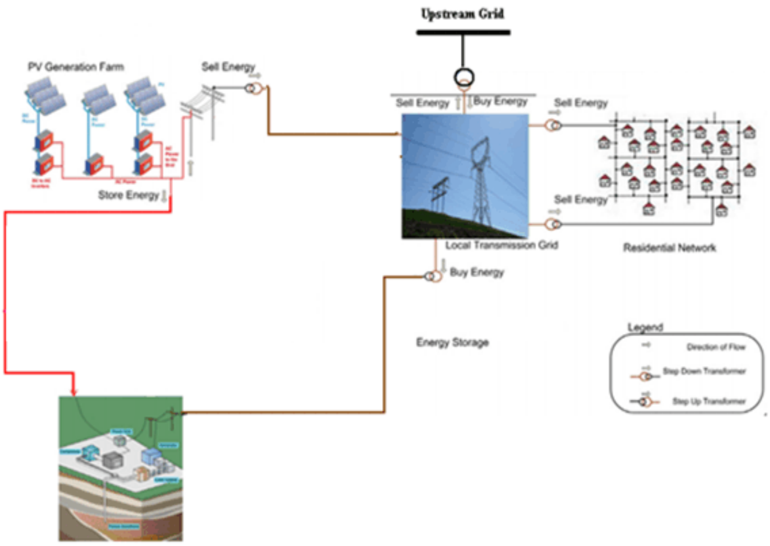

Fig. 2: structure of proposed HRES

Photovoltaic Specifications:

Solar (photovoltaic) energy is a major renewable energy source at the forefront of stand-alone and distributed power systems.

Photovoltaic (PV) power systems are, however, dependent on climatic conditions and their output depends on the time of year, time of day and the amount of clouds. Hybridization of fuel cell with PV will therefore form a very reliable distributed generation where the fuel cell acts as back up during low PV outputPhotovoltaic system is realized as an energy source that transforms the solar radiation energy into electrical energy. The radiation energy is transferred by means of the photo effect directly to the electrons in their PV crystals.

The solar power generation for any solar radiation can be predicted by using the formula given below:

$$P = A_{pv} x^2 + B_{pv} x + C_{pv} \quad (1)$$

Where x is solar radiation [W/m2] and P is power generation [W] and A_{pv}, B_{pv} and C_{pv} are constants, which can be derived from measured data. By using the above formula, solar power generation at any solar radiation can be predicted. This is also useful in estimating the suitable solar photovoltaic panels for many required load. Figure 3 shows the Voltage-Current characterization of a Photovoltaic array.

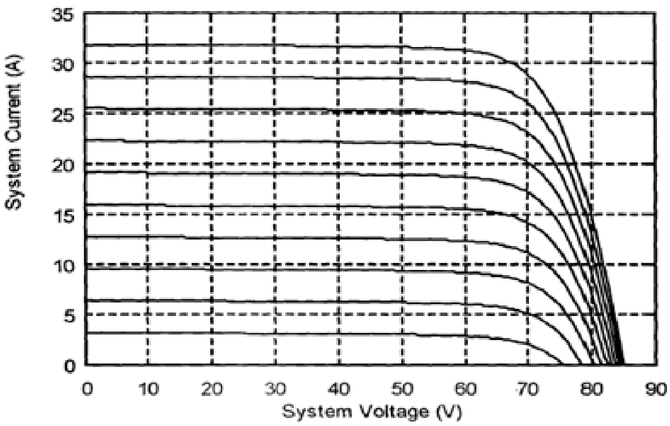

Fig. 3: Voltage-Current characterization of a Photovoltaic array

Figure 4 shows that the output power of PVs varies from very small amount of power nearly zero to a large amount up to 10 MW.

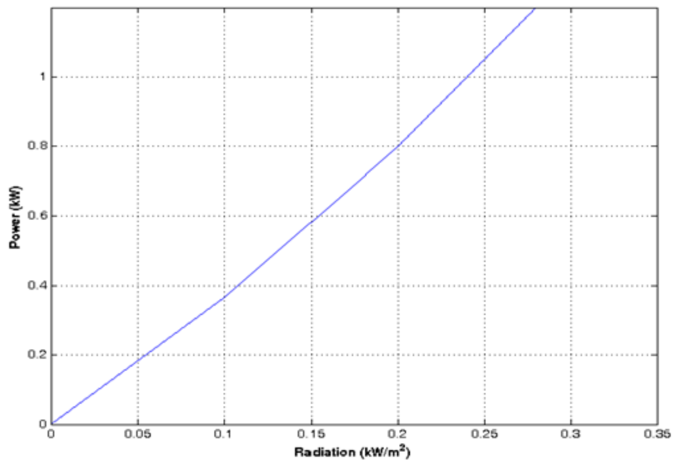

Fig. 4: Fuel-Power curve for the Photovoltaic Array

The technical data of PV includes average of annual radiation for Photovoltaic arrays, average of wind speed, lifetime of each energy sources, DG capacity and economical specifications such as, interest rate, capital recovery factor, annualized capital cost, annualized replacement cost and cost coefficients of each DGs. In order to accommodate the varieties of DG units, assumptions are made on the basis of the cost characteristics of central generation. The cost comparison among the various units is made as per the incremental cost. Incremental cost is a function of power output of the unit where slope indicates cost to produce incremental quantity and intercept indicates no load cost. Other conditions remaining the same, the lesser the slope, the lower the incremental cost and higher the penetration. The crossing over of two different incremental cost characteristics reveals that operational cost effectiveness depends on power output. The crossing over is determined by no load cost and slope of the curve.

The cost characteristic of DG units considered in test system is shown in Figs.5.

Also the capital cost and replacement cost characteristics of various DGs considered in this study is shown. The cost characteristics considered have wide variety of slopes and accordingly, intersection at several points. Hence, the comparative study of operational cost among the units relies on power output.

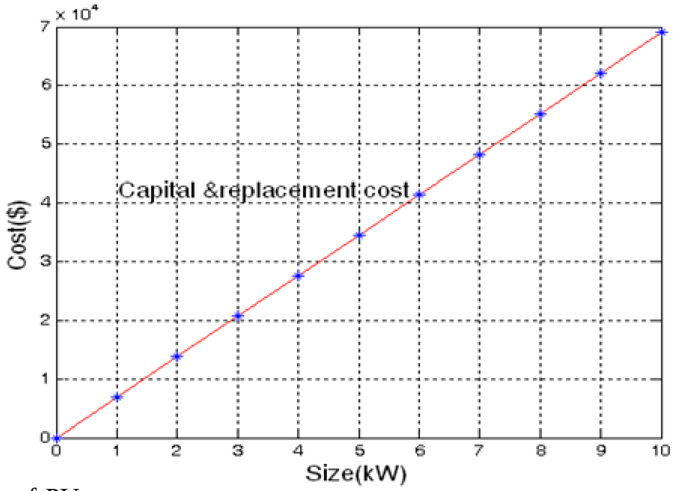

Fig. 5: .Cost characteristic of PV

Value-Based Method Indices:

The value-based method evaluates the reliability cost associated with different power system configurations. The reliability cost is the capital cost of the utility invested to improve reliability for consumers. It is usually difficult to evaluate the reliability cost directly; hence it is obtained by calculating some indices .The most popular using indices are explained as fallow:

$$SGIEB = \frac{EENS_{bpv} - EENS_{apv}}{Incremental\ \ Solar\ Generation\ \ Capacity} \quad (2)$$

$$SGICB = \frac{ECOST_{bpv} - ECOST_{apv}}{Incremental\ \ Solar\ Generation\ \ Capacity} \quad (3)$$

$$ENCG = \frac{RNCG}{RNSG} \quad (4)$$

$$ECGC = \frac{RCCG}{RCSG} \quad (5)$$

Where:
$EENS_{bpv}$: Expected Energy Not Supplied before adding PVs
$EENS_{apv}$: Expected Energy Not Supplied after adding PVs
$ECOST_{bpv}$: Expected Interrupted Cost before adding PVs
$ECOST_{apv}$: Expected Interrupted Cost after adding PVs
SGIEB: Solar Generation Interrupted Energy Benefit
SGICB: Solar Generation Interrupted Cost Benefit
ENCG: Equivalent Number of Conventional Generation Unit
ECGC: Equivalent Conventional Generation Capacity
RNCG: Required Number of Conventional Generation Unit
RCCG: Required Capacity of Conventional Generation Unit
RNSG: Required Number of Solar Generation Unit
RCSG: Required Capacity of Solar Generation Unit

In this paper, the indices EENS, Ecost, SGIEB, RNCG, RNSTG and ENCG are only used for evaluating the reliability of the distribution power systems.

RESULTS AND DISCUSSION

The system under consideration is the part of a distribution power system in Manjil site in Iran as shown in Figure 6.

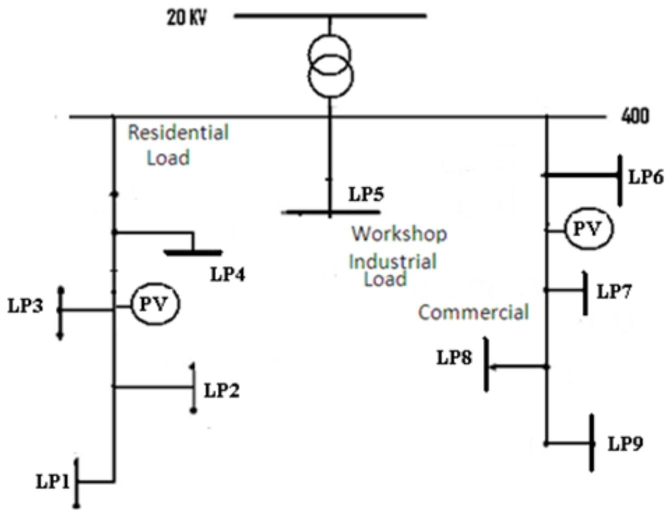

Fig. 6: Test distribution network

As can be seen, the network is supplied by CG units on the grid side and PVs on the opposite side of the network. The size of PVs is more than the total loads and therefore, some part of generated energy by PVs could be exported to the grid. The load points are indicated by LP1 to LP9 with the total amount of 8.4 MW. LP1 to

LP4 are residential load points, LP5 is industrial loads and LP6 to LP9 are commercial load points. The output power of PVs is as a function of wind velocity, humidity and other environmental circumstances; therefore the output power varies when the environmental conditions change.

In this simulation, three different cases have been selected for analyzing the reliability of the network.

Case 1 No PVs are connected to the network.
Case 2 2*5 MW PVs are connected to the network. (2 PV units are connected)
Case 3 10 MW Conventional Generation unit is used instead of 2*5 MW PVs.

In each case, the reliability of the network is obtained by calculating the introduce indices. For this purpose, the fallowing procedures have been used.

-Determination of fail operation probability of each section of the network and PVs. (The probabilities of fail operation of PVs are given 7%)

-Determination of loss of power cost for each load.(10 $ per MW is considered as the penalty for commercial consumers and 40$ per MW is used as the penalty for industrial consumers and 30$ for residential load points. load points 1 to 4 are considered as the residential consumers ,The load points 6 to 9 are considered as the commercial consumers and the load points 5 is industrial consumers).

-Determination of EENS for each load points before and after adding PVs.

-Determination of Ecost before and after adding PVs.

-Determination of indices values.

Results of Simulations:

The MATLAB software is used for obtained results. The Figure 7 and Figure 8 show the simulation results for each three cases introduced in section 5. Figure 7 shows that the EENS value for the case 1 is higher than the values for other cases. When 10 MW PVs are added to the network, then the value of EENS reduces. The minimum of EENS will be obtained when a 10 MW conventional energy source is used instead of the PVs. Furthermore, the EENS values have linear relation with the load points' power. For example, the EENS value of LP5 is higher than the EENS value of LP6.

Figure 8 shows the Ecost values for each load points. As can be seen, the variations of Ecost values are similar to the EENS values in Figure 7. Because, the relation between Ecost and EENS is:

$$E\cos t_i = EENS_i \times COST_i$$

Where
COSTi: The loss of power cost of the load point i.

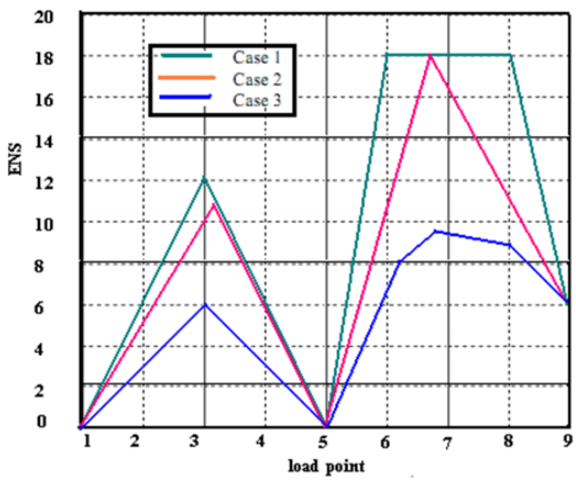

Fig. 7: Variations of EENS in each load point

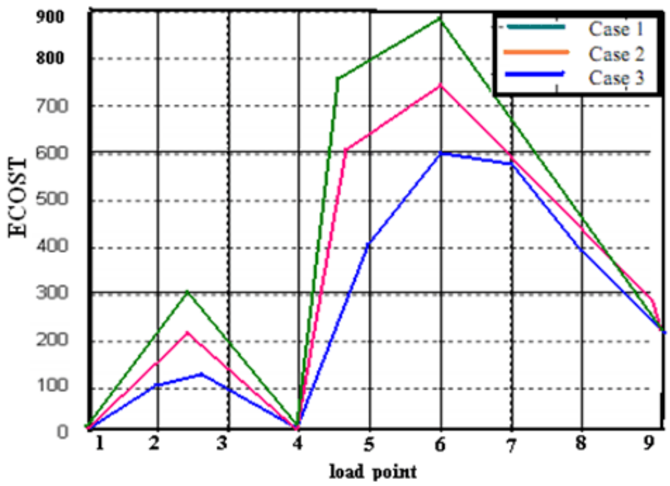

Fig. 8: Variations of ECOST in each load point

As stated before, it is considered that 10 $ per MW is the loss of power cost for load points 1, 2, 3 , 40$ per is assumed for load points 4, 5 and 6 and 30$ per MW for load points 7,8 and 9. Figure 7 and Figure 8 show that the reliability of the power system will be changed. For obtaining the reliability of the network, it is necessary to calculate the EENS and Ecost of the network. The expressions (6) and (7) explain the EENS and Ecost relations.

$$EENS = \sum_{i=1}^{i=9} EENS_i \tag{7}$$

$$E\cos t = \sum_{i=1}^{i=9} E\cos t_i \tag{8}$$

The values of EENS and Ecost for the entire network in each three cases are shown in Table 1.

Table 1: EENS and ECOST of the Network

	Case 1	Case 2	Case 3
EENS(MWh/yr)	26.20	23.34	18.24
ECOST($/yr)	1672.3	1457.2	821.87

Table 1 show that the EENS value decreases when PVs and conventional energy source are added to the network. By adding PVs, the EENS value reduces by 11% percent, while adding conventional energy source decreases the EENS by 31%. It is evident that adding conventional energy sources has better effect than PVs on the reliability of the power system. The value Ecost also reduces when PVs are added to the network. For example, the difference of Ecost value between the case 1 and the case 2 is about 11%. In addition, the annual outage of load points in three cases are studied and shown in Table 2.

Table 2: Calculated Annual Outage of Load Points (Hours/Years)

Load Point	Case 1	Case 2	Case 3
LP1	0.62	0.28	0.17
LP2	4.30	1.10	0.90
LP3	0.20	0.95	0.86
LP4	12.7	10.10	9.10
LP5	13.6	11.23	9.86
LP6	2.24	2.24	1.34
LP7	4.30	1.95	1.45
LP8	2.20	0.15	0.10
LP9	3.10	1.80	1.56

As the third column of Table 2 shows, the annual outage of load points where are near PVs have been decreased, but the related values for load points are far from PVs have less variations. Better figure of the reliability will be obtained if the SGIEB index is calculated. Figure 9 shows the variations of SGIEB when the number of PV changes. In this case, each PV has 1 MW capacity.

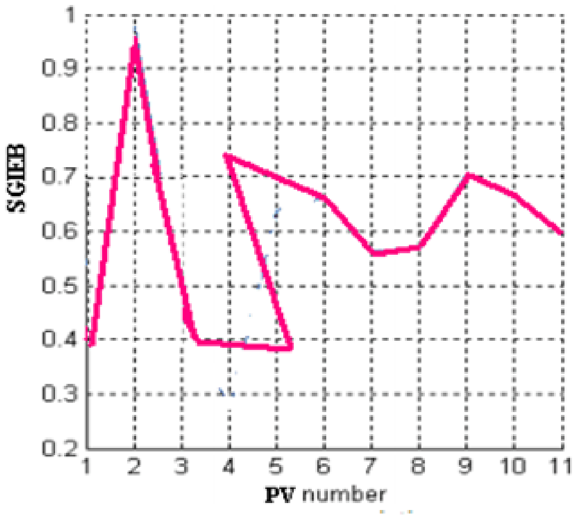

Fig. 9: variations of SGIEB versus the number of PV

Figure 9 shows that better benefit obtained when the number of PVs is 2. For calculating ENCG, it is required to calculate the Ecost variation of the network when the number of PVs and conventional generation unit change. The variation of Ecost has been shown in Figure 10. Figure 10 shows that for a specific Ecost, for example near 1300 $/Year, The required number of PV is 10 (RNSG=10) and for the same Ecost the required number of conventional generation unit is 3.6. Therefore, ENCG is 0.36.

In other words, the Ecost of 10 unit of PV is equal with the Ecost of 3.6 conventional generation unit.

Case 1 No PVs are connected to the network.
Case 2 2*5 MW PVs are connected to the network. (2 PV units are connected)
Case 3 10 MW Conventional Generation unit is used instead of 10 MW PVs.

In each case, the reliability of the network is obtained by calculating the introduce indices. For this purpose, the fallowing procedures have been used.

-Determination of fail operation probability of each section of the network and PVs. (The probabilities of fail operation of PVs are given 8%)

-Determination of loss of power cost for each load.

-Determination of EENS for each load points before and after adding PVs.

-Determination of Ecost before and after adding PVs.

-Determination of indices values.

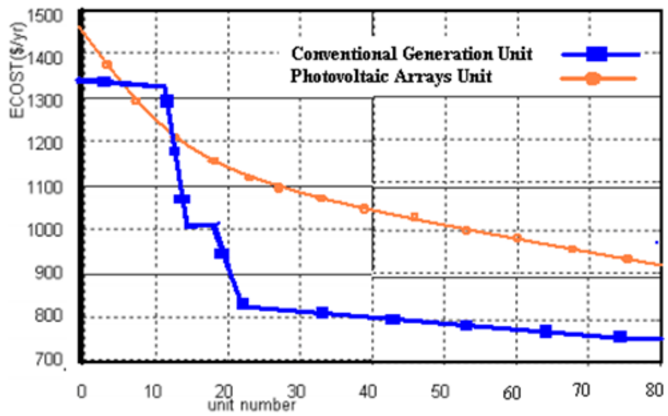

Fig. 10: Ecost Variations when PVs or Conventional Generation Unit Varies

Conclusion:

This paper showed that the effects of PVs on the reliability of the network had a different affect in compare with conventional generation unit. The reliability of the network changed when the velocity of solar radiation and output production of PVs varied. This feature of PVs is the main factor for reducing the reliability of the network in comparison with the conventional generation units, although adding PVs to the network increases the reliability of the entire network.

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