Technical Analysis of Photovoltaic System in Distribution Network with Considering Environmental Conditions in Iran

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Abstract: In the recent years the power system is changing and distributed generation (DG) units are used in power systems at the distribution level regularly. The power demand is increasing and it can be fulfilled by use of renewable energy sources like solar energy. This paper discusses the using of Photovoltaic power plant as a DG in Iran with considering environmental conditions. The main objective of this paper is to specify the adjustment coefficients for real maximum output power of Photovoltaic panels in different parts of Iran. In order to scrutinizing the effect of PV system placement as a DG in redial distribution system, in most appropriate part of Iran according to obtained adjustment coefficients, a 12-node radial distribution network is simulated with Digsilent software. Reducing in power loss, considering solar irradiance and temperature in different months of a year, is obtained.
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I. introduction

The traditional way in electric power generation is centralized power plants and a broad distribution network. However, the power system is changing and distributed generation (DG) units are used in power systems at the distribution level. DG placement in distributions system has some benefit [1]. One of important benefits is reducing in power losses.

DG has different types depending on the type of energy sources, such as renewable and non-renewable energy sources. Accelerated tendency to industrialization and raised interest in environmental issues recently led us to explore the use of renewable sources such as solar energy. Photovoltaic (PV) power plants are increased as a renewable source due to its advantages, like absence of fuel cost, short lead time for designing and installing a new system, static structure, no moving parts, no noise, inexhaustible and pollution free, highly mobile and portable because of its light weight, etc. Compared to other electricity generating technologies, however, PVs are still more expensive; improvements in technology will hopefully bring this cost [2].

Most electrical characteristics of PV panels are presented by manufacturers in Standard Test Conditions (STC), i.e. the irradiance is 1000 W/m^2 and the temperature is 25 C. It is clear that in real operation conditions commercial panels do not necessary behave as given in the specifications. Two factors affect the overall performance of PV panels particularly: temperature and solar irradiance. For best practical use, the PV cells must be operated at their maximum power point (MPP).

The operating point of a photovoltaic generator that is connected to a load is determined by the intersection point of its characteristic curves. In general, this point is not the same as the generator's maximum power point. This difference means losses in the system performance. DC/DC converters together with maximum power point tracking systems (MPPT) are used to avoid these losses. MPPT is used in PV power systems to force the PV module operating at MPP. In this way the PV module produces the maximum power output. For this operating point, it overcomes the disadvantages of high initial installation costs and low energy conversion efficiency [3].

In this paper Iran in terms of latitude and longitude is divided into 9 parts and in order to installing the PV in the best place in Iran potential survey is conducted considering the temperature conditions and solar irradiance. In addition an analytical method to find the MPP of a specific PV panel and the effect of power loss in distribution system is investigated. In order to calculate the power loss, a 12-node radial distribution network is simulated with Digsilnet software.

Monthly average hourly exterior daylight luminance levels is estimated in [4] in order to estimating the PV voltage-current curve. A hybrid wind, photovoltaic, battery generation system is designed for the region in south- west of Iran in [5]. In the cases where the experimental data in all over the operating range of the PV array is available, the parameter extraction can be performed by genetic algorithm or any other curve fitting schemes [6]. In [7] a proposal for the integration and implementation of PV technologies in buildings is personated, particularized for a city (Mashhad) in north east of Iran through a case study.

This paper is organized as follow. Section II describes the usage of temperature and solar irradiance level to determine the MPP for a specific PV panel. Section III presents validation tests and results by using the proposed analytical method and specifies the adjustment factor for each 9 areas of Iran. The effect of the PV in a standard test system in appropriate area is presented in section IV. Section V presents the conclusion of the paper.

II. solar cell model and mpp equation

In this section used PV model and its equations to consider the MPP are introduced.

A. PV Model

The modeling of PV cells and modules can be carried out by means of equations that provide different degrees of approximation to the real device. In this paper the one exponential model for PN junction has been chosen (five parameters) [8].

Fig. 1 shows the equivalent circuit.

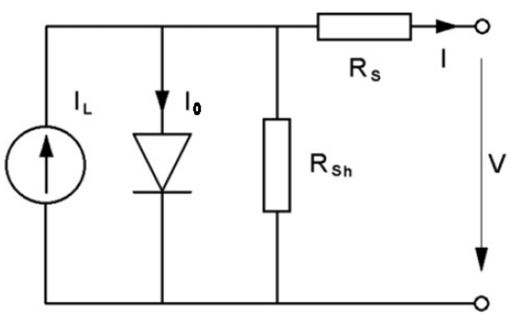

Figure 1. Equivalent circuit for PV cells

The equation that describes its behavior is:

$$I_L = \frac{I_{sc}.(R_s+R_{sh})}{R_{sh}} + I_0.\left(\exp\frac{I_{sc}\cdot R_s}{n\cdot v_{tn}} - 1\right) \quad (1)$$

$$I_L \approx \frac{I_{sc}.(R_s+R_{sh})}{R_{sh}} \quad (2)$$

$$I_L = I_0.\left(\exp\frac{V_{oc}}{n\cdot V_{th}} - 1\right) + \frac{V_{oc}}{R_{sh}} \quad (3)$$

$$I_O \approx \frac{I_{sc}.(R_s+R_{sh}) - V_{oc}}{R_{sh}}.\exp\left(-\frac{V_{oc}}{n.V_{th}}\right) \quad (4)$$

$$V_{th}(T) = \frac{k.T}{q} \quad (5)$$

$$I = I_L - I_O.\left(\exp\left(\frac{V+I.R_s}{n\cdot v_{tn}}\right) - 1\right) - \frac{V+I.R_s}{R_{sh}} \quad (6)$$

Where:

I_L = photocurrent
I_O= reverse saturation current of the diode
n = ideality factor
R_S and R_{Sh} = series and shunt resistances
V_{th} = thermal voltage of a cell
K = Boltzmann constant
T = absolute temperature of the cells
q = electron charge
V_{oc} = open-circuit voltage
I_{SC} = current of sort-circuit

For a given irradiance and temperature, the equations support different combinations of n, R_S and R_{Sh} .Taken separately, these values of n, R_S and R_{Sh} are not relevant. What really makes them significant is the relationship formed by the three parameters. Normally, for crystalline silicon PV modules this model requires an ideality factor between 1 and 1.3. Nevertheless, different studies have shown that n = 1 is adequate for modeling purposes. So, in this work it will be taken that n= 1 [9].

B. MPP In Real Conditions

Maximum power point in PV is not necessarily obtained in maximum voltage and maximum current. The MPP is gained in voltage and current that called V_{MP} and I_{MP}. These two characteristics are depended on ambient conditions. At the maximum power point the following condition is met:

$$\frac{\partial P}{\partial V} = \frac{\partial}{\partial V}(V.I) = I + V.\frac{\partial I}{\partial V} = 0 \;\rightarrow\; \frac{\partial I}{\partial V} = -\frac{I}{V} \quad (7)$$

Using the (1) to (6) and substituting in (7), these equations could be obtained [9]:

$$I_{MP} \approx \left(\frac{V_{MP}-R_S.I_{MP}}{n\cdot v_{tn}}\right).\left(I_{SC} - I_{MP} - \frac{V_{MP}-n\cdot v_{tn}}{R_{Sh}}\right) \quad (8)$$

$$V_{MP} \approx V_{OC} - I_{MP}.R_S - n\cdot v_{tn}.Ln\left(\frac{V_{MP}-n\cdot v_{tn}-I_{MP}.R_S}{n\cdot v_{tn}}\right) \quad (9)$$

RS and RSh have been calculated from follow equation:

$$R_S = \frac{1}{I_{MP}} \cdot \left[V_{OC} - V_{MP} - n \cdot v_{tn}.Ln\left(\frac{V_{MP} - n \cdot v_{tn} - I_{MP}.R_S}{n \cdot V_{tn}}\right)\right] \quad (10)$$

$$R_{Sh} = \frac{(V_{MP} - n \cdot v_{tn}).(V_{MP} - I_{MP}.R_S)}{(I_{SC} - I_{MP}).(V_{MP} - I_{MP}.R_S) - I_{MP}.n \cdot v_{tn}} \quad (11)$$

In order to calculate the new amount for I_L and I_O, these equations are used [10]:

$$I_L = \frac{S}{S_n}\left(I_{Ln} + k_i(T - T_n)\right) \quad (12)$$

$$I = \frac{I_{scn} + k_i(T - T_n)}{e^{\frac{V_{ocn} + k_v(T - T_n)}{na V_t}} - 1} \quad (13)$$

Where, K_i is I_{SC} temperature coefficient, K_v is V_{OC} temperature coefficient, S is the irradiation level and α stands for the quality factor of the diode (here α=1). The subscript n represents the parameters in STC.

R_S and R_{Sh} can be assumed constant but, I_L and V_{th} are highly dependent on the environmental condition [10], therefore using the equations mentioned, it is impossible to gain V_{MP} and I_{MP} in a real condition.

Using (10) and (11) both parallel and series resistance could be achieved. Then by (2), I_L is calculated in STC. By use of (12), this value can be updated to the real condition. Also, using (4) and (13) I_O is gained and it is also get update with new conditions (real temperature and irradiance). The valuation for I_{SC} and V_{OC} could be calculated by (1) and (3).

After these steps, using (8) and (9), and multiply the two numbers together, maximum output power for real temperature and radiation irradiance is obtained.

III. evaluating the potential use of solar energy in iran

In order to evaluate and compare the potential use of solar energy, in terms of longitude and latitude, Iran is divided into 9 districts. In technical and financial aims, it is necessary to know the real output power of DG. In this section, an adjustment coefficient is calculated for each part of Iran. The intensity of solar radiation and the average annual temperature for each area are specified for using on the presented model in the previous section.

C. *Latitude And Longitude Division*

Iran's map is similar to a quadrilateral with unequal and non-parallel length and width. Fig. 2 shows the map of Iran.

Figure 2. Map of Iran

The mentioned quadrilateral with the numbered regions is shown in the Fig 3.

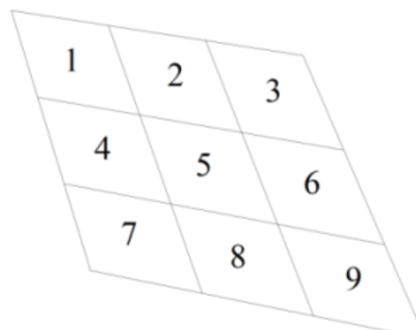

Figure 3. Number of districts

Latitude and longitude of the center of each area is described in table 1.

Table 1. *Latitude and longitude of areas*

Area Number	Longitude	Latitude
1	47.7	37.4
2	53.6	35.7
3	58.8	35.7
4	48.5	34.6
5	54	33.2
6	59.2	30.9
7	50	31.5
8	55	29.4
9	60	27.5

D. *Temperature and solar irradiance in areas*

Required Information is obtained from reputable websites [11] [12]. Details are shown in the table 2.

Table 2. *Average temperature and solar irradiance in 9 areas*

Area Number	Average Annual Irradiance (W/m2)	Average Annual Temperature (C)
1	594	10.85
2	618	17.85
3	613	13.85
4	647	11.85
5	670	19.85
6	702	15.85
7	678	14.85
8	705	18.85
9	705	26.85

E. Adjustment coefficient in 9 regions

In this paper, a model of solar panel, which is produced in Iran, is used [13]. Parameters of the panel are described in the following table:

Table 3. *characteristics of used PV Panel*

PMPP	VOC	ISC	Ki	Kv
120 W	21 V	7.54 A	0.037	0.34

By putting the values of Table 2 in equations that are mentioned in section 2, the maximum output power of a PV in each area, can be estimated. By division real MPP on nominal MPP, Adjustment coefficient is achieved. Using coefficient, the amount of MPP for any size of PV in each region can be estimated. The table IV shows the final results of these calculations.

Table 4. *Adjustment Coefficient in 9 areas*

Area Number	Real Output Power (W)	Rated Output Power (W)	Adjustment Coefficient
1	81	120	0.67
2	86	120	0.72
3	84	120	0.7
4	88	120	0.73
5	94	120	0.78
6	97	120	0.8
7	93	120	0.78
8	98	120	0.82
9	101	120	0.84

According to the results, the region number 9 is the best place to install the PV power plant. In this area average monthly temperature and average monthly solar irradiance for the months of a year is shown in table 5.

In order to calculate the effect of PV system in reducing the power loss in a distribution system, it is necessary to fine monthly adjustment coefficient for this area (9^{th} area). Like the previous part, real MPP and adjustment coefficient could be calculated for this area in each month. The results are shown in table 6.

IV. Simulated test system

The PV system is tested in radial distribution standard test system in order to reduce the power loss in a distribution network. Determination of appropriate size and location of DG is important to maximize overall system efficiency and to ensure stable and reliable operation of power distribution network. A good number of research works have been done on DG sizing and allocation issues. In this paper the result of a recently study is used. In the study [1] author discusses the sizing and sitting issue of single DG placement in radial distribution network. The main objective of the paper is to minimize active power loss and improve voltage profile of overall system. The paper presents three optimization techniques – Particle swarm optimization (PSO), Craziness based particle swarm optimization (CRPSO) and Gravitational Search algorithm (GSA) for optimal placement of distributed generators. The methods are tested with IEEE standard test case (12-node radial distribution network) and the results obtained by three algorithms are compared. The result of study shows that the optimal location of DG placement is node 9 and optimum amount of DG is 235.6 kW.

For the load flow study, the following parameters are considered: substation voltage=11KV, base MVA=100, total active load =455.71 kW. The system parameters are available in [14]. In base case total power loss of system is 20.71 kW and it would be 10.07 when DG is placed in node 9.

In this paper, according to the maintained study results, the 12 nod radial distribution network is simulated in Digsilent software.

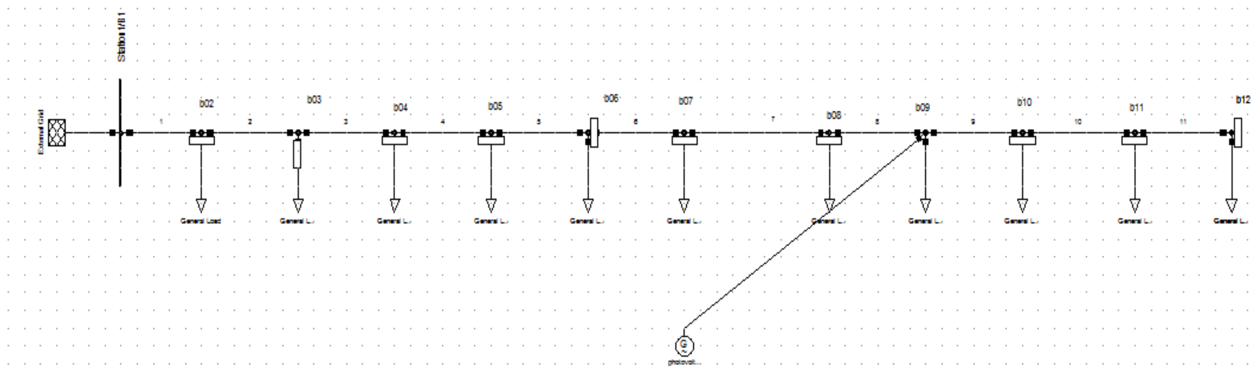

Figure 4. Simulated network in Digsilent software

The power of DG is modified by adjustment coefficient that is obtained from table 6. Therefore, the average real output power of DG and network power loss with that DG in the months of a year are like amounts in table 7.

TABLE I. AVERAGE TEMPERATURE AND SOLAR IRRADIANCE IN 9TH AREA

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Monthly Temperature (C)	13.9	17.9	21.9	27.9	33.9	36.9	37.9	36.9	33.9	27.9	21.9	16.9
Average Monthly Irradiance (W/m^2)	550	640	690	780	820	850	840	810	750	670	560	500

TABLE II. AVERAGE MONTHLY ADJUSTMENT COEFFICIENT IN 9TH AREA

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Real Power (W)	75.849	89.147	97.253	111.6	119.46	124.79	123.88	119.39	110	96.792	79.72	70.022
Rated Power (W)	120	120	120	120	120	120	120	120	120	120	120	120
Adjustment Coefficient	0.63	0.74	0.81	0.93	0.99	1.03	1.03	0.99	0.91	0.8	0.66	0.58

TABLE III. MONTHLY GENERATED AND REDUCED POWER IN 9TH AREA

mounts	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
adjustment coefficient	0.63	0.74	0.81	0.93	1	1.04	1.03	0.99	0.92	0.81	0.66	0.58
Rated MPP (kW)	235.6	235.6	235.6	235.6	235.6	235.6	235.6	235.6	235.6	235.6	235.6	235.6
Real MPP (kW)	148.92	175.02	190.94	219.1	234.55	245.01	243.22	234.4	215.96	190.03	156.52	137.48
Base power Loss (kW)	20.71	20.71	20.71	20.71	20.71	20.71	20.71	20.71	20.71	20.71	20.71	20.71
New power loss (kW)	12.05	11.39	11.11	10.82	10.77	10.79	10.78	10.77	10.84	11.12	11.83	12.41
Power loss (kW)	8.66	9.32	9.6	9.89	9.94	9.92	9.93	9.94	9.87	9.59	8.88	8.3

V. CONCLUSION

Characteristics of a specific PV panel are used to find the MPP in 9 districts in Iran with different solar irradiance and temperature. According to results that are shown in table 4, 9th area is the best for installing the PV power plant. This area is in southwest of Iran that some important cities are located on it. According to the obtained results, real output power of PV panel in this area is %84 of nominal output. Table 7 shows the result of installing a PV power plant in this area in a 12 bus distribution network test in 12 months of a year. The results show that reduction in power loss is different in particular mounts and less than reduction in power loss with a usual DG like Diesel Generator. It is an important point and should be noticed in financial aims.

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