Development of a Strategy for the choice of PVG installations in the Radial Distribution System

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Abstract: Distributed generation (DG) is the only option for the electricity sector, as an effective alternative for electricity supply instead of the traditional centralized power generation. In this paper PV Generation (PVG) is considered as a Distributed Generation, installed at different nodes of the radial distribution feeders. The Power Utilities are beginning to acknowledge PVG as an economically viable alternative to deferring investment at generation, transmission and distribution levels, meeting demand growth and reducing the power loss and improving the voltage profile, thereby improving the distribution network performance and security. The benefits of installing of the PVG in a node in the radial feeder vary widely. Therefore, appropriate siting and sizing of PVGs could lead to many positive effects for the distribution system concerned. This paper presents a simple methodology to develop a strategy for deciding upon the location and the size of the PVG for installation in the radial distribution feeders. For this purpose, a 400V radial distribution system from the Kanchipuram district in Tamil Nadu is taken for testing the methodology proposed and to present a guiding chart developed for the Distribution system personnel.

keywords- Photovoltaic Generation (PVG); Distributed Generation (DG), Internal Rate of Return.

I. INTRODUCTION

Electricity serves as a main driver for the economic development in any country. The energy sector constitutes relatively a modest share of Gross Domestic Product (GDP) in most of the countries. Traditional fossil fuels, such as coal, petroleum and natural gas, are major forms of energy. Coal fired Electricity generation forms the major share of energy resources in the world. Coal-fired electricity generation represents about 78% of the installed capacity in India. But, as per the Greenpeace report the extractable coal reserve of 18.2 billion tons of Coal India Limited (CIL) would exhaust in about 17 years, while the demand for electricity is increasing at an annual growth rate of 7.3% in India, as per the Bridge to India report. In addition, according to official figures, nearly one third of villages (5665) out of the total of 18452 villages in India are waiting for electrification. As a result, there is a heavy demand for the electricity needs. In addition to the fast depletion of the Coal reserve and increased T&D losses, including the degradation of the air quality and human health care due to high particulates and sulfur dioxide (SO_2) and carbon dioxide (CO_2) emissions from the coal fired thermal power stations affecting the world's climate strongly. This situation has compelled many countries in the world for the adoption of Distributed Generation (DG). The increasing penetration of distributed generation (DG) in power distribution systems presents technical and economic benefits. However, inappropriate sitting and sizing of DGs could lead to many negative effects on the distribution systems concerned, such as voltage profiles going beyond permissible limits, and increased network losses. Therefore, it is becoming increasingly important to decide on sitting and sizing of the DGs optimally in active distribution networks while planning. This work aims to develop an optimal planning strategies and methods to decide on the installation of PVGs exploiting the abundant Solar energy resources available at low cost. In the past, a number of studies have been carried out by the Researchers for installing different types of DG systems, using sophisticated computing methods and tools, but not easily accessible to the practicing field engineers.

Thomas Ackermann et al define the DG as electric power generation within distribution networks or on the customer side of the network. They have suggested that further research is required regarding the analysis of the impact of distributed generation on the reliable and economic operation of distribution systems. Thereby it is important to consider the benefits of distributed generation, such as reduction of network losses, as well as additional costs, such as the redesign of the protection system [1]. Fahad Iqbal et al, discusses the optimal location and sizing of DG generation for improving the voltage profile of the system and saving energy loss [2]. Ken Kuroda discusses the optimal location and sizing of DG in a pilot system using Exact Solution method. The test is conducted on a six bus pilot system. The optimal location of real power injection and reactive power injection and both real and reactive power injections for the pilot system are measured. [3]. The Allahabad et al propose a new method to reduce the Distribution system losses by optimal location and sizing of the DG in the system, using Genetic Algorithm. The proposed method is tested in a 16-bus distribution system using MATLAB. N.Vijaysimha discusses the optimal location and sizing of DG in the Distribution system by multi objective index. The multi objective index is converted into single objective by a certain weight. [5]. Nguyen et al discusses the optimal location and sizing of single DG using Bees colony algorithm. The proposed system is tested in an IEEE 33 bus system [6]. Soumya A et al discuss the optimal location and sizing of distributed generation in a distribution system using a genetic algorithm. The IEEE 5-bus,16-bus and 30-bus systems are used to test the algorithm [7]. K.Divya discusses the optimal location of the DG in a distribution system by Voltage stability index(VSI). ***Particle Swarm Optimization (PSO) algorithm.*** is used for the optimal sizing of the DG in the optimal location. The test is carried out in the 12-bus radial distribution system [8]. S.A Chithra Devi discusses about the multiple DG placement and sizing of in a radial distribution system using Stud Krill herd Algorithm. The DG in the distribution system reduces the voltage deviation, the power loss and minimizes the system cost [9]. Rugthaicharoencheep, N., and S. Auchariyamet. Discusses on the Technical and economic impacts of distributed generation on the distribution system. The impact of DG in the distribution system are well explained in the paper [10]. Gil, Hugo A., and Geza Joos. Presents Models for quantifying the economic benefits of distributed generation. The paper presents that DG in the distribution system improves the reliability and reduce the electricity bill. The paper further highlights that utility is benefited by investment deferral, avoid electricity purchase and reduce the losses [11]. McDermott, Thomas E., and Roger C. Dugan. Presents Distributed generation impact on reliability and power quality indices. [12]

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II. SCOPE OF THIS STUDY

This study presents a a Strategy for the choice of PVG installations in the Radial Distribution System as a ready reckoner to the practicing distribution engineers. The practicing distribution engineers need a simple methodology for assessing the voltage profile and the power and energy losses in the system they are controlling. They also need to decide on which node the PVG should be connected that will give maximum benefit. They also need a simple method to determine the economic benefits. For these purposes this paper discusses the simple methods used for determining the nodal voltages, the power and energy losses and the Internal Rate of Return of the investment.

III. METHODOLOGY

a) Nodal Voltage calculation

The voltage at a node in a radial distribution feeder is a function of the Load Moment, M of the section and the Voltage Regulation constant, H of the conductor size used in the feeder section, as given in (1),

The nodal voltage of section i is given by

$$V_i = M_i/H_i + V_{i-1} \qquad (1)$$

Where $M_i = P_i.d_i$, P_i being the load flow in section i in kVA and d_i is the Length of the feeder section in km.

And H_i is the Voltage Regulation constant of the conductor used in section i in km-kVA, given by

$$H_i = 10\ kV^2 / \ ((r_i \cos(theta) + x_i \ \sin(theta)),$$

r_i and x_i are the resistance and reactance per

km of the conductor used

theta being the power factor angle [13] (2)

a) Power Loss Calculation

By definition, the power loss is given by

$$P_{Li}=3*I_i{}^2R_i \text{ Watts} \qquad (3)$$

But the total Power loss in the feeder is given by [13]

$$P_L = (0.001r\ (LDF/PLDF) / kV^2)\ MP, \qquad (4)$$

Where LDF if the Load Distribution Factor of the feeder given by

$$LDF = (P\ L /M), \qquad (5)$$

P is the total load in the feeder in kVA, L being the total length of the feeder in km and M being the total Load Moment in the feeder.

b) Energy Loss Calculation

Energy Loss, EL is calculated using

$$EL = PL\times LLF \times 8760 \text{ units} \qquad (6)$$

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Where LLF is a function of load factor, and is defined as

$$\text{LLF}= A(LF)^2 + B(LF) \qquad (7)$$

$$\text{and} \quad A+B=1 \qquad (8)$$

As per British formula, A= 0.8 and B= 0.2, [13]

c) Determination of IRR for the optimal cases

The Cash inflow and the cash out flow for the investment are computed first which constitute the following components:

Cash Outflow is the sum of the following:

(i) The initial investment to install the PV system during year 1.

(ii) The present worth of O & M charges spent every year during the life cycle of the PVS.

Cash Inflow is the sum of the present worth of:

(i) The cost of Saving of Energy losses in the feeder and in the Transformer, every year.

(ii) The cost of Energy due to capacity release in the feeder and Transformer capacity to meet the load growth in the system without augmentation of the feeder or the Transformer capacity.

(iii) The Cost of Energy supplied by the PV System every year during the life cycle of the PV System.

The economics of the investment is computed using the Discounted Cash Flow Technique. The formula used for computing the present worth P_w of future value (FV) is given by (5).

$$P_w = F_v/(1+i)^n \qquad (5)$$

Where i is the rate of interest and n is the year of future value.

The **Internal Rate of Return (IRR)** is that rate of interest at which Net Cash flow is zero.

IV. MERRITS OF THE LOCATIONS FOR PVG INSTALLATION

Every location in a radial Distribution feeder has its own influence on the quality of service to the customers and on the economic benefit to the Utilities. Hence it becomes essential to determine the optimal location and optimal sizing of PVGs. Also, it becomes essential to determine the order of merit of the locations in terms of benefits to the customers and to the Utilities. To establish the strategy for a given system, a 400 V Radial Distribution Feeder, shown in Fig.1 is taken for analysis:

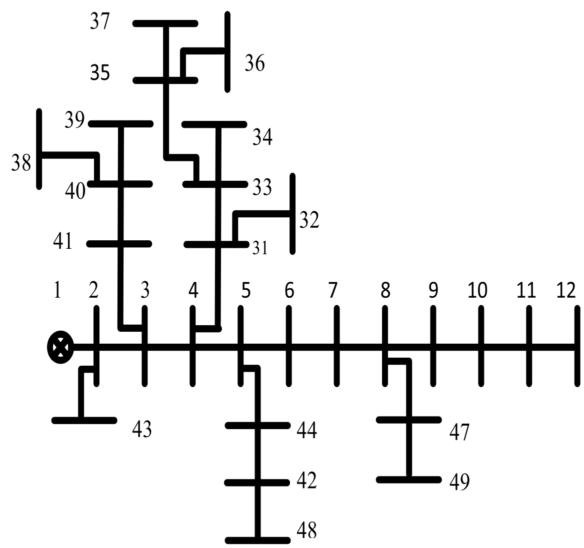

Fig 1: 400V the radial distribution System

Fig 1 a 400V the radial distribution System in the Kanchipuram district distribution system, in Tamil Nadu. Load Data of the Test System is given in Table-1.The resistance and reactance of the feeder is given in Table-2

Table 1

Load Data of the Test System

BUS	2	3	4	5	6
P[kW]	-	-	-	-	3.730
Q[kVAR]	-	-	-	-	2.797
BUS	7	8	9	10	11
P[kW]	3.73	-	2.238	2.238	3.730
Q[kVAR]	2.797	-	1.678	1.678	2.797
BUS	12	43	41	40	39
P[kW]	2.238	2.238	2.238	-	11.190
Q[kVAR]	1.678	1.678	1.678	-	8.3925
BUS	38	37	36	35	34
P[kW]	2.238	2.238	2.238	3.730	2.238

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Q[kVAR]	1.678	1.678	1.678	2.797	1.678
BUS	33	31	32	46	44
P[kW] Q[kVAR]	- -	- -	2.238 1.678	0.040 0.03	0.040 0.03
BUS	42	48	47	49	
P[kW] Q[kVAR]	.320 .270	0.040 0.03	2.238 1.678	2.238 1.678	

Table 2
Resistance and Reactance values of the Test System

LINE	1-2	2-3	3-4	4-5
Resistance (Ω) Reactance (Ω)	0.0194 0.01387	0.0235 0.0167	0.1170 0.0835	0.0306 0.0219
LINE	5-6	6-7	7-8	8-9
Resistance (Ω) Reactance (Ω)	0.03066 0.0219	0.0996 0.07117	0.2646 0.3968	0.2044 0.3066
LINE	9-10	10-11	11-12	2-43
Resistance (Ω) Reactance (Ω)	0.165 0.252	0.644 0.966	0.1064 0.1596	0.1834 0.27508
LINE	3-41	41-40	40-38	40-39
Resistance (Ω) Reactance (Ω)	0.4718 0.707696	0.1848 0.2772	0.084 0.126	0.084 0.126
LINE	4-31	31-32	31-33	33-34
Resistance (Ω) Reactance (Ω)	0.11648 0.256	0.098 0.14	0.182 .4	0.1064 0.2054
LINE	33-35	35-36	35-37	5-44
Resistance (Ω) Reactance (Ω)	0.2128 0.3192	0.2128 0.3192	0.28 0.42	0.2758 0.4137
LINE	44-46	44-42	42-48	8-47
Resistance (Ω) Reactance (Ω)	0.1148 0.1722	0.2716 0.4095	0.0434 0.0650	0.427 0.64
LINE	47-49			
Resistance (Ω) Reactance (Ω)	0.2128 0.3192			

Choice of the size of PVGs

Depending upon the Load size the PVG considered are 3kWp, 5kWp and 15kWp. The Energy supplied by the 3kWp PVG every year is given in Table 3. Energy supplied by the 5kWp PV System every year is given in Table 4. Energy supplied by the 15kWp PV System every year is given in Table 5. Table 6 shows the investment, operating and maintenance cost of 3kW PV. Table 7 shows the investment, operating and maintenance cost of 5kW PV. Table 8 shows the investment, operating and maintenance cost of 15kW PV.

Table 3

Energy supplied by the 3kWp PV System

Year	Energy supplied by PV System (Units)	Year	Energy supplied by PV System (Units)
1	4467	14	3920
2	4422	15	3881
3	4378	16	3842
4	4334	17	3803
5	4291	18	3765
6	4248	19	3728
7	4206	20	3690
8	4164	21	3654
9	4122	22	3617
10	4081	23	3581
11	4040	24	3545
12	3999	25	3510
13	3959		

Table 4

Energy supplied by the 5kWp PV System

Year	Energy supplied by PV(Units)	Year	Energy supplied by PV(Units)
1	7445	14	6533
2	7371	15	6468
3	7297	16	6403
4	7224	17	6339
5	7152	18	6276
6	7080	19	6213
7	7009	20	6151
8	6939	21	6089
9	6870	22	6028
10	6801	23	5968

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11	6733	24	5908
12	6666	25	5849
13	6599		

Table 5

Energy supplied by the 15kWp PV System

Year	Energy supplied by PV(Units)	Year	Energy supplied by PV(Units)
1	22275	14	16028
2	21718	15	15627
3	21175	16	15237
4	20646	17	14856
5	20130	18	14484
6	19626	19	14122
7	19136	20	13769
8	18657	21	13425
9	18191	22	13089
10	17736	23	12762
11	17293	24	12443
12	16860	25	12132
13	16439		

The cash outflow due to the PVGs are given in Tables 6,7 and 8 respectively for the 3, 5 and 15 kWp PVGs.

Table 6

Cash Outflow(3kWp)

year	Cost(Rs)	year	Cost(Rs)
1	253250	2 to 25 every year	2000

Table 7

Cash Outflow (5kWp)

Year	Cost(Rs)	Year	Cost(Rs)
1	420750	2 to 25 every year	2000

Table 8

Cash Outflow(15kWp)

Year	Cost(Rs)	Year	Cost(Rs)
1	2600000	2 to 25 every year	4000

IV. DISCUSSION OF THE RESULS

The total power input to the distribution system, considered is 58.45051kW without adding PV in the system. The power loss in the system is 4.964kW. The power factor is 0.8. The Saving in Energy losses, Release in capacity and the internal rate of return for each PV is calculated. The result is given in Table 9.

The Choice location of PVG can be based on the following three different criteria:

i) Saving of energy losses
ii) Release of capacity
iii) Internal Rate of Return on Investment

Based on the criteria (i) the highest priority goes to the location at node No. 11 and the last priority goes for location at node No. 43.

Based on the criteria (ii) the highest priority goes to the location at node No. 15 and the last priority goes for location at node No. 43.

Based on the criteria (iii) the highest priority goes to the location at node No. 12 and the last priority goes for location at node No. 43.

For this system optimal location and PVG size were determined, taking all the benefits together. The study showed that the optimal location is node No.16 and the optimal size of PVG is 32kWp.

Table 9

Sl. No	PV at node No	Capacity release (Unit)	Saving in energy loss (Unit)	IRR (%)
1	3kWp PV at node 12	23159.20	6987.919	68.5
2	3kWp PV at node 10	18710.00	3389.285	50
3	3kWp PV at node 9	18376.33	3186.528	51
4	3kWp PV at node	15306.14	2314.111	43

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	49			
5	3kWp PV at node 47	24311.59	3412.722	41.5
6	3kWp PV at node 32	15447.99	1384.790	41.4
7	3kWp PV at node 34	15958.96	1691.380	43
8	3kWp PV at node 36	18014.98	2924.980	49.5
9	3kWp PV at node 37	16476.53	2003.700	44.6
10	3kWp PV at node 38	18636.154	2070.94	49
11	3kWp PV at node 41	18105.08	1726.312	47.3
12	5kWp PV at node 11	37076.91	9137.660	63
13	5kWp PV at node 7	27085.25	3158.440	44.4
14	5kWp PV at node 6	26314.47	2695.870	43
15	15kWp PV at node 39	78000.00	6153.704	36
16	5kWp PV at node 35	26821.98	2935.232	43.5
17	3kWp PV at node 43	13349.86	126.220	34.5

V. CONCLUCTION:

The paper has presented a simple method for the determination of Nodal voltages, Power and Energy losses in the Radial Distribution feeders and economical rate of returns on investment. The methods presented can be used to study without any sophisticated computing facilities. Based on the results obtained a strategy can be developed for implementation.

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