International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 7 (2018) pp. 4796-4801

Economic of Distributed Photovoltaic Generation Installed in a Typical Distribution System

G. Lincy[1], Dr. M. Ponnavaikko[2] and Dr. Lenin Anselm[3]

[1]Research Scholar, Department of Electrical and Electronics Engineering, Bharath University, Chennai-600073, India.

[2]Provost, Bharath University, Chennai-600073, India.

[3]Lecture, Shinas College of Technology, Shinas, (P.O.Box 77 PC 324), Sultanate of Oman.

Abstract

During the recent past, the interest towards the adoption Distributed Generation (DG) has significantly increased among electric power system utilities. It has been well established that installing PV Generation at the load points in a distribution system is great advantages for both consumer and utility. The question arises whether the maximum beneficiary is the Utility or the consumer and who has to bear the cost. This research work analyses the economics of the DG with PV systems, taking a typical 400V distribution system. A detailed procedure adopted for performing the economic analysis is presented in this paper. Benefits considered includes Saving in the energy losses, Energy substitute by the PV system, Capacity release in the Feeder and in the Transformers. The PV system is installed at the selected consumer load points, based on the size and location of the loads. This paper presents an economics policy for adoption of PV based DG System.

Keywords: Microgrid; Photovoltaic(PV); Distributed Generation(DG)

INTRODUCTION

The Distributed generation(DG) is an important concept in the power distribution system. The distributed generation into the electric power system is of great interest to the stakeholders in the electrical energy supply industry today. The Distributed generation widely used in many countries around the world. J.A Pecas Lopes et al. say that the distributed generation reduces the greenhouse gas emission and avoids the construction of new transmission circuits and large generating plants. It is a low cost small generating units and improves the power quality and reliability. This paper discusses the details on the drivers of DG integration and the challenges to be overcome for the increased penetration of DG. The paper also discusses the impacts of DG on transmission system operation. The paper has considered with generation as DG and not considered PV system [1]. Rajiv K. Varma discusses the harmonic impact of large solar 20MW form connected to the 27.6kV Distribution system [2]. Paul Westacott discusses the impact of photovoltaic penetration across an entire low-voltage distribution network containing 1.5 million customers. With the installation of PV 20% in the low voltage network reduces the power flow from HV to LV [3]. Mahmoud Kabalan develops the framework for rural electrification by the combination of solar photovoltaic and micro-hydroelectricity. The framework is aimed at local NGOs and government that is not capable of completing the more complex framework [4]. The potential impact of PV panels in New Zealand has been investigated by Jermy D.watson, et al. The PV in the low voltage network creates the over voltage and reverse power flow problem. The over voltage problems are mitigated by line drop compensation. It does not tell about the improvement of voltage sag problems in the distribution system [5]. Sarav Ms Banet discusses the off-grid hybrid generation (PV-Diesel gen_Battery-Converter and PV-Diesel gen-PHS-Converter) to fulfil the demand in Dapkha village in Nepal. The main objective is to provide power to 3-4 hours in the morning and evening for household application. It also provides the electricity for the irrigation, fishpond, drinking water [6]. Sang-Seung Lee develops a new framework for South Korean power distribution system with the implementation of smart/microgrids. The State Business Unit (SBU) map was subdivided into nine strategic business unit. This business unit improves the profit and the efficiency [7]. Naveen Ahmed Khan discusses the combined emission economic dispatch for solar integrated power systems. This work concentrates on the solar PV integrated power system which could minimize the fuel cost, emission, solar cost and could maximize the solar share and the number of solar plants. The constraints of power balance and the bounds on generators, renewable energy, voltage magnitude, transformer taps and line capacitors were considered in the joint optimization problem [8]. Yanzhi Wang discusses a Stackelberg Game-based optimization framework of the smart grid with Distributed PV power generation and data centres. It talks about the power dependent pricing signal at each power bus depends on the load power consumption and renewable power generation. In this case, cloud controller gives the workload to the buses through renewable power generation. In time-ahead pricing scenario, power grid controller will optimize the price by utilizing the renewable power generations [9]. Stadler discusses the challenges faced by the Electric vehicle (EV) connected to the smart grid. The work was carried out to reduce the cost and increase the storage capacity in the school building and the healthcare facility in two different parts of California. The total cost of the building is reduced using an electric vehicle in the buildings. The connection of electric storage technology to smart grid increases the efficiency, reduces cost and reduces the Co2 emission. The electric vehicle store the energy during the high demand period. It reduces the Co2 and cost of electricity supply. Here, the stationary storage is efficient compared to EV. Stationary storage manages the power for 24h. EV transfer electricity from residential building to commercial building. [10]. A.P Agalgaonkow et al. presents their study on the planning of a typical medium-voltage rural distribution system in the state of Maharashtra, India, is considered for different loading conditions. The different attributes, viz. capital costs, energy not served per annum, and profits from injecting power into the grid at peak load, representing the typical characteristics of a developing country, are considered. A novel approach of DEA based on analytical hierarchy processes (AHP) is proposed and compared with the interval-based MADM technique for finding the preferential ranking of various configuration plans, such as single source DG, hybrid DG micro-grid, etc. A new concept of the composite utility function is also proposed for getting information about infeasible values of different attributes [11]. The optimal location in the of DGs in the radial distribution system could be determined using load flow studies.

STUDY OF DISTRIBUTED GENERATION INTEGRATED PV WITH ECONOMIC IMPACT

This paper presents the study conducted for a distribution system with the solar system connected to the loads directly. The capacity release to the system is also discussed. It also discusses the benefit to the system and benefit to the customers for optimal location. Fig 1 shows one of the radial distribution systems from Kanchipuram district. Fig 1 shows the 400V power distribution system. The system contains two main feeders. The typical radial distribution system supply power to a mix of consumers, viz. residential, commercial, industrial, street light and agricultural pumps. In this section, numerical results are presented to verify the performance of the feeders. The power loss depends on line length and the resistance of the conductor. The iris rose, mink, ferret conductors are used in the feeders. The conductors are from substation to A iris and C to E is iris conductors are used, and substation to CD mink and ferret conductors are used. The rest of the places rose conductors are used. The bolded line and dotted line in fig 1 shows whether the line is single phase or three phase line. The distance and nodes are available in fig 1 which is a 400V and 100KVA substation. The diversity factor of 1.3945 is taken in the main feeder. The voltage control and flow management related issues are solved in this paper. The distribution system feeds to fifty-four loads in the system.

A) Load Factor(LF):

In electrical engineering load factor is defined as the average load divided by the peak load in a specified period. The load factor in this feeder is taken as 0.5.

B) Loss load factor(LLF):

LLF is a function of load factor, LF and is defined as LLF= $A(LF)^2 + B(LF)$ and A+B=1 (1)

C) Energy Loss:

Energy loss = power loss×LLF×8760 (2)

The energy loss in the feeder is calculated from the above formula. The power loss in each section is calculated.

D) Energy Consumption:

Electric energy consumption by the loads is completed with the formula (3)

Energy Consumption

$$= \frac{Total\ load\ in\ watts \times load\ factor \times 8760}{1000} \text{ Units} \quad (3)$$

The energy consumption in the feeder is calculated from the above formula. The energy consumption cost is calculated by multiplying the cost of energy supply.

E) Saving of energy loss:

Saving of energy loss with solar generation =Energy loss without solar system-Energy loss with solar system (4)

The saving of energy loss is calculated by the above formula.

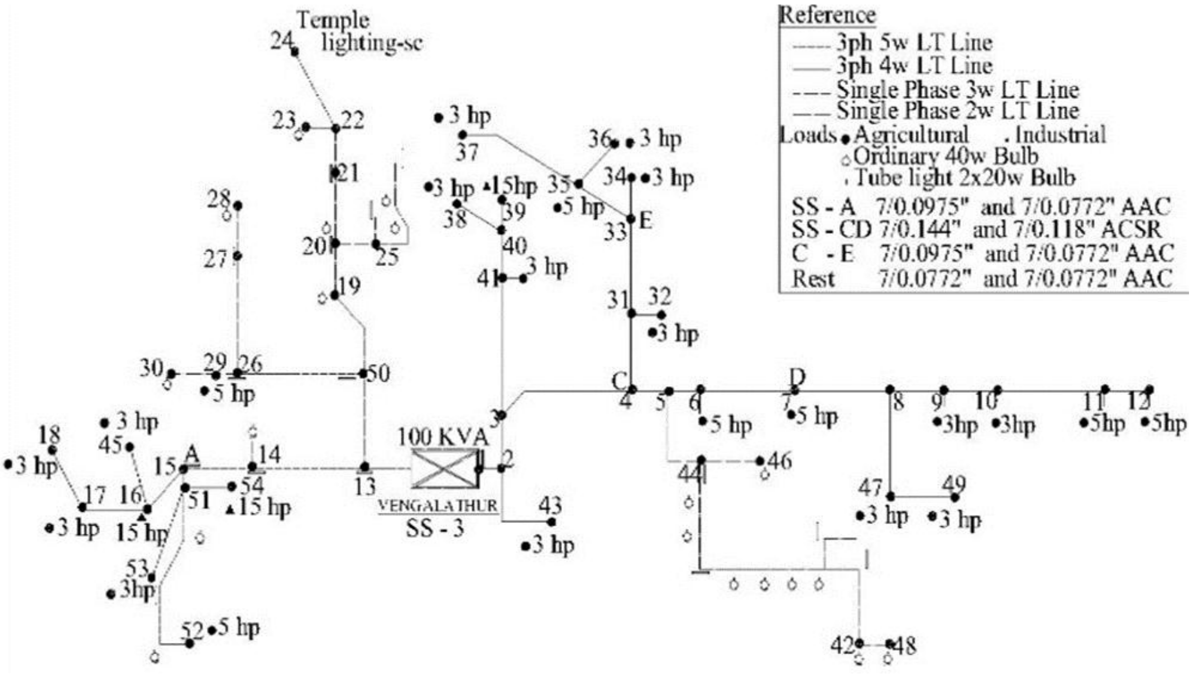

Figure 1: The 400V distribution system without PV

Table 2: Voltage drop in the distribution system

Node	Voltage (p. u)	Node	Voltage (p. u)
1	1.00	28	0.920
2	0.988	29	0.917
3	0.973	30	0.917
4	0.923	31	0.893
5	0.914	32	0.890
6	0.905	33	0.854
7	0.882	34	0.851
8	0.807	35	0.826
9	0.766	36	0.818
10	0.739	37	0.815
11	0.661	38	0.804
12	0.656	39	0.791
13	0.942	40	0.807
14	0.780	41	0.849
15	0.694	42	0.912
16	0.627	43	0.982
17	0.610	44	0.912
18	0.598	45	0.618
19	0.927	46	0.912
20	0.927	47	0.774
21	0.927	48	0.912
22	0.926	49	0.766
23	0.926	50	0.930
24	0.926	51	0.663
25	0.920	52	0.640
26	0.920	53	0.656
27	0.920	54	0.649

F) Economic evaluation:

The economic impact of PV system at a different location is calculated to know the revenue from the PV system. The 15KVA,3KVA,5KVA PV system unit cost rates are 2.07Rs,2.50Rs,2.25Rs. The PV system connection in the Distribution system has some revenue and investment. This is studied by the following formula. The agricultural load tariff rate is 4.6/Unit, and the industrial loads, tube light, and ordinary bulb tariff rate are 6.35/Unit.

Table 2 shows the node voltage in the feeder. The lowest voltage in the system is 0.598 p. u at bus no 18. The reduction in voltage increases the power quality problems and increases the reliability of the far end node.

The losses in the system depend on the flow of current and resistance. The power loss is directly promotional to I^2 . So, the flow of current increases the loss in the system. The total power loss in the system is 22.933 kW. The energy loss in the system is 60267.924Unit. The energy input to the feeder without the solar system is 507773.4 Unit. The total energy loss percentage without the solar system is 11.86%. The total cost of energy to all customers without solar system is 1051549Rs. In this distribution system, the energy loss and cost of energy high. So, we introduce proposed distribution system with low energy loss cost saving by the solar implementation.

The following scenarios are discussed

a) Installing PV system in ten consumer locations

b) Installing PV system in five consumer locations

c) Installing of PV system at all the customer point

Case 1: INSTALLING PV INSTALLATIONS IN TEN CONSUMER LOCATIONS

Because of increasing electricity demand the transmission of electricity through large distance cause more loss. So, the distribution systems are replaced by renewable sources. The solar systems benefit the end-user customer. Fig 2 shows the modification of feeder with the solar system. Some agricultural and industrial loads are taken from the end of the feeder and connected to the solar system. The nodes are 11,12,34,37,39,18,16,52,54,29 taken from the feeder and connected to the solar system. It is a 400V radial distribution system. The diversity factor of 1.3945 is taken in the main feeders. The distribution feeder is modified to the solar system. The study was conducted to analyse the impact of adding a solar system to the distribution system. The energy loss and power loss in the feeder were calculated for the proposed feeder. By the connection of solar system, a large amount of current flowing from the substation reduces.

The ten solar systems are connected to the loads and switch off from the distribution system which improves the reliability ,power quality and reduces the power loss . The 3KVA ,5KVA,15KVA solar system is connected to the loads .The 3KVA is connected to 3hp loads, two 15KVA is connected to 15hp loads, and three 5KVA is connected to 5hp loads.

Table 3: Voltage in the Distribution system with ten PV

Node	Voltage(kV)	Node	Voltage (kV)
1	1	27	0.991
2	0.994	28	0.991
3	0.986	29	0.991
4	0.955	30	0.991
5	0.949	31	0.937
6	0.944	32	0.934
7	0.930	33	0.917
8	0.894	35	0.898
9	0.880	36	0.891
10	0.874	38	0.948
13	0.993	40	0.951
14	0.973	41	0.957
15	0.962	42	0.947
16	0.951	43	0.988
17	0.946	44	0.948
19	0.989	45	0.946
20	0.989	46	0.948
21	0.989	47	0.864
22	0.988	48	0.947
23	0.988	49	0.857
24	0.988	50	0.992
25	0.989	51	0.960
26	0.991	53	0.955

Table 3 shows the voltage of the node with the solar system. The lowest voltage in the circuit is 0.857 p.u. at bus 49. The voltage in the distribution system improved in solar implementation. Because of reduced load demand the voltage profile of the feeder increases. The solar system provides the voltage support or overload reduction. Such an analysis will reduce the power flows in the transmission lines and increases the voltages in the system buses. This will provide complete detail about the node voltage. The role of DG in load side can produce the beneficial impact power quality and supply reliability. One area of improvements is voltage profile improvements

The system contains two main feeders and fourteen spur line feeder. Because of solar implementation, the power loss in the feeder reduces. The power loss in each feeder was calculated. However, if the increase in DG takes place in industrial and agricultural areas, clearly a reduction of power and energy losses with consequent large economic benefits. The losses in each line reduce from without solar system and solar system with five loads.

The power loss in the system is 2.858kW. The total energy input to the feeder with the solar system is 184573.2 Unit. The energy loss in the feeder is 7510.824 Unit. The loss in the feeder reduces in the proposed system so; this system is challenging for the new electricity world. The energy loss with the solar system is 4.06%. The proposed system reduces the power loss from 11.86 % to 4.06 %.

INSTALLING PV SYSTEM IN FIVE CONSUMER LOCATIONS:

The nodes are 18,52,54,12,39 taken from the feeder and connected to the solar system. The five loads are disconnected by switches. The rated line voltage of the radial distribution system is 400V. The diversity factor of 1.3945 is taken in the main feeders. The three typical PV system is used for the supply to the end loads which are 3KVA,5KVA,15KVA solar systems.

Table 4 shows the voltage in each node. The voltage in the system improves with the solar system. Here, the lowest voltage in the circuit is 0.759 at node 11. The voltage profile improves in the solar system with five loads. The voltage profile increases with increase in the solar system. The voltage problem in the far end node connected with the solar system. The solar system connection improves the reliability of the system. The solar implementation reduces the usage of voltage regulators and cost of implementing regulators reduces. The maintenance cost of regulators reduces.

The spur line losses reduce with the solar system. The feeder contains eighteen spur lines and two main feeders. The losses in the system reduce from without solar system and increase from a solar system with ten loads. The PV system reduces the flow of current in the system. So, the losses in the distribution system reduce. So, the cost of energy losses reduces in the system.

Table 4: Voltage in the feeder with five PV

Node	Voltage(kV)	Node	Voltage(kV)
1	1.000	28	0.955
2	0.991	29	0.952
3	0.981	30	0.952
4	0.937	31	0.908
5	0.930	32	0.904
6	0.923	33	0.870
7	0.930	34	0.844
8	0.847	35	0.842
9	0.818	36	0.834
10	0.801	37	0832
11	0.959	38	0.943
13	0.976	40	0.946
14	0.916	41	0.952
15	0.883	42	0.928
16	0.840	43	0.986
17	0.834	44	0.928
19	0.962	45	0.833
20	0.962	46	0.928
21	0.961	47	0.815
22	0.961	48	0.928
23	0.961	49	0.808
24	0.961	50	0.964
25	0.962	51	0.880
26	0.955	53	0.875
27	0.955		

The power loss in the system is 7.672kW. The system connected with five loads by PV reduces the losses in the system. The losses in the system reduce the cost of energy losses. The total energy input to the feeder with the solar system is 306950.4 Unit. The energy loss in the feeder is 20162.016 Unit. The loss in the feeder reduces in the proposed system, so this system is challenging for the new electricity world. The energy loss with the solar system is 6.56%. The proposed system reduces the energy loss from 11.86 % to 6.569%. The saving of energy loss with five PV system is 20820.0266 Unit.

INSTALLING OF PV SYSTEM AT ALL THE CUSTOMER POINT

The all the loads are connected to the solar reduces the losses and improves the customer's benefit. The benefit to the system is equal to the energy loss cost of the system without a solar system. The benefit to the system is 236591.069Rs. The cost of energy to all customers without PV is 1051549.236Rs. Cost of energy to all customers with PV is 433891.35Rs. So, the benefit to the customers is 617657.886Rs. The benefit to the customers increases with PV at all locations. So, the PV system increases the customer's benefit. The solar system reduces electricity bill and increases the customer benefit.

CONCLUSION

The conventional framework is to achieve the voltage in the presence of solar system. The advantage of using the solar in the feeder increase the feeder voltage reduces the energy loss and reduces the system cost. In this research, the problem of Distributed Generation using PV systems at the load points is studied. To start with an LT Distribution in the Kanchipuram Distribution System was studied with PV Systems located randomly in ten and five locations. The voltage profile and the Power and Energy losses in the system with and without PV systems were assessed, and the savings were computed. It is observed that solar system approach can reduce the power and energy losses appreciably and a good amount of Transmission and Distribution line capacities are released.

The distribution system also reduces the need for adding new lines and installing new transformers and voltage regulation devices. It reduces the protection devices and voltage regulation devices. A sustainable technical, economic and environmental benefit is obtained by the substitution of PV generation in the Distribution network. It is observed that solar system approach can reduce the power loss and increase the reliability. The block diagram of the proposed distribution system made with the solar system. The solar system avoids constructing power plants and greenhouse gas emission. For the above three cases, the cost to the system and cost to the customers are estimated as the benefit to the customers also estimated.

REFERENCES:

[1] Lopes, JA Pecas, N. Hatziargyriou, J. Mutale, P. Djapic, and N. Jenkins. "Integrating distributed generation into electric power systems: A review of drivers, challenges and opportunities." *Electric power systems research* 77, no. 9 (2007): 1189-1203.

[2] Varma, Rajiv K., Shah Arifur Rahman, Tim Vanderheide, and Michael DN Dang. "Harmonic Impact of a 20-MW PV Solar Farm on a Utility Distribution Network." *IEEE Power and Energy Technology Systems Journal* 3, no. 3 (2016): 89-98.

[3] Westacott, Paul, and Chiara Candelise. "Assessing the impacts of photovoltaic penetration across an entire low-voltage distribution network containing 1.5 million customers." *IET Renewable Power Generation* 10, no. 4 (2016): 460-466.

[4] Kabalan, Mahmoud, and Benaiah Anabaraonye. "Solar photovoltaic versus micro-hydroelectricity: A framework for assessing the sustainability of community-run rural electrification projects." In *Global Humanitarian Technology Conference (GHTC), 2014 IEEE*, pp. 6-13. IEEE, 2014.

[5] Watson, Jeremy D., Neville R. Watson, David Santos-Martin, Alan R. Wood, Scott Lemon, and Allan JV Miller. "Impact of solar photovoltaics on the low-voltage distribution network in New Zealand." *IET Generation, Transmission & Distribution* 10, no. 1 (2016): 1-9.

[6] Basnet, Saurav MS, Haneen Aburub, Ward Jewell, and Amir Poudel. "Case study of microgrid for electrification and its benefits in rural Nepal." In *Global Humanitarian Technology Conference (GHTC), 2015 IEEE*, pp. 33-39. IEEE, 2015.

[7] Lee, Sang-Seung, Sang-Ho Ahn, Joon-Hyung Park, Jae-Haeng Heo, Dong-Hyeon Kim, Jong-Keun Park, Min-Uk Yang, Kern-Joong Kim, and Yong Tae Yoon. "South Korean power distribution system-based operation, market structure and regulation strategies under distributed generation and smart grid." In *Power and Energy Society General Meeting, 2012 IEEE*, pp. 1-7. IEEE, 2012.

[8] Khan, Naveed Ahmed, Guftaar Ahmad Sardar Sidhu, and Feifei Gao. "Optimizing Combined Emission Economic Dispatch for Solar Integrated Power Systems." *IEEE Access* 4 (2016): 3340-3348.

[9] Wang, Yanzhi, Xue Lin, and Massoud Pedram. "A Stackelberg game-based optimization framework of the smart grid with distributed PV power generations and data centres." *IEEE Transactions on Energy Conversion* 29, no. 4 (2014): 978-987.

[10] Stadler, Michael, Chris Marnay, Maximilian Kloess, Gonçalo Cardoso, Gonçalo Mendes, Afzal Siddiqui, Ratnesh Sharma, Olivier Megel, and Judy Lai. "Optimal planning and operation of smart grids with electric vehicle interconnection." *Journal of Energy Engineering* 138, no. 2 (2012): 95-108.

[11] Agalgaonkar, A. P., S. V. Kulkarni, and S. A. Khaparde. "Evaluation of configuration plans for DGs in developing countries using advanced planning techniques." *IEEE Transactions on Power Systems* 21, no. 2 (2006): 973-981.

[12] M. Ponnavaikko, ‘Mathematical modelling for optimal distribution system planning’, Proc. Diamond Jubilee Symposium on Optimization of Electrical Apparatus and Systems, Banaras Hindu University, India, pp. 104-109, March 1979.