INFLUENCE OF PV PENETRATION IN SAUDI DISTRIBUTION GRID

ESSAM A. AL-AMMAR

Department of Electrical Engineering, College of Engineering
King Saud University, Riyadh, Saudi Arabia
essam@ksu.edu.sa*

Abstract:
Ever increasing power demand around the global urged countries to find out other techniques of generation and power grids with higher efficiency and lower cost comparing with the existing ones. Solar energy is an effective alternative source of electricity which can be used instead of coal and other traditional resources. The photovoltaic distributed generation is a very useful choice since it combines the advantages of smart grid and those of solar energy. It is recommended that the optimized algorithm for optimal size and location of PV distributed generators in Grid and its implementation on specific substation network of Riyadh area.

Keywords: PV; Saudi; Solar; distribution; Grid.

1. Introduction

In today's highly technological world, the generation and delivery of electricity is vital to all global economic sectors. Today's electricity generation and transmission infrastructures largely require fossil fuels and are relatively inefficient. Environmental pressure, transmission and distribution power losses, growing electricity demand and requirement for power reliability and quality has raised unprecedented challenges and opportunities for current power industry [Shafiullah *et al.* (2010), Ackermann and Knyazkin (2002) and Rjula *et al.* (2010)]. Therefore, a new sort of power system of environment friendly, economic, high performance, low investment, safety, reliability and flexibility has been a goal of engineers in power industry. Smart grids technologies could enable load leveling of the electrical grid, allowing a power company to run cleaner power sources such as hydroelectric, wind, or solar and reducing the need to use carbon-emitting gas, coal, or oil plants to meet peak demand [Italy and K.T. (2009), Murphy (2010), Keogh (2010), DOE (2010), Xue-song and You-jie (2010), T.C.E. Association(2010) and NEDP (2011)].

Researchers suggested that distributed generation is smart grid technology useful for generating electricity by renewable energy techniques at the load location. However, the effect of the penetration of DGs with a grid is verily a complicated process with many constraints and other important effects. As far as PV penetration in grid is concern, power loss reduction has a significant effect on the efficiency of existing power system [Lawrence (2003), Guney and Onat(2010), UEI, FPT Inc. (2010), Shayani (2011) and Gallego (2010)].

This paper represents equations for power loss difference between the existing and the smart grid with the PVDG. Paper also analyzes the effect of the installation of PV cells on the busses with the lowest actual voltage levels among the network busses since it is expected to be places of high power loss in the network.

2. Network Modeling

Modelling of unbalanced power systems is provided in [Gallego (2010)], many trials were done to find the suitable model of radially balanced power systems. As, the penetration level is determined by the ratio generated power over total network load. So, the current at each bus is given by the equation:

$$I_{bus} = Y_{bus} \times V_{bus}$$

While Vbus and Ibus representing the column matrices of voltages and current of all busses and Ybus is the admittance matrix of the system. However, the reactive current IQ injected in each bus shifts the Ibus by 90◦ over the Vbus angles.

$$IQ_{bus} = |I_{bus}|\ e^{j(90\ +\delta)}$$

Where δ represents the angles of the bus voltage. So, the value of IQ at the PVDG bus (the bus where the PV cells are installed) can be expressed as:

$$IQ_i = conj - (S_i / V_i)\ conj\ (Y_{bus}\ (i, i)) \times V_i$$

While i is the number of the PVDG bus. Where, the error in the voltage at the PVDG bus can be calculated as:

$$\Delta v = Z_{bus} \times IQ_{bus}$$

Where; Zbus is the inverse of the Ybus matrix. Thus, the voltage at the PVDG bus with the penetration of the PV cells will be as follow:

$$V_i = V_{rated} - \Delta v\ (i)$$

Furthermore, the total power loss in the network can be calculated by applying the following equation along all the lines of the network.

$$P_l = \Delta v / R$$

Where, V is the difference in voltage between the two busses at the line ends and R is the resistance of the line. Fig. 1 shows the algorithm based on discussed mathematical equations for optimum allocation and sizing of PVDG in grid network.Major headings should be typeset in boldface with the first letter of important words capitalized.

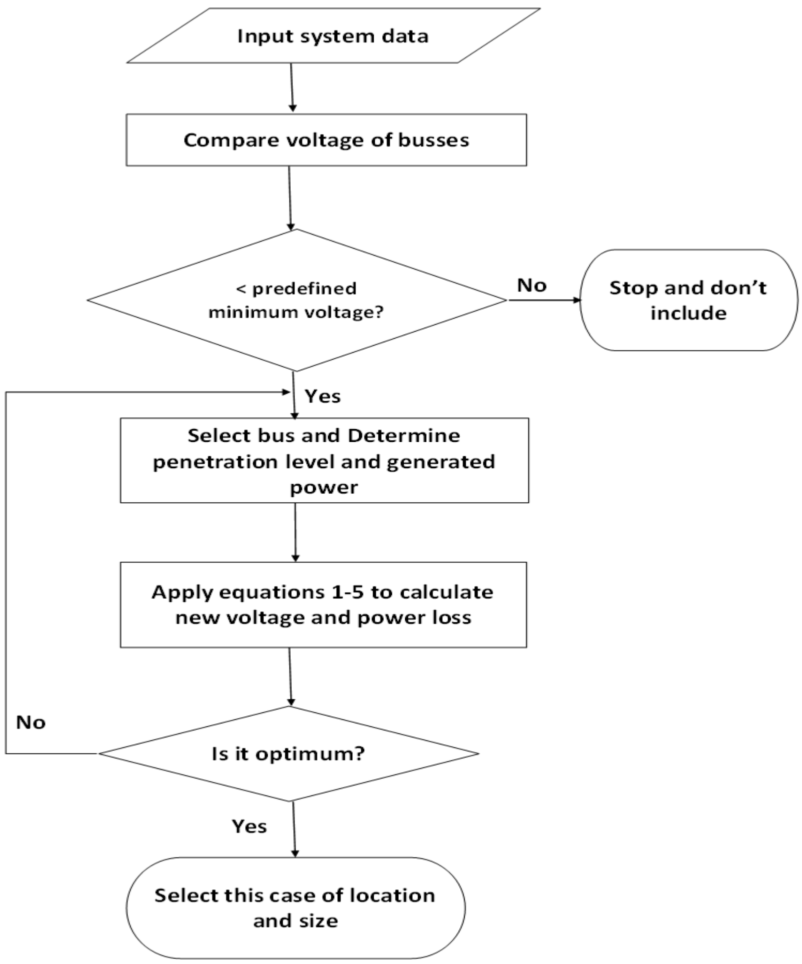

Fig. 1. Flow Chart of Optimization Process

3. Simulation Results and Analysis

Algorithm is simulated in MATLAB and applied at specific substation 8001 of Riyadh power system network provided from Saudi Electricity Company (SEC). The substation 8001 provides power to three 33-kV metal bus bars. These bus bars provide power to 7 spread busses representing the load of different following feeders for each bus. The diagram of this substation is shown in Figure. 2 show actual values of voltages and complex powers at each node. The total load power in the network is 445.4 MVA with 0.109 p.u. (3.823 MW) power loss.

As per the algorithm, the busses 4, 6, and 7 are used for calculation as they have the lowest actual voltage level among the network busses (31 kV). The calculation of actual voltage levels with different possibilities of penetration level resulted in Table 2. It is observed that the installing of PV cells on bus 7 resulted in over voltage case. As a result, this bus would not consider in the calculations of power loss. Table 3 explains the cases which are considered in calculation.

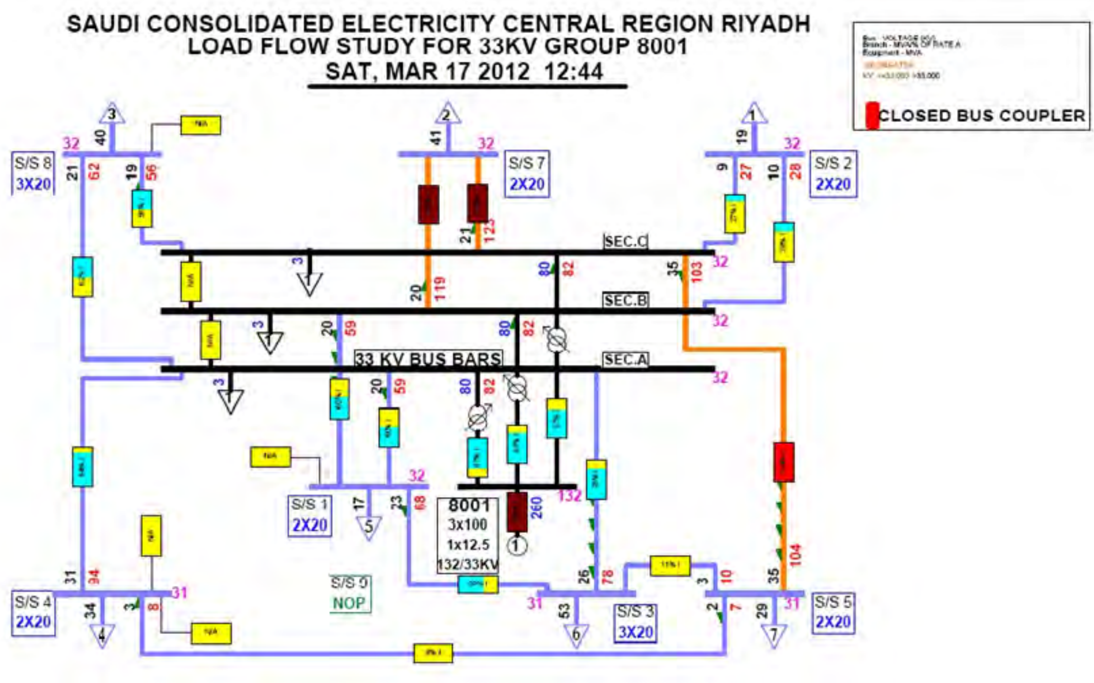

Fig. 2. Network of Distributed Generation

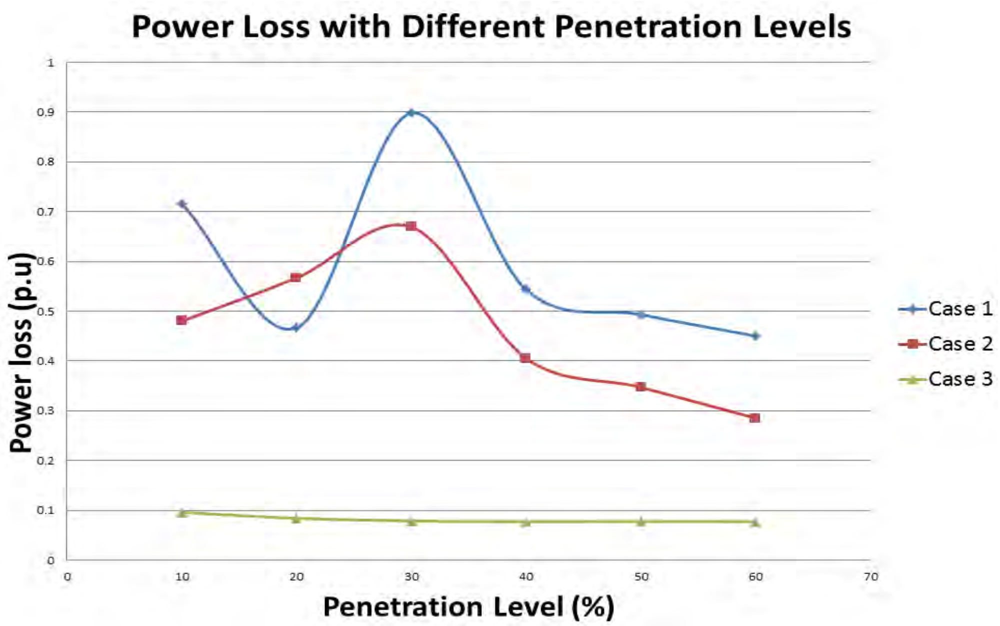

Fig. 3. Chart of Power Loss with Different Penetration Levels

The optimization process has four main constraints. First, the main constraint is that the voltage on the PV bus should not exceed the rated voltage value (33 kV in this network). Next, lower power loss must be achieved to the system when the PV cells are installed and the harmonics must be kept as low as possible. Also, the financial cost is essential to be taken into consideration since the economic analysis is a basic major of concern for engineering projects. The optimized region is the one where all the constraints are intersected.

These constraints cause to ignore the installation of PVDG on bus 4 since the power loss is higher than the bus 6. Consequently, the optimum case for PV installation is on bus 4 with 10% penetration level (45.5 MVA generated power). It reduces power loss to 0.096 p.u. (3.36 MW) because the difference in power loss is limited while the increase in generated power results in an increase in cost and harmonics. The installation cost of PV generated power was about 724.61 million SR/kW comparing with 317.42 million SR/kW with natural gas. This increase in initial cost reduces annually while the annual profit of the reduced power loss is 101.40 million SR according to the current selling price of SEC with half-day operation. This means that the extra initial cost is expected to be covered within the first 4 years. The saved fuel cost is an extra profit of PVDG.

4. Conclusion

The paper has discussed an algorithm for the optimal size and location of PVDG in Power Grid. The model incorporates the major constraints of PVDG that are rated voltage level, lower power loss, lower harmonics and cost of installation. The optimized result is found after detailed analysis of these constraints for different level of penetration and suggests the prime bus for PV installation. The proposed algorithm is implemented on Station 8001 belonging to Saudi Electricity Company (SEC) and shows successful results. It is anticipated that this algorithm will be useful for utilities in determining optimal size and location of PVDG in their existing grid network.

TABLE 1
ACTUAL VOLTAGES WITH DIFFERENT PENETRATION LEVELS

Penetration Level (%)	**Number of PV Locations**	**Power Generated (MVA)**	**Bus Voltage (KV)**		
			Bus 4	**Bus 6**	**Bus 7**
10	3	15.05	33.74	32.08	45.35
	2	22.75	33.7	32.06	45.3
	1	45.5	33.15	32	45.13
20	3	30.1	33.67	32.04	45.25
	2	45.5	33.15	32	45.13
	1	91	33.36	31.89	44.84
30	3	45.5	33.15	32	45.13
	2	68.25	33.47	31.94	44.98
	1	136.5	33.58	31.78	44.54
40	3	60.55	33.51	31.96	45.03
	2	91	33.36	31.89	44.84
	1	182	32.95	31.68	44.26
	2	127.4 / 54.6	33.2	31.98	—
	2	145.6 / 36.4	33.11	32.02	—
50	3	75.95	33.43	31.92	44.93
	2	113.75	33.25	31.83	44.69
	1	227.5	32.78	31.58	43.98
	2	159.25 / 68.25	33.05	31.94	—
	2	182 / 45.5	32.95	32	—
60	3	91	33.36	31.89	44.84
	2	136.5	33.15	31.78	44.54
	1	273	32.57	31.5	43.75

TABLE 2
POWER LOSS WITH DIFFERENT PENETRATION LEVELS

Penetration Level (%)	Total Power Loss (p.u.)	Cost of generated power (MS.R/KW)		
	Case 1	Case 2	Case 3	
10	0.716	0.48	0.096	724.61
20	0.467	0.567	0.084	1449.22
30	0.898	0.669	0.079	2173.83
40	0.543	0.405	0.077	2898.45
50	0.493	0.347	0.078	3623.07
60	0.45	0.285	0.077	4347.67

TABLE 3
CASES USED IN POWER LOSS CALCULATIONS

Case Number	Busses of Installation
1	4 and 6 (Equally divided)
2	4 (Fully installed)
3	6 (Fully installed)

References

[1] Shafiullah, M.T.O. Amanullah and P. Wolfs, “Potential challenges: Integrating renewable energy with the smart grid,” in Curtin University of Technology, Universities Power Engineering Confer- ence, 2010.
[2] T.Ackermann and V.Knyazkin, “Interaction between distributed genera- tion and the distribution network: Operation aspects,” in Royal Institute of Technology, Transmission and Distribution Conference and Exhibition, 2002.
[3] J.A. J. L. A.A.B Rjula, J.M. Amada and J. Navarro, “Definition for dis-tributed generation: a revision,” Department of Electrical Engineering, Centro Politcnico Superior, University of Zaragoza.
[4] Italy and K. T. in consultation with MEF Partners, “Technology action plan: Smart grids,” in Major Economies Forum, December 2009.
[5] P. Murphy, “Enabling tomorrows electricity system,” in Ontario Smart Grid Forum, September 2010.
[6] M.Keogh, “The smart grid: Frequently asked questions for state commis- sions,” in The National Association of Regulatory Utility Commissioners, June 2010.
[7] U.D. of Energy, “The smart grid: An introduction,” in Technical Report, September 2010.
[8] C.L.-q. Z. Xue-song and M. You-jie, “Research on smart grid technology,” in International Conference on Computer Application and System Modeling, China, 2010.
[9] T.C.E. Association, “The smart grid: A pragmatic approach,” in Discus- Sion paper, 2010.
[10] I.E. Info book, “Solar energy,” in The Nationl Energy Education Development Project, Technical Report, 2011.
[11] R. Lawrence, “Distributed generation: The new guy on the block,” in IEEE PCIC September 2003.
[12] I.Guney and N.Onat, “Cost calculation algorithm for photovoltaic systems,” in Paths to Sustainable Energy, December 2010.
[13] U.E.I. Administration, “Updated capital cost estimates for electricity generation plants,” in U.S. Department of Energy.
[14] F.P.T. Inc., “Solar electricity costs,” in Solar Cell Central, Scottsdale, 2010.
[15] R.A.Shayani, “Photovoltaic generation penetration limits in radial distribution systems,” in IEEE Transactions on Power Systems, August 2011.
[16] L.A.Gallego, “Distributed generation modeling for unbalanced three-phase power flow calculations in smart grids,” IEEE Transmission and Distribution Conference 2010.