Design and analysis of 33-bus solar based MLDG distribution system

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Abstract: Demand of energy increases day by day, to meet the energy demand it is the time to shift towards renewable sources, (solar energy, wind energy, tidal energy, bio-mass energy etc.). Renewable energy attract interest of researcher due to its environment friendly nature . At the large scale of renewable energy generation, power quality into the grid is an important parameter. In this paper area of focus is the design and analysis of IEEE-33 bus solar based MLDG (multiple location distributed generator) system with maximum penetration in grid with operational scenarios of LV network. The main aim of this paper is to design a MLDG IEEE 33- bus system for rural location of United Kingdom of Saudi Arabia with reduced power loss and improved voltage profile with economic benefits. In this proposed model DGs (distributed generators) are placed at multiple locations to enhance the performance of hybrid solar system with respect to improve power quality and reduced power losses.

Keywords: Distributed generator1, 11-level inverter2, STATCOM3, MPPT4, Solar photovoltaic5, 33- bus IEEE distribution system6.

1-Introduction

Distribution generators (DGs) normally connected to the LV network, the rating of DG should be nearly 50 - 100 MW (small scale generation). Solar is not the only solution of energy demand bio-gas, wind power or any other renewable sources as a DG at different location can also be connected. Location should be selected such that penetration loss should be minimum[1]. There are some problems with MLDG system like DG integration to grid, power quality control, required efficient protection scheme etc that need to be addressed. Figure -2 shows the proposed model of IEEE -33 bus solar MLDG system. In this paper IEEE-33 bus PV based MLDG system with grid has been proposed . Each DG system has been connected with MPPT to boost the DG voltage and for reduction in transmission losses [2][13]. To improve the power quality there is a need of reactive VAR compensation for that STATCOM, shunt capacitor has been used at load end[2]. Normally loads are inductive or capacitive that's why load can release or absorb reactive VAR other than this SP connected to grid with inverter (power electronics device), which release large amount of reactive VAR[3]. To compensate reactive VAR, STATCOM (Static synchronous compensator) is used. STATCOM can work as source or sink of reactive VAR and it has very little capacity of active power. Reactive power capacity of STSTCOM depends on amplitude of voltage source, when system voltage is high STATCOM absorbs reactive VAR and when system voltage lower than base voltage, the STATCOM injects reactive VAR so it works both as source and sink[4].

2- IEEE-33 bus solar based MLDG system: IEEE -33 bus distribution system has been shown in fig-2. The main aim of optimal size and location of DG unit in IEEE-33 bus distribution system is to minimize penetration loss[3]. Optimal Location of DGs also improves voltage profile of distribution system. For the analyzing the power flow in distribution system Newton Raphson load flow MATLAB has been used. Our designed MLDGs system (shown in fig-2) has 3 DGs at different locations. DGs are connected at bus 12, 18, 22 respectively. Size of DGs can be categorize according to their rating :
Micro DG: Rating 1 to 5 kW
Small DG: Rating 5 KW to 5 MW
Large DG: 50 to 300 MW.

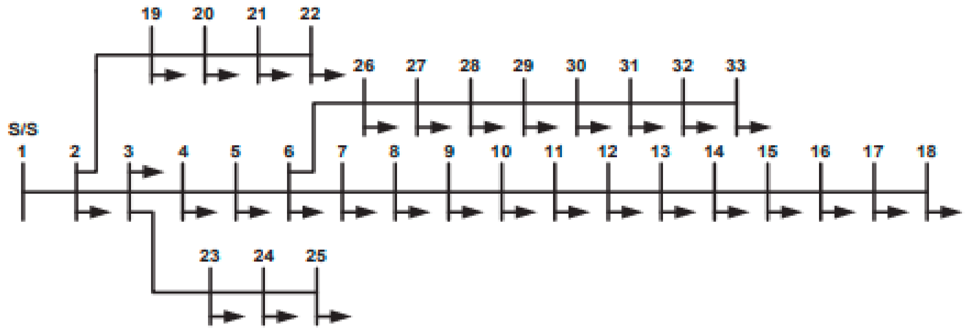

Fig-2 single line diagram of IEEE-33 bus test system

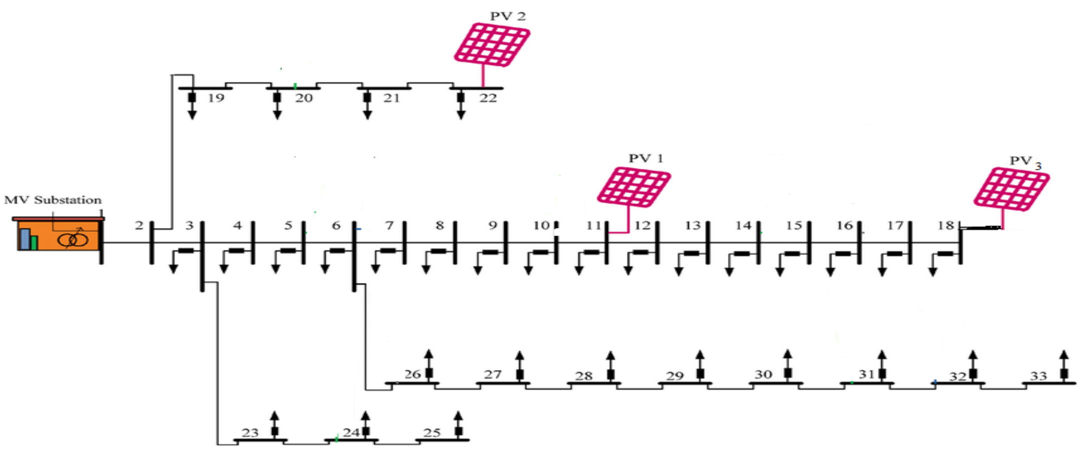

Fig-3 single line diagram of solar based IEEE-33 bus MLDG test system

Line impedance of IEEE-33 bus system has been shown in table-1 where as bus voltage and active power at each bus has been presented in table-2(per unit).

Table-1 IEEE -30 bus line impedance in per unit

From Bus	To Bus	R (pu)	X (pu)	B	Tap
1	2	0.0152	0.0575	0.0264	1
1	3	0.0452	0.1652	0.0204	1
2	4	0.0570	0.1737	0.0184	1
3	4	0.0232	0.0379	0.0042	1
2	5	0.0472	0.1983	0.0209	1
2	6	0.0581	0.1763	0.0187	1
4	6	0.0119	0.0414	0.0045	1
5	7	0.0460	0.1160	0.0102	1
6	7	0.0267	0.0820	0.0085	1
6	8	0.0120	0.0420	0.0045	1
6	9	0.120	0.2080	0.0	0.978
6	10	0.0	0.5560	0.0	0.969
9	11	0.0	0.2080	0.0	1
9	10	0.0	0.1100	0.0	1
4	12	0.0	0.2560	0.0	0.932
12	13	0.0	0.1400	0.0	1
12	14	0.1531	0.2559	0.0	1
12	15	0.0662	0.1304	0.0	1
12	16	0.0945	0.1987	0.0	1
14	15	0.2610	0.1997	0.0	1
16	17	0.0824	0.1923	0.0	1
15	18	0.1073	0.2185	0.0	1
18	19	0.0639	0.1292	0.0	1
19	20	0.0340	0.0680	0.0	1
10	20	0.0836	0.2090	0.0	1
10	17	0.0324	0.0845	0.0	1
10	21	0.0348	0.0749	0.0	1
10	22	0.0127	0.1499	0.0	1
21	23	0.0116	0.0236	0.0	1
15	23	0.1000	0.2020	0.0	1
22	24	0.1150	0.1790	0.0	1
23	24	0.1320	0.2700	0.0	1
24	25	0.1885	0.3292	0.0	1
25	26	0.2544	0.3800	0.0	1
25	27	0.1093	0.2087	0.0	1
28	27	0.0	0.3960	0.0	0.968
27	29	0.2198	0.4153	0.0	1
27	30	0.3202	0.6027	0.0	1
29	30	0.2399	0.4533	0.0	1
8	28	0.0636	0.2000	0.0214	1
6	28	0.0169	0.0599	0.065	1

Voltage rating, active power, voltage angle has been represented in table-2. Negative sign of active power shows bus as sink where as positive sign show bus as a source. Voltage and active power has been calculated again After connecting DG at bus 12, 18, 22 respectively in IEEE-30 bus system. That modified network known's IEEE -30 bus MLDG system (shown in fig-2. The bus voltage and active power of MLDG system has been shown table-3.

Due to the expensive of the PV cell manufacturing process and comparative it has low energy conversion efficiency [5]. The maximum power point tracking technique is one of the very crucial for finding the peak operating point or highest power that is to be find out from PV array. A MPPT is one of the important algorithm which adjust the solar power interfaces and also achieve the highest feasible power harvest, in the duration of moment to moment changes of light level, temperature, and the PV module characteristics. The purpose of this MPPT algorithm is to adjust solar operating voltage, which is close to the MPPT under the changing of atmospheric conditions [6]. PV generation is reliable and it has no moving parts therefore, its maintenance and their operating costs are very less and PV modules are the basics for the solar photovoltaic (PV) power generation unit. Electricity is generated by cells of a solar PV system, which are from solar energy and these are on depend of photoelectric effect. The PV cell is one of the main building blocks of PV system and it is based on semiconductor materials device which can convert the solar energy in to DC electrical power. The photoelectric system is rated up to 50 Watt to 300 Watt[8]. The photoelectric systems are very highly modular type and these modules may be combining together for supplying power from some watts to megawatts[7].

Table-2 voltage and active power at each bus of IEEE-30 bus test system

Bus No.	Voltage pu	Angle Degree	Active power MW	
1	1.060	0.000	5.219	
2	1.043	-5.347	0.366	47.
3	1.022	-7.545	-0.048	
4	1.013	-9.299	-0.152	
5	1.010	-14.154	-1.884	35.
6	1.012	-11.088	0.000	
7	1.003	-12.873	-0.456	
8	1.010	-11.804	-0.600	30.
9	1.051	-14.136	0.000	
10	1.044	-15.734	-0.116	
11	1.082	-14.136	0.000	16.
12	1.058	-14.942	-0.224	
13	1.071	-14.942	0.000	10.
14	1.043	-15.824	-0.124	
15	1.038	-15.910	-0.164	
16	1.045	-15.549	-0.070	
17	1.039	-15.886	-0.180	
18	1.028	-16.542	-0.064	
19	1.025	-16.727	-0.190	
20	1.029	-16.536	-0.044	
21	1.029	-16.246	-0.350	
22	1.035	-16.074	-0.000	
23	1.029	-16.253	-0.064	
24	1.024	-16.441	-0.174	
25	1.020	-16.054	-0.000	
26	1.003	-16.471	-0.070	
27	1.027	-15.556	0.000	
28	1.011	-11.744	0.000	
29	1.007	-16.778	-0.048	
30	0.995	-17.655	-0.212	

Number Of Ieration 5
Elapsed time is 0.177739 seconds.

Table-3 voltage and active power at each bus of IEEE-30 bus MLDG system

Bus No.	Voltage with DG pu	Angle Degree	Active power with DG MW	MVAR
1	1.060	0.000	2.034	
2	1.043	-2.096	0.366	1.546
3	1.045	-2.395	-0.048	
4	1.041	-2.895	-0.152	
5	1.010	-8.749	-1.884	25.085
6	1.034	-3.929	0.000	
7	1.017	-6.411	-0.456	
8	1.020	-4.351	-0.600	-5.881
9	1.086	-2.378	-0.000	
10	1.103	-1.591	-0.116	
11	1.082	-2.378	0.000	-2.007
12	1.121	-0.372	0.776	
13	1.111	-0.372	0.000	-8.257
14	1.115	-0.765	-0.124	
15	1.120	-0.606	-0.164	
16	1.107	-1.124	-0.070	
17	1.099	-1.634	-0.180	
18	1.159	0.959	0.936	
19	1.133	-0.177	-0.190	
20	1.125	-0.553	-0.044	
21	1.096	-1.738	-0.350	
22	1.138	-0.238	1.000	
23	1.099	-1.648	-0.064	
24	1.102	-1.732	-0.174	
25	1.068	-3.692	0.000	
26	1.051	-4.072	-0.070	
27	1.057	-4.758	0.000	
28	1.034	-4.149	-0.000	
29	1.037	-5.911	-0.048	
30	1.026	-6.736	-0.212	

Number Of Ieration 10

Normally H-bridge configuration inverter use for inverting the power supply with THD 42.34% to improve the power quality, reduce the harmonics in supply system. To decrease the THD multilevel inverter is better option. 11-level inverter is the cascade connected H-bridge inverters; number of switches and control complexity is one of the reasons that's why the cost of multilevel inverter increases [10]. 11-Level inverter is the combination of inverter and DSTATCOM, inverter regulate active power and reactive power in between grid and solar cell. It works in 2 modes:

1- When the inverter transforms active power from PV cell to grid as well as work as DSTATCOM to compensate the reactive power in order to control power quality of hybrid system[11].

2- In second mode, 11-level inverter (there is very low intensity of sun light or zero intensity of sun light) works as DSTATCOM to control reactive VAR in order to improve power factor of supply system[12].

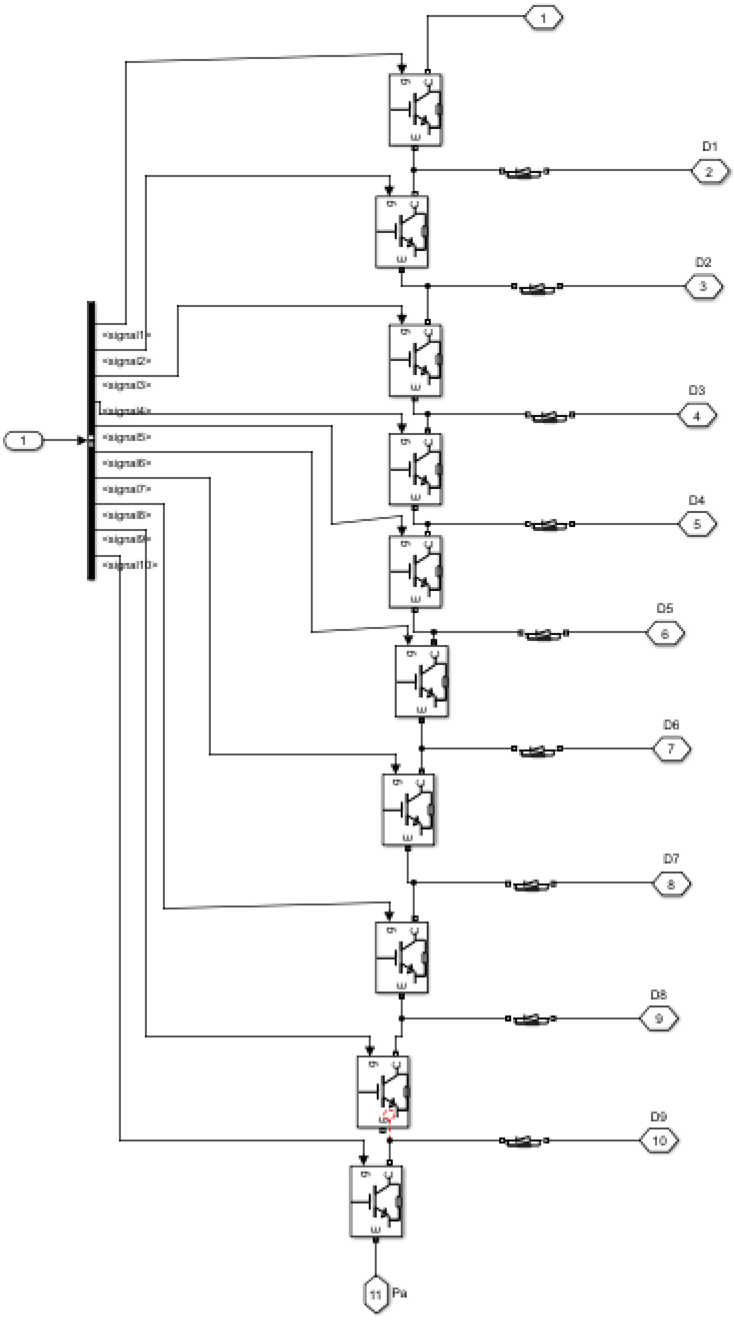

Figure - 4 Switching diagram of 11-level inverter

The average value of the output voltage.

$V_{av} = 10/T \int_{T/2}^{T} V(t)dt = 2.5\ Vs$ (1)

V_s is the rms voltage of input supply.

Rms value of output voltage.

$V_{rms} = \sqrt{\frac{10}{T}\int_{T/2}^{T} V(t)^2} \, dt = 1.18V_s^2$ (2)

Fourier series of output voltage is given by

$V_o(t) = \sum_{n=1,2,3}^{\infty} \frac{10V_s}{n\pi} * \mathrm{Sin}(\omega t)$ (3)

Fundamental voltage = $10\frac{Vs}{\pi}$ sin(ωt)

Rms value of Fundamental voltage = $10\frac{Vs}{\pi\sqrt{2}}$

Rms value of other harmonics voltage = $10\frac{Vs}{\pi n\sqrt{2}}$

Total harmonics distortion = harmonics/V_{1rms}

= $\sqrt{-4.9Vs/2.25Vs}$ = 0.983

Distortion factor can be calculated as

DF = $1/V_1\sum_{n=3,5}^{\infty}(Vn/n^2)^2$ (4)

= 3.2%

Total harmonic distortion for 11-level inverter is 0.93%, which shows very little harmonics content are present in inverted supply. Inverter is a power semiconductor device that's why it demands large amount of reactive VAR during operation it can also absorb reactive VAR during operation depending on the load behavior[14].

3- Problem formulation

Power flow analysis of LV network of MLDG hybrid system is necessary to calculate rating of buses. To calculate voltage, active power, reactive power at different buses Newton Raphson method should be used[13]. Figure-7 shows the LV network power distribution at different buses, where parameters are denoted as ;

Real power at kth bus (P_k)
Reactive power at kth bus (Q_k)
Real power loss at Kth bus ($P_{loss,k}$)
Reactive power loss at Kth bus ($Q_{loss,k}$)
Real load at (Kth+1) bus (P_{Lk+1})
Reactive load at (Kth+1) bus (Q_{Lk+1})
Resistance between bus Kth and Kth+1 (R_k)
Reactance between bus Kth and Kth+1 (X_k)
Shunt admittance connected at bus kth (Y_k)
Voltage at Kth bus (V_k)
Real power supplied by nth DG (P_{pvn})
Reactive power supplied by nth DG (Q_{pvn})
Distance from grid to PV in km (G)
Length between grid to Kth bus in km(L)

Power of MLDG system can be calculated

$P_{k+1} = P_k - P_{loss,k} - P_{Lk+1}$ (5)

$P_{k+1} = P_K - \frac{P_k}{{V_k}^2}\{P_k^2 - (Q_k - Y_kV_K^2)\} - P_{Lk+1}$ (6)

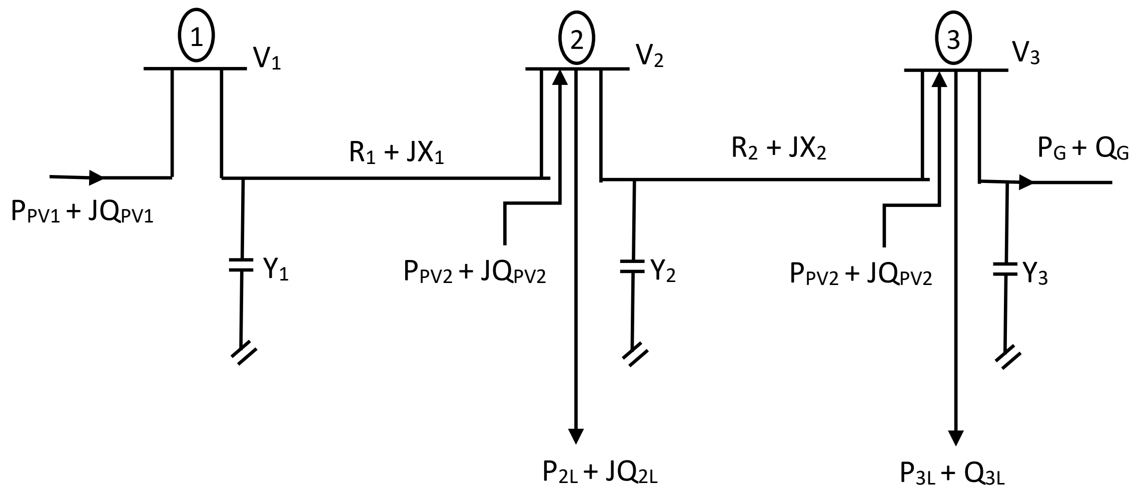

Figure -5 LV Network

PV Power at bus-n

$$P_{Vn} = \left[\frac{V_n^2}{R_3} P_{VnLoss} - (P_n^2 + Q_n^2) - \left(Q_{PVn}^2 - 2P_2P_{Vn} - 2Q_nQ_{Vn}(G/L)\right)\right]^{1/2} \quad (7)$$

$$Q_{Vn} = \left[\frac{V_3^2}{R_3} P_{VnLoss} - (P_n^2 + Q_n^2) - \left(P_{PVn}^2 - 2P_nP_{Vn} - 2Q_nQ_{Vn}(G/L)\right)\right]^{1/2} \quad (8)$$

PV Power Loss

$$P_{PVDG,Loss} = \frac{R_n}{V_n^2}(P_n^2 + Q_n^2) + \frac{R_n}{V_n^2}\left(P_{pv}^2 + Q_{pv}^2 - 2P_nP_{pv} - 2Q_nQ_{pv}\right)\left(\frac{G}{L}\right) \quad (9)$$

Active power loss from DG -1

$$P_{V1Loss} = \frac{R_1}{V_1^2}(P_1^2 + Q_1^2) + \frac{R_1}{V_1^2}\left(P_{pv1}^2 + Q_{pv1}^2 - 2P_1P_{v1} - 2Q_1Q_{v1}\right)\left(\frac{G}{L}\right) \quad (10)$$

Active power loss from DG -2

$$P_{V2Loss} = \frac{R_2}{V_2^2}(P_2^2 + Q_2^2) + \frac{R_2}{V_2^2}\left(P_{pv2}^2 + Q_{pv2}^2 - 2P_2P_{v2} - 2Q_2Q_{v2}\right)\left(\frac{G}{L}\right) \quad (11)$$

Active power loss from DG -3

$$P_{V3Loss} = \frac{R_3}{V_3^2}(P_3^2 + Q_3^2) + \frac{R_3}{V_3^2}\left(P_{pv3}^2 + Q_{pv3}^2 - 2P_3P_{v3} - 2Q_3Q_{v3}\right)\left(\frac{G}{L}\right) \quad (12)$$

4- **Description of Location:**

Proper location and size are very important for DGs installation to minimize the power loss and for better power quality. Improper selection of DGs location leads to high power loss than without DGs.

For optimum penetration and minimum loss the rating of DGs should be 2/3 capacity of incoming generation at 2/3 length of line[13][9].

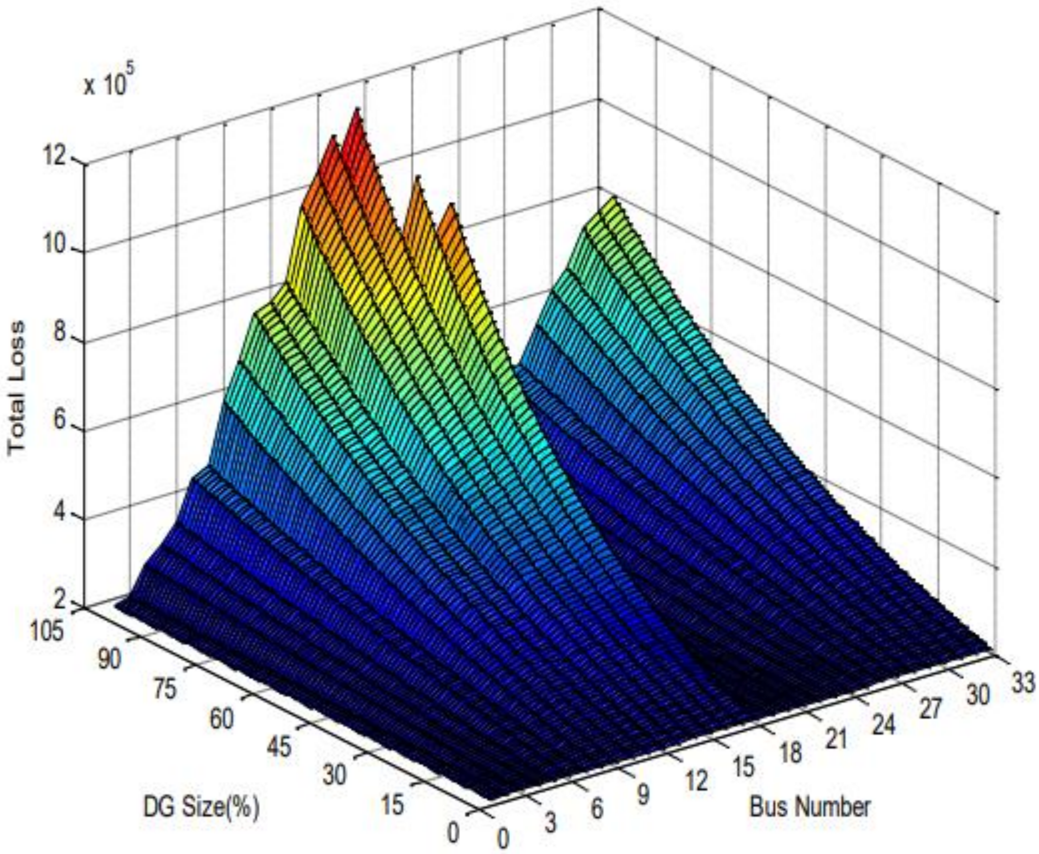

Figure -6 Impact of size and location of DG on system loss for standard IEEE 33

5- Environmental effect

SPV generation technology reduces the CO_2 emission by replacing fuels in power generation in industry and transportation.

Life cycle CO_2 emission is very much lower than fossil fuels. Life cycle balance is one of the important parameter in the calculation of heat generation and transportation. According to IEA analysis, 1.7 Gt of CO_2 emission save due to renewable energy generation in the year 2008[11].

IEA also analyze, BRIC countries will save CO_2 emission 5.3 Gt in year 2030 by using RES.

For decrease in total CO_2 emission if use solar power sources in place of thermal power source for same power output can be calculated for ‘n’ years[7].

$$\text{Save in } CO_2 = \sum_1^n E_t N_t \alpha_t \beta_t \quad (13)$$

E_t = Electric Energy;

N_t = No. of Sunny Days;

α_t = Amount of fuel used for production of 1 unit electric energy in TPP;

β_t = Amount of Co_2 for 1 unit coal;

6- Results:

Active power at different bus of IEE-33 bus network has been calculated in table-2 where as fig-6 shows the bar graph of same power. The active power of solar based MLDG system has been shown in table-3 where as fig 7 shows the bar graph of same power.

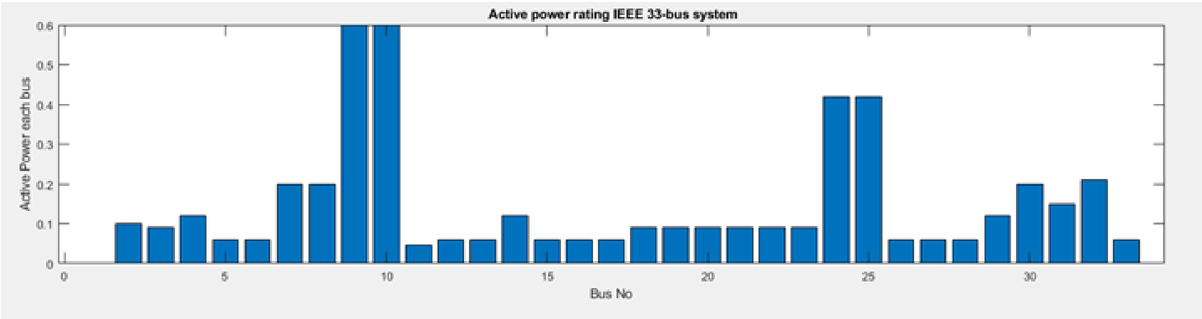

Fig-7 active power rating of IEEE-33 bus system (pu)

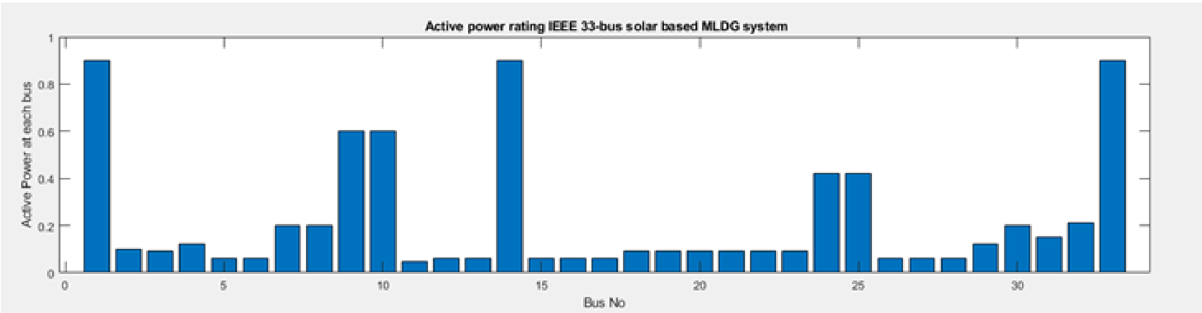

Fig-8 Active power rating of IEEE-33 bus MLDG system (pu)

The voltage profile of 33- bus test system has been shown infig-8 which is nearly constant for each bus. The behavior of constant voltage at each bus shows the better power quality hybrid system.

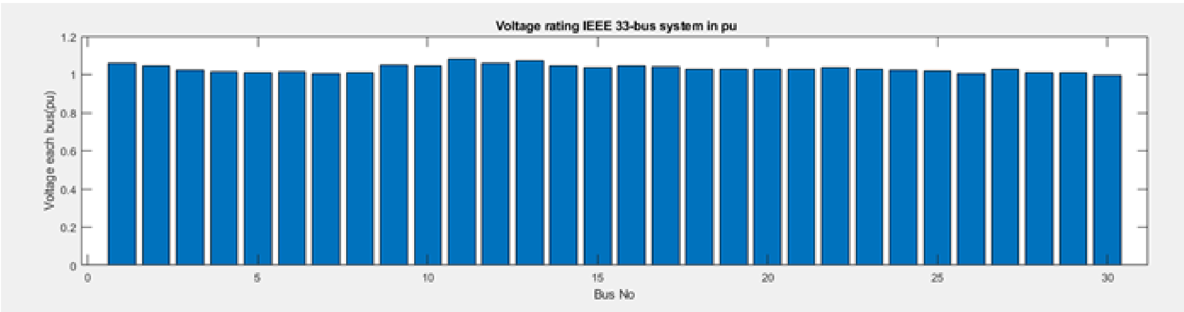

Fig-9 Voltage rating of IEEE-33 bus system (pu)

The voltage profile of 33- bus solar based MLDG system has been shown in fig-9 which is nearly constant equal to base voltage at each bus. The behavior of constant voltage for all buses shows the better power quality hybrid system.

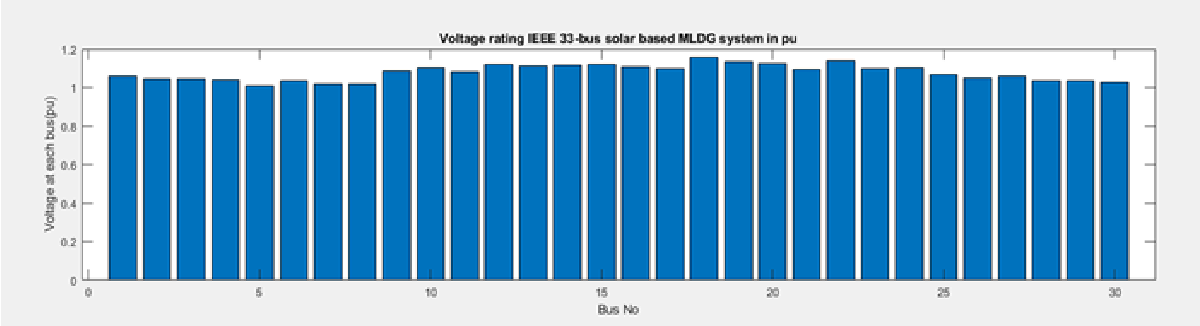

Fig-10 Voltage rating of IEEE-33 bus MLDG system(pu)

Compression of MLDG bus voltage to 33 bus test system bus voltages has been shown in fig- 10. The fig indicate that solar based MLDG system has better voltage profile than 33-bus test system.

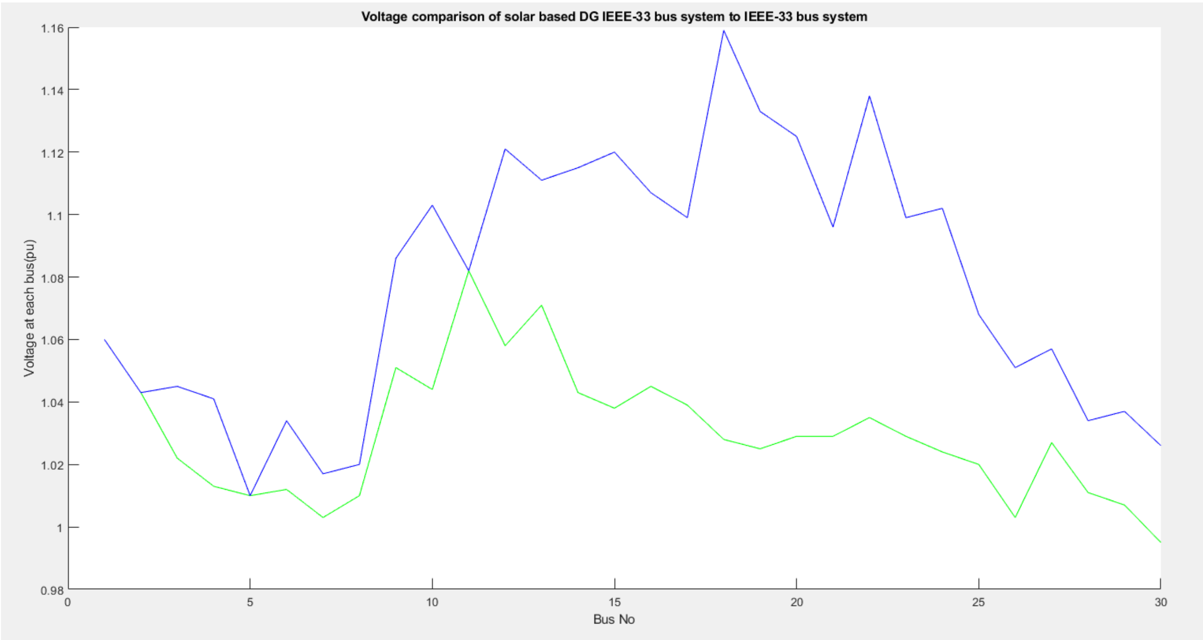

Fig-11 Voltage comparison of solar based 33 bus MLDG system to IEEE-33 bus test system

Voltage compression of one DG , two DGs, three DGs 33- bus system has been shown in fig- 11. The fig indicates that solar based MLDG system (having three DG) has better voltage profile others.

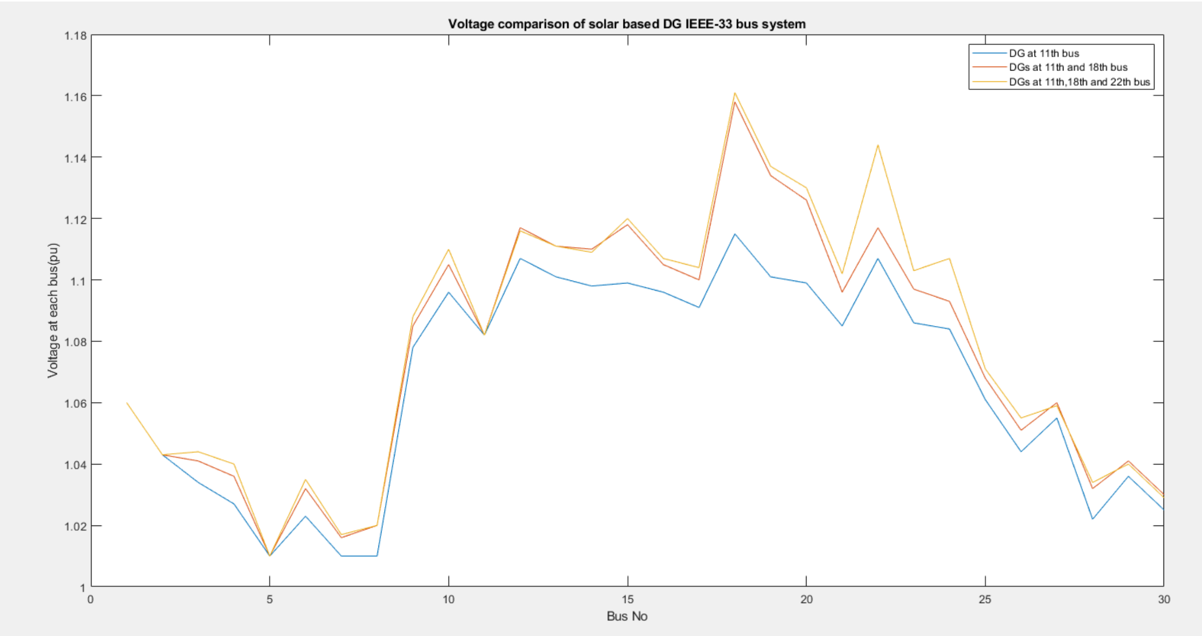

Fig-12 Voltage comparison of solar based 33 bus MLDG system

Active power compression of 33 bus system with DG and without DG has been seen in fig-12. The fig indicates that Active power with MLDG has higher average active power than without DG 33- bus system.

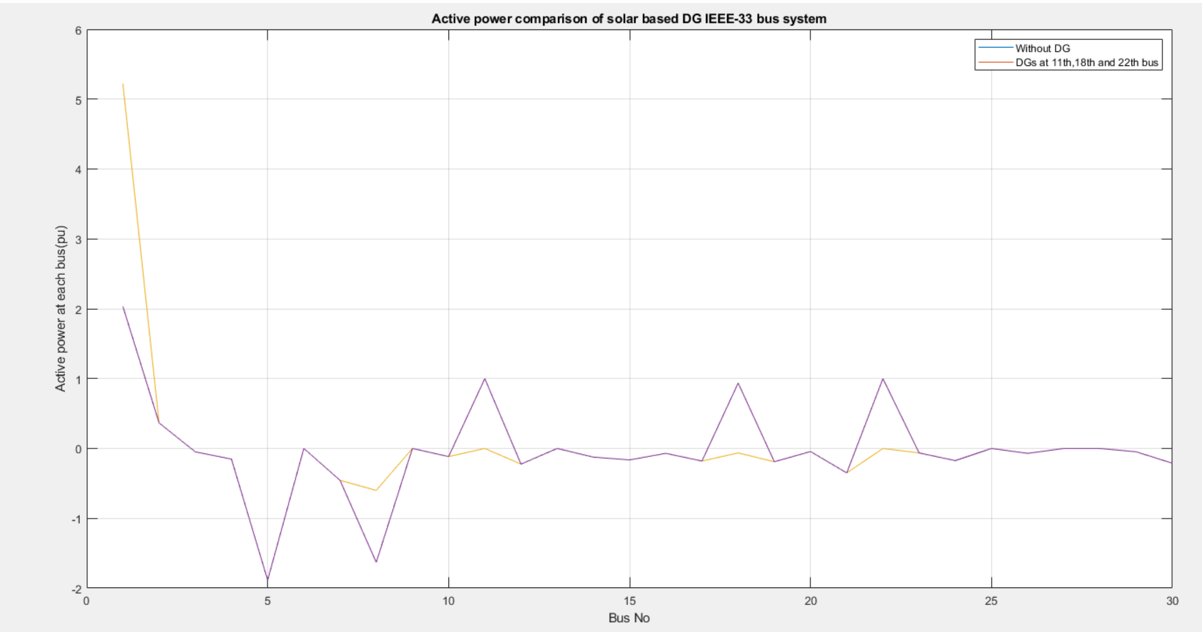

Fig-13 Active power comparison of solar based 33 bus MLDG systems to IEEE-33 bus test system

7- CONCLUSION

In the proposed solar MLDG hybrid system penetration in grid due to solar MLDG has been analyzed at different buses. The proposed solar based MLDG system provides reliable electrical energy to rural location of United Kingdom of Saudi

Arabia. Design of a suitable dynamic control scheme is required to mitigate the power quality issues of a large scale grid connected RESs. The results from our work, attest the satisfactory performance of the total designed control and can be developed for grid – tied PV systems at remote places or to promote renewable energy usage, using MPPT technique. The proposed design is validated with existing design which is in literature. The result of my proposed work is almost similar and comparable with the well established approach. The work can be extended for the 69 bus too. It has been observed that MLDG placed at 4 to 5 location has not been very significant .Therefore it has been conclude that calculation have been made up to 3 locations.

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