DESIGN AND MODELLING OF 11 KV SOLAR MICRO GRID

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Abstract - Solar Energy plays a key role in various Electrical Applications like Solar Water Heater, Solar cookers, Solar Chimney, Solar Pumps, Solar LED lights, and so on, These are considered to be the lowest application levels when we combine it to the grid, then we can make a difference in revolutionizing the existing power Grid with Solar Micro Grids at a required level. Nowadays the carbon footprint is increasing and there is a necessity to control the Ecology and preserve Energy to the maximum extent, using various Electricity Generation and utilization techniques. So, in a perspective to decrease the carbon footprint from Many Thermal generating stations, A 11KV Solar Distributed Micro Grid with P&O MPPT Technique is being designed in Matlab Simulink, will help to neutralize the losses in the existing grid at various voltage levels and also help in the complex Distributed network which is equipped to Thermal Power Generating Units. The results are evaluated with the IEEE-15 Distribution Network Bus Test using Matlab.

***Key Words*:** Solar Energy, Distributed Generation, Solar PV Array MPPT, Perturb & Observe MPPT, 11KV Solar Micro Grid, IEE-15 Distribution Network Bus Test, Load Flow Analysis

1. INTRODUCTION

Solar Energy is distributed all over the world, and PV Generation is the next source of the future in reducing Carbon Footprints from various Thermal power stations and also, a redundant power source which could reduce the burden on the grid in most of the commercial and industrial applications.

The only problem with the PV generation is the voltage fluctuations as these sources are completely dependent on the daylight and their Current & Voltage Characteristics [6] could vary according to the Irradiance and Temperature levels. On the other contrast, the converted efficiency is minimum in Solar Power Generation and electric power from solar PV changes as per weather conditions. As these sources can't be centralized to generate a bulk capacity of electricity, the decentralized way of power generation could help deliver reliable power to the end customer in implementing a generating station near to the consumer end or at a Distribution level. This kind of power generation into the grid is called Distributed Generation (DG) and not only solar but other generating systems like, wind, solar, biogas, piezoelectricity and wave energy could revolution the traditional grid involving in long transmission lines to feed the end customer.

"Solar Photovoltaic system can act as a source to feed the existing Distributed Network at the receiving end of the consumer." Our Electricity Grid is connected to Renewable & Non-Renewable Generating systems with difference in power generation limits. These limits vary as per the Wattage and the Voltage that have been Generated by a generating station [11] in the already existed Network and hence classified as given below:

Distributed Generation system Classification:

Micro- Distributed Generation system < 5KW

Small- Distributed Generation system < 5MW

Medium- Distributed Generation system <50MW

Large- Distributed Generation system <300MW

On the other hand, these DG could help the end customer in delivering power to remote areas where it rakes huge investments to set up the grid. This could regulate voltage profile in the grid at various distribution levels, Improves losses in a distribution network, and reduces loading on a feeder [12]. It could act as a secondary power supply on power failure.

The Main Aim and objective of this research are to develop an 11kV Solar Micro Distributed Generation system fed to the existing grid and check the load flow analysis using the IEEE-15 Distributed Network Test to locate the proper integration of the DG to the grid.

2. INFLUENCE OF DISTRIBUTED GENERATION ON GRID

2.1. Impact of Distributed Generation on Distributed Networks

DG can impose various technical strategies since, these alter the traditional concepts of power flow in maintaining System operation reliable and safe.

Most of the challenges include the Technical parameters of power quality in maintaining the voltage profile, stabilizing the various categories of Distribution network, Load Demand & Level of DG penetration. As the Distributed Network is being Radial type in which the Power flow from Highest level of Voltage to Lowest level of Voltage with Resistance to Reactance ratio of >1 (R/X). Because of the Greater values of R/X in the distribution level, DG penetration will also have the same challenges in maintaining the voltage profile on the Grid. Voltage profile should be maintained at all loading conditions and it has to be controlled since, the Grid is fed with Low and Medium voltage levels. The analysis from the various research states that, the PV generated [9] voltage have high penetration with Voltage profile of Grid.

Power Grid is designed with a frequency limit which cannot be controlled as easily as the DG system goes down. The main effect of DG on the voltage profile is because of the inconsistency of the power generation capability of DG all round the clock. Solar PV generation can be utilized mostly on the Day time and may even vary as per atmospheric and seasonal conditions.

2.2 Strategies to be implemented

The connection of distributed generation to a distribution network may introduce a big impact on the voltage profile and power flow. These impacts could also be positive or negative counting on the distribution system characteristics, and therefore the DG location, and size.

The voltage control is considered a significant challenge that may inhibit the penetration of any further amount of DG capacity into the distribution networks. Various techniques like, AC Optimal Power flow with Active Network Management system, Voltage control using Reactive power Compensation etc., is implemented and established with various DG systems.

3 MODELLING OF 11KV SOLAR MICRO GRID

3.1 Photo Voltaic System

Photovoltaic system is a device used to convert the solar energy from sun to Electricity. They generate DC Voltage & Current and require additional converters and protection devices to feed AC into the Grid. In addition MPPT Extracts maximum power output from the PV Cells, various Algorithms like, the Incremental Conductance (IncCond) technique, Perturbation and Observation (P&O) [9], Ripple Correlation and Open Circuit Voltage (OCV), Short Circuit Current (SCC) techniques were used. Out of these based on applications and irradiance factors of PV Conversion, P&O algorithm best suited for the modelling of 11kV Solar Grid system.

The Solar DG module consists of Photo Voltaic array, DC-DC Converter, Inverter, MPPT Controller. Solar module is designed by considering all these components in MATLAB. The system is modeled to get the output of 11kV.

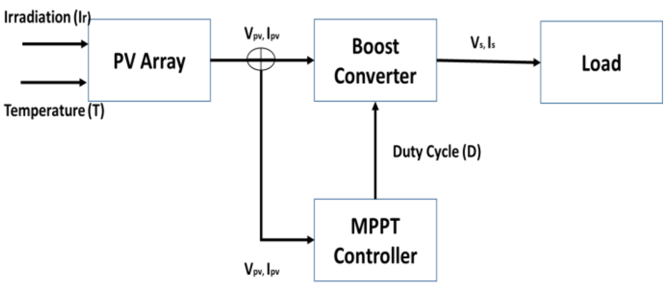

Figure- 1. Block Diagram of Solar Modules

3.2 Perturb & Observe Method MPPT

The P&O algorithm works on the perturbation of duty cycle of the power converter. Operating Voltage fluctuations occur in the DC link between the PV array and the power converter and may vary according to the irradiance levels of the Solar system. In the case of perturbing duty cycle of the converter alters the voltage of the DC link between the PV array and the power converter. In this method, last perturbation value and the last incremental value within the power limit cannot be decided about the subsequent perturbation. The system is designed in a way of controlling the up's and down's of the Solar Irradiation level that vary as per the atmospheric conditions. The more the irradiance the more the power output from the PV. Hence, An algorithm is developed in such a way that it keep tracks on the last and present limits of voltage output from the PV cell and holds the value of maximum power that could be extracted from the solar cell.

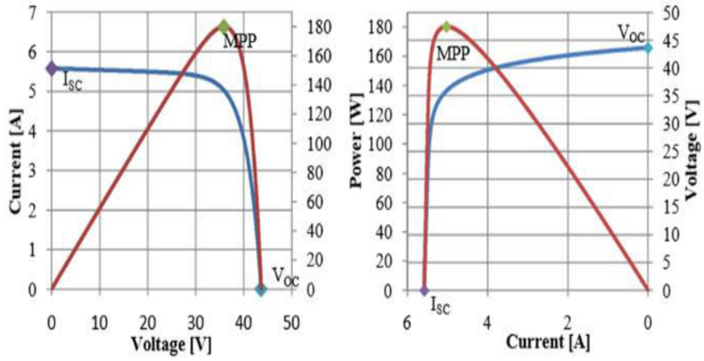

Figure-2. MPPT Curve of a PV Cell

3.3 Algorithm P&O

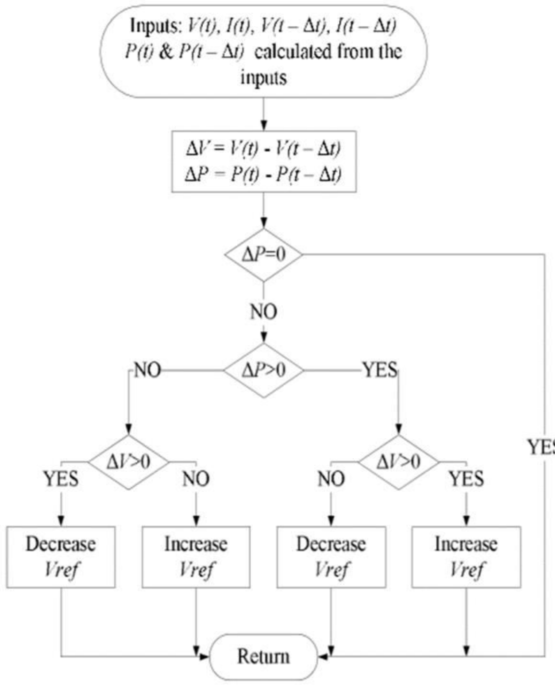

Figure-3. Algorithm representation

3.4 Analysis of DC-DC Converter

A Boost/Step-up converter converts low voltage level from PV to Higher voltages as required by the application or battery voltage. The output of the Boost converter is designed in Matlab/Simulink [4] and Output voltage & Current waveforms have been showed in the below figure 4.

The same Converter is equipped with a Three Phase inverter topology to convert the existing PV Modules Output to the required 11kV AC Grid to operate as a Distributed Generation.

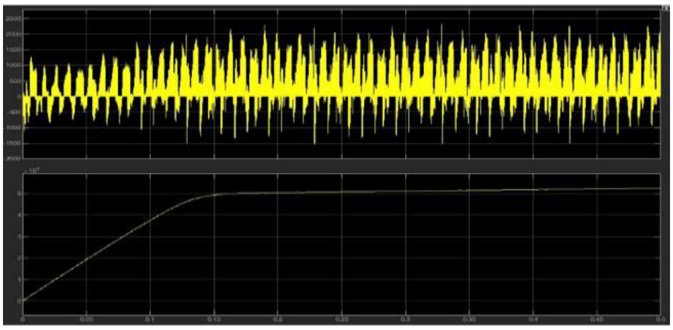

Figure-4. Output voltage and current of boost converter

3.5 Simulink model of Solar Module

The complete design of the solar module is modeled in MATLAB/SIMULINK. The complete operation is explained as below: Solar irradiation and temperature are given as the inputs to the PV array and the output of PV cell is given as an input to the boost converter in order to increase the voltage. MPPT technique [14] is also used and the algorithm is written. An inverter is equipped to convert the DC to AC output of 11kV and given to the grid. The whole modeling of solar module is shown in the figure below:

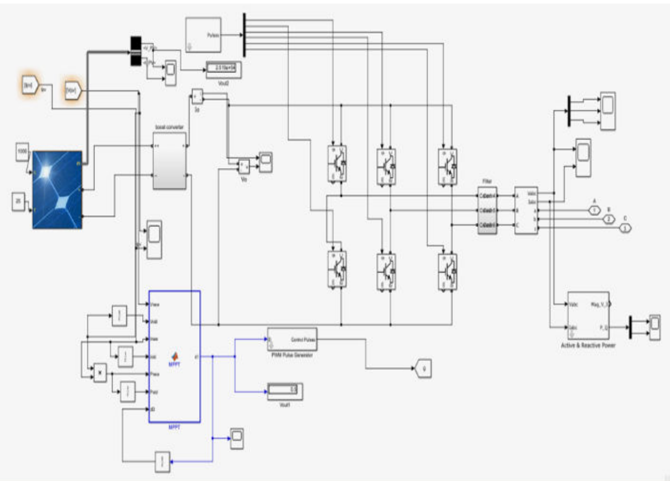

Figure-5. MATLAB Modelling of PV Module

An LC filter helps to reduce the harmonics. The three-phase measurement block is also connected to view the voltages and currents. The 11kV output of the solar module is shown in the scope that is connected to an inverter. The output is shown in the figure below:

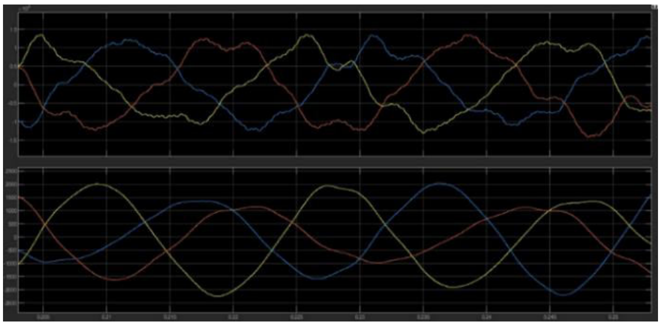

Figure-6. 11KV Solar PV Module Output

4 IEEE 15 BUS NETWORK DISTRIBUTION TEST

4.1 Load Flow Analysis without any DG

A radial distribution test system is selected with 15 buses connected to a substation of 11kV. The SLD is shown in Figure 7. This system is described as test feeder operating at 11kV.

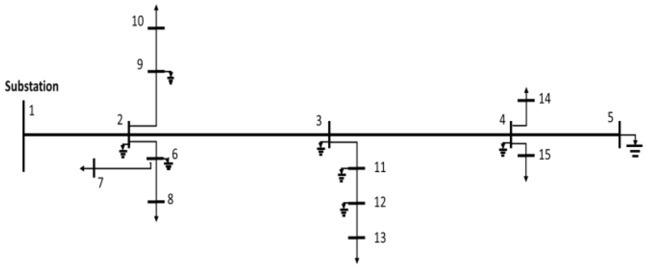

Figure-7. 15 BUS System SLD

According to the SLD, the system is designed in MATLAB/SIMULINK with Electrical System components. The SIMULINK diagram is shown in the figure below.

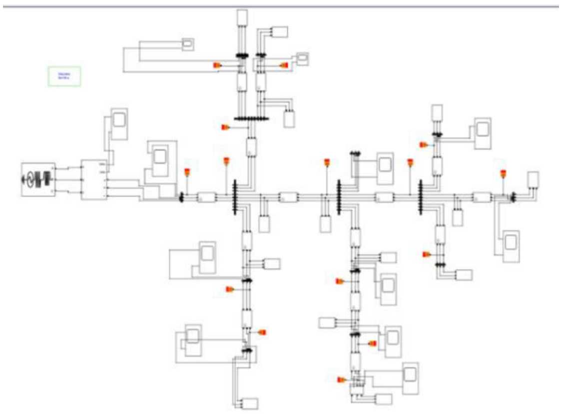

Figure-8. SIMULINK Diagram

IEEE 15 Bus Network Test is a distribution network which will represent a line load data given in table 1. The load data is with respect to the receiving bus from table 1, the IEEE 15 bus Network has a total load of 1000KW and 1200

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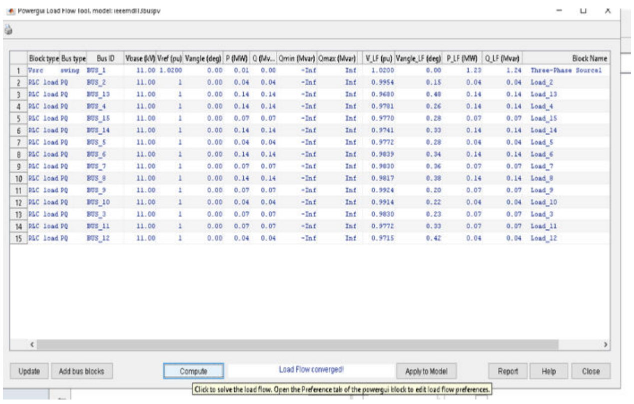
KVAR. The values are given according to the line load data sheet. It is simulated in MATLAB and the load flow analysis is carried out.

Table 1. IEEE 15 Bus Network Line Load Data

Bus No.		Line data		Load data	
From	To	Resistance (Ohms)	Inductance (Henry)	Active Power (KW)	Reactive power (KVAR)
1	2	1.35309	1.32349	44.1	44.99
2	3	1.17024	1.14464	70.1	71.44
3	4	0.84111	0.82271	40	142.82
4	5	1.52348	1.0276	44.1	44.99
2	9	2.01317	1.3279	70	71.44
9	10	1.68671	1.1377	44.1	44.99
2	6	2.55727	1.7249	140	142.82
6	7	1.0882	0.734	140	142.82
6	8	1.25143	0.8441	70	71.414
3	11	1.79553	1.2111	140	142.82
11	12	2.44845	1.6515	70	71.414
12	13	2.01317	1.3579	44.1	44.99
4	14	2.23081	1.5047	70	71.414
4	15	1.9702	0.8074	140	142.82

The simulation is carried out and the load flow analysis is done. The load flow results that are obtained are:


Powergui Load Flow Tool. model: ieeemdl13buspv

	Block type	Bus type	Bus ID	Vbase (kV)	Vref (pu)	Vangle (deg)	P (MW)	Q (Mv...	Qmin (Mvar)	Qmax (Mvar)	V_LF (pu)	Vangle_LF (deg)	P_LF (MW)	Q_LF (Mvar)	Block Name
1	Vsrc	swing	BUS_1	11.00	1.0200	0.00	0.01	0.00	-Inf	Inf	1.0200	0.00	1.23	1.24	Three-Phase Source1
2	RLC load	PQ	BUS_2	11.00	1	0.00	0.04	0.04	-Inf	Inf	0.9954	0.15	0.04	0.04	Load_2
3	RLC load	PQ	BUS_13	11.00	1	0.00	0.14	0.14	-Inf	Inf	0.9680	0.48	0.14	0.14	Load_13
4	RLC load	PQ	BUS_4	11.00	1	0.00	0.14	0.14	-Inf	Inf	0.9781	0.26	0.14	0.14	Load_4
5	RLC load	PQ	BUS_15	11.00	1	0.00	0.07	0.07	-Inf	Inf	0.9770	0.28	0.07	0.07	Load_15
6	RLC load	PQ	BUS_14	11.00	1	0.00	0.14	0.14	-Inf	Inf	0.9741	0.33	0.14	0.14	Load_14
7	RLC load	PQ	BUS_5	11.00	1	0.00	0.04	0.04	-Inf	Inf	0.9772	0.28	0.04	0.04	Load_5
8	RLC load	PQ	BUS_6	11.00	1	0.00	0.14	0.14	-Inf	Inf	0.9839	0.34	0.14	0.14	Load_6
9	RLC load	PQ	BUS_7	11.00	1	0.00	0.07	0.07	-Inf	Inf	0.9830	0.36	0.07	0.07	Load_7
10	RLC load	PQ	BUS_8	11.00	1	0.00	0.14	0.14	-Inf	Inf	0.9817	0.38	0.14	0.14	Load_8
11	RLC load	PQ	BUS_9	11.00	1	0.00	0.07	0.07	-Inf	Inf	0.9924	0.20	0.07	0.07	Load_9
12	RLC load	PQ	BUS_10	11.00	1	0.00	0.04	0.04	-Inf	Inf	0.9914	0.22	0.04	0.04	Load_10
13	RLC load	PQ	BUS_3	11.00	1	0.00	0.07	0.07	-Inf	Inf	0.9830	0.23	0.07	0.07	Load_3
14	RLC load	PQ	BUS_11	11.00	1	0.00	0.07	0.07	-Inf	Inf	0.9772	0.33	0.07	0.07	Load_11
15	RLC load	PQ	BUS_12	11.00	1	0.00	0.04	0.04	-Inf	Inf	0.9715	0.42	0.04	0.04	Load_12

Update Add bus blocks Compute Load Flow converged! Apply to Model Report Help Close

Figure-9. IEEE 15 Bus Network Load flow of System without any DG.

4.2 Load Flow with DG at Bus 13

Any Distributed Generation allocated with respect to the voltage profile of the Network. The location at lowest voltage profile in the Distribution Network can be selected and allocated with a Generation Source like, Solar Photovoltaic DG system. Here, a Solar DG system is developed with the help of Matlab SIMULINK program.

The Network is divided in to three Different Zones and voltages are analyzed. Consider at Bus 13 the voltage profile is low and allocating the DG of 10-30% of that feeder will increase the voltage profile and also reduce in power loss.

According to the load flow report obtained, as the voltage is low at bus 13, DG is connected at bus 13 as shown in the figure below.

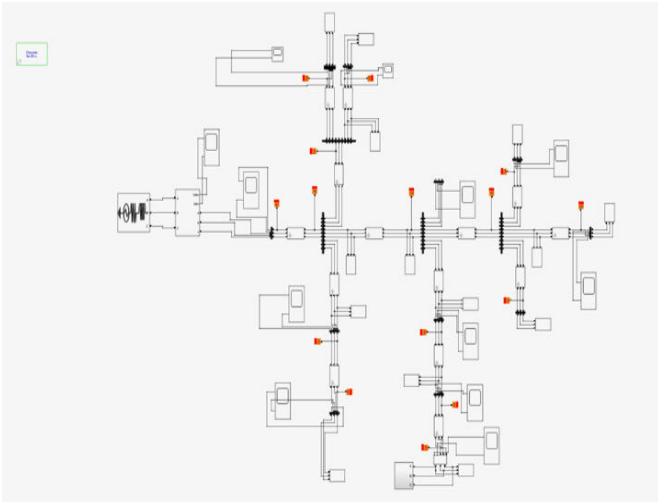
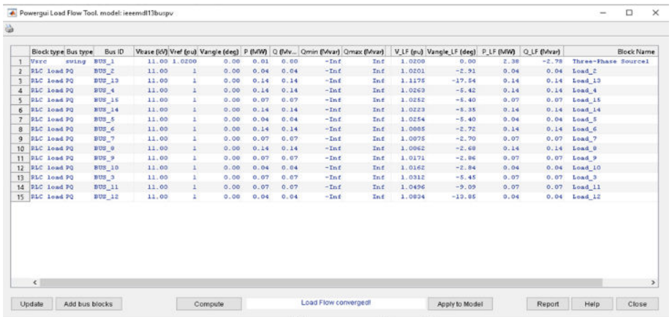


Figure-10. Simulink IEEE 15 Bus Network with DG

The load flow report of IEEE 15 bus system when connected to DG is sown in the figure below:


Powergui Load Flow Tool. model: ieeemdl13buspv

	Block type	Bus type	Bus ID	Vbase (kV)	Vref (pu)	Vangle (deg)	P (MW)	Q (Mv...	Qmin (Mvar)	Qmax (Mvar)	V_LF (pu)	Vangle_LF (deg)	P_LF (MW)	Q_LF (Mvar)	Block Name
1	Vsrc	swing	BUS_1	11.00	1.0200	0.00	0.01	0.00	-Inf	Inf	1.0200	0.00	2.38	-2.78	Three-Phase Source1
2	RLC load	PQ	BUS_2	11.00	1	0.00	0.04	0.04	-Inf	Inf	1.0201	-2.91	0.04	0.04	Load_2
3	RLC load	PQ	BUS_13	11.00	1	0.00	0.14	0.14	-Inf	Inf	1.1175	-17.54	0.14	0.14	Load_13
4	RLC load	PQ	BUS_4	11.00	1	0.00	0.14	0.14	-Inf	Inf	1.0263	-5.42	0.14	0.14	Load_4
5	RLC load	PQ	BUS_15	11.00	1	0.00	0.07	0.07	-Inf	Inf	1.0252	-5.40	0.07	0.07	Load_15
6	RLC load	PQ	BUS_14	11.00	1	0.00	0.14	0.14	-Inf	Inf	1.0223	-5.35	0.14	0.14	Load_14
7	RLC load	PQ	BUS_5	11.00	1	0.00	0.04	0.04	-Inf	Inf	1.0254	-5.40	0.04	0.04	Load_5
8	RLC load	PQ	BUS_6	11.00	1	0.00	0.14	0.14	-Inf	Inf	1.0085	-2.72	0.14	0.14	Load_6
9	RLC load	PQ	BUS_7	11.00	1	0.00	0.07	0.07	-Inf	Inf	1.0075	-2.70	0.07	0.07	Load_7
10	RLC load	PQ	BUS_8	11.00	1	0.00	0.14	0.14	-Inf	Inf	1.0062	-2.68	0.14	0.14	Load_8
11	RLC load	PQ	BUS_9	11.00	1	0.00	0.07	0.07	-Inf	Inf	1.0171	-2.86	0.07	0.07	Load_9
12	RLC load	PQ	BUS_10	11.00	1	0.00	0.04	0.04	-Inf	Inf	1.0162	-2.84	0.04	0.04	Load_10
13	RLC load	PQ	BUS_3	11.00	1	0.00	0.07	0.07	-Inf	Inf	1.0312	-5.45	0.07	0.07	Load_3
14	RLC load	PQ	BUS_11	11.00	1	0.00	0.07	0.07	-Inf	Inf	1.0496	-9.09	0.07	0.07	Load_11
15	RLC load	PQ	BUS_12	11.00	1	0.00	0.04	0.04	-Inf	Inf	1.0834	-13.85	0.04	0.04	Load_12

Update Add bus blocks Compute Load Flow converged! Apply to Model Report Help Close

Figure-11. Load Flow Report connected with DG

5 CONCLUSIONS

Photovoltaic Systems are readily available Generation Sources which could equip to any certain Loads like, Domestic, Industrial, Commercial & Agricultural consumers. Net metering in various parts of India, constitutes to connect Solar PV to Grid which not only benefits consumers from incentives but also to reduce their bills. Moreover, it acts like a Distributed Generation system which also enhances the Voltage profile of the corresponding feeder.

These Sources could create disturbances in optimal operation of Grid since, these sources are intermittent and vary as per atmospheric conditions. Hence, the output of these sources will also be effected and hence, an MPPT algorithm technique is used which is most preserved technique which has a Perturb & Observe Algorithm to enhance the PV Module Output to its maximum efficiency. The whole system is implemented in Matlab/Simulink with MPPT using a boost converter, to operate continuously. The simulation results show that Characteristics of the system doesn't defer or deviate the standards. The model is simulated with Perturb & Observe Algorithm which enhance the PV Output. The results of the proposed control system tracks the PV array to its maximum power generation capability improving the efficiency of the Solar PV system. The same is simulated with the with IEEE 15 bus radial distribution system to check the performance of the PV array as it is interconnected with the Grid. The results observed as DG can reduce the power losses and improves the voltage profile of the system. Location of the DG is to be considered in the Bus Network at the lowest voltage profile feeder, such that it will enhance the grid stability and also reduce the burden on the Grid feeding anonymous loads.

Hence, A Design for 11KV Solar Micro Grid is established and tested for IEEE 15 Distributed Network System and the results shown which determine the Load flow analysis with and without DG. As a result no deviation of power flow is seen and also, improved voltage profile is observed at Bus 13 as the complete analysis is done at that Bus.

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[10] L.Karunakar R.Sai Sankar Rao described the hundred kilowatt solar PV grid connected PV system design in MATLAB and observed the performance evaluation of the system. Solar PV system is taken as primary source three phase inverter is used to convert the DC source to AC source in this voltage source control is used the main advantage of this controller is the output waveform does not depend upon the type of the load.

[11] Md. Shohag Hossain, Naruttam K. Roy and Md. Osman AliRef studied the impact of photo voltaic on power flow, voltage, short circuit and relay protection respectively on 10 kV distribution network. PV located at two different locations, where three-phase short circuit current is tested on one of these locations. Simulation tool used was not provided in this paper.

[12] Villalva MG, Gazoli JR and Filho ER presented the major issues that affect the distributed networks operation and control as a consequence of connecting huge amounts of DG. These are stability issues; change of short circuit level and voltage profiles; harmonics; malfunction of protection schemes; load losses variations; and power quality. Also, a load flow study has been performed to investigate the impact of a 3 MW wind turbine on the power system losses. The study was carried out using Neplan software for the IEEE 14-bus distribution test system. For this case study, they concluded that the connection of the DG has reduced the power losses.

[13] Ishaq M, Ibrahim UH, Abubakar H. presented that the electrical energy demand (load) of Government Technical College Wudil was estimated. The estimated load is 48.787kWh/ day. System sizing and specifications were provided based on the estimated load. The results show that a 13kW PV array capacity of 72 modules, 20 (12V, 325Ah) batteries, a 15kVA, 48V inverter and a 60A, 24Vvoltage regulator are needed to supply the electrical load of the college. The proposed off grid PV system requires copper wires of cross-sectional area 1.22mm2, 32 mm2 and 3 mm2 for its installation. The cost estimate of the of the system is relatively high when compared to that of fossil fuel generator used by the college but the payback period of the system is estimated to be 2.8 years, which is obviously much shorter than the lifespan of the selected PV modules which is 30 years. The recommendation would be that the system can be made utility- interactive to enable the purchase of surplus solar energy from users.

[14] Zaki AM, Amer SI, Mostafa M. studied that a neural network control system for Maximum Power Point Tracking (MPPT) for a PV array was presented. The back propagation neural network was used with the error calculated in its usual form and also with a modified error function which takes into consideration the derivative of the error. The two cases were tested and results were compared. Although both cases give good results, the modified error function resulted in faster convergence rate which give superiority in case of on-line control of the PV array.

[15] Zainudin HN, Mekhilef S. has presented a comparison of two most popular MPPT controller, Perturb and Observe Controller with Incremental Conductance Controller. This paper focus on comparison of three different converter which is connected with the

controller. One simple solar panel that has standard value of insolation and temperature has been included in the simulation circuit. From all the cases, the best controller for MPPT is incremental conductance controller. This controller gives a better output value for buck, boost and cuk converter. Hence this controller will give different kind of curves for the entire converter. In simulation Buck converter show the best performance the controller work at the best condition using buck controller.

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