Designing and Commissioning of a Solar PV-DG Hybrid Power Plant for an Industry

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Abstract – A renewable energy network integrating energy storage systems can alleviate the intermittent as well as high-frequency interruption in network by providing output power to a specific load or the grid-connected systems. Fluctuations in solar radiations incident on a SPV panels and variations in the wind velocity can significantly affects in the generated output by such networks. Instability in the off-grid power plant occurs, when an off-grid system incorporates significant amount of solar generated energy due to unavoidable fluctuation of the solar irradiation. Under such scenario, the energy storage system can act as buffer ensuring the supply of uninterrupted and stable power. As more and more of the energy is preferred to be derived from solar, maintaining a stable power supply has become increasingly challenging. A solution to this problem was identified as an off-grid hybrid power plant integrated with energy storage. The proposed work in the form of case study emphasizes on designing and commissioning of an off-gird 3.5 MWp SPV-DG hybrid power plant, with storage system. 5 units of 500 KVA DG set each are installed at site location of Rajasthan, INDIA.

Index Terms – Hybrid power plant, solar power plant, off grid solar power plant.

1. INTRODUCTION

Increased dependency on energy for day to day choruses has motivated to think about global energy supply and demand. Economist worldwide confirms that the economic growth and human development is depend on the secure, affordable, and reliable energy supply. World's energy consumption is gradually increasing mainly due to population growth and development in developing countries. One of the concern is use of renewable and sustainable energy[1-32]

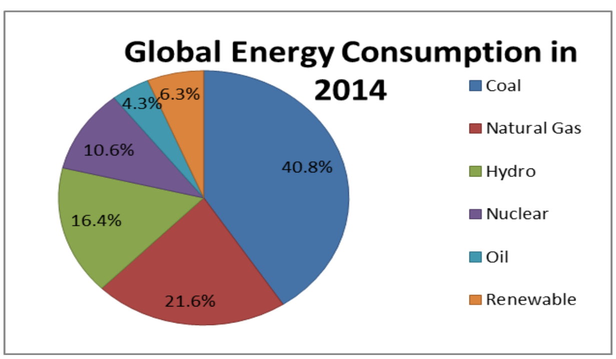

Figure 1 Global energy consumption in 2014 as recorded by International Energy Agency

The global energy consumption as of 2014 was cited in a report published after the investigation by the International Energy Agency (IEA) in 2016 [1]. It is made clear from the Figure 1 that the maximum dependency worldwide is on the fossil fuels particularly the coal and natural gas**.** Renewable energy sources contributed only 6.3% to the total global energy consumption.

2. RENEWABLE ENERGY SOURCES

Renewable energy sources such as hydropower (<25 MW capacity), solar power, wind power, bioenergy, geothermal energy, etc. often provides energy predominantly for electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services. The global installed capacity of these renewable energy sources are tabulated in Table 1. [2]

Table 1 Global installed capacity of renewable power

Installed renewable power capacity: the world (2016) (March)		
Source	Total installed capacity(GW)	Share (%)
Wind power	487	24.15
Solar power	307.8	15.27
Biomass power	112	5.55
Small hydropower	1096	54.36
Geothermal power	13.5	0.67
Total	2016.3	100.00

The Ministry of New and Renewable Energy (MNRE) in India has set up an ambitious target of achieving 175 GW of installed capacity through renewables. The present date installation comprises of grid connected as well as off-grid systems and shares of the same are shown in Table 2 [3] and Table 3 [3].

Table 2 Grid connected renewable power capacity

Grid connected renewable installed power: India (2017) (March)		
Source	Total installed capacity(MW)	Share (%)
Wind power	32279.77	56.39

Solar power	12288.83	21.47
Biomass power	8182	14.29
Small hydropower	4379.85	7.65
Waste-to-Power	114.08	0.20
Total	57244.53	100.00

Table 3 Grid connected renewable power capacity

Off-grid renewable installed power: India (2017) (March)		
Source	Total installed capacity(MW)	Share (%)
Biomass cogeneration	651.91	44.12
SPV Systems	471.16	31.88
Biomass Gasifier	161.45	10.93
Waste to Energy	171.22	11.59
Water mills / micro hydel	18.81	1.27
Aero-Generators / Hybrid systems	3.15	0.21
Total	1,477.70	100.00

Out of all the renewable energy sources in India, the solar energy especially the Solar Photovoltaic (SPV) has seen a tremendous rise in the market. The intermittency in the nature of the renewable energy sources is one of the greatest challenge and a setback for the use of these sources to the fullest. Yet the use of renewable energy has increased the energy quantity, but still, the demand is way ahead of the supply and a major problem of power quality. Another challenge is the quality of the power supply which is characterized by a large voltage and frequency fluctuations also the scheduled and unscheduled power cuts with load restrictions pertaining on the grid. Hybrid energy systems with energy storage are one of the brilliant ways to tackle the intermittency problem associated with the renewables.

3. DESCRIPTION OF HYBRID POWER PLANT

In this project is a stand-alone system which requires the DG sets to remain in the operating mode even at zero loads to provide the reference voltage and frequency to the solar inverters to operate. In the case of SPV power plant, it is well known that the power fluctuates due to the fluctuation in the solar irradiation on every instant. To meet this fluctuation, the DG set of the hybrid system operating at no load shall respond and fulfill the load requirement thus providing an uninterrupted supply.

The role of the battery storage system is equally crucial in the hybrid power plant. It comes into the picture when the SPV has generated an excess amount of energy. The battery shall release all its stored energy before the energy is derived from the DG set typically in the early morning, late evening and the fluctuating hours.

The present research work focuses on 3.5 MW DG-PV off grid hybrid power plant with energy storage in Rajasthan. Details about specification and components of hybrid power plant are tabulated in Table 4.

Table 4 Specification and components of the hybrid power plant

Particulars	Description
Site location	Rajasthan
Latitude	27.97°N
Longitude	76.39°E
Available Solar Plant area	40468.56 m^2
Technical details of PV modules	
PV Module type	Polycrystalline Silicon
Module Dimension (L*W*T in m)	1.662*0.990*0.046
Maximum Power Rating	270 Wp
Rated current	8.71 A
Rated voltage	31 V
Short circuit current	9.43 A
Open circuit voltage	38.3 V
Type of structure	Unlimited shades and fixed tilt ground mounting
Tilt angle of PV module	25°
Pitch	6.5 m
Technical details of DG set	
Capacity	5*500 KVA
Maker	STERLING WILSON
Alternator	HCI544E1
Technical details of solar inverter	
Inverter rating (AC output)	500 kW
Maximum AC current rating	1049 A
Nominal output voltage	300 V ± 10%
Maximum DC power	600 kW
MPPT Voltage Range	460-900 V
Maximum DC input voltage	1000 V
Minimum DC input voltage	460 V

Technical details of solar battery	
Type of battery	Tubular lead acid batteries
Battery voltage	12 KVA
Capacity	150Ah Durability(30 Min)

4. DESIGNING OF SPV POWER PLANT

- Twenty-four PV modules were connected in series in a string.
- Two such strings were connected through a Y-connector.
- Per SMB, 15 Y-connectors were connected except for SMB-3 which has 9 Y-connectors and SMB-6 has 8 Y-connectors.
- SMB-1 to 3 were connected to Inverter-1, and SMB-4 to 6 were connected to Inverter-2.

Table 5 Voltage drop and power loss in percentages per SMB for the case study.

SCB /SMB	SMB-1	SMB-2	SMB-3	SMB-4	SMB-5	SMB-6
No of input -Y connection	15	15	9	15	15	8
No. of module add	720	720	432	720	720	408
DC capacity (kWp)	194.4	194.4	116.64	194.4	194.4	110.16
String Voc (V)	919.2	919.2	919.2	919.2	919.2	919.2
String Vmp (V)	744	744	744	744	744	744
String Isc (A)	282.9	282.9	169.74	282.9	282.9	150.88
String Imp (A)	261	261	156.6	261	261	139.2
DC power cable length (m)	97.65	118.65	186.9	171.15	144.9	212.1
Power in the inverter (kWp)	505.44			498.96		
Voltage drop %	0.52	0.63	0.90	0.90	0.77	0.87
Power loss %	0.515	0.626	0.431	0.903	0.765	0.387

In 1 MWp solar power plant the PV module are arrange in series with the 24 Nos in a string and two string connected parallel by use of Y-Connector. And 1 module capacity is 270 W. So every string Y String capacity is 12.96 KWp and the Voc of 1 module is 38.3 V, The Voc of a string is 919.2 V because the Voc is add in the series connection. The Vmp of a module is 31 V the Vmp of a string is 744 V because it also increases in the series connection.

In SMB-1 there are 15 Nos of Y-string used, Every Y-string in parallel so that string Voc and Vmp are same because in parallel connection Voc and Vmp are constant. And the power capacity is 194.4kWp because in SMB-1 720 module are used. The SMB-1, SMB-2, SMB-4 and SMB-5 are same because the No of module is same. But in SMB-3 and SMB-6 are different because the no of modules are 432 and 348. So the power capacity of SMB-3 and SMB-6 are 116.64 KWp and 103.68 KWp.

In Inverter-1, 3 SMB are connected the inverter max Voc is 1000 V and max DC power capacity is 600 kWp, But our total power is 505.44 KWp in first 3 SMB. And Voc and Vmp are 919.2 V and 744 V.

Two inverter have been used of capacity 500 kW and the total capacity of the solar PV plant is 1 MWp. The nominal output of the inverter is 300 V

5. SOFTWARE USED

There are mainly two standard software have been used in this study for studying, sizing and analyzing the complete SPV power plant, and visualization of the plant in 3D view.

6. SINGLE LINE DIAGRAM

SLD is a simplified notation of a three-phase power system into a single phase for understanding the entire electrical circuit design in an SPV power plant. This diagram as the name suggests is a one line diagram and is made in AutoCAD. The SLD was drafted based on the output of the Solar PV design software, and it contains all the details about the SPV power plant's designing that are needed at the time of installation.

Figure 8 below shows the DC side SLD for the SPV power plant. From the figure, it can be seen that 24 PV modules are connected in series and two such strings are connected through a Y-connector. There are 15 Y-connectors which are connected to SMB-1 and similarly to the SMB-2, 4, 5 whereas; SMB-3 has 9 Y-connectors and SMB-6 has 8 Y-connectors. The three SMBs are further connected to the 500kW Inverter-1.

Figure 9 below shows the AC side SLD for the SPV power plant In the AC side, the SLD contains designing in continuation to the Iverter-1 and Inverter-2. Each inverter is connected to individual inverter transformer of 630KVA; 0.3/11KV step-up transformer is also used. After the voltage is stepped-up, the power was transmitted through the high tension (HT) cable and the rating for the same are specified in the AC side's SLD provided in the Annexure. Measuring equipment and protection circuit are further connected to the HT cable before feeding to the bus-bar. At the bus-bar, both the inverters are combined, and the power is transmitted to the load. Before the power is actually used at the load side, the step-down transformer was used along with the protection circuits to bring the voltage back to the operative level such that the equipment works.

SYSTEM CONFIGURATION						
SMB No	SMB-1	SMB-2	SMB-3	SMB-4	SMB-5	SMB-6
NO OF INPUT -Y CONNECTION	15	15	9	15	15	8
NO. OF MODULE ADD	720	720	432	720	720	408
DC CAPACITY (KWp)	194.4	194.4	116.64	194.4	194.4	110.16
STRING VOC	919.2	919.2	919.2	919.2	919.2	919.2
STRING Vmp	744	744	744	744	744	744
STRING Isc	282.9	282.9	169.74	282.9	282.9	150.88
STRING Imp	261	261	156.6	261	261	139.2
DC POWER CABLE LENGTH MTR	97.65	118.65	186.9	171.15	144.9	212.1
POWER IN THE INVERTER	505.44			498.96		
VOLTAGE DROP %	0.52	0.63	0.90	0.90	0.77	0.87

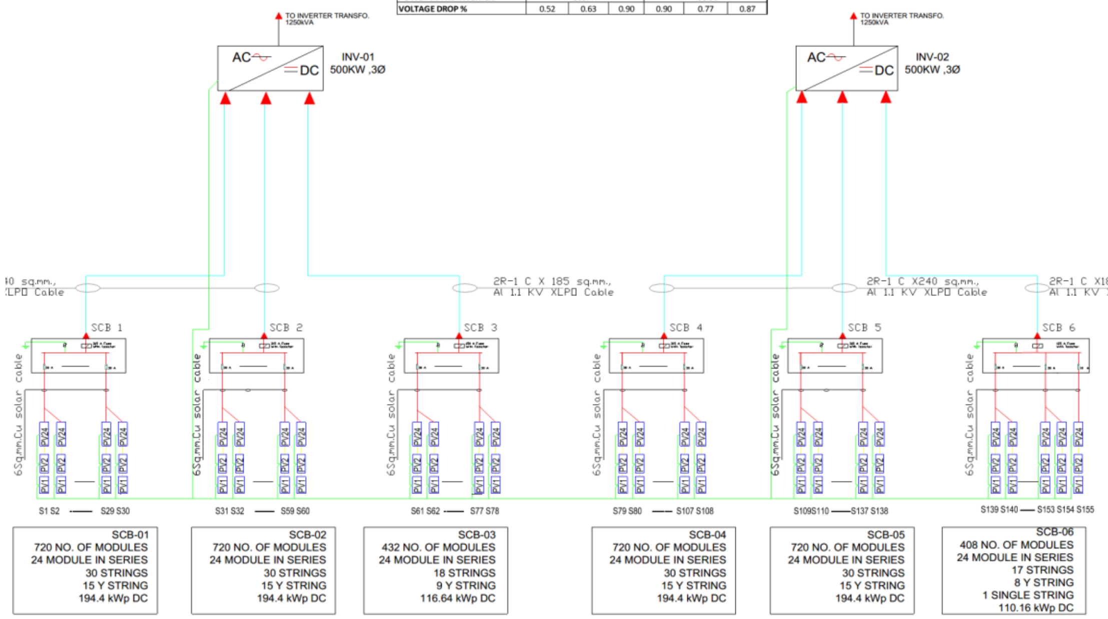

Figure 2 DC Single Line Diagram

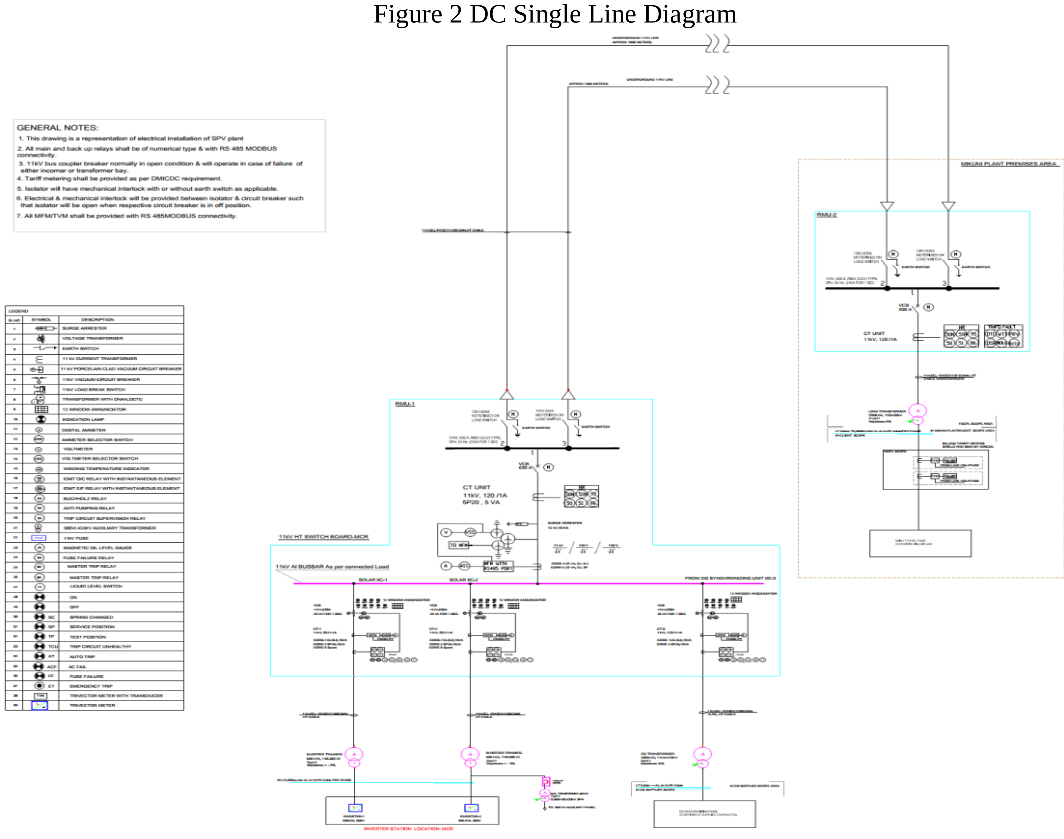

Figure 3 AC Single Line Diagram.

7. CONCLUSIONS

The research essentially aims at the designing of the DG-PV-Battery off-grid Hybrid power plant for fulfilling the industrial load at Neemrana, Rajasthan (India). The designing of the 1 MWp SPV power plant was done using the Solar Designing Software and AutoCAD software. Based on the site location the site area was studies and the array layout was designed in the AutoCAD. The tilt angle was optimized at 25º and the pitch between the two arrays was kept 6.5 m to reduce the losses due to shadow between 08:00 am to 4:00 pm for the entire year which was verified with the Solar Designing Software software. The losses due to the incorrect sizing of the cable were decreased with proper designing and selection of cable such that, the DC loss is less than 1% in all the SMBs.

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