Design of a MPPT Controller along with a Reconfiguration Technique for a PV System under Partially Shaded Condition

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Abstract— A solar power plant is an integration of different electrical and electronic components comprising of power conditioners, measurement devices, power converters, transformers etc. It also includes a storage system of lead-acid batteries, ultra-capacitors etc. Sometimes these systems also have the facility of grid integration. Thus for the proper functioning of the entire power plant requires that all the equipments operate well within their operating limits like voltage, current, power, frequency. To ensure proper operation a well defined maintenance scheduling is required which includes monitoring of the safety limits and taking necessary actions. This paper focuses on the operation and maintenance of a grid connected solar power plant of 100 KW, 240V. A detailed analysis of the installed solar power plant is done on the basis of power generated and connected load in different operating months. Based on these analyses, basic load management method has been proposed for an economical operation. Battery storage system used along with this solar power plant is also studied and different maintenance requirements for its safe operation under different load conditions have also been discussed.

Key words: Photovoltaics, Solar Power Plant, Operation and Maintenance

I. INTRODUCTION

Solar PV systems have proved to be one of the most effective ways to tackle power shortage in different parts of the world. Thus solar installations of both isolated and grid connected type has taken place to support the power requirements of the consumer. However with such increasing use of PV systems it is important to focus on the operation and maintenance of the system for safe and reliable operation in a longer time period.

Contrary to popular belief, photovoltaic (PV) power plants are not maintenance free; they require a course of continual monitoring, periodic inspection, scheduled preventive maintenance, and service calls. These actions address unplanned outages, repair and restart, and various O&M activities needed to enhance long term uptime, performance, and economic viability.

The PV plant operates with the following basic modular building blocks: Solar Inverter, Solar Batteries, Solar Charge Controller and Solar Panels. Proper plant operation requires a thorough knowledge of the voltages and currents at different points of the system. Remember when we add components in series the voltages go up and parallel additions raise the current. Thus for a large system the level of perfection goes much higher in designing of the plant. BoS or Balance of System components play a huge role in the operation of the plant and these include, system wiring (capacity and size), Earthing and Lightening protection equipment and AJB/ DCDB/ACDB which are basically Junction Boxes.

System operations and maintenance (O&M) is a broad area, and is the continuing focus of several industry/ government/national laboratory working groups that are working to better define the issues and develop consensus approaches. To maximize the system production and Return of Investment (ROI) system uptime is a key O&M objective.

An important part of ensuring the long-term safe operation of solar PV plants is to execute a thorough commissioning process, followed by regular periodic testing and an effective maintenance program. Commissioning verifies that the installation has been completed satisfactorily and safely according to the plans and applicable codes. Many of these tasks are also conducted routinely over the system lifetime as part of scheduled maintenance.

Maintenance plans should be developed as early in the project planning phase as possible. Maintenance plans are often revised and refined over time, based on plant operating experience and site-specific requirements. Scheduled maintenance includes periodic inspections, testing, cleaning, calibrations, and other recurring requirements to sustain nominal plant operations.

II. SOLAR POWER PLANT

A solar photovoltaic power plant is an assembly of different equipments like solar modules power conditioning unit, Battery bank, Array junction box etc. It is aimed at providing trouble free, long lasting and cost effective power solution to the consumer. One such Solar PV power plant is installed at Shri Shankaracharya group of Institutions (SSGI) located in Junwani, Durg, and Chhattisgarh. It was installed to provide power compensation to its loads using the Solar power and also has a grid connecting facility to supply excess energy to the grid.

Solar photovoltaic (PV) systems are like any other electrical power generating systems. In solar PV system, just the equipment used is different than that used for conventional electromechanical power generating systems. However, the principles of operation and interfacing with other electrical systems remain the same. Although a solar PV array produces power when exposed to sunlight, a number of other components are required to properly conduct, control, convert, distribute, and store the energy produced by the array.

A. Solar Modules

The solar modules are manufactured and supplied by TATA BP solar. They are designed for general purpose use for operating DC loads directly or AC loads in an inverter equipped system. The enhanced efficiency silicon cell charges batteries efficiently. They may be used in single-module and multi-module systems to meet the current and voltage requirements of a wide range of applications with its nominal power. It is well suited to utility grid systems and

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traditional applications of photovoltaic such as Telecommunications, off-shore platforms, remote villages and clinics, water pumping, grid-connect and standalone systems. The specification of a single module is given below.

Parameter	Value
Maximum power (P_{max})	175W
Voltage at P_{max} (V_{max})	35.4V
Current at P_{max} (I_{max})	4.94A
Short circuit current (I_{sc})	5.45A
Open circuit voltage (V_{oc})	43.6V
Module efficiency	14%
Nominal voltage	24V

Table 1: Module Specifications

In SSGI polycrystalline silicon material based solar modules installed which give sometime 20 to 40 ampere current in coldly whether, which is good thing for our connected load to 100kW solar system. The solar modules are made up of 72 monocrystalline silicon cells connected in series. Schottkey diodes are connected to avoid hot spots during partially shaded conditions. In the present site of the institution 580 solar modules are connected to generate power of 100KW.

B. Junction Box

The solar power plant has two main junction boxes - Array Junction Box (AJB)(Figure 1) and Main Junction Box (MJB).

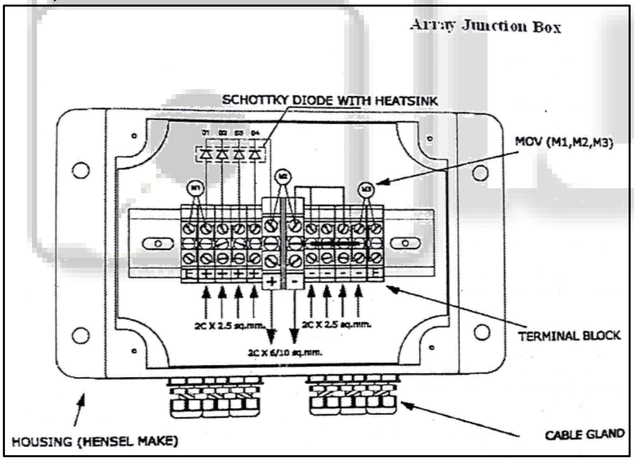

Fig. 1: Array Junction Box

The series connection of modules is called array, all combination of connection in a box, this box is called AJB. This is very clear from above diagram that there are three AJB here which connected with parallel connection and another three AJB are connected also in same parallel connection. Both three sets are connected to two MJB individually. Finally this two MJB 1 and MJB 2 present to bring DC supply up to inverter by DC cable.

In the current location of solar PV plant each module has a maximum capacity of 175W, 4A. After series connection the value of current of each module increases. AJB has different number of module connections as shown in the table below. Each AJB has more than 220A, which is very high value of current.

C. Power Conditioning Unit

The three phase DSP based Support Conditioner (GSC) is designed to operate as a multi function power conditioning unit combining the functionality of a grid interactive solar with a true on-line single conversion UPS. The GSC system allows the option of combining renewable energy sources on priority with the functionality of an industrial UPS system. Based on the solar power available, connected load and battery state-of-charge, the unit configures itself as either a charger or inverter and will intelligently start an optional back up diesel generator if the battery reserve cannot be maintained by the renewable system's contribution and there is loss of grid power.

D. AC Distribution Box (ACDB)

The main purpose of the ACDB is to eliminate the operation of the load at the immediate PCU O/P end and also provide flexible operation of different loads like Street lights, general home or office lights and optional loads that optionally operated (ON/OFF).

E. DC Distribution Box (DCDB)

The DC Distribution Box is used to provide flexibility for the operator of the solar power plant to disconnect and connect both the inward solar supply and battery terminals. Here an MCCB and a fuse of proper rating depending upon the capacity of the power plant and the battery bank are used.

F. Earthing

Earthing the solar PV system is important for both safety and protection against lightning. Earthing the equipment ensures that the system voltage cannot drift away from ground potential and thus reduces the risk of electric shocks. Adequate earthing also provides a path for fault currents induced by lightning. To make the solar power system as safe and secure, all exposed metal (e g. solar array structure, charge Controller panel enclosure, metal cable conduits etc.) should be earthed.

G. Grounding

Grounding is one of the most important safety factors of any electrical system and solar PV is no different than the other electrical system, So it is also important to ground the PV modules. This article is concerned about how grounding of modules will help to increase the quality life.

H. Lightning

Lightning is one of the most powerful phenomena of nature and produces both electric and magnetic fields which vary with distance, frequency and time. Due to the advantages of low maintenance and autonomous operation, solar power arrays are situated in many diverse, isolated and extreme locations throughout the world. Protection against a direct lightning strike should only be necessary for critical applications or where the probability of a lightning strike is high. In general effective earthing of solar array structures and associated equipment will give adequate protection in the field.

III. SOLAR PV PLANT OPERATION

The solar PV power plant is an electricity generation power plant same as thermal and nuclear power plant, the difference are here is that it is non-conventional energy resources based power plant. The operating cost of SPV PP is less as compared to the same capacity of thermal power

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plant. Solar panels reduce the peak to peak average ratio of power demand [1]. These are the following process of operation of Solar PV power plant.

The solar system generation depends on sun radiation. The operation of the 100 kW solar system installed in the campus of SSGI is observed for a period of six months i.e. from December 2014 to May 2015. The 100 kW/240V solar PV plant works from morning 8.30AM to evening 6.30 PM. The system performance is good and it continues generate electricity for the whole day which is supplied to the block either to block 01 or hostel 02. The load is also connected with state electricity board, in case of solar PV failure. The load is connected to the mains by the help of a three phase change over switch. SSGI campus load detail is varying and there is always a gap between the connected load and generation. TATA BP solar inverter gives different types of details related to generation, load, solar radiation, power factor, gird connectivity, unit consumption, battery Ah, and other important parameters. These are the following points which should be noted carefully –

1) Record all the data related to solar power plant.
2) Keep daily record for future action.
3) Perform load management in case of high generation.
4) System monitoring should be done continuously.
5) In case of over-load condition all loads are switched to mains by change over switch.
6) All data can be recorded manually or taken from the inverter.

The SSGI campus is supported by solar PV system with 100kW/240V capacity. For proper operation and maintenance we need to understand the type of problem and lack in system requirements. There are following graphs drawn on the basis of manual data collection. Figures [2] to[5] describes system and work performance –

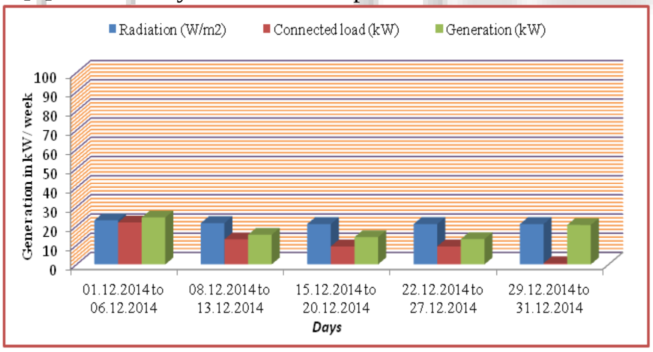

Fig. 2: Average generation & average connected load with average radiation - December 2014

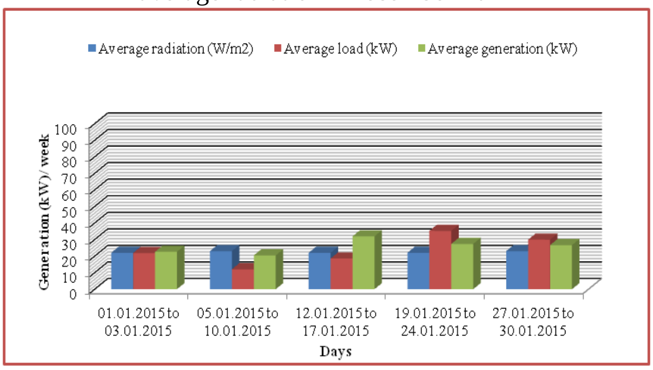

Fig. 3: Average generation & average connected load with average radiation - January 2015

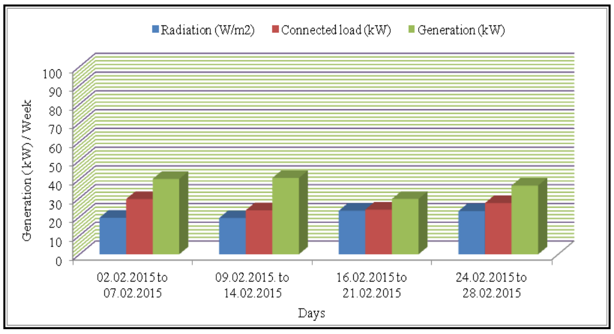

Fig. 4: Average generation & average connected load with average radiation - February 2015

Low power factor is another reason for energy losses. Power factor status of SSGI 100 kW solar system is shown in below figures.

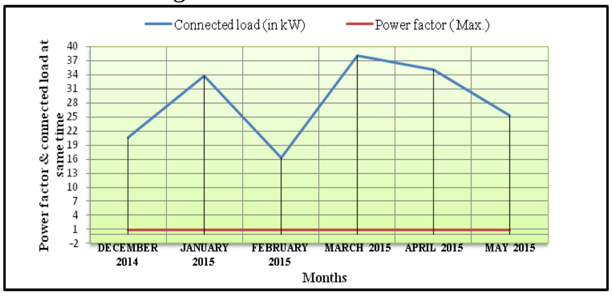

Fig. 5: Power factor & connected load versus months graph

IV. LOAD MANAGEMENT

A. First method: Load tuning method

Generation	Load
-	A
-	B
-	C
-	-
X	-
-	-
-	N

Table 1: First Method

1) Case 01

Under loaded condition (the selector selects the load which is the minimum) for greater efficiency.

$$(X - A) = \min$$
$$(X - B) = \min$$
$$(X - C) = \min$$
$$(X - D) = \min$$
$$f(x) - f\,(\text{Alphabetical symbol}) > 0$$
$$F(x) = \text{Generated power}$$
$$F(\text{Alphabetical symbol}) = \text{Connected load}$$

B. Case 02

Over load condition (Which is maximum the selector switch select the loads automatically to mains) for greater efficiency.

$$(X - A) < 0$$
$$(X - B) < 0$$
$$(X - C) < 0$$
$$(X - D) < 0$$
$$f(x) - f\,(\text{Alphabetical symbol}) < 0$$

Note – Here solar and battery is used for load. Here load is greater than the generation thus battery releases its stored energy to load.

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1) Advantages

- Fine use of generated energy.
- 100 % back-up supply present for institute load at all times.

2) Disadvantages

- High initial cost for hardware & Software material (Estimated cost 3 to 5 Lakhs)

C. Second Method: Total Feeding Method

1) Case 01

The selector loads which is least for greater efficiency

$$(X - Y) = \min$$
$$(X - P) = \min$$
$$(X - Q) = \min$$
$$(X - Z) = \min$$

2) Case 02

The selector automatically selects the load which is greater for greater efficiency.

$$(X - Y) < 0$$
$$(X - P) < 0$$
$$(X - Q) < 0$$
$$(X - Z) < 0$$

Tuned method – Remain feed method

3) Advantages

- No large calculation is required.
- No load management is required i.e. 100 % economical method.

4) Disadvantages

- No back-up supply is present in case of grid failure.

V. MODULE AND BATTERY MAINTENANCE

A. Module Maintenance

Photovoltaic modules require very little maintenance as compared to other parts of the system. These are the following maintenance required for optimum performance

1) In view of the till angle of the PV modules, normal rainfall is sufficient to keep the module glass surface clean in most weather conditions. However, if dirt build up becomes excessive, clean the glass surface only with a soft cloth or sponge using water. The 100 kW capacity modules clean by water on last day of Dec2014, Jan 2015, Feb 2015 and May 2015 but March 2015, April 2015 two month not clean because water level of bore in campus decrease and management give order orally don't use water in other work & save water.
2) A mild non abrasive cleaning agent can be used for stubborn dirt. Do not use high pressure water spray or chemicals to clean the module.
3) In SSGI cleaner clean modules with low pressure water and using rubber type wiper, which depend on the PV penetration level [11]
4) In order to insure proper operation, should check all wiring connections, condition of the insulation and mechanical connections every six months.
5) Observe the maintenance instructions of all components used in the systems such as support frames, inverters, battery and charge controllers etc.

B. Battery Science

1) Special features of low-maintenance cells / Batteries

- Special alloy for grids to minimize water loss & self-discharge.
- High impact resistance rugged hard rubber containers and covers
- Reduced frequency of water topping up.
- High charging efficiency
- Low self-discharge
- Long service life under deep cycle usage.

Low maintenance lead acid cells / batteries consists of tubular positive plats, Pasted negative plats and micro porous separators assembled in high impact resistance rugged hard rubber containers and covers. Each cell provided with bolted type terminals, micro porous vent plugs and float guides.

2) Tubular Positive Plate

Spine grids are made of corrosion resistant lead alloy and are pressure die casted. Multi-tubular bags fitted to grids have high outstanding (better to replace with some other word) characteristics of porosity, acid resistance, oxidation resistance and high rupture (word "puncture" may be more appropriate) strength. This design of tubular positive plate enables the active material to be retained within the bags so that shedding is restricted during its service life.

3) Pasted Negative Plates

It consists of grids with ribbed structure made from lead alloy and having pockets, which holds the active material firmly. The active material is prepared under controlled conditions with necessary additives for an efficient electrical performance of the cell / battery including features of long life.

4) Micro Porous Vent Plugs

Micro porous vent plugs minimize evaporation of water from the cell / battery and the porous structures trap the escaping water vapour and allow only gases to go out.

5) Float guides / Level indicators

An aid level indicating float guide with level marking is located at the top of each cell for showing the acid level.

C. Battery Maintenance

Here are four major types of problem in solar LMLA (Low maintenance lead acid) battery-

1) Battery terminal sulphation problem
2) Low gravity problem
3) Swelling of battery
4) Low level of distilled water
5) Solution of above problems
6) New nut bolt & copper strip fitting
7) New same capacity battery require
8) Remove the swelled battery form line
9) Filling distilled water

General battery life is up to 5 years. After 5 years following problem are created

1) Battery specific gravity decreasing
2) Voltage of battery decreasing
3) More distilled require
4) Solution of above three problems-

- Generally battery gravity should be between 1100 to 1250 but gravity decreases continuously with time. Sometimes dilute H_2SO_4 is mixed with distilled water of battery to increase its gravity. After some week each

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battery voltage is checked again, battery voltage decreases from 2V. If its gravity does not increase to 1100 then battery is removed from line. The above picture shows after removing battery from line.

- After adding dilute H2SO4 in battery, battery voltage monitoring is continued. In case of decrease in voltage the first method is repeated.
- For maintaining battery charging it is necessary here that battery charging continues when sun radiation is from 24 to 25 W/m2. Distilled water boils fast and finally battery dries. In same condition if battery charging continues then internal lead plate terminal damages permanently. So to protect above bad effects add distilled water (PH-07 value) from time to time in battery. The required amount of distilled water easily can be identified by float indicator which is shown in the figures above.

VI. Regular Operation and Maintenance

There are following methods here at same time require protection without come to knowledge may be danger electrical and chemical accident possible –

A. Distilled Water Filling Method

The above figure shows the method to fill distilled water. First of all take one plastic funnel and a five liter can, then fill the can with distilled water with the help of hose pipe as shown in the above figure. Then bring the can towards battery bank. There are six caps on top of battery, open any one cap remote from you and keep it on top of the battery slowly. It is important that this cap does not touch our cloth or skin as dilute H_2SO_4 sticks on surface of cap. Now insert funnel in the hole of battery and fill distilled water through funnel slowly. This time continuously monitor float level, when float level reaches its maximum level then stop filling water and try to avoid from over flow.

B. Battery Removing Method

There are seven switches and one change over switch here. Before low gravity and zero volt battery removing its very necessary that flowing steps are followed –

1) Operate change over switch and convert supply of first block from solar to mains.
2) Switch OFF DC charging switches which located in DCDB box, both switches OFF.
3) Switch OFF AC supply switches located in ACDB box step by step. This switches isolates inverter from load completely.
4) Inverter OFF by gave virtual switch as shown in picture.
5) Battery switches OFF step by step both switches located in inside of inverter. This two switches switching OFF is very important and necessary protection point of view.

C. Specific Gravity Checking Method

We check specific gravity by the help of hydrometer. Checking of gravity is very careful work. On top of the hydrometer there is a cape by which the distilled water is sucked by vacuum method from inside of battery. The hydrometer is kept at as much distance as possible. The water level is read carefully water is refilled inside the battery after registering the gravity level carefully. All 120 nos. of battery should undergo specific gravity checking step by step and all the data is registered. After completely checking gravity the hydrometer is washed by normal H2O. Washing method is same as gravity checking method only difference is that we use simple normal water for washing.

D. Spongy Filter Replacing Method

The inverter has two FD fan for cooling of internal parts and circuits of inverter. This fan continues to suck the air. This air is filtered by spongy filter before entering the inverter. Spongy filter is a simple filter which filters the dust inside of the inverter circuit. This filter should be changed after every 6 months. Five years have passed since the installation of this power plant but filter has not been changed by management of SSGI. This filter was changed on 15th May, 2015.

VII. Conclusion

Regular maintenance should be done during whole life of the system as shown below. All maintenance was done during 6 months from Dec 2014 to May 2015 step by step. The results are as follows –

1) Work performance of solar system increased as compared to previous months.
2) Life of system mainly battery life increased after removing non-functioning battery.
3) Efficiency of solar system like generation and inverter working increased.
4) Over all every main parts of solar system is perfect and working nicely.
5) Replacement of major costly parts is avoided i.e. above all regular maintenance gives economic benefit.

After analysis these methods are tried to remove generation losses

1) This battery can be used to back-up solar system and replace grid connected string inverter to use generated energy one hundred percent.
2) Management of SSGI is trying to appoint a separate technical person for proper monitoring and regular maintenance of system.
3) Module cleaning is a regular and necessary duty of cleaning staff.

The following points were noted –

1) Generation is more only in Dec 2014 (highest in winter season) as compared to other months.
2) Power factor (PF) of the SSGI campus is very low.
3) Generated energy is lost continuously.
4) Solar system completed their life so maintenance cost increases with time.
5) System upgrade is required.
6) Energy audits are required to increase economical operation.

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