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String Monitoring and Control System for Solar Photo Voltaic Power Plants

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Abstract:
This paper presents String Monitoring and Control System developed for Solar Photo Voltaic Power Plants. The developed system allows the operator to monitor and record the plant parameters at sub-system (string) level. Thus, bad strings if any alone can be isolated from remote, thereby preventing the bad string from making the plant operate at lower efficiency and reducing power generation. Also, array or the entire plant need not be shut down for fault in one string.

Keywords: *Solar Photo Voltaic (SPV) Power Plants, SPV Module, String, Array, Power Conditioning Unit/ SPV inverter, String Monitoring and Control System (SMCS)*

1. Introduction

Solar energy based power plants are the need of the hour. Jawaharlal Nehru National Solar Mission (JNNSM) has set an ambitious target of deploying 20,000 MW of grid connected solar power by 2020 and is aimed at reducing the cost of solar power in the country through long term policy, large scale deployment goals, aggressive R&D and domestic production of critical raw materials, components and products as a result to achieve grid tariff parity by 2022.

BHEL has installed more than 20 MW of grid connected SPV Power plants at number of sites. The major components of SPV Power plant[1,2] consists of SPV modules, Power Conditioning Unit (PCU) or SPV Inverter, plant monitoring system at String or Array level including Supervisory Control & Data Acquisition (SCADA) and installation structures for mounting SPV modules, cables and transformer & switch gear accessories. At present, BHEL is producing SPV modules with an annual capacity of 25 MW at its Electronics Division Unit, Bangalore. BHEL has taken an initiative for in-house development of Inverter, and other required C&I for SPV Power Plant to provide total solution to the customer.

A 250 kW Solar Photo Voltaic (SPV) Power Plant has been installed at BHEL Corporate R&D Division, Hyderabad. The generated power is supplied to the grid. An experimental platform is available to test and to evaluate the long term field performance of products/technologies that are being developed in house such as different types/sizes/wattage of SPV module, tracking, module cleaning and cooling technologies and different ratings of Inverters.

String Monitoring and Control System has been developed to monitor and control plant at string level. This helps in quick fault detection & isolation and quick outage recovery.

2. SPV Power Plant Setup at Corporate R & D

SPV power plant is of 250 kW rating and has been configured into forty seven Strings (S1 to S47) stacked in five Arrays (A1, A2, A3, A4 & A5). Twenty SPV Modules connected in series make one string. Ten number of such strings are connected in parallel to form an Array. There are four such arrays (A1, A2, A3 and A4). The last and fifth array (A5) has only seven strings connected to it. The output of the five arrays is given to PCU via combiner box. The AC output of the PCU is fed to grid via transformer unit.

The SPV Module is of BHEL make [3,4] and is of 270 Wp rating. It is made with single glass laminated type with 72 Nos. of 156mm mono crystalline silicon solar cells (12x6) in series configuration. The plant consists of 940 Nos. of such modules. Ten number of SPV modules are mounted on one structure.

Monitoring and control circuits are installed at string level in String Control Junction Boxes (SCJB). To isolate at array level, MCB based tripping mechanism is present in five Array Junction Boxes (AJB). SCJBs & AJBs are located in the field.

The PCU is located in the control room. It consists of Inverter Unit and Transformer Unit.

Inverter Unit converts the DC output of SPV plant into AC and exports the power to the grid by harvesting maximum power from SPV plant through Maximum Power Point tracking (MPPT) algorithm. The cut-off and cut-in for inverter operation are based on DC voltage values which are programmable. The Inverter is of Grid Interactive type and has an in-built mechanism for auto tripping on grid failure and auto cut-in on grid-on condition. The Inverter Unit has breakers at its input and output for manual operation.

The Inverter Unit has a number of sensors to measure various currents and voltages at both input DC side and output AC side. The environment parameters such as wind speed, ambient and SPV module temperatures are brought to Inverter Unit. The read data can be visually seen on a display unit mounted on front side of the unit. Also this data is stored and is made available to control system via RS232 interface.
The Transformer Unit also has a number of sensors to measure various currents and voltage parameters at secondary (grid) side. The signal is first fed to an energy meter which has an RS485 port as control system interface.

3. String Monitoring and Control System (SMCS)
Power from SPV plants is channeled via arrays (i.e. arrays JBs). This is mainly to avoid low cross-sectional area cabling coming directly from strings/modules to Inverter Unit(s) and thereby reducing the cable power loss. Also, tripping the entire plant for maintenance is avoided by use of arrays. However, since arrays are few in number, a substantial portion of power is still lost in the event of maintenance shutdown of an array. This can be avoided if shutdown of plant can be carried out at string level.
The power from each sting is first brought to a SCJB via incoming cables to suitably rated MCB. From MCB, cables are connected to a Surge Protection Device (SPD)[5,6]. SPD is connected across the lines to protect from surges. The positive cable then is connected to a DC rated fuse which in-turn is connected to a diode of suitable rating. An isolated DC current sensor is used to measure string current. To measure string voltage, a DC voltage sensor is mounted in SCJB. These signals are routed to control system located in the Control room.
MCB in SCJB has feature of control command based tripping via a shunt relay. An auxiliary pole provides feed back to control system on the status of MCB. MCB is designed to trip on over current, thermal and reverse polarity conditions.
The MCB feedback together with the current and voltage signals forms the monitoring part, whereas the relay part is the Control part of String Monitoring and Control System at the field end.
Data Acquisition & Control (DAC) System is based on in-house Metso platform. The field signals are brought to Metso control panel located in control room via signal cables. The field signals pass through SPD (signal level).
The signals from Inverter and Transformer Units are Modbus based and brought to Metso network via LAN.

4. Human Machine Interface
Human Machine Interface (HMI) is Graphical User Interface (GUI) based and has been developed using software engineering tools of BHEL in-house Metso platform [7]. The Data Acquisition System (DAS) collects data (current, voltage & MCB status of each string, MCB status of each array & solar radiation) from the solar plant. Data related to Inverter/Transformer Units and environmental data is obtained from PCU. The collected data is displayed on the computer screen. It provides an overview of the SPV power plant consisting of forty seven strings with respective SCJBs and AJBs as laid out physically in the field. It indicates the ON/OFF status of the forty seven strings and five arrays of SPV power plant.
The GUI is designed for ease of operator interface. Using GUI, plant operator can monitor the plant status at different levels such as string, array and overview level and trip the plant from a remote location (control room). A snapshot of the HMI screen of Single Line Diagram (SLD) of the plant is shown in Figure1.

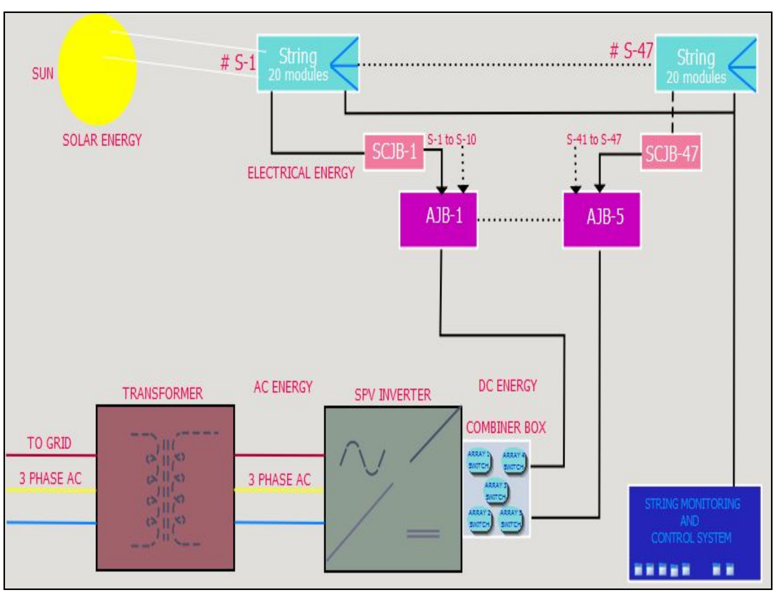

Figure 1: Single Line Diagram of the plant

SLD[8] displays various stages of the plant and the flow and conversion of energy from solar into electrical. The first stage indicates solar energy i.e. solar radiation received by the plant. The second stage is the SPV plant which converts the solar radiation into DC

power. The third stage indicates status of Inverter Unit of PCU. The Inverter Unit receives DC Power from solar plant and converts it into AC Power and exports to grid through Transformer Unit.
A snapshot of the HMI screen of one SCJB schematic (SCJB01) is shown n Figure 2

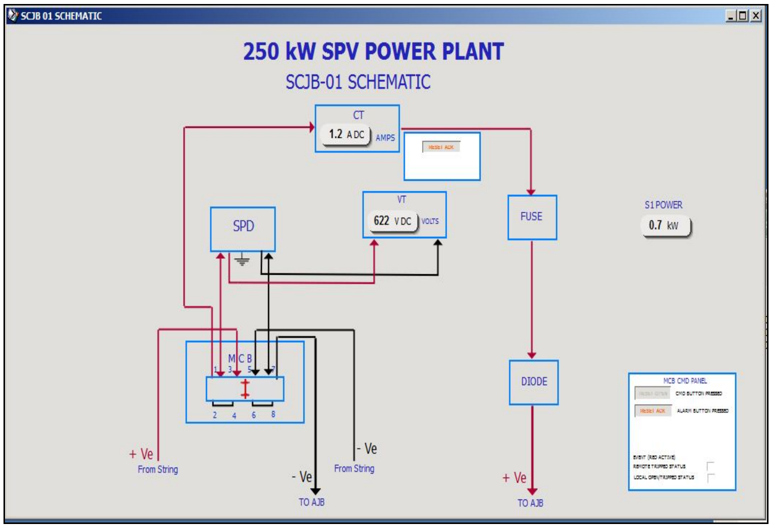

Figure 2: HMI screen snapshot of SCJB schematic

The schematic displays both power circuit and signal status for one of the strings. It displays DC current & voltage of the String along with DC power generated. The ON/OFF status of the string is displayed via MCB contact status. The option of tripping the MCB thereby disconnecting the string from rest of the plant is provided. The current is compared with other strings and an alarm is raised in case of excessive deviation. Also, if the current approaches rated short circuit value then, string is tripped by protection logic programmed in Metso Control panel.
A snapshot of the HMI screen for one AJB (AJB01) is shown in Figure 3.

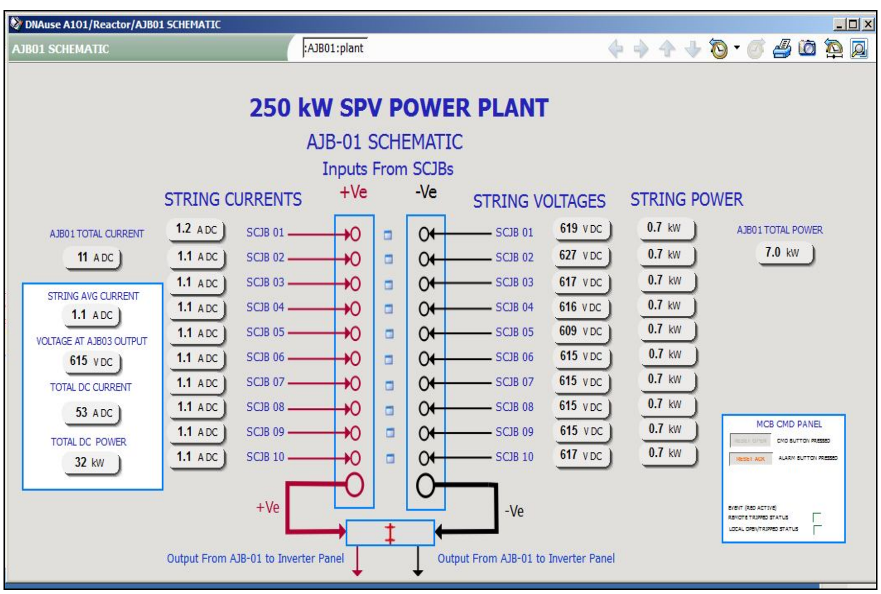

Figure 3: HMI screen snapshot of AJB schematic

The schematic displays series of strings joined in parallel at AJB and DC voltage & power at AJB level. MCB contact status and tripping option is also shown.

5. Data Logging
The Metso platform is equipped with a database which records the data, at user specified interval. Critical data is logged and trends are used to display long term data. The stored data can be retrieved to Excel or PDF files for further processing.

6. Advantages of String Monitoring and Control System (SMCS)

SMCS allows the operator to monitor and record the plant parameters at sub-system (string) level. The recorded data can be used for analysing long term performance of plant. Snapshot of string currents of AJB01 is shown in Figure 4.

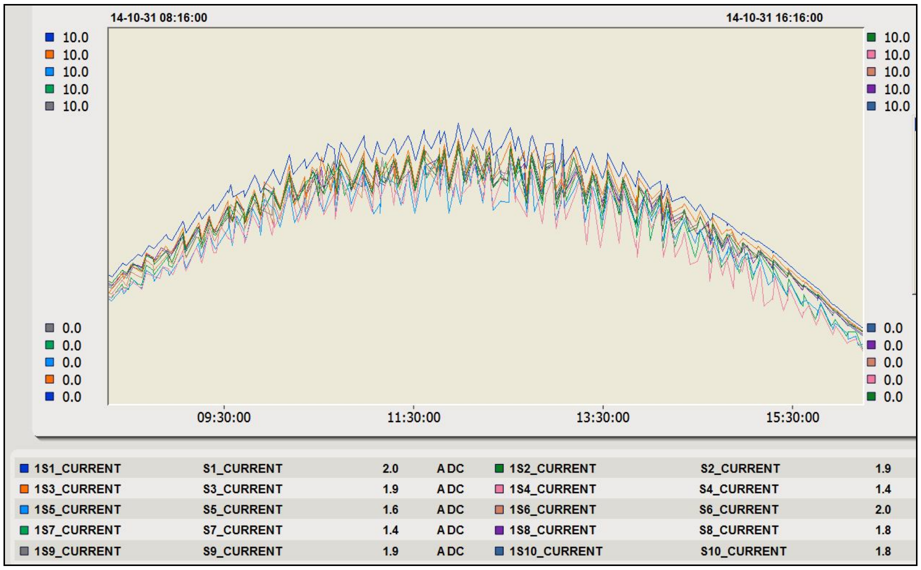

Figure 4: String currents of AJB01

The GUI indicates the status/healthiness of all strings. Using a GUI, a selected string can be isolated from the rest of the plant for maintenance/repair works. If there is any over current in any string, the MCB in the SCJB trips and thereby isolates the string from rest of the plant. This action helps in preventing the bad string from making the plant operate at lower efficiency and generating lower amount of DC Power for given solar radiation. Now only one string is isolated and the rest of the plant can operate at rated voltage with full efficiency and thereby generate maximum power for given environmental conditions.

7. Improvement upon Plant Efficiency

The output of SPV plant depend on various factors such as solar radiation, time of day, month & year, SPV Module/cell & ambient temperatures, collection of dust on the SPV modules. The DC power generated is directly proportional to solar radiation incident on the SPV modules. On the other hand, DC power generated is inversely proportional to SPV Cell temperature and dust on the SPV Modules. Also, any shadow drastically reduces the plant output. To reduce this plant should be located far from any tall structures. Vegetation should be minimum in the plant area especially near SPV modules. This reduces the shadow effect and increases air circulation in plant area. Further, angle of incident radiation (which depends on time of year) has bearing on the plant output. The effects on some of these factors on plant output can be seen from the graphs Figure 5 & Figure 6.

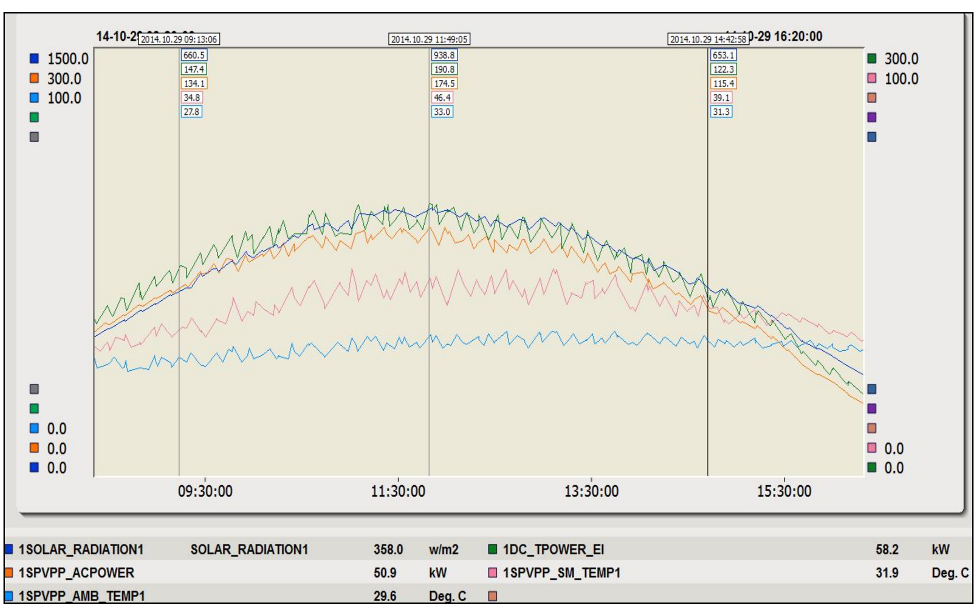

Figure 5: Effect of solar radiation and angle of incidence

The effect of solar radiation and angle of incidence can be seen from Fig.5. The plant DC output faithfully follows the solar radiation curve. However, the time of day thus angle of incidence also has effect on the DC output. The DC output is higher in morning compared to afternoon for same radiation (the curve is slanting faster).

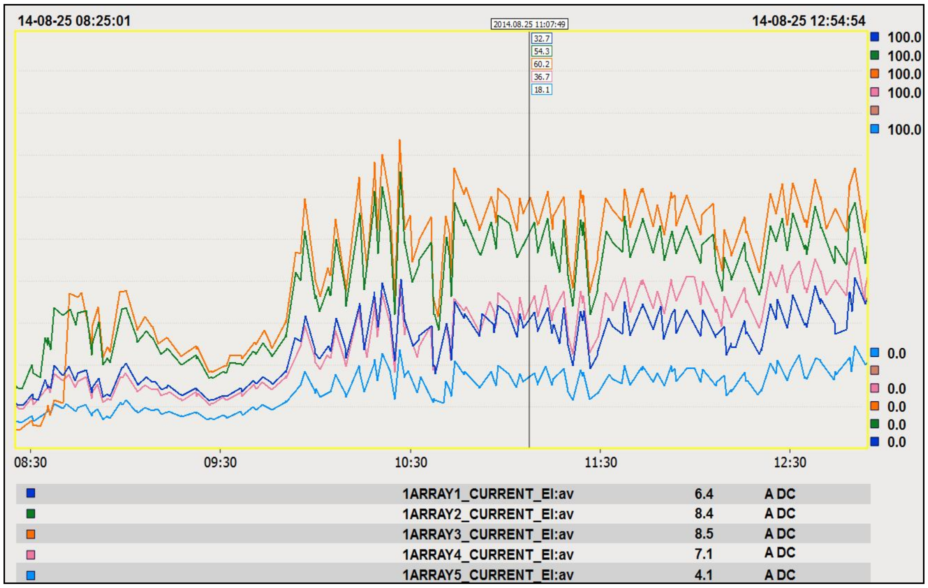

Figure 6: Effect of vegetation

The effect of vegetation can be seen from Fig.6. The DC output of array 2 & array 3 (where vegetation was removed) is higher than array 1 & array 4.

8. Conclusion

This paper presents String Monitoring and Control System developed for Solar Photo Voltaic Power Plants. SMCS allows the operator to monitor and record the plant parameters at sub-system (string) level. Thus, bad strings alone can be isolated from remote, thereby preventing the bad string from making the plant operate at lower efficiency and reducing power generation. Also, array or the entire plant need not be shut down for fault in one string.

The effect of solar radiation, angle of incidence and effect of vegetation near solar modules on plant performance is discussed in detail with logged data.

Optimization in plant design in key areas such as SPV module, civil & mechanical structures, control & instrumentation (C&I) and module cleaning/cooling are being taken up as part of developmental work. Also, development of SPV Inverter of higher ratings is underway.

9. References

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