Power Electronics Unit With Grid Interactive Facility.

G.R. Mohapatra, A. Kalam, A. Zayegh
Save Energy Research Group
School of Communications and Informatics
Victoria University
P.O. Box 14428 MCMC Melbourne
VIC 8001 Australia

Abstract

100kW Solar Photovoltaic Power Plants have been installed in East Brunswick by CitiPower Ltd. Funding for the project came via a Local Government Development Program (LGDP) grant from the Federal Government. In the absence of prior experience on such a large capacity Solar PV Power and Wind Turbine Plants, an experimental pilot PV power plant of 25kW capacity was installed in East Brunswick by CitiPower Ltd. to gain hands-on experience. The lessons learnt were made use of while installing the two power plants. This paper briefly describes the features of the two power plants. The developmental approach adopted is based on "Building Block Philosophy" with 25kW system as the basic unit. It includes the indigenous design and development effort made for grid connected operation. Most importantly the special design features incorporated to ensure a very high degree of safety and protection necessary in the community. The paper is concluded with some important lessons learnt from both the technical and logistics point of view for guiding installation of similar plants in the community in Australia.

1.0 Introduction

Custom power [1] concept, initiated by electric power research institute (EPRI), provides the electric utility industry with a low loss technology, in the range of 0.5% to 1% to meet the power quality needs of customers. In early 1991, to gain experience in setting up of large Stand Alone and Grid Interactive Solar PV power plants, CitiPower took a lead role in conceptualising and setting up of two identical 100kW Power Plants in Melbourne. The Federal Government funded the project and was closely associated in pioneering efforts from the very beginning, providing both technical and financial support. Butler Solar, a private sector company, was enthrusted by CitiPower in mid 1992 the task of design, indigenous development, installation and commissioning on a turn-key basis of both the PV Power plants. CitiPower is continuing the association that its predecessor Brunswick Electricity had for over a decade with CERES (Centre for Education and Research into Environmental Strategies) in East Brunswick. This is a community organisation with some 18,000 students and as many other visitors per year. The wind/PV system provides power for CERES, with the excess going to other users on the grid.

The fact that the Power Electronics Unit (PEU) with Grid Interactive Facility was being developed for the first time in the country suiting the Australian Grid conditions, Butler Solar decided, in mid 1992, to set up a 25 kW pilot PV power plant at its premises to gain hands-on experience. It also validated the indigenous development approach. The lessons learnt were made use of while installing the two power plants.

2.0 Developmental Approach

In view of the wide fluctuation in the voltage (±10 %) and frequency ($\pm 1Hz$) in the Australian grids, a PEU of 25 kW capacity was indigenously developed. The building block philosophy using a modular approach has the following advantages:

Flexibility: The basic units of 25 kW capacity can be suitably combined to provide upto 100 kW capacity, depending upon arrangement of sub-arrays connecting them. This permits configuration of the PV array as required to meet any load and transferring the remaining generated power to the electric grid, thus optimally utilising the generated power.

Redundancy: The use of single PEU, for community load has a serious disadvantage of total disruption in case of failure of the PEU. On the other hand, two or three PEUs (of 25 kW capacity) paralleled to cater for the total village load has the advantage that in case any one of them fails or is shut-down for maintenance, power to the community will not be affected. Such redundancy automatically ensures the availability of uninterrupted power from the plant to the end-users.

Reliability: Since the basic unit handles only 25 kW power, the solid state devices used are of lower ratings and thus, enhances the reliability of such devices.

Efficiency: The inverters have better efficiency when operated at 50% of the load or above and maximum efficiency at near full load conditions. Thus a 25 kW PEU will be more efficient than a 100kW PEU for smaller load.

3.0 Salient Features

Both the 100 kW PV Power plants consist of two independent parts.

Stand Alone Mode: 75 kW

Grid Interface Mode: 25 kW

Stand Alone Mode:

The stand alone mode has been designed to provide electricity for the domestic loads. The domestic load has a solar water heater and some non-electric appliances. Broadly it consists of the following subsystems/ Balance of Systems (BOS).

a) A PV array of 75 kW comprises of 72 panels of 1.05 kW each made of vintage amorphous silicon modules operating at approximately 2.5% efficiency [2,3]. Each panel has 30 PV modules all connected in series to provide a panel DC output of 1.05 kW at 480 Volts. The interconnection of 24 such panels in parallel arranged over two rows forms a sub array of 25 kW and three numbers of such sub arrays in parallel forms 75 kW. The DC output from each of the three sub-arrays is routed through necessary junction boxes and isolator switches to Direct Current Distribution Board (DCDB) from where it is fed to the PEUs.

Power Electronics Unit (PEU): The PEUs used in the stand alone mode have

i) A charge controller for protection of the battery bank from over charge/deep discharge.

ii) An inverter to convert DC output of the PV array to AC power, meeting all the safety, wave shape and transient behaviour requirements laid down by the Electricity Authority.

iii) Provision for control and protection of components within the PEU as well as certain equipment outside the PEU.

All the three charge controllers are connected in parallel to charge the battery bank of 360 volts, 2000 AH. The inverter inverts the DC power into 415 V,AC, 50Hz, 3 phase. The output of all the three PEUs is synchronised and is fed to an AC Distribution Board (ACDB), from where the power is distributed to different loads i.e., domestic loads through an overhead LT transmission line.

Battery Bank: The battery bank is of 360 V, 2000AH capacity using tubular positive plate, lead acid cells of 2V each which are housed in transparent containers.

Electric Load: The plant in the stand-alone mode caters to the domestic loads of compact fluorescent lamp (CFL) of 9W each, 6 nos. street lights and 2 nos. of submersible centrifugal water pumps of 3 HP each.

Grid Interactive Mode:

The PEU used for grid interface is to directly convert the input power to AC, three phase. The DC output from one of the sub-arrays (25 kW) is fed to PEU. The three phase 415V, 50Hz, output from PEU is interfaced with grid through appropriate power switching and protection devices as shown in Figure 1. Provision of an indigenously developed data logger has been made to record the specified PV array parameters and the energy transferred to the grid.

Key parameters addressed in the design and development of the PEU:

i) High efficiency charge controller and inverter based on PWM technique have been used. The output voltage and frequency are maintained constant over a wide band of load variations and input voltage variation. Total harmonic distribution in the output sine-wave form is maintained within 5%.

ii) The inverter is capable of handling surge currents of the order of 150% of its rated capacity for a duration of one minute for operation of 3 phase induction motors.

iii) The inverter is designed to protect itself from output overload and short circuit conditions. It will trip in case of any short circuit for overload conditions.

iv) It accepts a wide window of DC voltages viz 330V to 600V.

v) The PEU start and shut-off procedure needs to be very well defined and understood. Initiation of starting procedure must be contingent upon the availability of the PV and grid power. Connection of de-energised PEU or a PEU out of phase with grid power can result in reverse flow of power which can lead to components damage.

vi) The PEU must not be attempted for interconnection with a de-energised power grid. It can lead to damage to the PEU and the safety of staff working on grid line is jeopardised. The paralleling/interfacing of the PEU with the grid may be utilized only when the grid power and the minimum required solar power are available. Also the interfacing must be carried out automatically when the synchronous conditions are met.

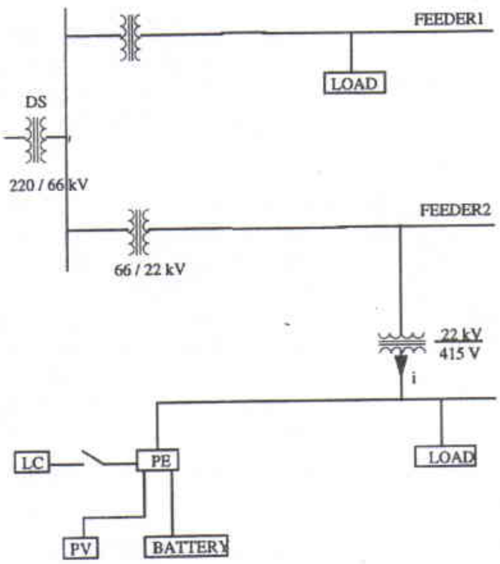

Figure 1: A distribution network utilising PV modules

PE	POWER ELECTRONICS
PV	PHOTO VOLTAIC
LC	INDUCTOR AND CAPACITOR
DS	DISTRIBUTION SUBSTATION

4.0 Safety Considerations

Human safety is the most important consideration in the PV Plant installation, operation and maintenance. Therefore, all possible safety aspects have been incorporated in the plant. Some of the important aspects are as follows:

i) Floating ground of the battery bank;

ii) All non-current carrying metallic parts in the PV array are grounded;

iii) Fool proof grounding scheme for the PV array, PEU and the transmission line;

iv) ON/OFF switching procedures for grid interfacing to avoid reverse flow of power;

v) Suitable junction boxes to isolate the PEU from the PV array;

vi) Use of MOVs to protect the array from high voltage transients;

vii) Use of MCCBS to isolate the Battery bank from PEU/PV array.

5.0 Lessons Learnt For Future Guidance

Some of the important lessons learnt during execution, operation and maintenance of the PV Plants are summarised below:

i) Behaviour of the leakage current to ground in PV panels and sub-arrays.

ii) Insulation requirement at various points in the PEU and Junction boxes under high voltage.

iii) The module up-keep at high voltages and their behaviour over a long period of time and their maintenance.

iv) The behaviours of high voltage battery bank over a period of time and the problems associated with its safe installation, operation and maintenance.

v) The requirement of isolation control and protection switch gears when interfaced with the grid.

vi) The problems associated with the transmission and distribution line in rural areas with respect to safety and efficient use of power.

6.0 Conclusion and future direction

Currently the trend is to use advanced power electronic controllers, such as solid state circuit breakers, Dynamic Voltage Regulators (DVR) and Static Condensers (STATCON) along the distribution line. Future direction is to integrate these power electronic controllers with non-conventional energy sources which are connected through power electronic controllers to the distribution network Figure 2. For a small generator connected to a utility distribution system, both the terminal voltage and frequency are fixed by the network and so it has little control over its terminal voltage and none over the system frequency [4]. Synchronous generators are attractive for utility interconnection as they allow independent control of real and reactive power [5]. Integrating such a system can provide electric utilities with a technology option that gives high quality, value added power supply suitable for customers' sensitive loads. Connecting dispersed sources of generation and storage battery through power electronic controllers combined with solid state circuit breakers, STATCON and DVR has several impacts on the operation and protection of the whole system [6]. The placement of a variety of controllers at the load centre will require significant coordination to insure proper operation under a variety of circumstances. Safety, protection of equipment, detection of faults, restoration of services, quality of services, and cost all need to be considered when connecting all these equipment with a distribution network.

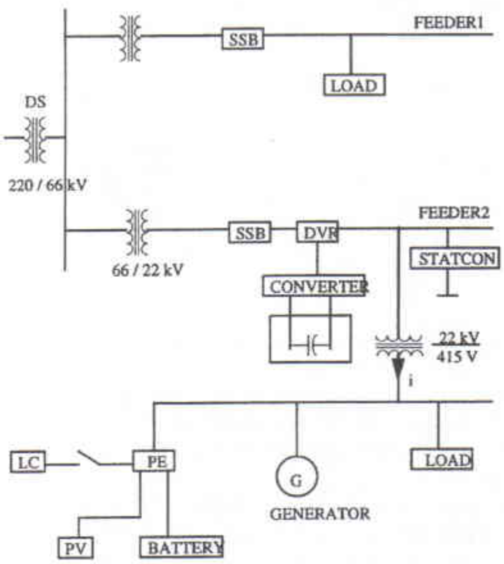

Figure 2: A distribution network utilising variety of controllers

SSB	SOLID STATE CIRCUIT BREAKER
DVR	DYNAMIC VOLTAGE REGULATOR
STATCON	STATIC CONDENSOR
PE	POWER ELECTRONICS
PV	PHOTO VOLTAIC
LC	INDUCTOR AND CAPACITOR
DS	DISTRIBUTION SUBSTATION

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7.0 References

[1] V.H Tahiliani, H. Mehta: Custom Power-Utility's Response to Power Quality Issues Presented at the America Power Conference, April 1992.

[2] D.A. Fagnan, R.V. D'Aiello and J. Mongon, "Solarex/Philadelphia Electric Amorphous Silicon PV Test Site", Proceedings of the 20th IEEE photovoltaic Specialists Conference, New Orleans, LA, May 1987.

[3] D.A. Fagnan, R.V. D'Aiello and E.N. Twesme,"Performance of Solarex/Philadelphia Electric Amorphous Silicon PV Test Site", Proceedings of the 21th IEEE photovoltaic Specialists Conference, Las Vegas, NV, September 1988.

[4] N. Jenkins "Embedded generation", Power Engineering Journel, IEE, Vol. 9, No.3, June 1995, pp 145 - 149.

[5] P.M. Anderson and A.A Fauad "Power system control and stability", Iowa State University Press, 1977.

[6]G.R.Mohapatra,A.Kalam,A.Zayegh "Dynamic stability analysis of renewable enegy sources interconnected to the distribution network",MS'97,Victoria University, Melbourne,1997.