SOLAR ENERGY INITIATIVES AT THE DAYALBAGH EDUCATIONAL INSTITUTE

D. Bhagwan Das, A. K. Saxena
Faculty of Engineering
Dayalbagh Educational Institute,
Agra – 282 005, INDIA

The Dayalbagh Educational Institute (Deemed University) (*www.dei.ac.in*) is one of the premier Universities of India. Situated in Dayalbagh, which translated into English means 'Garden of the Merciful', the institute provides education from High School to Post Graduation level. The Institute has introduced a scheme of innovative and comprehensive education at university and non-university, general and technical education levels which aims at excellence but not at the cost of the relevance, which inculcates dignity of labour, encourages initiative and creative work, which is multi-disciplinary, which prepares men for the increasingly techno-oriented society of tomorrow without uprooting them from their agricultural moorings, which will generate in the alumni the basic values of humanism, secularism and democracy by exposing them to the principles of all the major religions of the world and to their own cultural heritage, thus developing in them an integrated personality of a well-adjusted complete man.

In order to attain the lofty vision through sustainable developmental activities in agreement with the concept of Eco-Village, Dayalbagh Educational Institute (D.E.I.) has taken initiatives in harnessing the renewable energy through Solar thermal and Solar Photovoltaic (SPV) power plants. The institute has Solar Thermal Cooking systems in all the hostels. The whole university campus is powered by 11 Distributed Roof-Top Solar PV power Plants aggregating to a total of 658.2kWp, installed during 2011-2016. The micro grid is being converted into a Smart Micro Grid with centralized monitoring and control of all power plants with the help of a need-based R&D project funded by DST CERI. A 200 kWp solar-agriculture farm is being developed in the Dairy campus as part of DST Mission Innovation R&D project. Apart from the Dayalbagh campus of the institute, a total of 40kWp has been installed at its ICT Distance Educations Centers in various cities and about 150 kWp within Dayalbagh colony for residential quarters and institutions. The Dayalbagh Town Area has been declared as a Green Campus by MNRE, Government of India. D.E.I. was given Excellence Award and Certificate of Appreciation for Effectively using CST system for Community Cooking in the Institution and Second Prize for Energy Conservation measures adopted in the Institute in UP State on 29th April 2016 by Mr. Piyush Goel, Hon. Minister, MNRE, GoI.

RENEWABLE ENERGY INITIATIVES AT DEI

A brief description of the various renewable energy projects (completed and ongoing) in the institute is as follows:

Renewable Energy Microgrid at Dayalbagh Educational Institute

The Dayalbagh renewable energy microgrid is a modern, small scale electricity system comprising a group of distributed loads and distributed renewable energy resources acting as a single controllable entity in synergy with the grid. It is being designed to achieve specific local goals, such as energy reliability, security, carbon emission reduction, diversification of energy sources, and cost reduction. Like the bulk power grid, microgrids generate, distribute, and regulate the flow of electricity to consumers, but do so locally. Such smart microgrids are an ideal way to integrate renewable resources and allow for customer participation in the electricity enterprise. They form the building blocks of the Perfect Power System.

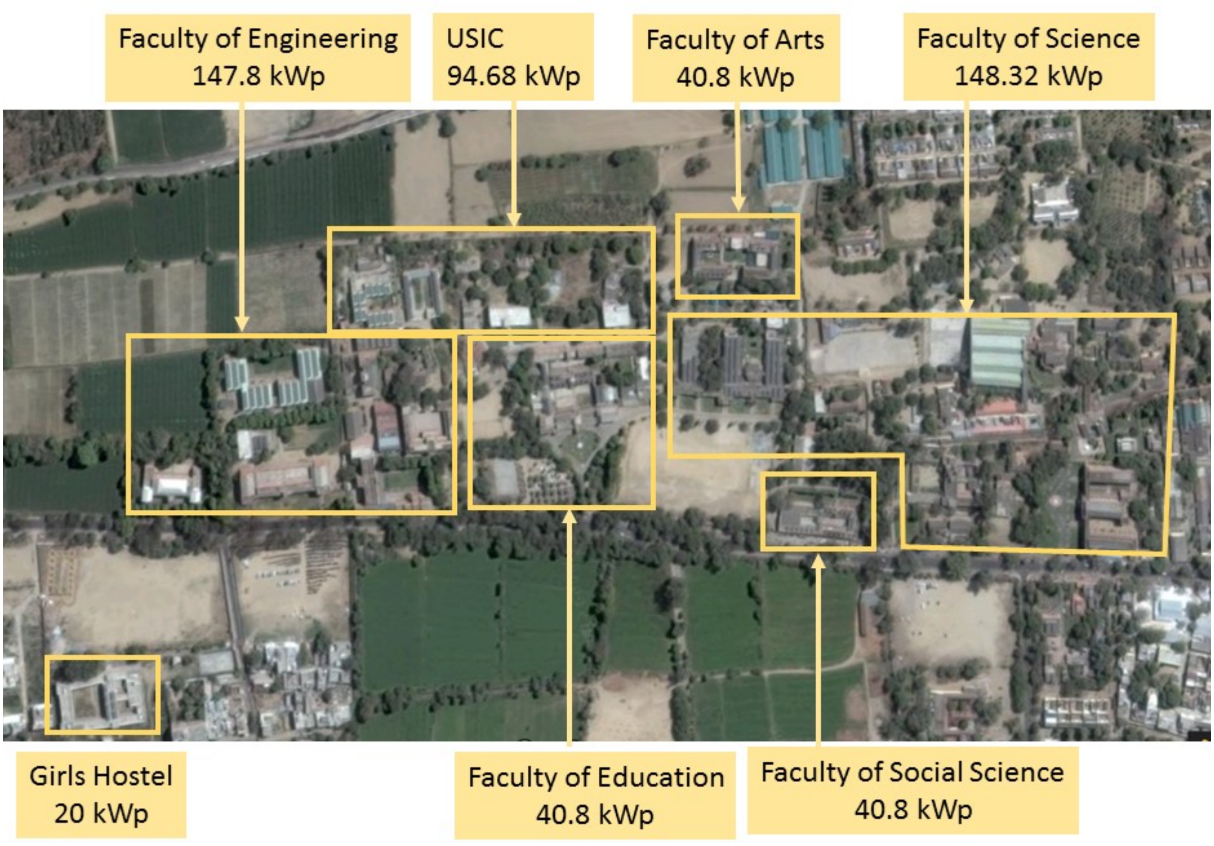


Fig 1 : Satellite view of the institute showing seven of the eleven existing plants and their coverage

Table 1: Distributed SPV power plant locations and capacities

Sl. No.	Site	SPV Capacity
1	Faculty of Engineering	147.8 kWp
2	Faculty of Science	148.32 kWp
3	Faculty of Arts	40.8 kWp
4	Faculty of Education	40.8 kWp
5	Faculty of Social Science	40.8 kWp
6	USIC Complex	94.68 kWp
7	Boys Hostel	5 kWp
8	New Girls Hostel	20 kWp
9	Seminar Hall Complex	20 kWp
10	Tannery Campus	50 kWp
11	Dairy Campus	50 kWp

All the power plants are Hybrid PV Power Systems, primarily intended to power independent localized loads as well as to export excess PV power to grid. The three phase DSP based, Grid Support Conditioners (GSC) (*Fig 2*) are designed to operate as a multi-function power conditioning unit combining the functionality of a grid interface solar inverter 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 can start an optional back up Diesel Generator, if the battery reserve cannot be maintained by the Solar power and there is loss of grid power. In charging mode the system maintains the battery voltage at a user specified value and charges the battery in accordance with standard procedures, thus maximizing the life of the battery bank. The DSP based GSC provides output voltage conditioning when operating in a grid interactive mode and has the ability to export excess Solar power to the

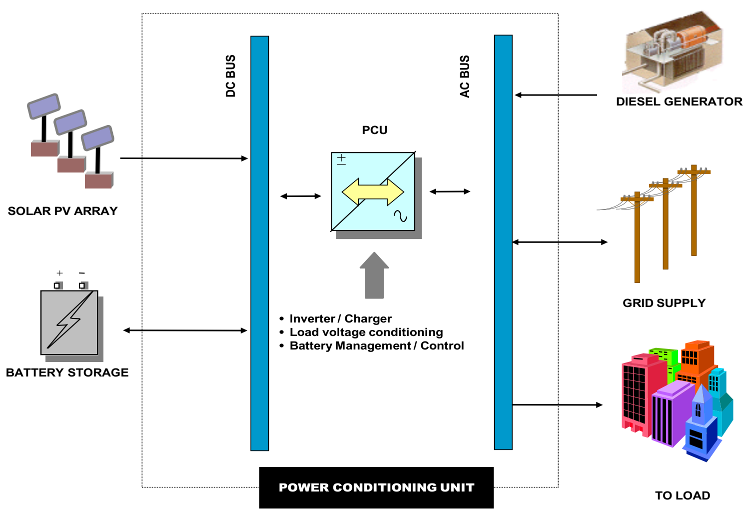


Fig 2: Grid Support Conditioner System

grid. The PV Panels are mounted on fixed stands facing south and inclined at an angle of 30^0 from horizontal.

The effectiveness of renewable energy microgrid was quite evident during the major grid collapse on two consecutive days on 30th and 31st July 2012 in India when over 600 million people (nearly half of India's population), in 22 out of 28 states in India, were without power. The outage caused "chaos" for Monday morning rush hour, as passenger trains were shut down and traffic signals were non-operational Trains stalled for three to five hours. Several hospitals reported interruptions in health services, while others relied on back-up generators. Water treatment plants were shut down for several hours, and millions were unable to draw water from wells powered by electric pumps. Excessive use of diesel generators (a popular backup resource) caused local pollution and high cost for the consumers. However, Dayalbagh Educational Institute, having its own SPV microgrid, was not affected and the teaching – learning- co-curricular activities continued normally in a pollution free environment and economic fashion. Even on normal sun-shine days, the institute is self- sufficient in power and not affected by the frequent power outages. Under cloudy conditions, a careful battery management ensures uninterrupted power supply to the whole campus.

Having commissioned the distributed SPV based micro grid of the institute, the challenge now is to make the system efficient, reliable and economically viable in the face of dynamic loading conditions, generation sources dependent on the vagaries of weather and the utility supply which is not very reliable. This is possible by integrated remote monitoring, communication, control and fault diagnosis of the system at the central control station, resulting in a **Smart Micro Grid**. The following multi-dimensional R&D activities are in progress to indigenously develop the necessary infrastructure (sub-systems) which would ultimately enable the development of a Decision Support System for Optimal efficiency, economics and reliability. Financial support for the development of Smart Micro Grid has been received through DST Clean Energy Research Initiative R&D project.

- **DEI Smart Micro Grid (DST CERI R&D Project, Project Cost:Rs. 58.5 Lakhs)**: The indigenously designed system involves remote monitoring of
    - ***Inverter parameters*** viz. inverter voltage, current, power, grid source for inverter parameters, solar current, voltage, power, solar irradiance, ambient temperature, heat sink temperatures, data logs etc. All of these parameters can be accessed from the central control station through our institute LAN. As per the requirement, the inverter behaviour can be controlled by remotely changing the software set points and selecting different modes of operations. All the inverters are on the institute LAN and accessible remotely through the front end program.

- ***Load Parameters***: Load currents, voltages, powers on all the outgoing circuits can be accessed at the central control station through smart meters over the institute LAN. A prototype in 150kWp power plant at the Faculty of Engineering has been developed.
- ***Switchgear and change-over switches***: Change-over switches for the selection of source (grid or solar) are installed for every outgoing circuit in various control rooms. A system has been designed and implemented to monitor the status of the switches and remotely control the selection through the software at the central control station. The prototype system has been implemented in a 150kWp power plant at Faculty of Engineering.
- ***Battery charging*** : Battery charging is a very important feature of the system affecting the life of the battery and overall system efficiency. Battery charging is to be closely monitored and controlled so as to utilize the solar power fully and ensure float operation of the battery as far as possible. Grid charging schedules (in rainy, cloudy days) for all the 7 power plants are carefully scheduled to prevent overloading of the sub-station. Battery storage should also be available to store the surplus solar power, which can be used during evening and night. Smart Battery management is also being integrated to the control station software.
- ***Water Pumping***: A scheme is being designed for remote monitoring and control of water pumps in the institute for punctual and efficient operation of water pumps. This will be integrated to the central control system software. A prototype with remote control and monitoring using Short Messaging Service on GSM mobiles has been developed and implemented for field testing.

- **Sun Tracking Stands**: R&D is also being done in design and fabrication of 2-axis sun tracking stands which follow the sun so as to ensure that the sun rays are always perpendicular to the panel. Such a strategy improves the solar generation by 15-20% (annual average) and 40% (peak) as obtained from simulation studies. A prototype of an economical, simple and rugged design has been developed and is being tested in the field (Fig.3). The stand utilizes the power generated by the panel itself and no hydraulic components are used. The prototype can accommodate three 170Wp panels. Initial results are encouraging and show a good prospect of commercialization.

Fig 3a : Some of the prototype designs of 3 panel dual axis stands

Fig 3b :Experimental setup with fixed stand(right) and dual axis tracking (left)

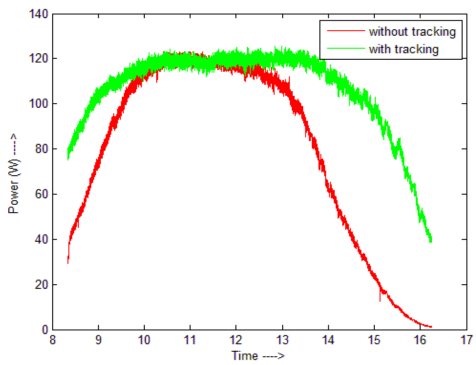


Fig 3c: Comparison of power output of dual axis tracking stand (green) and fixed stand (red)

In view of the target of Government of India to install 100 GW of solar power plants by 2020, the amount of land required for achieving the target could pose a strain on India's available land resource. Therefore, a new sun-tracking structure has been developed in the institute that accommodated 50 solar modules at a minimum ground clearance of 12’, thereby facilitating multiple land use, viz. Solar-Agri farm where agriculture can be performed in the land beneath the solar modules, e-Vehicle Station with parking underneath the modules or on highway dividers.

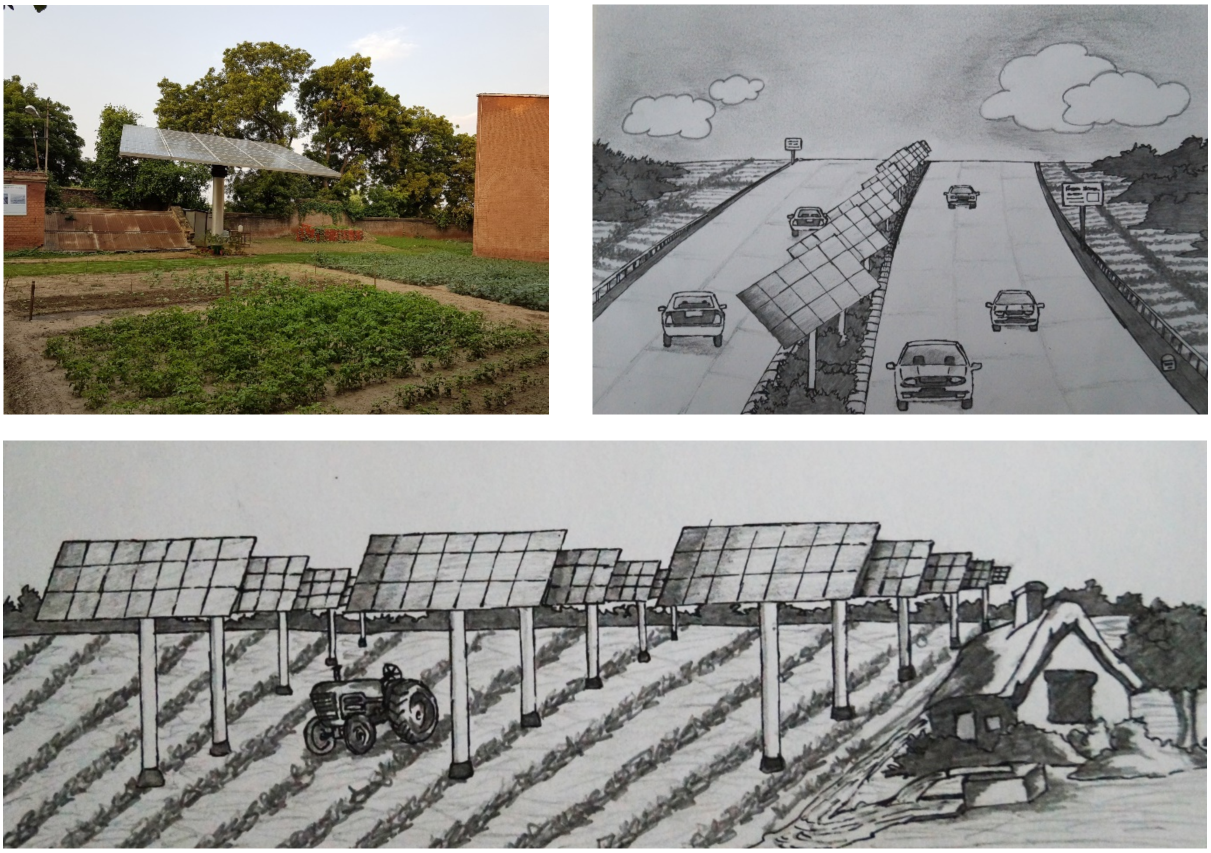


Fig 4: Single Axis Sun Tracking structure accommodating 50 modules with possible applications of Solar-Agri farm and e-Vehicle charging

- **String monitoring and fault diagnosis**

  With thousands of panels in the institute, it is difficult to identify a mal-functioning panel. The requirement has prompted development of a ZigBee based wireless monitoring system for string current measurement. All the measurements of a plant would be collected at a central computer for processing and analysis. An alarm would be raised if some string is found to be mal-functioning along with the geographical location of the string. A prototype of the same has been developed (Fig.5).

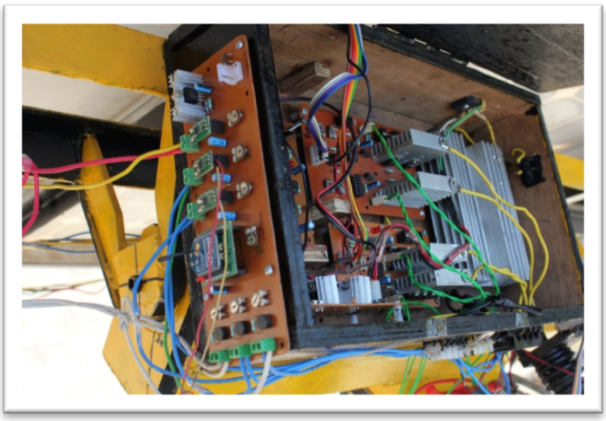
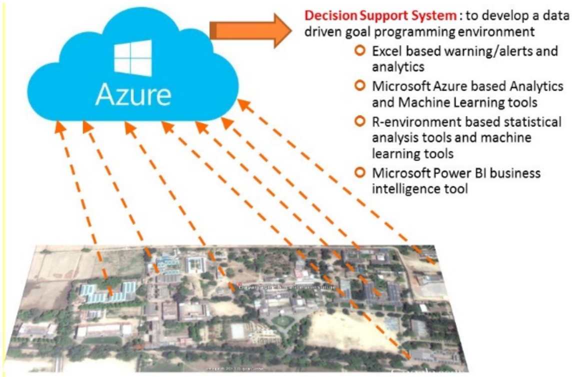


Fig 5 :Current, Voltage sensors with ZigBee

Decision Support System

- **Audio, Visual and E-mail alerts** of various faults / loss of grid / inverter tripping etc.
- Facility to save **daily logs** as csv files
- Upload the **real-time data on a cloud based sql server** for logging and analytics.
- Software platform for Cloud based storage and data analytics has been created for the high-resolution data being generated by remote monitoring system for inverters and loads. All the logs are stored in an sql-server in **Microsoft Azure cloud**.



- Development of Data Analytics using the following tools for drawing inferences for decision making is ongoing:
    - Microsoft Excel **based real-time visualization and comparison** of the performance of various plants in real time
    - **R environment** based Data Analytics and Machine Learning tools
    - Microsoft **Azure based Data Analytics and Machine Learning** tools

Man-power Development

- Running B.Voc (Renewable Energy) with an intake of 60 students.
- Modular certificate courses on Solar Photovoltaic Power Plants with intake of 50.
- B.Tech, M.Tech. major projects
- Ph.D.

DEI Solar-Agriculture Farm (DST Mission Innovation R&D Project, Project Cost:Rs. 300 Lakhs):

The project envisages multi-pronged RD and demonstration and has been raised to contribute to the Government's two major targets by 2022

i.To increase the capacity of solar power plants to 100 GW
ii.To double the income of farmers

Accordingly, the following major takeaways are proposed from the project

1. Solar-Agriculture Farm with multiple land-use to increase the farmer's income
2. Hybrid AC/DC Smart Microgrid for integration of diverse renewable energy resources with utility grid and rational end use of renewable energy in the microgrid
3. Development of solar powered value chain machinery for agriculture and dairying for empowering farmers

A brief outline of each takeaway is as follows

Solar-Agriculture Farm

It is proposed to install 200 kWp Solar Power Plant on elevated structures so that it facilitates solar as well as agricultural farming (Fig.4). The proposed setup will host a set of 20 towers, each accommodating 50 transparent solar modules at a height of 16', in an agriculture land to enable multiple land use, viz., for agriculture as well as for solar energy farming. Such a strategy increases the overall land yield which now includes agricultural yield and solar yield and provides a stable source of income for the farmer. A full-scale prototype of the structure was developed in Faculty of Engineering, DEI, in January 2016 and is working satisfactorily since then. The solar power generated would be used for electrical loads in the Dairy complex and nearby places viz., Gowshala, X-Ray center, dairy workshop, irrigation load in Dairy, ICNC TALL, Crèche, Prem Vidyalaya, DEI Girls Hostel, DEI Food Processing Lab etc.

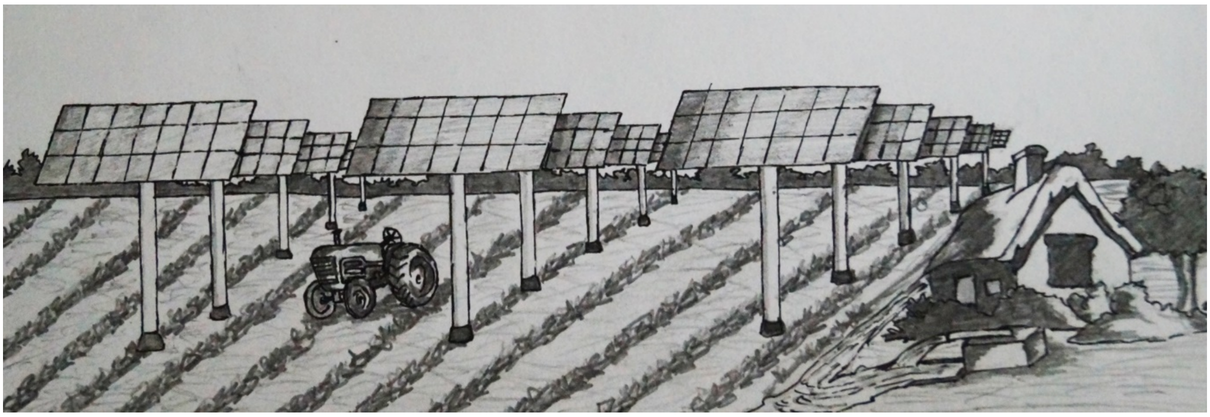


Fig 7 :Artistic rendition of Solar-Agriculture Farm

Hybrid AC/DC Smart Microgrid

The rapid use of renewable energy resources in the field of distributed generation has led to the development of AC micro grid. Although the loads, in general ac in nature, are fed from this grid but there are number of applications where dc is required and ac to dc conversion is required. Therefore, to improve the efficiency, it was felt that dc micro grid is required. The proposed objective deals with the development of Hybrid Micro Grid consisting of coexisting ac and dc sub-grids with corresponding loads. However, due to presence of ac-dc micro grids and the utility ac grid, the operation of the hybrid grid is a challenge and the issues need to be dealt with. Smartness is introduced in the hybrid micro grid by having remote monitoring, diagnosis and control of the generation and loads for efficient and easy operation.

In the proposed project, different scenarios of operation of the hybrid MG system will be addressed, i.e., 1 surplus or deficit dc-grid generation, 2 surplus or deficit ac-grid generation and 3 surplus or deficit generation for whole MG. This provides a proper vision to achieve coordination control of both sub-grids. Different droop control requirements i.e. voltage control in dc sub-grid while voltage and frequency control in ac sub-grid needs separate algorithms to be developed. The performance of the system both under steady state and dynamic conditions needs to be investigated to achieve the desired performance. The stability issues during mode transitions are also to be investigated. A scaled down prototype model would be developed in the laboratory for verification of the proposed scheme. The designed and verified scheme in the laboratory setup would then be implemented in the field for the establishment of hybrid renewable energy smart micro-grid with value chain applications for Agriculture Dairy farm at DEI, Agra.

The solar towers would be connected to a battery bank through suitably sized charge controller. The battery bank feeds to the DC sub-grid to feed local DC loads through DC-DC converters. A sufficiently large capacity Solar Inverter will be installed to convert this combined DC storage to AC and will become the master controller for AC micro grid.

The master inverter will form the AC micro grid, taking DC grid as battery backup and AC mains as grid input. This inverter has the following main functions to perform

1.To control the AC micro grid voltage and power

2.To maintain the battery bank storage capacity using grid when sufficient solar generation is not available.

3.To export surplus power available in DC micro grid to the ESD distribution system.

The multistage grid interactive master inverter would be used to improve the reliability and efficiency of the system. Diverse renewable energy sources viz. bio-gas plant would be connected to the DC grid through AVR integrated alternator and an AC-DC converter.

A block diagram showing the AC-DC hybrid microgrid is shown in Fig.8.

Solar Powered Value Chain

Value addition in agriculture & dairy products is known to increase the profits and therefore, financial wellbeing of farmers. However, lack of dependable and reliable electricity supply in villages prevent the farmers to avail these benefits. Therefore it is proposed to design and develop of solar powered machinery viz. electric thrashers, electric boilers for milk pasteurization, DC compressor based efficient chiller/cold storage etc. to complete the demonstration setup and develop feasible business models to help the farmers.

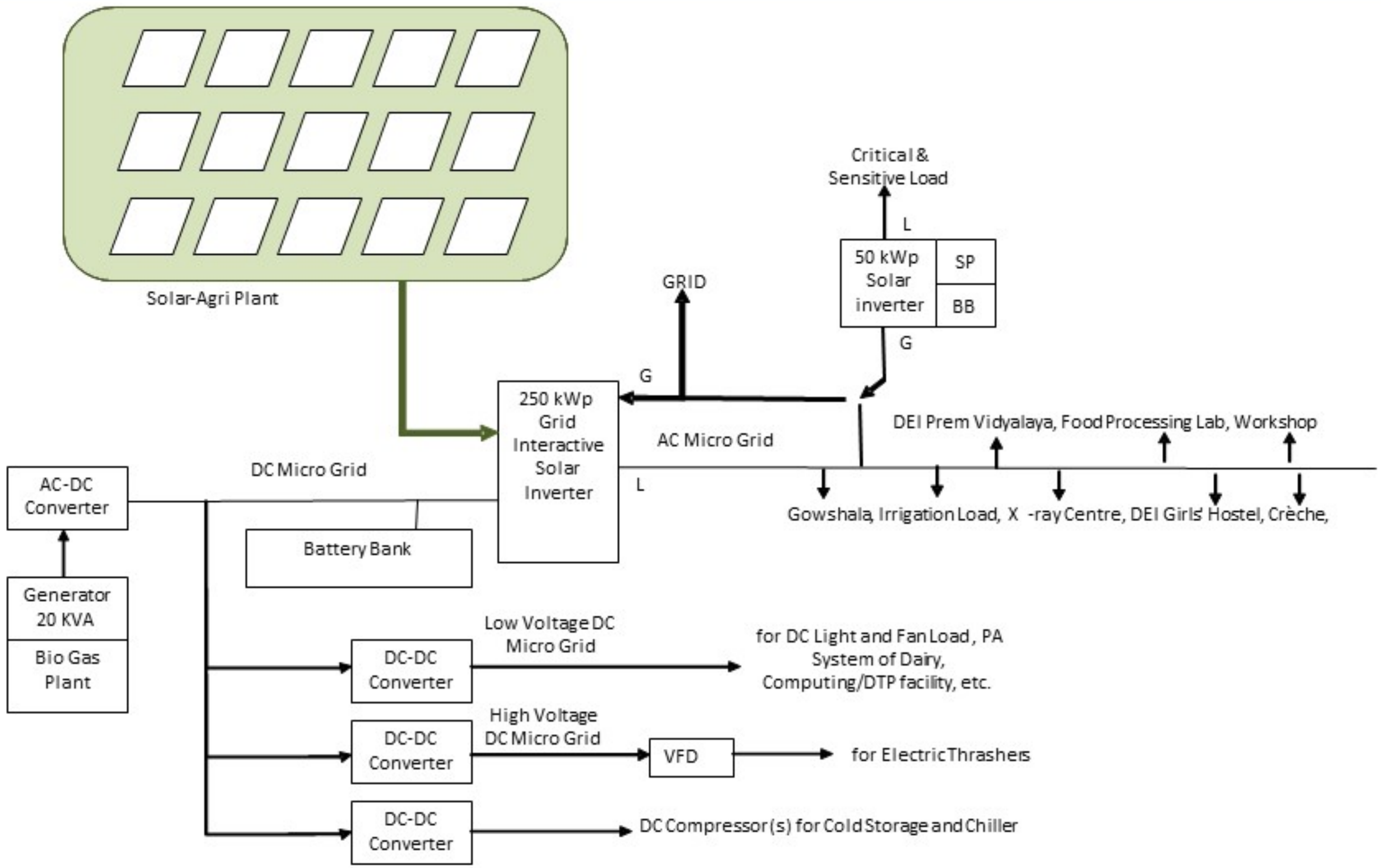


Fig.8: Hybrid AC-DC grid interconnecting diverse RES and utility grid

The proposed project presents a scheme to design and development of ac-dc MG and integration with main grid. The proposed scheme includes different types of renewable energy resources, mainly solar and biogas. The scheme also consists of different ac and dc loads. All these sources and loads will be modelled and the simulation will be carried out. The controllers used in the scheme will be designed for desired steady state and dynamic performance and control scheme will be finalized for changeover. Stability issues of the grid will also be addressed in the simulation. The team of investigators has already done some work in this direction.

A scale down prototype model will be developed at IIT Roorkee and performance of the developed system will be investigated. It is proposed to develop low power local ac and dc micro grids for this purpose and feed power to ac-dc loads through dc-dc converters and inverters as required.

The verified scheme will then be implemented at D.E.I. Dairy Complex, Agra as they already have working ac micro grid, agriculture farm, dairy machinery and gowshala. The institute has its own dairy farm with bio gas generation unit. This bio gas unit will be utilized to generate the electric power using bio generator and connected to the DC grid through AC to DC convertor.

Deliverables

The following deliverables are intended from the project

1. 200 kWp Solar-Agriculture farm with multiple land use
2. Development of viable business models for solar agriculture farms to increase the net land yield for farmers
3. Novel topology with hybrid ac-dc grid for integrating diverse renewable sources and improvement in plant utilization factor
4. Solar powered agricultural equipment which are traditionally operated using diesel viz. thrashers
5. Solar powered cold storage plant
6. Solar powered milk and cream pasteurization
7. Utilization of dairy bio waste to produce electric power

Techno-economic Analysis

A detailed techno-economic analysis would be done through following parameters:

1. Generation of Base Case through energy audit at the site including loads at various locations viz. Agricultural pumps, Gaushala, Dairy complex, Workshop, Prem Vidyalaya, ICNC TALL, Creche, Girls' Hostel, Food Processing Lab etc.
2. Annual power generation from RE sources
3. Increase in the land yield due to multiple land use
4. Estimation of Payback period of the plant
5. Estimation of increase in earning of farmer through solar Powered Value chain
6. Evolving a viable business model for common farmers.

25.5kWp Solar Electric Plant at Satsang Hall, Dayalbagh (Project Cost Rs. 75 Lacs)

Project Commencement: August 2009   Project Completion: December 2009

- Three 7.5 kVA solar inverters with MPPT charge controller and power export facility
- Three 240V, 150Ah battery banks for the inverters with Exide OPZs deep cycle tubular batteries in SAN containers
- Protection features :
  - Inverter continuous overload protection
  - Inverter peak current(short circuit) protection
  - Heat sink over temperature protection
  - Over/under voltage AC voltage protection
  - Over/under frequency protection
  - Over/under battery voltage protection
- Ethernet connection for each inverter for online monitoring and control of the inverters.

Fig 6 :Glimpses of the Solar Power Plant at Satsang Hall, Dayalbagh

Conversion of a Diesel Van into a Solar Electric Van (Project Cost : Rs. 5 lacs excluding solar panels) 2009

A diesel van has been indigenously converted in to a Solar Electric Van by replacing the diesel engine by a 25 HP electric DC motor powered by a 96V, 400Ah battery bank in a collaborative project with Department of Electrical Engineering and Automobile Engineering, DEI. The batteries are charged by Solar photovoltaic modules during the day time and through electric charging during the night. The Van is being used regularly to ferry the residents and staff of DEI in the Dayalbagh Colony.

Fig 7: Solar Van designed and developed in DEI

Design and commissioning of Solar Power plants with a total capacity of 20kWp at DEI Study Centers, Rajaborari and Timarni (2010-11)

Situated in deep forest region of Madhya Pradesh, Rajaborari is a remote village with very poor quality and reliability of electric power. The project was executed in collaboration with the MP Forest Department with judicious design to take maximum advantage of solar power and ensuring uninterrupted power for lighting and water pumping applications in schools, hostel, hospital etc. The capacities installed at various locations are as follows

a. **Rajaborari High School** : 5kWp Solar, (3kVA+2kVA) inverters, 2x48V, 900Ah Battery bank
b. **Hostel** : 2kWp Solar, 3kVA inverter, 48V 600Ah Battery bank (used for water pumping also)
c. **Hospital** : 5kWp Solar, 10kVA 3-Φ inverter, 48V 600Ah Battery bank (used for water pumping also)
d. **Rest House Complex**: 2kWp Solar, 2kVA inverter, 48V 600Ah Battery bank
e. **Rajaborari Office** : 1kWp Solar, 1kVA inverter, 48V 600Ah Battery bank
f. **Timarni High School**: 3kWp Solar, 3kVA inverter, 48V 900Ah Battery bank
g. **Timarni Office** : 2kWp Solar, 2kVA inverter, 48V 600Ah Battery bank

Fig 8 : Glimpses of the solar system installed at Rajaborari in deep forest region of Madhya Pradesh

Providing Solar Power to the intermediate Radio Tower of a 54 Km Wi-Fi link between Timarni and Rajaborari (August 2010)

The Wi-Fi link between Rajaborari and Timarni has an Intermediate Radio Tower powered by Solar Panels. The panel capacity was not sufficient and resulted in frequent shutdown due to deep discharged batteries. Moreover, as the tower was in remote area, the panels were frequently stolen resulting in disruption of e-classes and monetary losses. An alternative solution with revised solar capacity was proposed and implemented by DEI. The panels are mounted on the Radio Tower itself at 20' and 30' height. An electric shock fencing and hooter alarm system is also installed to prevent any attempt of theft. The system has been working properly since then without any disruption or theft.

Specifications :

Solar Panels: Two 24V, 170Wp panels

Battery: 2x 12V, 120Ah batteries

Charge Controller : Morning Star 24V, 30A

Electric Shock Energizer : 6kV, 5mJ pulses

24V Electric Charger (SOS)

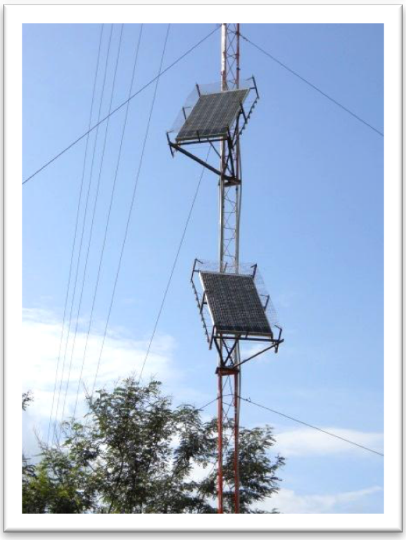


Fig 9 :Solar power for the radios of Wi-Fi tower with theft prevention measures in the forest region of Rajaborari, Madhya Pradesh

Solar thermal cooking systems in Hostels of DEI (Project Cost : 51 lacs) 2010

(i) Three solar thermal cooking systems have been installed in the three hostels in DEI. Each system comprises of 5 dishes, each 16 Sq m in diameter. The total average kcals generated by the concentrators in one system is 2,00,000 kcals / day, which is equivalent to 19 kgs of LPG. Considering the cost of LPG as Rs. 988/- per day, the average annual saving comes out to be Rs.3,06,280/-. The system installed in the Girls' Hostel is also equipped with water heating facility.

(ii) Boiling *Amla* and decoction of herbs for preparation of *Chyavan Prash* in the Ayurvedic Pharmacy of Dayalbagh during the time when the cooking systems are free and not being utilized. ***With conventional boiling process, there was a requirement of 80Kg of Hard Coke and the process time was 12 hours. In steam cooking the process time has reduced to 3 hours and no expenditure on fuel.***

Boiling *Amla* in Hard Coke Furnace

Steam Boiling in Solar cooking system

Fig 10 : Solar Thermal Cooking System at DEI Hostels

- **5 kW Solar – Wind integrated power plant at Melathiruvenkatanathapuram (MTV Puram), Tamilnadu (Project Cost : 8.5 lacs) 2013**

A solar-wind integrated system with 3kWp Solar and 2 kWp wind has been installed at the DEI ICT Distance Education Center, MTV Puram in Tirunelveli District of Tamilnadu. A remote monitoring system has been developed and deployed as part of an M.Tech. project for real time remote monitoring and data logging of various solar and wind parameters.

Fig 11 : 5kWp Solar-Wind Hybrid System

Conclusions

The Dayalbagh Educational Institute initiative has demonstrated that Universities, building intellectual resources through teaching-learning and research, offer a perfect platform for establishing renewable energy microgrids. In addition to sustainable development through clean energy technologies and self-sufficiency in energy, a university microgrid is an ideal test bed for conducting indigenous research and development through UG & PG projects and Ph.D. thesis. This would ensure quality research with relevance as well as development of skilled man power and intellectual property in the area. Universities can design and implement model curriculum for vocational diploma and certificate courses in solar energy technologies, provide earn-while-you-learn schemes to the students and encourage entrepreneurial start-ups through incubation cells.

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