Establishment of Solar –Wind –Biogas –BESS Based Hybrid Micro-grid

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*Abstract***:** *The demand for energy increased due to industrialization, urbanization and population growth. In order to meet the demand for energy, Renewable Energy Sources (RES) are exploited because of its advantages such as developed economic growth and sustainability etc. The micro-grid implemented with isolated distributed generators (DGs) of coordinated operation within it. A hybrid system with all available sources of renewable energy such as solar PV, wind, biogas and battery energy storage system (BESS) for the purpose of 24hrs uninterrupted power supply for the no grid or weak grid regions of rural sectors of India has been recently established in IIEST Shibpur. The design and establishment of solar-wind-Biogas with battery energy storage-based hybrid micro-grid system presented. In this paper design, development and installation of micro-grid consisting of 10kWp solar PV plant, 1kW wind generating system, 35 cubic meter bio digester with 15kVA biogas engine and 1kW, 6kWh VRF battery are described.*

*Keywords***:** *BESS, Biomass, Microgrid, Solar PV, Wind.*

I. INTRODUCTION

The generation of power from such source of energy was observed to be 21.43% as on28[th] Feb 2019.However, it can rise exponentially so to meet the energy demand of the future. Further, the advancement in solar photovoltaic (PV) technology which includes the improved efficiency of solar cells, maintenance of minority carrier's lifetime, minimization of optical losses and reduced cost of energy generation over last decades has attracted solar PV technology usage for generation of power. In addition, the motive behind the growing deployment of solar PV technology is diminishing the cost of photovoltaic systems given by the government of various countries. For Indian climatic conditions, the daily average solar energy varied from 4-7 kWh/m^2/day where about 300 days in a year are sunny and clear. Also, the sunshine hours observed is around 1,500-2,000 hours per year which is more than the current total energy consumption.

Hence, the conversion of solar energy into electricity for solar photovoltaic systems can effectively be harnessed for power generation in India. The large-scale penetration of solar PV technology in the smart energy management system has become a challenging task. The variation in power output of solar PV system can lead to the unstable operation of the system. The fluctuations in the output subsequently lower the capacity of PV generation. Damage may arise in the stability of the utility grid and the power quality because of the imbalance between the demand and supply. Many factors are involved that affect the power generation such as climatic variations, solar insulation, ambient temperature, solar panel temperature and topographical position. So, defining the output with the single model is a tedious task; therefore, in this thesis, the output is modeled based on sky-conditions namely clear sky, hazy sky, partially foggy/cloudy sky and fully foggy/cloudy sky-conditions, as such factors make a significant impact on the solar photovoltaic system power output. Simulations have been carried out for varied climatic conditions thereof, such as warm and humid, hot and dry, cold and cloudy, moderate and composite climate zone across India. Suitability of hybrid energy systems for rural areas has been studied. It was found that although renewable technologies have come a long way in terms of research and development, there are still certain obstacles in terms of their efficiency and optimal use. Major challenges found in the study have been highlighted. The renewable energy sources, such as solar PV, need innovative technology to harness more amount of useful power from them. The poor efficiency of solar is major obstruction in encouraging its use. The manufacturing cost of renewable energy sources needs a significant reduction because the high capital cost leads to an increased payback time. It should be ensured that there should be minimal amount of power loss in the power electronic devices. The storage technologies need to increase their life-cycle through inventive technologies. Standalone systems are less adaptable to load fluctuations. Large variation in load might even lead to entire system collapse. Though hybrid energy systems could be potential solutions for the electricity problems in the rural region yet vast research is needed in this aspect to make it technically feasible to be employed at these areas. The prime focus of study should be the cost of the system and its output. The energy management techniques of microgrid addressed by the other researchers focused mainly on power quality improvement and bus voltage stabilization, reactive power compensation during grid connected and islanded conditions as a part of the energy management.

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One of the major objectives of this work is to establish a hybrid microgrid comprising of renewable energy (RE) sources such as solar PV power plant, wind power generator, biogas power generating system and a battery storage unit for studying the impact of variability and intermittency of RE sources on the connected load and the utility/distribution grid.

India has shown a significant growth in implementing renewable energy sources based microgrid throughout the nation in past several years through central and regional energy implementing agencies of Government of India and private sectors. In most of the cases, microgrids have been implemented with isolated distributed generators (DGs) of coordinated operation within it [1].

II. MICRO-GRID OVERVIEW

A microgrid is a local grid which can accommodate different renewable energy sources within it and can be operated in grid connected as well as islanded mode. It strengthens the grid resilience in case of grid fault and able to act as a resource for fast recovery. It is essential for a remote location where the distribution grid is not present or weak in nature to support the critical loads. The major features of a microgrid are [2],

1. Microgrid consists of different renewable energy sources and controllable loads connected in the distribution network.

2. It can be operated in grid connected as well as off grid mode.

3. An intelligent centralized controller enables the demand side as well as source side management.

A. Architecture:

The distributed energy sources such as solar PV, wind, biogas, and energy storage system are connected together through the main bus bar and their associated converters. The microgrid system is connected to the main grid at the point of common coupling (PCC) and the power flows from the generator to the connected loads. Figure 2.1 indicates the microgrid architecture [12].
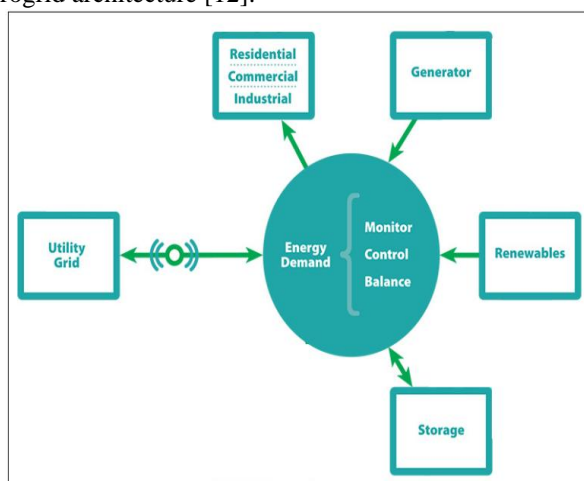

Fig.2.1. Microgrid structure [14]

B. Micro-grid Operation:

A micro-grid can operate in two different modes of operation,

(i)**Grid connected**: In this mode, the microgrid is directly connected to the local low voltage grid and take power fully or partially from the grid if deficit happens and export to grid if there is excess power.

(ii) **Off Grid/Islanded:** The microgrid can also power up the load uninterruptedly in absence of grid or if the grid is in the fault condition.

The microgrid can run smoothly for the long term when it is economically as well as technically viable. The economic condition satisfies if the capital cost and O&M cost are minimized and the revenue is maximized where as the technical condition describes to minimize the losses and maximize the efficiency. Voltage fluctuation, frequency regulation, and load balancing are also major technical aspects associated with microgrid operation.

C. Control:

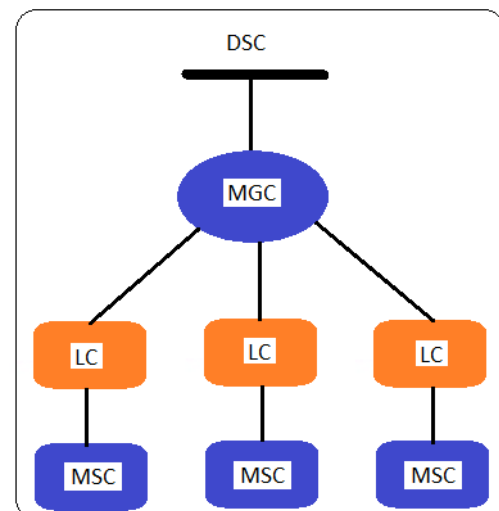The basic structure of microgrid control is described in Figure 2.2.

Fig.2.2. Architecture of Microgrid control [14]

The microgrid control consists of [3]
i) Micro source controller (MSC)
ii) Load controller (LC)
iii) Microgrid controller (MGC)
iv) Distribution system controller (DSC)

▪ The MSC controls and monitors the power flow from each renewable energy source connected within the microgrid. MSC sends the information from each distributed energy source to the MGC. It also takes care of the battery management system. MGC is responsible to carry out the most important work such as voltage and frequency control, controlling load consumption and curtailment. It acts as an interface to connect all micro sources and synchronizes with all MCSs and LCs. DSC takes the decision whether the microgrid will operate in grid connected mode or islanded mode. It also takes care of the protections of the whole system

III. PROJECT DISCRIPTION

This The purpose of this project is to install a hybrid system called microgrid at Microgrid Centre within IIEST campus. The microgrid consists of 10kWp solar PV, 1kW wind generator, 35 cubic meter biogas digester with 15kVA gas engine, associated piping and instrumentation, 1kW/6kWh VRF battery.

The capacity estimation of solar, wind, biogas have been carried out by HOMER software as describe in chapter 3. The output of the microgrid is connected with local low voltage grid and loads with a 500 meter low voltage distribution line. The purpose of the microgrid is to supply 24hrs power to the loads associated with Microgrid Centre.

The whole system is synchronized with the local grid through a synchronizing panel and the metering, monitoring and the control is done through Lab VIEW software which is located within the main control panel. The salient feature of the microgrid project is shown in the Table 2.1.

Table.2.1. Salient features of the microgrid project

1	Project Site	Microgrid Centre, IIEST Campus
2	Location	22.55 deg N & 88.36 deg E
3	Irradiation and wind speed considered	SRRA, IIEST campus
4	Type of system	Microgrid
5	Type of technologies Considered	Solar PV, wind, biogas and VRF battery storage
6	Proposed capacity	23kW Hybrid system
7	Capacity of each system proposed	
8	Solar PV	10kWp
9	Wind	1kW
10	Biogas	12kW
11	VRF Battery	1kW/6kWh
12	Projected Energy Production per year	27,907.9 kWh
13	Total Project Cost	Rs. 26,77,500
14	Project Owner and funding authority	IIEST, Shibpur
15	Name of the utility company	Calcutta Electric Supply Corporation
16	Approved Tariff	Net Metering
17	Expected Life of Power Plant	25 years

Figure 2.3 shows the location of microgrid within IIEST campus. The solar PV modules and wind generator are installed on the roof of the Science and Technology Building along with a sub control room. And the biogas plant and the VRF battery have been installed within the Microgrid Centre which is 500m away. The main control panel, metering and the Lab VIEW monitoring system are also located within the Microgrid Centre. The local low voltage grid line has been drawn up to the main control panel from 100m away.
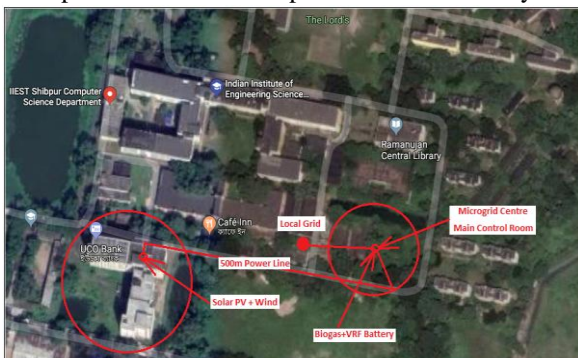

Fig.2.3. Location of microgrid within IIEST campus by Google map view

IV. PROJECT SPECIFICATIONS

A.Specifications of major items for 10kWp Solar PV plant:

(i)Solar PV Modules:

The Solar PV module comprises of PV cells connected in series combination to achieve the required module power output. PV cells directly produces DC power on receipt of solar irradiation. The PV cells in a module shall be protected by encapsulation between glass and back sheet. The glass shall be made of high transmissivity and front surface shall give high encapsulation gain.

It performs satisfactorily with ambient temperatures between -10°C & +60°C and withstands gust up to 150 Km/h on the surface of the panel. Module is made up of poly-crystalline silicon cells. And also be PID resistance. The module frame is made of corrosion resistant materials, having aluminum anodized finish. The anodizing thickness is 15 micron. Module(s) are provided with three (03) bypass diodes within the junction box. Each Solar PV modules used in solar power plants/ systems is warranted for their output peak watt capacity, which is 90% at the end of 10 years and 80% at the end of 25 years from the completion of the trial run. Each PV module deployed is having a Radio Frequency identification (RFID) tag for traceability. Junction box of the module is high quality IP 65 and fitted at the back side which is weather proof and designed to be used with standard wiring or conduit connection. Each module is having two 4 sq.mm stranded UV resistant cables as per of TUV specification 2 Pfg 1169/08.2007 and terminated with DC plug-in connector directly. The positive (+) terminal has a male connector while the negative (-) terminal has a female connector. All the modules in the PV plant are arranged in a way so as to minimize the mismatch losses. Table 2.2 shows the code of standards for PV modules [4].

Table.2.2. Code and standards for PV module

Codes	Description
IEC 61215 – Edition 2.0 2005-04	Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval
IEC 61730 – 1 Edition 1.2 2013-03	Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction
IEC 61730 – 2 Edition 1.0 2004-10	Photovoltaic (PV) module safety qualification – Part 2: Requirements for Testing
IEC 61701 – Edition 2.0 2011-12	Salt mist corrosion testing of photovoltaic (PV) modules

(ii) String monitoring unit:

String Monitoring Unit (SMU) is used in multi-string photovoltaic systems to combine the individual strings electrically and connect them to the Inverters. It is having protection devices to protect the PV modules from current/voltage surges. SMU is capable to monitor each input current, DC bus voltage and total current of all the strings connected to SMU.

SMU is equipped (but not limited to) with the following

1. DC Disconnect /Breaker to disconnect the PV strings from the Inverter for maintenance purpose.

2. Fuse in each string input to prevent the reverse current flow.

3. Surge Protection Devices for protection against surge currents and voltages.

4. Current and Voltage measurement is done through shunt based sensors.

5. Other associated items like cable glands, lugs, Vents and items are required for the protection and completeness of the system.

6. Suitable communication link/ media /Interface to communicate the data to SCADA on Modbus RS 485.

The following parameters are available at SCADA for monitoring the health of the each PV string:

a. SMU input Current
b. Voltage of SMU
c. Total current of SMU
d. Total Power of SMU
e. Status of Disconnect Switches and MOVs
f. Module temperatures wherever provided

The code and standards are shown in Table 2.3 [4].

Table.2.3. Code and standards of SMU

S NO.	CODES	DESCRIPTION
1	UL 94 V	Fire Resistant/ flammability
2	UL 746C	UV Resistant
3	IEC 62262	Mechanical Impact Resistance
4	IS 2147/IEC 60529	Enclosure Protection
5	IEC 61643-12	Surge Protection
6	IEC 62208	Enclosure for low voltage Switchgear and control gear assemblies

(iii)   Power conditioning unit:

Power Conditioning Unit (PCU) consists of inverter along with associated control & protection, filtering, measuring instruments and data logging devices. The PCU has been designed to supply the three phase AC power to the grid. The power conditioning unit is capable to adjust the output voltage & frequency to suit the grid condition. Rating of the PCU is 10 kW, 3phases. The minimum euro efficiency of the PCU is 97%. The PCU remains connected to the grid as per Central Electricity Authority Technical (standards for connectivity to the grid) regulation 2007 with all latest amendments and its components are designed accordingly. The PCU is protected against any sustained fault in the feeder line and against lightning discharge in the feeder line. The PCU have the adequate protection against earth leakage faults. Internal Surge Protection Device (SPD) has been provided in the PCU on DC and AC side. It consists of Metal Oxide Varister (MOV) type arrestors. The discharge capability of the SPD is 10kA at 8/20 micro second wave as per IEC 61643-12. During earth fault and failure of MOV, the SPD safely disconnects the system. SPD is having thermal disconnect to interrupt the surge current arising from internal and external faults. In order to avoid the fire hazard due to possible DC arcing in the SPD due to operation of thermal disconnect, the SPD extinguishes the arc. The PCU is designed for parallel operation through galvanic isolation. The PCU is having anti-islanding protection as per IEC 62116 or equivalent international standard. In case of grid failure, the PCU is re-synchronized with grid after revival of power supply. The codes and standards are shown in Table 2.4 [4].

Table.2.4. Codes and standards for PCU

IEC-61683	Photovoltaic systems –Power conditioners – Procedure for measuring efficiency
IEC 61000	Emission/ Immunity requirement Harmonics
IEEE 519	Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems
IEC 60068	Environmental Testing
IEC 62116	Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures
IEC 62109	Safety of power converters for use in photovoltaic power systems
EN 50530	Overall efficiency of grid connected photovoltaic inverters
BDEW 2008	Technical Guidelines for Generating plant connected to Medium voltage network

(iv)   Module mounting structure:

The module mounting structure designed for this project is very innovative and challenging because it is mounted on a roof where the load bearing capacity should be calculated accurately for preventing any future difficulties. The main challenge of designing the structure is the stability maintaining the aesthetic view. According to the site survey the height of the mounting structure will be about 1m from the ground. Each mounting structure is designed for holding 10 numbers of modules i.e. 2.5kW. Such 4 nos. of module mounting structures will be used. The frames assembly of the array structures is made of 80 micron Galvanized Iron.

Because the primary function of a photovoltaic system is to convert sunlight to electricity, often the role and importance of the mechanical aspects of the system are ignored. Most photovoltaic modules are designed to last 20 years or longer. It is important that the other components in the system, including mechanical components, have lifetime equivalent to those for the PV modules. It is also important that the mechanical design requirements of the system be consistent with the performance requirements as well as with the operational requirements of the system. The mechanical design of photovoltaic systems cuts across a variety of disciplines, most notably civil and mechanical engineering and, to a lesser extent, material science, aeronautical engineering and architecture. More specifically, the mechanical design involves:

• Determining the mechanical forces acting on the system.

• Selecting, sizing and configuring structural members to support these forces with an adequate margin of safety.

• Selecting and configuring materials that does not degrade or deteriorate unacceptably over the life of the system.

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- Locating, orienting and mounting the photovoltaic array so that it has adequate access to the sun's radiation, produces the required electrical output and operates over acceptable PV cell temperature ranges.
- Designing an array support structure that is aesthetically appropriate for the site and application and provides for ease of installation and maintenance.

The mechanical system can affect the array performance in several ways:

- Increasing the amount of incident solar radiation
- Avoiding shading
- Allowing the array to operate at lower cell temperatures
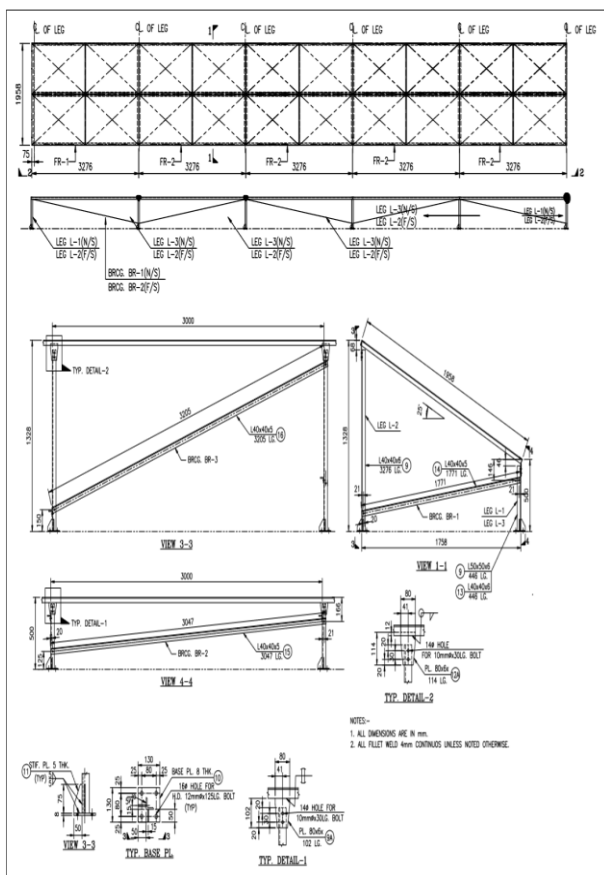- Figure 2.4 describes the detail drawing of module mounting structure.

Fig.2.4. Mechanical drawing of the module mounting structures

The codes and standards for design of the structure is shown in Table 2.5 [4].

Table.2.5. Codes and standards for design of structure

1	IS 875: Part 1 & 2	Code of practice for the design loads for buildings and structures-
2	IS 875: Part 3	Code of practice for the design loads for buildings and structures-Wind Loads
3	IS 800 : 2007	Code of practice for use of structural steel in general building construction
4	IS-4759	Hot-dip zinc coatings on structural steel and other allied products
5	IS 1868	Anodic Coatings on Aluminium and its Alloys

(v) LT Panel:

The grid connection of inverter has been done through a LT panel. According to the design, the output of inverter is connected to the LT panel through LT EXPORT energy meter which measures the solar energy generation. The LT panel also incorporates the output breakers, surge protecting devices, fuses & bus bars.

(vi) Monitoring Systems:

Computer Aided Data Acquisition Unit have features for simultaneous monitoring and recording of various parameters of different sub-systems, power supply of the Power Plant at the DC side and AC side. The unit is a separate & individual system comprising of different transducers to read the different variable parameters, A/D converter, multiplexer, de-multiplexer, interfacing hardware & software.

The data acquisition system performs the following operations which include the measurement and continuous recording of:

- Inverter output
- System frequency
- DC Bus input
- Energy delivered to the GRID in kWh

All data is recorded chronologically date wise. The data file is MS Excel compatible. The data logger is having internal reliable battery backup to record all sorts of data simultaneously round the clock. All data is stored in a common work sheet. Representation of monitored data in graphics mode or in tabulation form is displayed on the computer screen or can be printed out. All instantaneous data can be shown in the computer screen and also available for remote monitoring through GPRS system.

(vii) Electrical Design:

Each string consists of 20 nos. of solar PV modules which generates 5kW power. Such 2nos. of strings are connected to a 10kW string inverter. DC power from each string is combined within a SMU and such 1 nos. of SMU is installed. The output of 10kW string inverter is connected to the LT panel to combine AC power through proper metering & protection devices. The output of the LT panel is directly connected to the LT side of the local grid. The temperature de-rating for solar modules, & cable have been considered as a part of the design. The installation of PV modules, structures, string junction box and the LT panel are shown in Figure 2.5.

Figure.2.5. Installation of 10kWp solar PV power plant at IIEST roof top

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B. Specifications of major items for 1kWp wind plant:
(i) Wind turbine system:

The 1kW wind turbine is a downwind three bladed turbine. It comprises a steel frame mounted on a steel tower assembly. The turbine frame supports encapsulated windings and bearings that in turn support a rotating shaft and permanent magnet rotor assembly. One end of the shaft has a propeller blade assembly comprising glass thermoplastic composite that is hinged on a rotor plate. The blades are held in their correct position by a set of springs that allow the blades to form a cone shape in high winds. In this shape, the turbine is able to limit its rotational speed. The turbine frame also houses a service-brake assembly that acts upon a brake attached to the rotor shaft.

The tower that is connected to the turbine frame has a steel base plate that incorporates a raising and lowering mechanism. The top of the tower has a yaw bearing assembly that permits the turbine frame to rotate. The blades are therefore able to turn depending on wind direction and speed. A winch mounted inside the tower is connected to the service brake in the turbine frame.

The generator encapsulated stator windings are connected to a slip ring unit at the top of the tower for onwards connection to a certified junction box [5].

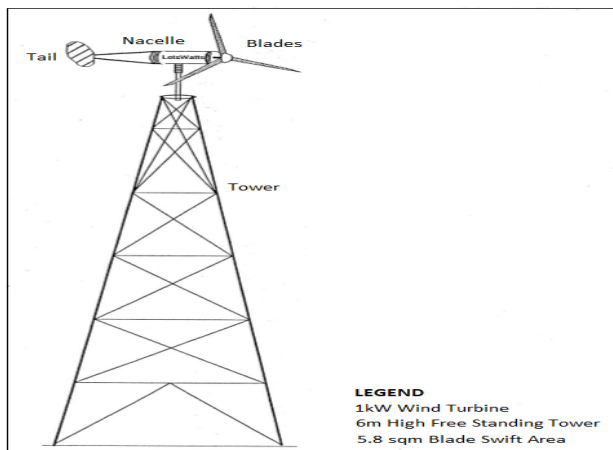The typical schematic diagram of a 1kW wind turbine system is depicted in Figure 2.6.

Fig.2.6. Schematic diagram of 1kW wind turbine system

The major components are described below,
(ii) Rotor:

The rotor swift area of this 1kW wind turbine is 5.8sqm and operates at 1200 rpm at rated wind speed. The rotor speed is controlled by generator torque control system. The rotor spinning is clock wise looking from up wind direction.

(iii) Blades:

The wind turbine consists of 3 blades and made of special type of hard polycarbonate material. The aerodynamic design of the blades are such as, the thicker air foil is located towards the blade hub and it gradually thinner towards blade tip.

(iv) Hub:

The three rotor blades are connected through the main shaft to the hub.

(v) Gear box:

The gear box is used to transmit power from low rpm turbine rotor to high rpm generator. The gear inside the gear box is designed like multistage helical type and mounted on the machine bedplate. The gear box also contains a parking blade on the top of the shaft.

(vi) Bearing:

The main shaft bearing is located in a pillow block housing arrangement and the type of the bearing is a roller bearing. The gear box bearing is a cylindrical, spherical and tapered roller type. It normally aligns the internal gearing shaft and takes the axial and radial loads.

(vii) Brake system:

The normal braking of the wind turbine is done feathering the blades out of the wind. A single feathered rotor brake slows down the rotor and each brake associated with each rotor blade has its own back up to powering up the drive system in case of grid loss.

In addition to the electric brakes, turbine has its mechanical brake also. It is attached to the high speed shaft gear box and is used along with the main aerodynamic brake to reduce the speed of the rotor as required.

(viii)Generator:

The generator is a permanents magnet synchronous generator (PMSG). The protection standard is followed as IP54. It is mounted on the bed plate and the design has been done to reduce the vibration and the noise during operation.

(ix) Flexible coupling:

Flexible coupling is located in between generator and gearbox as a torque limiting device. It maintains the torque to the drive train within the maximum limit.

(x) Yaw system:

The yaw bearing is a roller bearing and located in between the nacelle and the tower. It helps the turbine to track the wind direction. The automatic yaw brake is used to restrict the wind turbine from reaching the peak load. The yaw controller places the turbine within the average wind speed zone by sensing the wind direction with the help of wind vane which sits on the top of the nacelle.

(xi) Tower:

The wind turbine is mounted on the top of a lattice tower of height 6m. The tower is made with the GI members such as angles, channels and hollow pipes. Access to the turbine nacelle is done through the ladder mounted in the body of the tower and service platform.

(xii) Nacelle:

Nacelle is holding all main components of the wind turbine. The entry point of the nacelle is the bottom of the tower which attached a ladder. The rotor inside the nacelle is safe with a rotor lock system.

(xiii)Anemometer, wind vane and lightning rod:

An anemometer, a wind vane and a lightning rod is attached on the top of the nacelle. The access to these sensors is achieved through the ladder attached with the tower.

(xiv) Wind turbine control system:

The wind turbine can be controlled and monitored manually as well as automatically. The control signal can be sent from a remote computer through a SCADA associated with the system. Service switches are located on the bottom of the nacelle.

At the time of maintenance this switch is operated for safety purpose.

(xv) Power converter:

A power converter for the wind turbine contains rotor side converter, DC intermittent circuit and a power inverter with proper protection in DC as well as in AC side. Again the converter consists of IGBT based power module and required electrical arrangements. The generator has a variable voltage and variable frequency output.

(xvi) Inverter:

The heart of the wind energy system is the inverter. The inverter converts the DC power to AC power to facilitate feeding into the grid. In addition, it performs the synchronization with grid.

Inverter is having efficiency levels of equal or more than 95% and has with minimum capacity of 1kW. The output power factor of the inverter is suitable range to supply or sink reactive power. The inverter is having internal protection arrangement against any sustained fault in feeder line and lightning in feeder circuit. It has three phase static solid state type power conditioning unit. Both AC & DC lines are equipped with suitable fuses and contactors to allow safe start up and shut down of the system. Fuses used in the DC circuit are DC rated. The inverter is having provision for input & output isolation and also consist a mechanism for trip against sustainable fault downstream and does not start until the fault is rectified [6].

Inverter front panel displays (LCD or equivalent) to monitor the following:

- DC power input
- DC input voltage
- DC current
- AC power output
- AC voltage
- AC current
- Power factor

Provision is available in the inverter for Remote Monitoring to monitor all major electrical parameters.

The codes and standards for wind turbine are described in Table 2.6.

Table.2.6. Codes and standards for wind turbine [7]

IEC Standard	Purpose
61400-1, Wind turbines – Part 1: Design requirements	Design Requirements
61400-2, Wind turbines – Part 2: Design requirements for small wind turbines	Small Wind Turbine Design Requirements
61400-11, Wind turbine generator systems – Part 11: Acoustic noise measurement techniques	Acoustic Noise Measurement
61400-12-1, Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines	Power Performance Testing
61400-24, Wind turbine generator systems – Part 24: Lightning protection	Lightning Protection

The installation of wind turbine, structures, rectifier, inverter and control panel are shown in Figure 2.7.

Figure.2.7. Installation of 1kW wind Turbine-Generator system at IIEST roof top

C. Specifications of major items for 35 cubic meter biogas digester with 15kVA biogas generator:

A portable biogas plant is normally used to generate flue gas for domestic usage for cooking purpose as well as generation of electricity. Several canteens, guest house and residential buildings are located within the IIEST campus and nearly 900kg of bio degradable waste e.g. kitchen waste and table waste per day is generated. A 35 cubic meter bio digester is made to process this amount of waste and connected with a 15kVA biogas generator to produce the electricity.

The waste from different locations within university campus is brought to the waste collecting area and segregated bio degradable waste manually. Then these are shredded to small pieces and are converted to paste by pouring water in it. This paste is then sent to the inlet or mixing tank of the digester and mixed with water as 1:1 ratio. After making the slurry, it is then fed to the digester with its inlet pipe. The gas is stored within the gas holder and comes out from the gas outlet pipe located on the top of the gas holder whereas the slurry comes out from the outlet pit. The slurry is then sent for making compost. Before sending the gas to the gas generator it is cleaned by extracting water and hydrogen sulfide from it by a gas cleaning system. The gas generator is connected to push power to the grid. Figure 2.8 shows the process flow of the biogas plant.
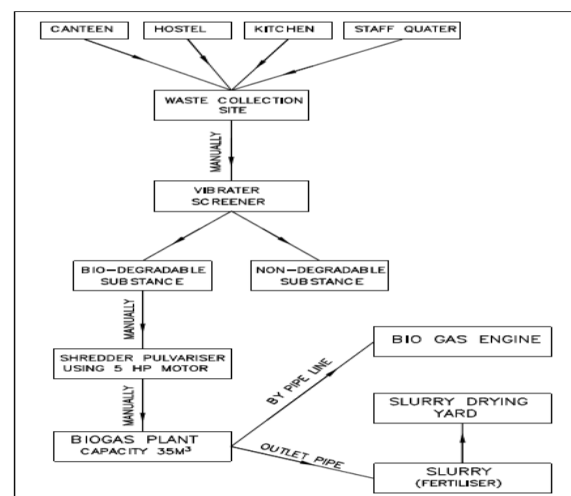

Fig.2.8. Process flow diagram of biogas plant

The biogas power generating plant in IIEST consists of,
1. Shredder machine
2. Biogas digester including input and output pits and floating gas holder
3. Gas cleaning system
4. 15kVA, 3 phase gas generator
5. Control panel with synchronizer
6. Piping and electrical accessories

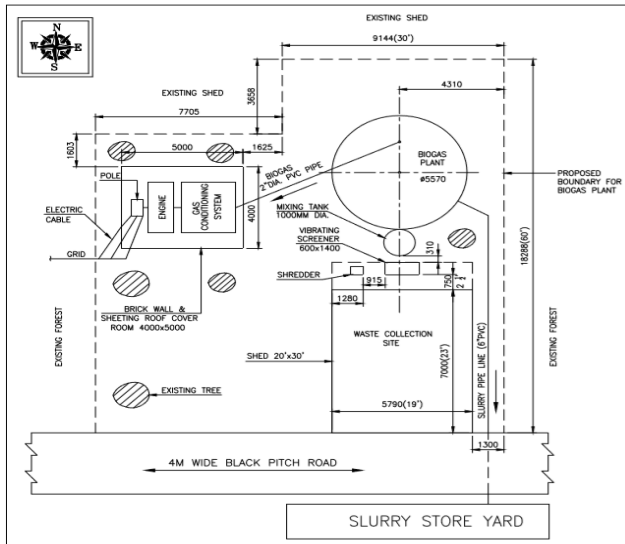The layout of the biogas plant is shown in Figure 2.9.

Fig.2.9. Layout of biogas plant

The major components of the biogas plant are described below.

(i) Shredder:

The shredder is a mechanical device and used to cut the bio degradable waste in small pieces for easy digestion. It consists of a hob on the top to collect the materials to be shredded, a motor, a round blade with several teeth, a steel mesh and a collection point on the bottom of the machine. The round blade is mounted on the shaft of the motor and the steel mesh is located just after the blade.

The waste is collected in to the hob with water and sent it to the shredding compartment. In the shredding compartment it is cut in small pieces, converted to a paste and collected from the bottom side. This paste is applied to the digester directly. Figure 2.10 shows the typical diagram of the shredder machine.
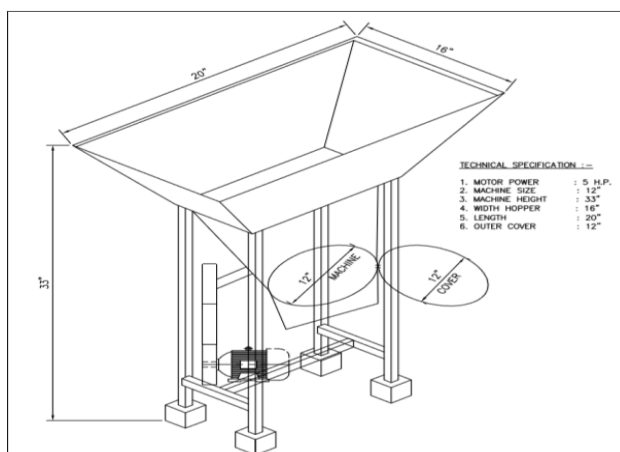

Fig.2.10. Schematic diagram of shredder machine

(ii) Digester:

The volume of the digester is 35 cubic meter. The biodegradation of the organic wastes is a three step process (a) hydrolysis (b) Acetogenesis and (c) Methanogenesis. The present digester involves a batch process going through these three distinct steps and for completing all three steps were generally takes 30 to 40 days. The composition of the biogas varies based on the digester internal temperature, pH and substrate concentration. The composition of the gas contains methane 60%, carbon-di-oxide 30%, water vapor 10% and negligible amount of hydrogen sulfide [8]. The mixing tank and the slurry tank are connected with the digester through a inlet and outlet pipe respectively. The gas is coming out from the top of the has holder through a suitable pipe connection.

The volume of the gas holder is also 35 cubic meter. The gas holder is sitting on the top of the digester and can move vertically up and down based on the gas pressure within the digester resting on a central guide. The dead weight of the gas holder is responsible for the gas pressure to the inlet of the gas generator combustion chamber. Figure 2.11 shows the schematic diagram of a biogas digester and gas holder assembly.
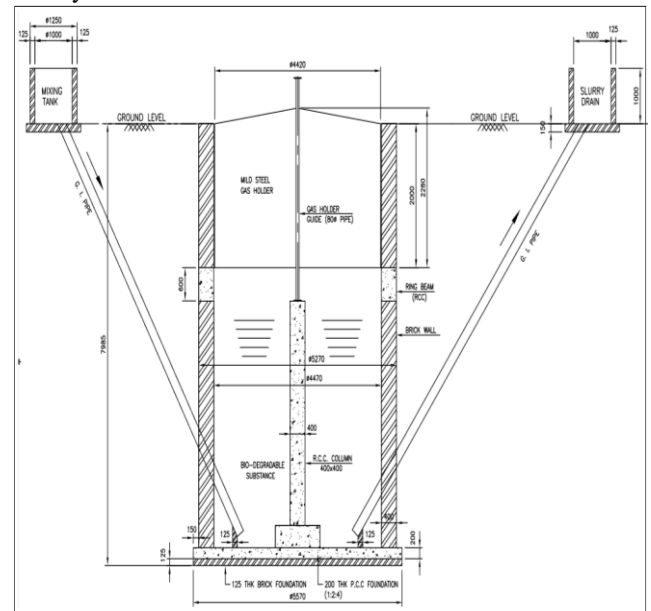

Fig.2.11. Schematic of biogas digester and gas holder assembly

(iii) Gas cleaning system:

Presence of moisture in biogas to be used as fuel may corrode metallic parts of engine and fuel supply system. Also this moisture may react with SO2 present in the gas. This reaction produces sulfuric acid which may corrode engine pipe lines carrying exhaust gases and combustion system. The carbon dioxide reacts with the moisture present into biogas to form a weak acid which will readily attack metals as well.

Similarly, in this case, removal of sulfur from biogas involves wet technique where solution of NaOH is used. Hydrogen sulfide reacts with sodium carbonate present in solution, forming sodium hydrosulfide [9]. The schematic of the gas cleaning system is shown in figure 2.12.
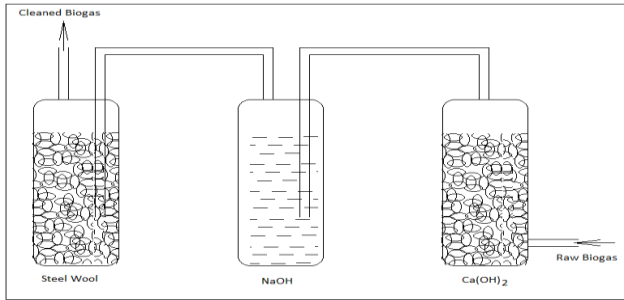
Fig.2.12. Biogas cleaning system

(iv) Gas engine:

The electrical rating of the generator is 15kVA/12kW. It has two parts; engine and alternator. The engine is a direct injection, water cooled, 2 cylinders and 4 stroke type. The rated RPM is 1500. The governor is an electronic type and is controlled according to the load requirement. The engine is started with a separate battery of 12V, 100Ah rating.

The alternator is a brush less, self excited and self regulated type. The insulation class is H and having single pole with automatic voltage regulation facility [10]. The installation of biogas power generating system is shown in Figure 2.13.

Figure.2.13. Installation of 15kVA biogas plant at IIEST campus

3.4 Specifications of major items for Vanadium Redox Flow Battery (VRFB) storage:

The vanadium redox flow battery (VRFB) has been selected for this project since it shows a no of advantages over other types of batteries such as lead acid, lithium ion, sodium sulfide etc.

VRFB stores chemical energy and generate electricity by a redox reaction between vanadium ions dissolved in the electrolytes. VRFB are essentially comprised of two key elements describes in Figure 2.14: the cell stacks, where chemical energy is converted to electricity in a reversible process, and the tanks of electrolytes where energy is stored [12].

The variability of renewable power sources requires quick response and highly efficient storage devices with larger power and energy density. Vanadium Redox Flow Battery (VRFB) has been proven to be a viable energy storage technology for portable, scalable micro grids due to its high capability of peak shaving, fast response, deep discharge capacity, longest lifecycle, and low maintenance requirements. The most important advantage of VRFB over other conventional battery technologies is that the amount of energy it can store is independent of its power rating. The size of the stack determines the power rating whereas the amount of electrolyte determines the energy capacity.
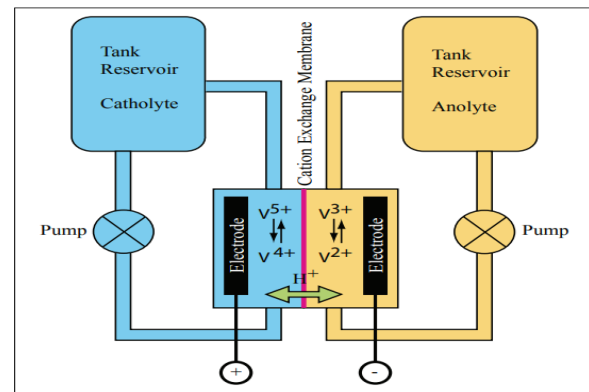

Fig.2.14. Schematic of vanadium redox flow battery

The installation of VRF battery is shown in Figure 2.15.

Figure.2.15. Installation of 1kW 6kWh VRFB storage at Microgrid Laboratory, IIEST

V. MICROGRID INTREGATION AND MONITORING

The integration of different micro sources has been done through a main control panel with proper protection systems. All renewable energy sources are connected to the main bus of the control panel through digital multi function meters to measure the energy generation from each source. Solar PV plant and the wind generator are connected to the main grid through inverter where the synchronizing facility is designed as inbuilt where as biogas generator is connected to the LT grid through an external synchronizer. The whole system is controlled and monitored through Lab VIEW software.

The main protection system includes,

- Over current
- Over voltage
- Under voltage
- Over frequency
- Under frequency
- Short circuit
- Reverse power
- Surge protection
- Earth protection and
- Lightning protection

The detail schematic of the grid integration of the microgrid is shown in Figure 2.16.
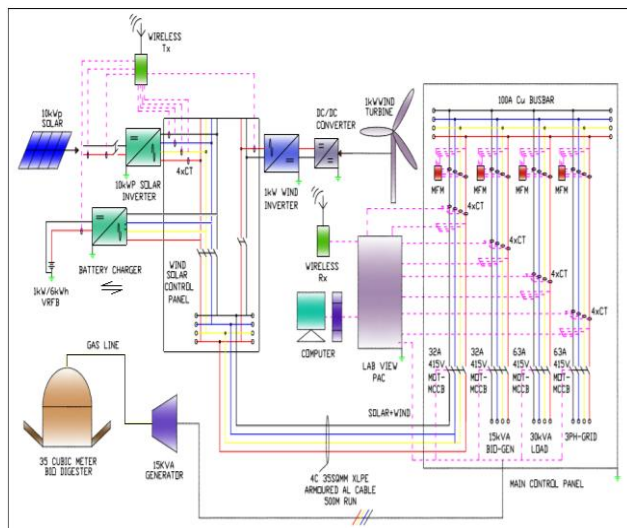

Fig.2.16. Schematic diagram of microgrid installed at IIEST [14]

The applied codes and standards for this project are shown in Table 2.8. The installation of main control panel is shown in Figure 2.17.

Table.2.8. Codes and standards for microgrid implementation [13]

IEEE Standards	Title and Description
1547-2003	IEEE Standard for Interconnecting Distributed Resources with Electric Power Sources
1547.4-2011	IEEE1547.4 Guide for Design, Operation, and Integration of Distributed Resource Islanded Systems with Electric Power Systems
1547.7	IEEE P1547.7 Draft Guide to Conducting Distribution Impact Studies for Distributed Resource Interconnection (Approved Sept 2013)
P1547.8	IEEE P1547.8/D5.0 Draft Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies for Expanded Use of IEEE 1547 (Clause 8- Recommended Practice for DR Islanded Systems) Status: Ballot ready draft due 2Q2014
P1547a – Amendment	IEEE1547a Standard for Interconnecting Distributed Resources with Electric Power Sources – Amendment 1 (The amendment limited to address three topics for change 1) voltage regulation, 2) voltage ride-through, and 3) frequency ride-through.) Status: P1547a/D2 ballot achieved 91 % affirmation; recirculation Dec 2013)
1547 Revision	PAR December 2013; Working group Jan 2014

The operation, experimental observations and the analysis of the results of the different subsystem of the micro-grid are described in the subsequent chapter 3.

VI. CONCLUSION

The system is installed inside the IIEST campus for carrying out the experimental observations and analysis of the results on a regular basis. The solar and the wind has been installed on the roof top of the Science and Technology Building and the sub control room for solar and wind is also set up adjacent to the installation on the same roof. The biogas power generating system including digester, gas engine, gas cleaning system and synchronizer, the VRF battery, main control panel and the SCADA system based on Lab VIEW software are installed within the Micro-grid centre. The cable has been laid underground from sub control room to Micro-grid Centre which is about 500m away. The main control panel is connected with load as well as local grid. Holistically, this chapter describes the establishment of the micro-grid within IIEST campus.

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