Building Integrated Small Scale Standalone Solar PV-Wind Based Hybrid DC Microgrid Power System

Shafqat Hussain Memon[1,2], Pervez Hameed Shaikh[3], Zubair Ahmed Memon[3,4], Mohsin Ali Mari[2,4]

[1]*Directorate of Post Graduate Studies, Energy System Engineering, Mehran UET-Jamshoro, Sindh, Pakistan*
[2]*Department of Electrical Engineering, Mehran UET-Jamshoro, Sindh, Pakistan SZAB Campus Khairpur Mirs'*
[3]*Department of Electrical Engineering, Mehran-UET Jamshoro, Pakistan,*
[4]*Institute of Information & Communication Technologies, Mehran UET-Jamshoro, Sindh, Pakistan*

***Abstract*: Due to the rapid increase in industrialization, urbanization, population growth and changes in living style the energy demand has continuously been increasing. This tremendous increase in energy consumption throughout the world has raised serious concerns over the depletion of fossil fuels, climate change and scarcity in future energy supply, which leads to the development of renewable energy resources. Moreover, the energy consumption of domestic and commercial buildings has continued to increase in recent years, reaching 40-50% of total energy consumption. At present, some of the main concerns in urban areas are energy and building performance autonomy. Currently, in urban areas there is significant development in decentralized power plants which includes distributed energy resources mainly solar and wind energy. One of the ways to promote and integrate distributed energy resources in buildings is to develop microgrid power systems. Hence, in the context of sustainable buildings, this study proposes integration of solar-wind generation in DC microgrid setup. The proposed system is presented and modeled as small scale experimental setup. The performance analysis of proposed system is evaluated under various operating conditions of solar irradiance and wind speed. The proposed system aims to give better efficiency and satisfactory operation**.

***Keywords*: Buildings, Distribution generation, Microgrid, Standalone, etc.**

I. INTRODUCTION

Due to rapid increase in industrilization, population growth, developemnt in information technology sector the energy demand is continously been increasing worldwide [1]. In addition, the energy demand in both residential and commericial buildings has been increasng steadily since the last few years and has reached an average 40%-50% of the total energy consumption [2]. Coventionally, the fossil fuel resources are used to generate and meet energy demand. The depeltion of fossil fules, upfront costs of fossil fuel based power generation and envionrmntal impact have challenged the their future viablity. The large increase in energy demand has raised serious concerns over depletion of fossil fuels energy resources, heavy environmental impacts (i.e. green house gas emissions) and scarcity in future energy supply [3]. It is reported that residential energy consumption is some countries is greater than other sectors transportation and industrial application. As per report of United States Energy Information Administration (EIA) estimates, about 40% of the total U.S. energy consumptions were consumed by residential and commercial sectors [2]. Moreover, even today, around1.3 billion people among the world's population have no access to electricity which constitutes 18% of the total global population. Among these, more than 80% of people are from rural areas [2-4]. Unfortunately, Pakistan being a developing country faces the same dilemma. The main reasons behind scarsity of electricity are geographical location, remote distances from main power grid, expensive transmission system, tehnical constraints and various socio-economic barriers.

Under these circumstances, utilization of renewable energy resources can be the most promising option to meet energy demand and supply electricity to such areas which are not electrified yet [5]. The renewable energy integration has got global attention due to its zero fuel cost, cleanliness, availability and easy setup. Among various renewable energy resources, the photovoltaic (PV) and wind turbines (WT) as the distributed energy resources have got greater attraction due to abundant local availability in nature, technical advancements and economic benefits [3]. The hybrid combination of both distributed energy resources also eliminates intermittency of each other due to their adverse nature; hence reliability of the system will be enhanced. Currently, microgrid power system is attracting platform to promote and integrate distributed energy resources [6]. Microgrid can be used to supply electricity to buildings, community, small town and small particular region as well. Hence, this study proposes the solar-PV wind based hybrid dc microgrid power system for buildings and off-grid applications.

A. Comparison between DC Bus Distribution and AC Bus Distribution

In context of sustainable building environment, a great portion of building electric appliances can directly be supplied from dc bus voltages such as lightning based on LED lights, dc fans, electric devices based on microprocessors, power supply for computer system, switched mode power supply unit and variable frequency drive for motor speed control. The many research studies are conducted on dc distribution power system network, which shows current trend of the transformation towards dc system at generation and consumption level. The dc system has got momentum due to native dc nature of renewable energy resources, advancement in power electronic converter topologies, increasing utilization of electronic and solid state devices and loads. On the other hand, dc distribution power system network enhances the system efficiency due to less conversion stages, absence of reactive power and frequency control and no synchronization issues. Moreover, DC system possesses high compatibility with storage system which also maximizes reliability of microgrid [7-8].

B. Building-Integrated Small Scale Standalone Hybrid DC Microgrid

The proposed building-integrated standalone hybrid DC microgrid power system is modeled as small scale experimental setup which includes solar photovoltaic (PV) system, wind generator turbine system (WGTS), battery back as an energy storage system (ESS), charge controllers and DC loads linked to a common dc bus. The common dc bus is selected so far because of efficient operation of proposed system and to avoid frequency control issues; therefore only there will be need to control DC bus voltage to maintain stable output. Figure 01 shows the schematic flow diagram for building-integrated DC microgrid system consists of distributed energy resources, battery backup, charge controller and dc loads.

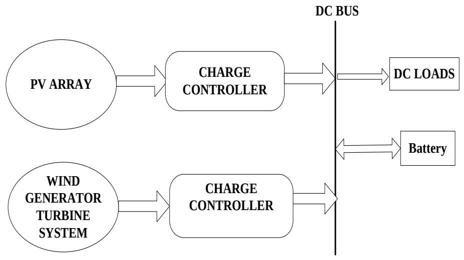

Fig. 1: Schematic flow diagram for building-integrated DC microgrid system

II. MATERIALS & METHODS

A designed prototype for proposed system is developed at coordinates 25.4084N°, 68.2605E° on the roof top of old administration building of Mehran UET Jamshoro, Sindh, Pakistan. According to data produced by alternative energy development board (AEDB) in association with the World Bank in march 2017, shows that selected site has an annual average wind speed of 8.5m/sc with power density of 770W/m2at 50m height and an average Global Tilted Irradiation (GTI) of 2250 kWh/m2/ day with Direct Normal Irradiation (DNI) of 1685kWh/m2/ day.

In this work, the 0.5kW hybrid solar-wind system is developed. In the designed system, photovoltaic (PV) system comprises of three monocrystalline structure solar panels each of 150Wp rating and total 450Wp (i.e.3×150Wp) combined capacity at standard testing conditions (STC). The wind generator system capacity is rated at 24V, 50Wp. The BESS includes one lead-acid battery of 12V, 50Ah capacity. DC loads will also be included.

A. Photovoltaic Solar Panels

In photovoltaic power generation, sun's light energy is converted into electrical energy. Solar photovoltaic power generation depends on solar irradiance, sunshine and temperature. In this work, monocrystalline type solar PV panel is selected with system efficiency 19.6%. The open circuit voltage (Voc) and short circuit current (Isc) of solar PV panel are 21.1V and 9A respectively. The PV panels are positioned at direction of angle 45 degree. The relationship between sun shine hours, temperature and irradiance of sun are given in Eq. 1;

$$I=NpIp - NpIrs[exp\frac{q}{KTA} * \frac{V}{Ns} -1], \quad (1)$$

I= Output current
V= Output voltage
Ns= Number of cells connected in series
Np= Number of cells connected in parallel
Iph = PV current
T = Cell temperature
Irs = Reverse saturation current
K = Boltzman's Constant
T = Junction temperature
q = Electron charge

B. Wind Generator Turbine System

The kinetic energy of wind energy system is converted to electrical energy with mass (m), wind velocity (v) and density of air (p). The mechanical power output can be defined as the kinetic energy per unit time.

$$Pw= ½ Adv3, \quad (2)$$

In this work, the horizontal axis wind turbine (HAWT) is chosen because it offers higher reliability, efficiency and stability as compared vertical axis wind turbine (VAWT). The designed wind turbine generator system (WTGS) consists of three rotor blades each of 10.5 inch length and permanent magnet brushless dc generator mounted on the 4feet tower-2inch high. The output of wind generator fluctuates from 0 to 24V due variation in wind speed. At no load condition, WG produces 36V at higher wind speeds (i.e.12m/sec) which can damage the designed hybrid charge controller; hence it can be avoided by using dc-dc voltage regulator. It limits the WG's output voltage up to 24V as well system stability will be ensured.

C. Battery Energy Storage System (BESS)

The performance of solar PV and wind energy generation depends on environmental conditions. As the output of solar PV and wind generator fluctuate due to change in solar irradiance and wind speed respectively. Due to their intermittent nature, the output becomes unpredictable and unstable. Therefore, to ensure the reliability and stability of system, battery energy storage system (BESS) is used. A 12V, 50AH BESS is used and connected with hybrid charge controller. Depending upon state of charge (SOC) of battery energy will be shared between battery and load. When battery is completely discharged, the power from distributed generation (DG) units will be supplied to battery to make it charged and if battery is partially charged available power will be shared between battery and load. When the battery is completely charged, the entire power output of distributed energy resources will be feed to load. When there is partial or unavailability of power from distributed energy resources, then battery will contribute to feed power to the loads.

D. Hybrid Charge Controller

This Hybrid charge controller is used to control power flow produced by distributed energy resources, towards the energy storage system and loads. In this work, hybrid charge controller with 24V, 30A rating is designed, which is used to charge battery from PV and WG outputs as well as distribute power among dc loads. The designed controller also offers additional features to provide protection against over charge and deep cycle discharge of battery. It also provides under-voltage and over voltage protection for load.

E. DC loads.

In the developed small scale developed system, the dc loads are included which comprised of 42LED lights each of 12V, 12W and dc fan load of 50W

III. RESULTS

The performance analysis of the designed small scale experimental system is conducted for consequent six days from 25 March 2017 to 30 March 2017. The graphical results of the developed system for the first five selected days of solar PV power generation, wind energy power generation, battery output and dc load power consumption integrated in microgrid are represented and analyzed. The real-time voltages and currents measurements of all selected days were taken using multi-clamp meter for all microgrid components (i.e. solar PV output, WG's output, battery output and DC load power consumption). The product of voltage and current computation yields power output data. The measurement results were taken from start of sunrise early morning (i.e.7am) till sunset at (i.e.8pm) for all the respective selected days.

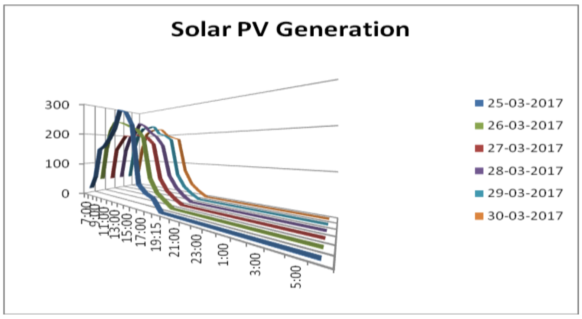

Fig. 2: Power characteristics solar PV generation from 25-03-2017 to 30-03-2017

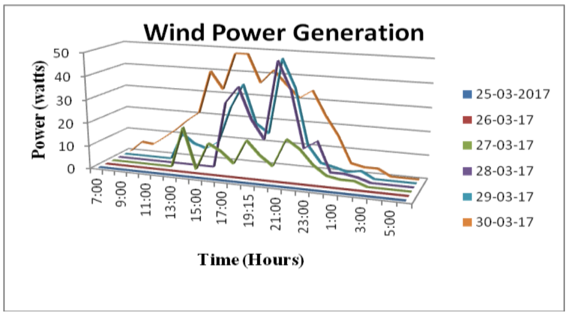

Fig. 3: Power characteristics of the wind turbine generator system from 25-03-2017 to 30-03-2017

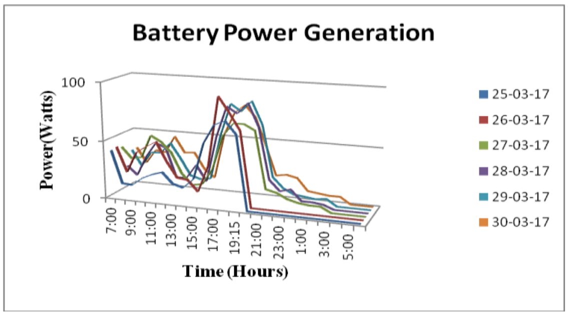

Fig. 4: Power characteristics of the battery from 25-03-2017 to 30-03-2017

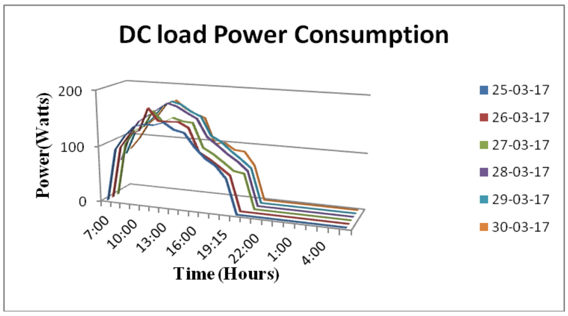

Fig. 5: Power characteristics of loads from 25-03-2017 to 30-03-2017

In the designed system, power characteristic pattern of all the system components for all selected respective days (i.e. 25-03-2017 to 30-03-2017) is observed and results are taken and analyzed. The following key points are noted with respect to the technical performance analysis of developed experimental system:

- The solar PV generation starts from early morning 7am with (40W-45) power output, which varies linearly with solar irradiance. It is analyzed that the solar panels produces peak output power (200-300W) between 10am to 1pm hours for all the different respective days as depicted in figure 02. During all the days, the power characteristics are nearly following the same pattern. The solar PV output decreases after 3pm becomes zero nearly at 7pm. The solar PV output is variable due to variation in solar irradiance throughout the day. Higher solar PV output is produced during peak shiny hours and output decreases during as solar irradiance decreases.

- The power output characteristics of wind energy generation for all the selected days are shown in figure 03. The wind generator's output is zero at early morning hours because it needs minimum 2.5m/sec wind speed to produce certain output. The output of wind turbine generator system fluctuates due to change in wind speed at different operating time conditions. As the wind speed increases, WG's output increases. During the first two days (i.e. 25-03-2017 to 26-03-2017) wind generator power output is zero so there is no contribution of wind energy generation in the hybrid operation of microgrid. During the days (i.e. from 27-03-2017 to 30-03-2017) wind generator supplies the energy all the day time and wind power output increases proportionally with respect to increase wind speed. The WG produces peak power output during even hours of the day (i.e.5pm to 7pm) Even though, the power rating of wind generator is smaller as compared to Solar PV panel due to availability of wind speed throughout day it contributes in hybrid operation of microgrid, especially during the times even solar output is unavailable.

- The power output characteristics of battery energy storage system for all the selected respective days are shown in figure 03. The battery energy storage system is getting charged during the time when solar PV is available till peak hours of the sun shine. As solar PV output decreases the load is shared with battery also. When solar PV output becomes nearly zero, the load is only feed by battery almost up to 8pm. The optimized utilization of battery power will increase its backup time to meet the required load demand.

- The load consumption profile is generated between 7am to 8pm as shown in figure 05. The peak demand of observed between 1pm to 4pm. All the day load demand is meet by microgrid smoothly.

It can be observed from analysis of above results that proposed dc microgrid system performs satisfactorily during all the day from 7am to 8pm, which ensures reliable, smooth and efficient operation of microgrid system.

IV. CONCLUSIONS

In this work, an isolated integrated wind solar-PV based hybrid dc microgrid is developed. The developed experimental system satisfactorily works as an efficient and reliable source of power generation. The proposed system can be used in backup or emergency power source, off-grid applications, rural electrification, power supply source for buildings and agricultural purposes as well. The proposed system would not only serve to supply electricity to off-grid applications but can also contribute to meet growing energy demand of domestic and commercial buildings environment in a grid-connected mode, which also reduces dependency on fossil-fuel based resources to achieve sustainable development goal as well.

V. RECOMMENDATIONS

The proposed system can be extended at large scale to supply electricity to entire building via microgrid power system. The optimized size would be selected keeping in view the load demand of selected building. In addition to this, for reliable and smooth operation of microgrid power system an efficient control strategy for power management and intelligent protection for continuous operation will need to be designed.

VI. ACKNOWLEDGEMENTS

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