Harnessing Electrical Power from Hybrid Biomass-Solid Waste Energy Resources for Microgrids in Underdeveloped and Developing Countries

Muhammad Amir Raza
Department of Electrical Engineering
NED University of Engineering and Technology
Karachi, Pakistan
amir.eed.neduet@gmail.com

Krishan Lal Khatri
Department of Electrical Engineering
NED University of Engineering and Technology
Karachi, Pakistan
engrkrishan@yahoo.com

Khalid Rafique
Azad Jammu and Kashmir Information
Technology Board
Muzaffarabad, Pakistan
khalidrafiquepk@gmail.com

Abdul Sattar Saand
Electrical Engineering Department
Quaid-e-Awam University of Engineering, Science and
Technology, Nawabshah, Pakistan
as-saand@quest.edu.pk

Abstract-This paper presents an energy plan for harnessing electrical power from hybrid energy resources, including biomass and solid waste, through hybrid technologies for microgrid development to overcome the current energy crisis and provide future sustainable electricity pathways for a developing country. Biomass and solid waste were collected from different dumping sites in Pakistan and were tested for their calorific value, which was found to be 6519Kcal/Kg. The total power was calculated based on this calorific value and it was found that there is a potential of total 11,989.5GW of power generation. Thus, hybrid energy resources are suitable for harnessing electrical energy through hybrid technologies. Different hybrid systems were examined for these resources and the gasification technique is finally proposed as the most suitable method for producing energy from biomass and solid waste resources in Pakistan. This technique is also found to be economically feasible for processing all kinds of waste.

Keywords-biomass; solid waste; electrical power; sustainable development; developing countries; underdeveloped countries

I. INTRODUCTION

A developing country may face an exponential growth of population and industrialization, which is resulting in huge requirements of energy. This further leads to the exploitation of fossil fuels, such as domestic coal, natural gas, and oil which are not renewable. The use of fossil fuels poses a threat to the environment and public health in terms of harmful Greenhouse Gases (GHG) and huge production of waste [1]. The generated Municipal Solid Waste (MSW) will globally reach 2200 million tons annually by 2025 which would increase to 2600 million tons by 2030 [2, 3]. Sewage sludge produced from industrial and household wastewater treatment produces thousands of tons of solid waste daily [4]. Proper treatment of biomass and solid waste is an alternative option for power generation which reduces ecological and social issues [5]. Facilitating biomass and solid waste renewable resources for power generation instead of fossil fuels provides better techno-economic opportunities for Pakistan [5]. If biomass and solid waste resources are exploited, the ratio of renewable power generation would be increased from 2% to 27% and would cater for the 56% of local energy needs [6]. The major advantage of biomass and solid waste is that they can be available at any location in contradiction with fossil fuels[6].

There are many biomass and solid waste resources including human waste, MSW, food waste, firewood, shrubbery waste, fabrics, paper products, latex, and plastics [7]. The quantity and composition of biomass and solid waste vary greatly depending upon the region and human living standards [7]. There are four major sectors involved in the production of biomass and solid waste in Pakistan: agriculture, domestic, industrial, and commercial. Easy accessibility to biomass and solid waste resources provides a sustainable option for harnessing electrical power while resolving the issue of inappropriate dumping of biomass and solid waste. Biomass and solid waste are considered as the most feasible option for biofuel production and biochemical energy generation [8]. Biomass and solid waste are converted into biofuel through thermochemical conversion processes including combustion, gasification, incineration, and pyrolysis [9]. Gasification is a suitable option for managing large quantities of biomass and solid waste in Pakistan because it produces multiple outputs including heat for commercial purposes, energy for residential purposes, and bio-oils for the chemical industries while it utilizes all types of biomass and solid waste products [10]. The

Corresponding author: Muhammad Amir Raza

incineration techniques, amongst all considered techniques, are responsible for large environmental pollution [10].

Economic activities in the developing countries lead to augmented generation of biomass and solid waste. These sources could be used for the generation of electrical energy, bio-oil, and biofuel [11]. The usage of biomass and solid waste is valuable because these sources are available in huge quantities [11]. The type of material and the quantity of generated waste are different in each region as shown in Table I. Pakistan generates over 64,000tons/day of biomass and solid waste. This material is useful for power generation because it has good calorific value (6.9J/kg) [12]. In the main municipalities, the total production capacity of solid waste is around 712 million tons/year [12]. However, in India, the intermediate and massive populated cities generate a large quantity of waste which is increasing at a rate of 6% every year [13]. The production of biomass at a global level is also high [13].

TABLE I.   PRODUCTION CAPACITY OF BIOMASS AND SOLID WASTE IN VARIOUS COUNTRIES

Ref	Country	Material type	Production capacity
[12]	Pakistan	Biomass	46886 million tons/year
		Solid waste	8536 million tons/year
[13]	India	Biomass	180 million tons/year
		Solid waste	600 million tons/year
[14]	Europe	Biomass	205 million tons/year
[15]	China	Biomass	850 million tons/year
[16]	Brazil	Biomass	597 million tons/year

The utilization of biomass and solid waste for power generation in Pakistan is the focus of this study. However, to overcome the environmental pollution and available energy issue in the country, the research is on the way for converting unused sources into useful sources by using hybrid technologies for the generation of energy and heat. The main aim of the current research is to develop an energy plan for the energy sector of Pakistan in order to overcome the energy crisis and identify a future path of electricity supply for sustainable development. This research identifies the quantity and quality of solid waste and biomass resources and it justifies the suitability of harnessing electrical power from them. An experiment was performed in the lab for the final testing of waste pallets and the waste calorific value was identified in order to calculate its total power capacity. Furthermore, hybrid technologies were examined and the most suitable technology for hybrid resources was selected.

II.   MATERIALS AND METHODS

A. Study Area

Pakistan is located in the north western part of South Asia and covers an area of $881,913Km^2$ with an overall population of 207 million with a growth rate of 2.4% [17]. Its neighboring countries are China from the northeastern side, India from the eastern side, Iran, and Afghanistan from the western side and the Arabian Sea from the southern side. The growth rate of the Gross Domestic Product (GDP) in Pakistan is 5.8% [18] whereas the per capita income is $1641 [18]. If the growth rate of the population continues to increase at a pace of 2.4% then

by 2050 the country will become the 4th largest in the world [18]. The power consumption per capita is around 500kWh which is quite low compared with the global per-capita of power consumption which is around 2603kWh [19].

B. Compostion of Biomass and Solid Waste

Table II shows the chemical composition criteria of biomass resources through ultimate and proximate analysis on the physicochemical characteristics [20]. These characteristics would help to identify the selectivity and suitability of biomass resources for power generation. The chemical composition of solid waste is quite different from the biomass in the sense that the quality and capacity of solid waste is affected by various factors including the living standards, weather conditions, surrounding region, and financial status. Solid waste normally comprises of organic waste, inorganic waste, hazardous waste, paper waste, plastic waste, and textile waste. The waste composition type and percentage is shown in Figure 1 [21]. The physicochemical characteristics of solid waste are obtained from ultimate and proximate analysis tests. The ultimate analysis test is used to find the proportion of oxygen, nitrogen, sulphur, carbon, and hydrogen in the total solid waste whereas the proximate analysis test is used to find the fixed carbon, ash, moistness, and volatile matter. The physiochemical characteristics of solid waste are shown in Figure 2 [21].
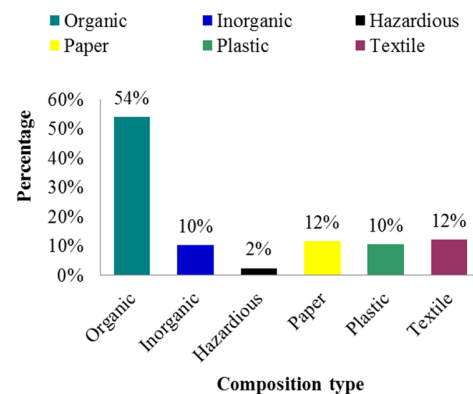

Fig. 1.   Composition type of solid waste in Pakistan.

C. Experimental Study of Biomass and Solid Waste Samples

An experimental setup is designed based on the quartering method as shown in Figure 3. Initially, 25kg of biomass and 25kg of solid waste were collected from different regions of Pakistan. Then, manual mixing and cutting were performed and all the waste was gathered at a single place. Further, this total waste was divided into 8 sections namely I, II, III, IV, V, VI, VII, and VIII. These sections were separated into even (II, IV, VI, and VIII) and odd sections (I, III, V, and VII). Even sections were mixed and again separated into two sections namely M and N. Similarly, odd section were mixed and separated into two sections namely O and P. Then these four sections (M, N, O and P) were mixed diagonally like M & P and N & O and separated into two sections like M & P into Y and N & O into Z. Finally, Y and Z were mixed for the final sample of analysis. The manual mixing and cutting were performed many times until the weight became 15kg.

|	Sulphur	Carbon	Oxygen	Hydrogen	Fixed carbon	Ash	Volatile matter	Moisture
Rice husk	0.02	35.6	59.7	4.5	14.6	26.2	59.2	8.8
Straw	0.21	39	35.46	5.73	17.5	10.1	64.43	8.32
Bamboo	0.09	50.52	42.80	6.04	16.05	1.95	83.95	6.14
Wheat straw	-	47.9	45.2	6.1	16.5	6.9	76.5	0.1
Sugarcane bagasse	0.09	46.6	43.3	5.92	8.30	3.90	82.5	5.25
Pine sawdust	0.36	49.79	44.12	6.36	13.91	1.29	82.03	2.77
Oat	-	42.3	40.9	6.3	-	1.5	-	7.1
Kenaf	0.05	46.71	54.32	6.71	17.18	5.45	73.64	3.73
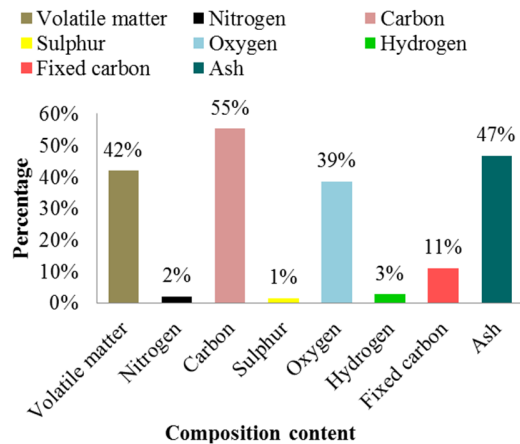
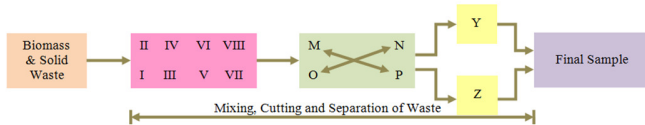Fig. 2.   Composition content of solid waste in Pakistan.

Fig. 3.   Quartering diagram method for waste sampling.

D. Determination of Heating or Calorific Value

The calorific value is highly dependent on the amount of heat produced during the combustion process. The calorific value of the final sample of waste pellets was determined in the laboratory using the Gallen Kamp Ballistic Bomb (GKBB) Calorimeter. The net calorific value is determined as 6519kcal/kg. However, from other research data, the calorific value ranges from 9MJ/kg to 44MJ/kg respectively [24]. Equations (1) and (2) were used for finding the higher and lower values of calorific of mixed biomass and solid waste pallets [25].

$$\text{Higher calorific value} = \frac{\sum Q_p \, (C.V)H}{T_p} \quad (1)$$

$$\text{Lower calorific value} = \frac{\sum Q_p \, (C.V)L}{T_p} \quad (2)$$

where $(C.V)L$ is the lower calorific value in kcal/kg, $(C.V)H$ is the higher calorific value in kcal/kg, Q_p is the quantity of the specific material in the total waste pallets in kg, and T_p is the total waste pallets in kg.

E. Theoretical Power Potential of Biomass and Solid Waste

The power potential of mixed biomass and solid waste pallets can be calculated by:

$$Ep = (C.V)L \times Aw \times 1.16 \quad (3)$$

where Ep is the energy potential in kWh and Aw is the aggregate waste in kg.

III.   RESULTS AND DISCUSSION

A. Net Power Calculations

Net power of biomass and solid waste pallets were calculated as follows:

The Heat Of Combustion (HOC) was calculated using the total Quantity of Waste Pallets (QWP) and Calorific Value (CV):

$$HOC = QWP \times CV \quad (4)$$

$$HOC = 55,422,000,000 \text{ ton } \times 6,519,000 \text{ kcal/ton}$$

$$HOC = 3.61296018 \times 10^{17} \text{ kcal}$$

The Heat Output (HO), considering efficiency of 25% [25], was:

$$HO = \text{overall efficiency} \times HOC \quad (5)$$

$$HO = 0.25 \times 3.61296018 \times 10^{17}$$

$$HO = 9.03240045 \times 10^{16} \text{ kcal}$$

With 1kWh equal to 860kcal the Units Generated/Annum (UGA) are:

$$UGA = HO/860 \quad (6)$$

$$UGA = 9.03240045 \times 10^{16}/860 \text{kcal}$$

$$UGA = 105,027,912,209,302.3 \text{kWh}$$

$$UGA = 105,027,912,209.3023 \text{MWh}$$

The Average Load on the System (ALS) is:

$$ALS = UGA/\text{total hours in a year} \quad (7)$$

$$ALS = 105,027,912,209.3023 \text{MWh } /8760 \text{h}$$

$$ALS = 11,989,487.69512584 \text{MW}$$

This mathematical framework calculated the total power production capacity from the hybrid energy resources based on authentic and realistic data. The available capacity and quality of waste pallets can generate a power of 11,989.5GW. This power capacity can drive the economy of the country at a great extent but there is a need to develop a proper energy harnessing system with sufficient financing and resources.

TABLE III.   TECHNOLOGY SELECTION PARAMETERS FOR POWER GENERATION

| Parameters	Pyrolysis	Plasma	Gasification	Incineration
Feedstock	Solid waste	Solid waste	Biomass and solid waste	Biomass and solid waste
Variable composition	Did not accept variable waste	Did not accept variable waste	Accept heterogeneous waste of all types	Little difficult to proceed variable waste
Product	Oil, Syngas and energy	Syngas and energy	Syngas and energy	Heat and energy
Operating cost	150$ per tone	120$ per tone	60$ per tone	60$ per tone
Annual capital cost	1500$ per tone	1300$ per tone	850$ per tone	775$ per tone
Disposal	Ash 0.3 tone per feedstock tone	Bottom ash around 10%	Less than 1% bottom ash	Around 5% bottom ash
Energy production capability	800 kWh per tone	600kWh per tone	800kWh per tone	850 Kwh per tone
Efficiency	Less than 18%	Less than 10%	18% to 30%	18% to 25%
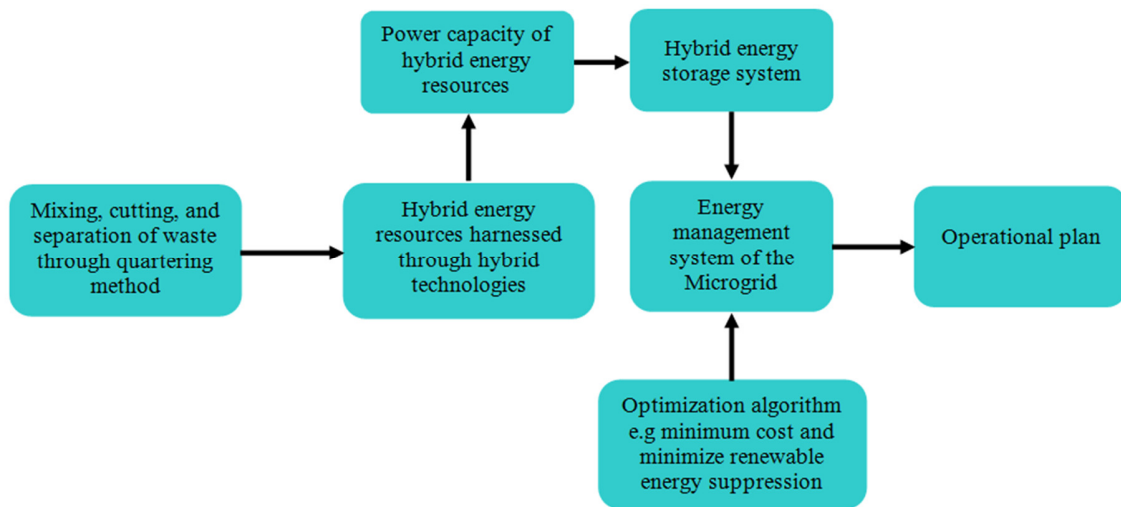
Fig. 4.   Hybrid energy storage systems for renewable source integration in the microgrid energy management system.

B. Power Generation Technology for Hybrid Resources

The gasification technique for power generation is more suitable than the other techniques mentioned in Table III [26-29]. The gasification technique accepts all types of waste (biomass and solid waste) for power generation with greater power production efficiency and has the capability of producing less ash. Gasification with its hybrid system opens the door for new development in the country because hybrid technologies based on other resources, including wind, solar, and nuclear, coupled with biomass and solid waste resources can provide more energy benefits to the community.

C. Integration of Hybrid Biomass-Solid Waste Energy Resources in a Microgrid

Most renewable sources are used in microgrids with lower power levels (around 200kW) and are connected with the main bus through power converters [28-31]. These systems are installed near the commercial and industrial sites for meeting the power demand. These systems produce low noise and emissions which ultimately provide reliable power on low cost. The selection of a suitable renewable source is a complex process. This research paper has described a step-wise feasibility study of hybrid biomass and solid waste resource for microgrid development. Figure 4 shows the hybrid energy

storage systems for hybrid renewable source (biomass/solid waste) integration in the energy management system of a microgrid. The integration of a hybrid energy storage system, distributed energy resources, and distributed loads with a renewable energy ecosystem is called microgrid. A microgrid helps to setup the smart and active electrical grid with the potential to increase the efficiency, reliability, and safety of the system.

IV. CONCLUSION

This study aims to alleviate the current energy crisis and suggests future electricity pathways to drive the economy of a developing country such as Pakistan. An experiment was performed in the lab in order to identify the suitability for power generation of waste pallets collected from different sites of Pakistan. The results of this study were examined quantitatively to justify the feasibility of the energy plan. The projected power generation is 11,989.5GW which is sufficient to alleviate the ongoing energy crisis and facilitate the future industrial development in the country. Pakistan therefore needs to develop a new policy that is economically feasible and environmentally friendly for longer tenure. Hybrid energy resources provide a suitable option through hybrid technologies for microgrid development.

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