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Renewable energy-focused hybrid supply system for optimal powering the cellular base station

Saurav Biswas
Department of EEE, Bangladesh University of Business and Technology, Dhaka-1216, Bangladesh
Corresponding Author's Email: sauravbiswas.eee@gmail.com

***Abstract*— With the enhancement of wireless communication and their higher data demand, telecom network operators are continuously deploying the cellular base stations (BSs). This enormous growth of cellular BSs receiving a huge amount of energy and creating immense pressure on the fossil fuel reservation by releasing the greenhouse gas (GHG) emissions. The main objective of this work to build a cost-effective and environment-friendly cellular network powered by the locally available renewable energy sources such as solar photovoltaic (PV), wind turbine (WT), and biomass generator (BG). This article addresses the key challenges of developing a green mobile communication to minimize the net present cost and GHG by maximum utilization of renewable energy. For ensuring the guaranteed continuity of power supply, an adequate battery bank is connected with the hybrid supply system. The technical criteria, optimal component size, and energy issues of the hybrid solar PV/WT/BG powered cellular BSs are critically evaluated using HOMER optimization software considering the dynamic fluctuation of the users and renewable energy sources. Simulation results illustrate that the hybrid solar PV/WT/BG system can satisfy the BS energy demand with the lowest value of net present cost. Moreover, the battery bank can support the cellular network for 162 hours during the emergency hours, which is sufficient time for fixing the renewable energy sources. In summary, the hybrid solar PV/WT/BG system along with sufficient energy storage devices is an effective solution for developing green cellular communication considering the geographical location.**

***Keywords*— Hybrid power, renewable energy, solar energy, wind energy, biomass energy, cellular network, sustainability**

I. INTRODUCTION

The rapid evolution of mobile traffic and wireless multimedia networks has contributed to a remarkable rise in the energy usage of wireless mobile communication over the last decade [1]–[5]. Telecom operators are gradually deploying more BSs to meet this ever-energy demand, leading to a rise in a large portion of their operating expenses (OPEX). It has been projected that global energy demand is expected to rise by about 37 percent from 2013 to 2035, or by a further 37 percent from 2013 to 2035 [6]–[10]. Consequently, the global energy bill for cellular networks is over \$10 billion per year and CO_2 emissions are also expected to increase by 6% annually through 2020 [11]–[15]. Another drawback is that Radio Access Network (RAN) BSs contribute approximately 60-80 % of total energy expenditure and put a heavy burden on conventional grid supplies to solve the problem of a stable supply of electricity [16]–[20]. In response to the call for a reduction in energy usage and the financial dimensions, cellular operators have focused extensively on green communications, with an emphasis on the environmental effects [21]–[25]. Recently, the access networks created by renewable, efficient, cost-effective, and clean energy resources in green radio communications systems have created an attractive solution that has attracted intense attention in both industry and academia [26]–[30]. For example, in Africa, Huawei [31] developed a 3G-supported green cellular BS based solar PV energy to reduce soul reliance on grid energy.

A diesel generator (DG) is usually used to power the remote cellular BSs if, due to the geographical position, the grid connection is not accessible or not suitable. From an economic, technological, and environmental viewpoint, the notion of putting the diesel generator as the primary source has become much less viable [32]–[36]. It is estimated that the greenhouse gas outflow of the ICT sector will grow to 170 metric-tons in 2014 to 235 metric-tons by 2020. Besides, fossil fuel supplies are constantly declining, and the cost of fuel is rising in nature [37]–[41]. In addition, the lower performance and regular operation and maintenance make the system even less efficient due to DG failure and subsequent outage. Motivated by the above problems, the renewable energy source (RES) and the mix of RES and non-RES / Grid are an excellent solution for network operators to achieve a minimum of green connectivity. Besides, numerous studies [42]–[48] have been undertaken to curb energy costs through the adoption of renewable energy sources to power large-scale cellular networks, and research in this area is not yet saturated. But the authors have not studied the successful solution for the real-time pattern of cellular networks. During the low traffic time, this approach can result in a huge dissipation of electricity.

Meeting the rapidly rising enormous demand for electricity from non-renewable energy sources harms both the economic and environmental impacts of higher capital costs and increasing emissions of greenhouse gases. Also, non-renewable resources are natural resources that, on a scale comparable to their use, cannot be remade. As a result, researchers have drawn deep attention to energy processing from renewable energy sources to generate sustainable and environmentally friendly energy [49]–[54]. Moreover, renewable energy sources such as solar, wind, biomass, etc. are reusable, cheap, clean, and accessible in many regions, while the technical development of renewable energy production is cost-effective, efficient, and reliable [55]–[60]. In [61], the authors explored the feasibility of deploying renewable energy-based cellular networks in different regions around the world and estimated that approximately 320,100 renewable energy-based off-grid BSs were deployed by 2014 and approximately 3,89,800 off-grid BSs will be running green energy by 2020.

The key contribution of this work to develop a hybrid solar PV/WT/BG-powered green cellular network in Bangladesh considering the dynamic nature of renewable energy sources and traffic rates. The technical criteria, economic feasibility, energy issues, and greenhouse gas emissions of the proposed system are critically evaluated using the HOMER optimization software package.

II. SYSTEM ARCHITECTURE

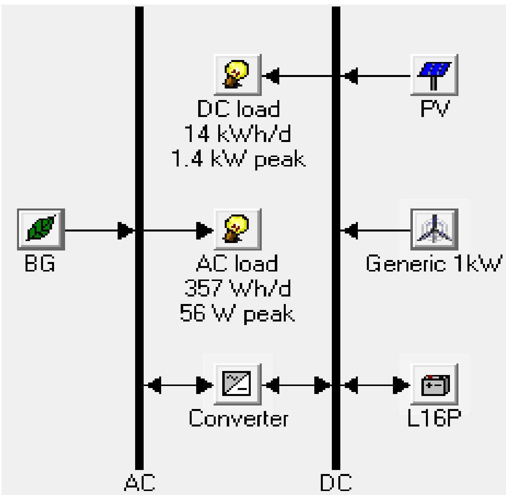

Figure 1: System model in the HOMER platform.

The architecture of the proposed system in the HOMER platform is shown in Fig. 1. The major component of the proposed system is solar PV panel, wind turbine, biomass generator, battery bank, and converter. The short description and mathematical modeling of the major component of the proposed system are presented below:

A. Solar PV panel

Solar PV panel collects the solar intensity and converts it into DC electrical energy. The detail of the electrical energy generated the solar PV system is shown below [34]

$$E_{SPV} = \gamma_{SPV} \times PSH \times \eta_{SPV} \tag{1}$$

Where γ_{SPV} the rated solar PV, PSH is the solar intensity in kWh/m^2/day and η_{SPV} is the efficiency of the solar PV. The daily average solar intensity and clearness index of the selected Chattogram division is shown in Fig. 2.

B. Biomass Generator

Biomass generator process biomass for generating green energy. In this work, the selected main source of biomass is agriculture residue such as rick husk. The amount of energy generated by the biomass generator is calculated as follows [34]

$$E_{BM} = P_{BM}(365 \times 24 \times f) \tag{2}$$

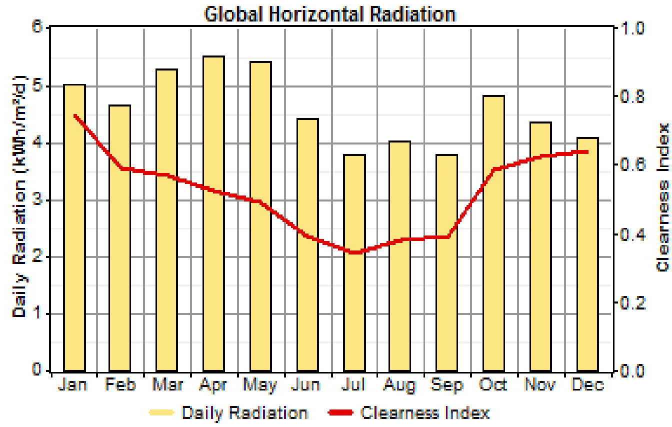

Figure 2: Solar radiation profile for the selected area.

Where f the capacity factor is the ratio of actual electrical energy output to the maximum possible electrical energy output over a given period. The characteristic of the biomass generator is shown in Fig. 2. On the other hand, the monthly statistic of biomass available in the selected location is presented in Fig. 3.

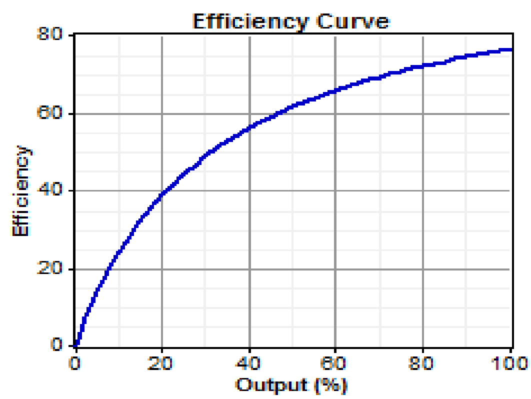

Figure 3: Characteristic curve of the biomass generator.

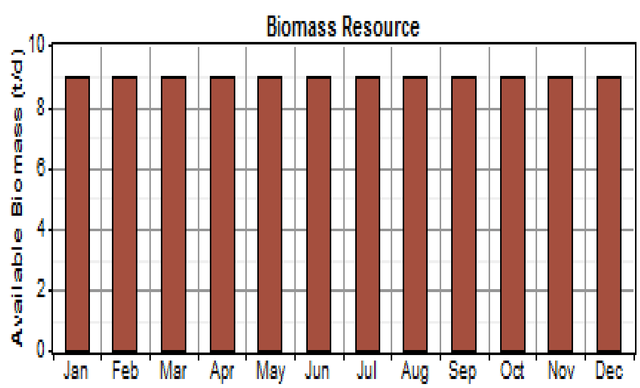

Figure 4: Biomass profile of the selected area.

C. Wind Generator

The annual power generated by the wind turbine is calculated by the following equation [34]

$$P = \frac{1}{2} pV^3 C_p \tag{3}$$

Where *p* is the air density of the selected location, V is the air velocity, and *Cp* is the coefficient of the Betz limit. HOMER calculates the harvested energy based on the above equation for the given time period. The characteristic of the wind turbine is shown in Fig. 5. In this work, the Whisper200 wind turbine has been selected for its satisfied wind speed versus output power characteristic. The monthly statistic of the wind speed of the selected location is shown in Fig. 6.

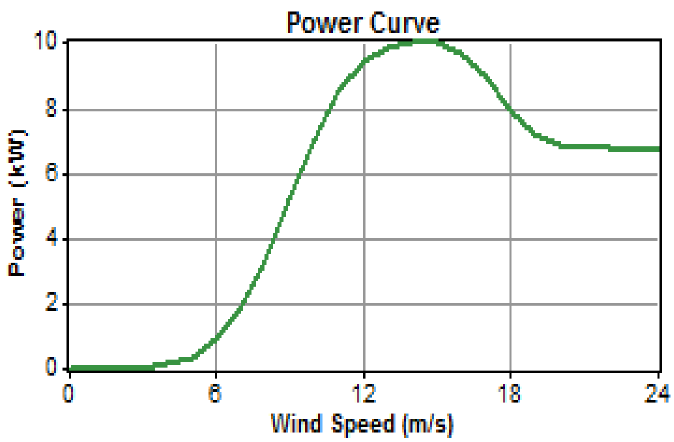

Figure 5: Characteristic curve of the wind turbine.

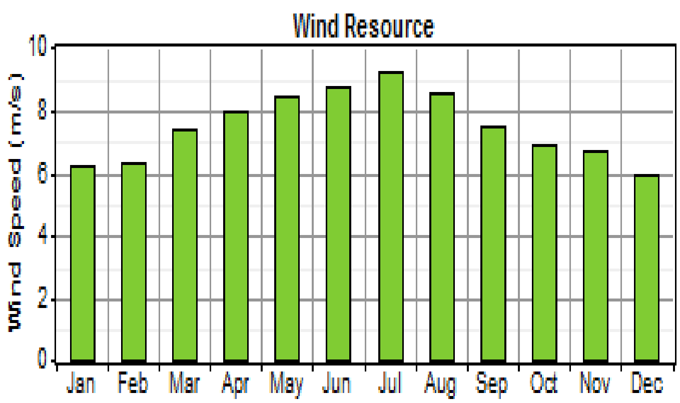

Figure 6: Wind profile of the selected area.

D. Battery Bank

For providing sufficient backup power in this work 'Trojan L16P' battery has been selected due to the low cost, and superior charging/discharging characteristic. The characteristic of the selected battery is shown in Fig. 7. The capacity of the battery bank that is required to support the backup power is calculated as follows [34]

$$B_{aut} = \frac{N_{batt} \times V_{nom} \times Q_{nom} \times B_{DOD} \times (24h/day)}{L_{BS}} \qquad (4)$$

Where N_{batt} is the number of batteries, V_{nom} is the nominal voltage of a single battery in V, Q_{nom} is the nominal capacity of a single battery in (Ah), B_{DOD} is the battery depth of discharge, and L_{BS} is the average daily BS load in kWh.

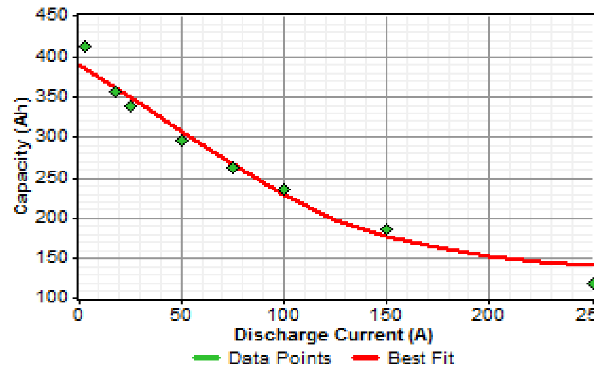

Figure 7: Characteristic of Trojan L16P battery

E. Load Profile

The amount of power consumed by the cellular network as a function of traffic intensity (χ) can be approximated as follows [34]

$$P_{in} = M_{\sec}(P_1 + \Delta_p P_{\max}(\chi - 1)) \text{ if } 0 < \chi \le 1 \qquad (5)$$

Where M_{sec} is the number of antennas in the base station, P_1, is the maximum power consumption, P_{max} is the transmitted power, χ is the traffic intensity, Δ_p is the load dependency of the power consumption. The dynamic traffic intensity of the selected location is illustrated in Fig. 8. The power consumed by the different component of the base station under 10 MHz system bandwidth is shown in Table 1.

Table 1: Power consumed by the different parameters of the BS under BW=10 MHz [34].

Components	**Parameters**	**Value**
BS	P_{max} [W]	20
	Feeder loss σ_{feed} [dB]	0
PA	Back-off [dB]	8
	Max PA out [dBm]	51
	PA efficiency, η_{PA} [%]	31.1
Total PA [W]		64.4
RF	P_{TX} [W]	6.8
	P_{RX} [W]	6.1
Total RF, P_{RF} [W]		12.9
Baseband (B)	Radio (inner Tx/Rx) [W]	10.8
	Turbo code (outer Tx/Rx) [W]	8.8
	Processors [W]	10
Total B, P_B [W]		29.6
DC-DC	σ_{DC} [%]	7.5
Cooling	σ_{Cool} [%]	0
Main Supply	σ_{MS} [%]	9
Sectors		3
Antennas		2
Total Power [W]		**754.8**

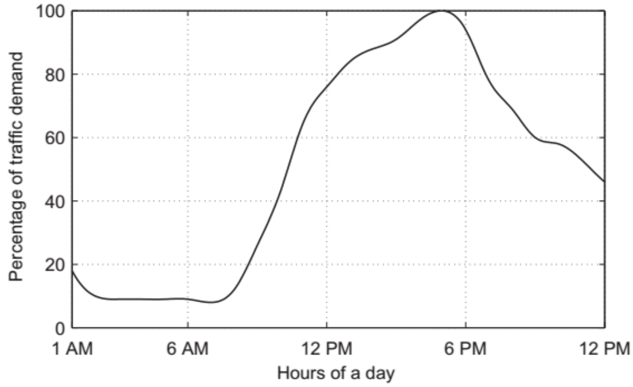

Figure 8: Dynamic traffic demand for the selected area.

III. SYSTEM IMPLEMENTATION

A. Simulation Setup

In this simulation setup, assignment length and the annual hobby rate have been regarded 20 years and 6.75 % respectively, which shows the long-term sustainability of the proposed system. For ensuring the higher-high-quality of service annual ability shortage has been chosen 0%. Moreover, dual-axis tracking mode PV panels are modeled and 10% returned to power is reserved to serve the BS load, even if the renewable strength generation all of the sudden decreases. HOMER decides at every time step to satisfy the energy demand of BSs and preserve provision for backup energy at the decrease net current cost.

In this simulation setup, the lifetime of the mission is regarded as 10 years with an annual activity fee of 6.75%. The normal fees together with capital cost, replacement cost, OMC cost, and salvage fees are often depending on this assignment's lifecycle and annual interest rate.

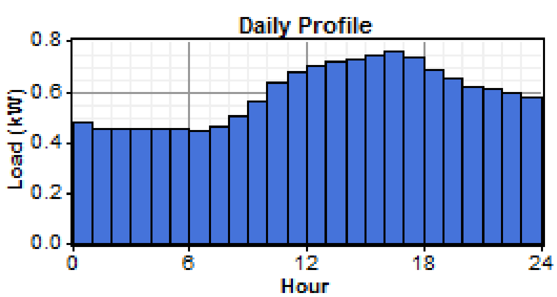

Figure 9: DC load profile under 10 MHz bandwidth.

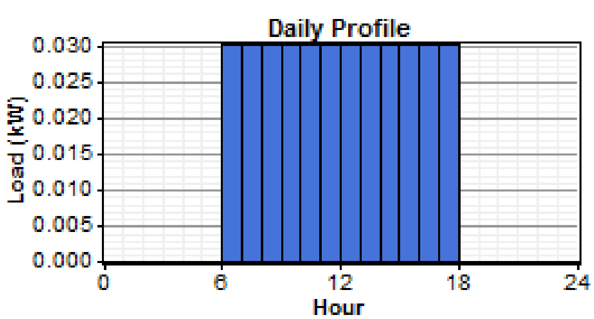

Figure 10: AC load profile under 10 MHz bandwidth.

The DC and AC load profiles of the cellular network under 10 MHz bandwidth are shown in Fig. 9 and Fig. 10 respectively.

B. Cost Modeling

HOMER is the optimization tool used in this study to evaluate the optimal solar power system that satisfies user-specified constraints with the lowest net present cost (NPC) including the capital costs (CC), replacement costs (RC), operation and maintenance costs (OMC), and salvage value (S) within the project duration. The NPC is computed as follows [23]

$$NPC = \frac{TAC}{CRF} = CC + RC + OMC - S \tag{6}$$

Total annualized cost (TAC) value and capital recovery factor (CRF) is described as follows [23]

$$TAC = TAC_{CC} + TAC_{RC} + TAC_{OMC} \tag{7}$$

$$CRF = \frac{i(1+i)^N}{(1+i)^N - 1} \tag{8}$$

Where N is the project duration and i is the annual real interest rate.

IV. RESULTS AND DISCUSSIONS

The result analysis section has been performed to emphasize the five key aspects: (i) Optimal Architecture, (ii) Technical criteria, (iii) Energy yield analysis, (iv) Cost analysis, and (v) GHG emissions. Additionally, relations of network sustainability, cost-effectiveness, and greenhouse gas emissions with that of various parameters like system bandwidth, transmission power, and daily solar radiation intensities are thoroughly investigated and critically analyzed.

A. Optimal Architecture

The optimal architecture of the proposed system under 10 MHz bandwidth is shown in Table 2. The optimal system architecture has been found simulating the system considering the average solar intensity, wind speed, and biomass available in the selected location. From the optimal results, it is seen that the proposed system is technically feasible due to its smaller size.

Table 2: The optimal size of the hybrid solar PV/WT/BG system under 10 MHz bandwidth.

PV (kW)	**WT (kW)**	**Battery (Units)**	**Converter (kW)**
3.5	2	64	1.4

B. Energy yield analysis

The annual energy generated by the different renewable energy sources is shown in Fig. 11. It is clearly seen that solar PV and wind turbines generated a higher amount of energy due to the superior solar intensity and wind speed on the selected location. It is also seen that the biomass generator contributes to a lower amount of energy. This is happening because the energy generation from BG involves a small amount of CO_2.

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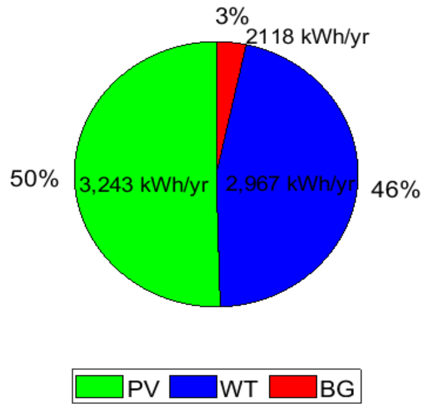

Figure 11: Energy breakdown for 10 MHz system bandwidth.

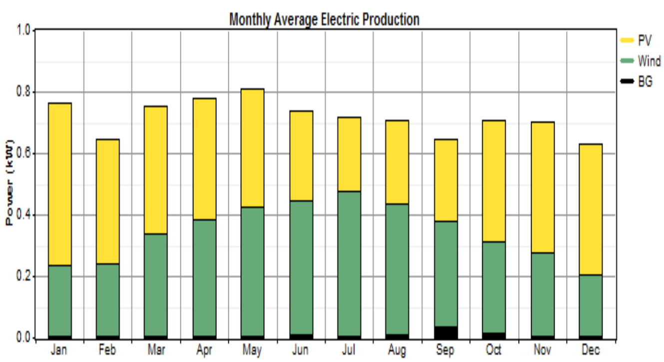

Figure 12: Monthly power contribution by the RES.

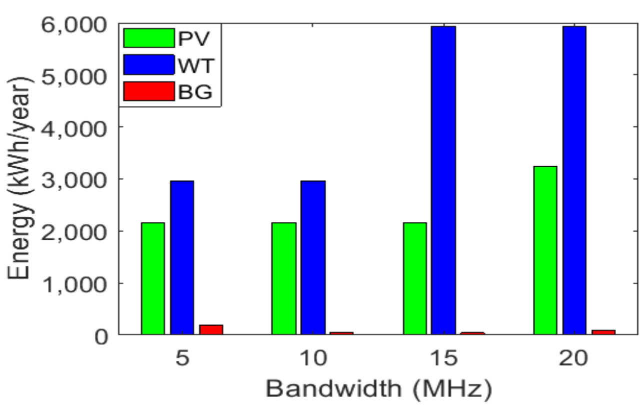

Figure13: Energy generated under different system bandwidth.

The monthly statistic of power contributed by the different renewable energy sources is shown in Fig. 12. The monthly statistic shows that the solar PV panel, wind turbine, and biomass generator complement each other. In the case of lower solar intensity solar PV generated higher energy. On the other hand, the wind turbine generates higher energy during the higher wind speed. Moreover, the biomass generator provides additional energy when the solar PV panel and the wind turbine is not sufficient to fulfill the required energy demand. The amount of energy contributed by the different renewable energy sources under different system bandwidth is shown in Fig. 13. Fig. 13 tells that the biomass generator contributes always minimum energy due to the involvement of a small amount of greenhouse gas by the biomass generator. However, the biomass generator supplies the backup power during the shortage and outage of renewable energy shortage.

C. Cost analysis

Different types of costs that are associated with the supply system are evaluated with the HOMER optimization software. The net present cost includes all the costs such as capital cost, replacement cost, operation and maintenance cost, fuel cost, salvage value. The net present cost of the proposed system for 10 MHz system bandwidth is shown in Fig. 14. It clearly mentioned that among the different types of component Trojan L16P involves the highest amount of cost due to a smaller amount of battery life and a huge amount of battery requirement.

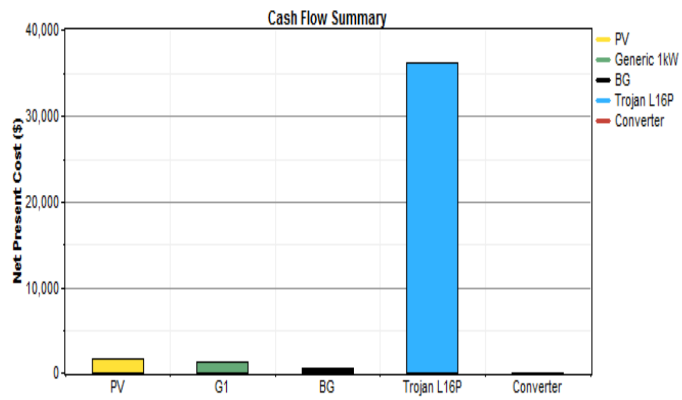

Figure 14: Net present cost of the proposed system.

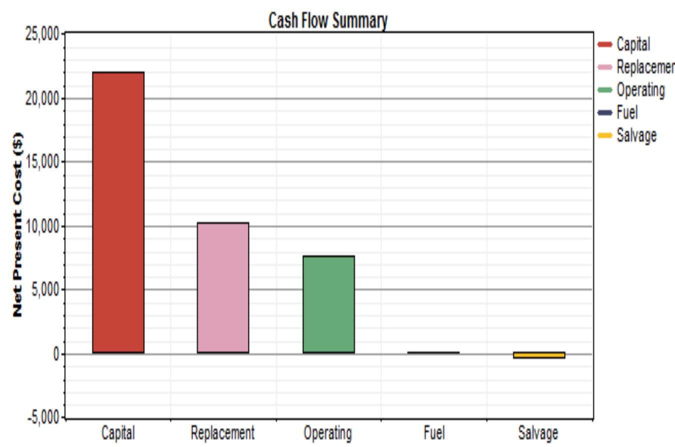

Figure 15: Cost breakdown of the proposed system.

The individual cost breakdown for the different types of costs is shown in Fig. 15. In line with our expectations, the initial capital cost the highest level of cost, and fuel cost is the lowest due to the minimum amount of biomass involvement in this project. The cost breakdown curves also represent that the small amount of capital cost can be returned after completing the project which is indicated in the figure as negative salvage value. Moreover, the proposed system involves a small number of operating costs due to the operation and maintenance of the supply system. The detail of the individual cost under 10 MHz system bandwidth is presented in Table 3.

Table 3: Individual cost breakdown.

Components	IC ($)	RC ($)	OMC ($)	Fuel ($)	Salvage ($)	Total ($)
PV	1,500	0	162	0	-81	1,581
WT	600	225	540	0	-108	1,257
BG	660	0	0	99	-75	684
Battery	19,200	9,991	6,914	0	0	36,105
Converter	40	15	11	0	-7	59
Total	22,000	10,232	7,627	99	-271	39,686

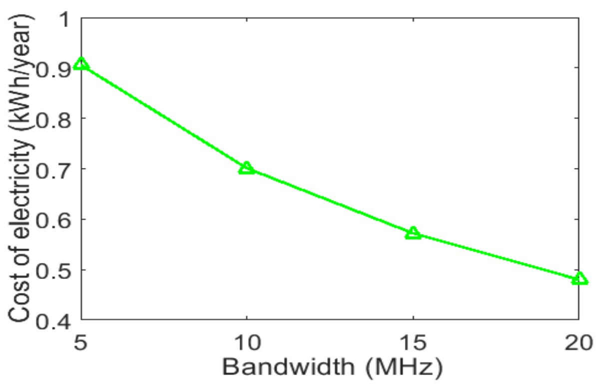

Figure 16: Cost of electricity for different system bandwidth.

An extensive comparison of per unit electricity generation cost for different system bandwidth considering the average renewable energy sources is shown in Fig. 16. In line with our expectation, the per-unit electricity generation cost is decreasing with the increment of the system bandwidth. This is happening because the higher system bandwidth has a comparatively lower net present cost.

D. GHG emissions

Table 4: Carbon contents for the 10 MHz bandwidth.

Waste product	Value (kg/yr)
CO_2	0.349
CO	0.00189
Unburned hydrocarbons	0.00033
Particulate matter	0.000332
SO_2	0
NO	0.0166

The number of carbon contents emitted in the hybrid supply system is summarized in Table 4. In this work, the biomass generator is the main source of greenhouse gas emissions. In line with our expectation, the proposed system emits a smaller amount of greenhouse gases. Table 5 also shows that among the different types of pollutant carbon dioxide is the highest amount. However, this higher volume of carbon content can be maintained at a lower value by using modern technology.

Conclusion

The main objective of this work to develop a sustainable, reliable, and cost-effective supply system by utilizing the locally available renewable energy sources. Extensive simulations are carried out to find the optimal system architecture, and quantitative advantages of the proposed scheme under different network conditions. Simulation results tell that the proposed hybrid solar PV+BG+WT system along with sufficient energy storage devices can fulfill the base station energy demand. The battery bank can carry the BS load demand without support from renewable energy sources during the intermittency time. It is also found that the renewable energy-focused supply system can save the environment by minimizing greenhouse gas emissions. In the future, the authors intend to expand the proposed dynamic model demonstrating to the operations of geologically dispersed several base stations building a trained algorithm for load balancing steerage of approaching solicitations relying upon the geological range of electrical energy fee and renewable energy generations.

Conflicts of Interest: The authors declare no conflicts of interest.

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