Optimal Sizing and Application of Renewable Energy Sources at GSM Base Station Site

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Abstract- Software products (such as HOMER), using for projecting and research of alternative energy systems in Nigeria are usually developed by European or American research centers or products supplying companies. There is a need for specific software product for projecting, analysis and simulation of electric power processes in technological buildings with specific electrical control. This paper discusses the development of a computer program for determining the renewable energy sources (RES) that can be used for electric power supply of GSM base station site at any given time. The program calculates the optimum configuration of the system according to the weather data as well as the period of operation of solar cells. From the simulation results, it was shown that the optimal load sizing (source and load characteristics are effectively matched) and the supplied energy is efficiently and rationally utilized. The structural analysis of the program is described in details through data flow diagrams. The program can be adapted for application in any area.

Keywords- Renewable energy sources, solar-pv, hydro, wind, base station site, Nigeria.

1. Introduction

Renewable energy sources (RES) are increasing being applied in power generation mainly because they are abundant and freely available, virtually pollution free. Renewable technologies are designed to run on a virtually inexhaustible or replenishable supply of natural "fuels." By definition, it is a strategy for sustainable growth, since operation of the facilities does not deplete the earth's finite resources. Renewable energy facilities enhance the value of the overall resource base of a country by using the country's indigenous resources for electricity generation to power base station sites.

Nigeria is endowed with very abundant renewable energy resources that remained unexplored and unexploited for alternative energy solutions for telecommunications particularly for the largely populated rural areas in the country. Nigeria lies along the Equator, with abundant sunshine all the year round. Nigeria is endowed with an annual average daily sunshine of 6.25 hours, ranging between about 3.5 hours at the coastal areas and 9.0 hours at the far northern boundary [1]. Similarly, it has an annual average daily solar radiation of about 5.25 KW/m^2/day, varying between about 3.5 kWm^2/day at the coastal area and 7.0kW/m2/day at the northern boundary. Nigeria receives about 4.851x 10^{12} KWh of energy per day from the sun. This is equivalent to about 1.082 million tones of oil equivalent (mtoe) per day, and is about 4 thousand times the current daily crude oil production, and about 13 thousand times that of natural gas daily production based on energy unit [2]. This huge energy resource from the sun is available for about 26% only of the day. Based on the land area of 924 x 10^3 km^2 for the country and an average of 5.535 kWh/m^2/day, Nigeria has an average of 1.804 x 10^{15} kWh of incident solar energy annually [3].

There are lots of canals, several minor streams and rivulets that crisscross the entire Nigerian land mass, tributaries of main river Niger, Benue, as well as tiny waterfalls having potentials for setting up mini/micro hydropower units that can power GSM Base Station Site. These can be found mainly in coastal regions of the country. Harnessing micro-hydro resources and setting up decentralized small-scale water power or micro-hydro schemes are a particularly attractive option in terrain areas without hampering the ecosystem [2].

Two principal wind currents affect Nigeria. The south-western winds dominate the rainy season of the year, while north-eastern winds dominate the dry season. Depending on the shifts in the pressure belts in the Gulf of Guinea, these winds are interspersed respectively by the south-eastern and the north-western winds in different parts of the year. The wetter winds prevail for more than 70% of the period due to the strong influence of the breeze from the Atlantic Ocean. Mean annual wind speed varies between 2 to 6 m/s. Speeds in dry season (November - March) are lower. In the wet season (April–October), daily average speed could rise to 15 m/s. Values of up to 25 m/s are sometimes experienced due to inducement by convective rainfall activities and relative diffusion [4]. From meteorological centres in Nigeria and satellite-derived meteorology and solar energy parameters from National Aeronautics and Space Administration (NASA), the average daily wind speed across the country, at 50meter height above the earth, is within the range of 2.7m/s in the central western parts to 5.4 m/s in the North East.

There is therefore a great promise for alternative renewable energy for the telecommunications industry in Nigeria, if only the country could endeavour to explore and exploit these available resources. Although, renewable energy sources have high installation costs, their costs can be minimized if there is optimal load sizing (source and load characteristics are effectively matched) and the supplied energy is efficiently and rationally utilized. It is essential to have accurate data on load demand and potential of RE source(s) of an area, before deciding on the type of source or system [5] for a particular application. In order to assess the need and adequacy for a RES, it is necessary to carry out the technical analyses. It involves a study of the sources and load characteristics, as well as system design and optimization. The aim of present research is working out a structural analysis and methods for software system RESs development. For the purpose of this study the three types of RE sources considered were PV solar, wind and hydro.

2. Establishment of Renewable Energy System

The first step for the establishment of renewable energy system is the prefeasibility analysis. In the system design,

Table 1. Wind, solar and hydro resource for University of Nigeria, Nsukka.

Month	Clearness Index	Average Radiation ($kWh/m^2/day$)	Wind Speed (m/s)	Stream Flow (L/s)
Jan	0.605	5.680	2.100	19.5
Feb	0.578	5.740	2.200	20.0
Mar	0.537	5.570	2.100	20.0
Apr	0.503	5.250	2.000	20.0
May	0.487	4.940	1.900	19.0
Jun	0.458	4.540	2.100	18.0
Jul	0.415	4.140	2.400	16.0
Aug	0.382	3.910	2.500	13.0
Sep	0.406	4.190	2.300	13.5
Oct	0.457	4.570	1.700	14.5
Nov	0.539	5.110	2.000	16.0
Dec	0.595	5.460	1.800	18.5
Scaled annual average		**4.950**	**2.1**	**17.3**

Table 2. The electrical load (daily load demands) data for the base station site [12]

Time	Daily Load Demands								Total (W/Hr)
	Radio Unit (W)	Base Band (W)	Power Supply & Rectifier (W)	RF feeder (W)	Remote Monitoring and Safety (W)	Signal Transmitting (W)	Security and Lighting (W)	Air Conditioning (W)	
00-01	4160	2190	1170	120	100	120	200	2590	10650
01-02	4160	2190	1170	120	100	120	200	2590	10650
02-03	4160	2190	1170	120	100	120	200	2590	10650
03-04	4160	2190	1170	120	100	120	200	2590	10650
04-05	4160	2190	1170	120	100	120	200	2590	10650
05-06	4160	2190	1170	120	100	120	200	2590	10650
06-07	4160	2190	1170	120	100	120	200	2590	10650
07-08	4160	2190	1170	120	100	120		2590	10450
08-09	4160	2190	1170	120	100	120		2590	10450
09-10	4160	2190	1170	120	100	120		2590	10450
10-11	4160	2190	1170	120	100	120		2590	10450
11-12	4160	2190	1170	120	100	120		2590	10450
12-13	4160	2190	1170	120	100	120		2590	10450
13-14	4160	2190	1170	120	100	120		2590	10450
14-15	4160	2190	1170	120	100	120		2590	10450
15-16	4160	2190	1170	120	100	120		2590	10450
16-17	4160	2190	1170	120	100	120		2590	10450
17-18	4160	2190	1170	120	100	120		2590	10450
18-19	4160	2190	1170	120	100	120	200	2590	10650
19-20	4160	2190	1170	120	100	120	200	2590	10650
20-21	4160	2190	1170	120	100	120	200	2590	10650
21-22	4160	2190	1170	120	100	120	200	2590	10650
22-23	4160	2190	1170	120	100	120	200	2590	10650
23-00	4160	2190	1170	120	100	120	200	2590	10650
Total	**99840**	**52560**	**28080**	**2880**	**2400**	**2880**	**2600**	**62160**	**253400**

resource is anything that can be used to generate electricity and comes from outside the system. RES available at a location can differ considerably from site to site and this is a vital aspect in developing the hybrid system. All of these resources depend on different factors – apart from seasonal or even hourly changes: Whereas the amount of solar energy available is dependent on climate and latitude, the hydro resource depends from the location's topography and its rainfall patterns; the wind resource is influenced by atmospheric circulation patterns and geographic aspects. The resources' dependence of various factors in turn influences when power can be generated and thus the behaviour of the hybrid system. The climatic conditions determine the importance and the availability of the solar, hydro and wind energy in a particular site. After the prefeasibility study, the sizing of the renewable hybrid system components follows. Renewable hybrid system component sizing is based on the climatic data and the maximum capacity, and plays a significant role in determination of the reliability of the system [6].

2.1. Prefeasibility Study

A prefeasibility study is based on the weather data (solar insulation, flow rate and wind speed) and the load required for the specific site.

2.1.1. Study area

The study area was University of Nigeria, Nsukka (UNN) located in a valley on a plateau at an average elevation of approximately 500 metres above sea level in the town of Nsukka, about eighty kilometers North of Enugu [7] at a specific geographical location of 6°51'56"N latitude and 7°24'22"E longitude [8] with annual average solar daily radiation of 4.95kWh/m²/d whereas its annual average wind is 2.1m/s. The data on potentials of the three types of renewable energy sources considered was obtained from the meteorological and hydrological maps of the area [9]. It was obtained as insolation levels, wind speeds as well as stream discharge rates and heads. Table 1 shows the solar, wind and hydro resource for University of Nigeria, Nsukka (Enugu State), Nigeria, used for the simulation.

2.1.2. Load variation of the GSM Base station site

A BTS is a tower or mast mounted with telecommunication equipment (e.g. antenna, radio receiver and transmitters at the top of the mast) that enables the transmission of mobile signals (voice and data) [10, 11]. All the facilities (Radio Equipment, Power Conversion Equipment, Antenna Equipment, Transmission Equipment, and climate equipment) at the base station site are all on for 24hrs (00:00h – 23:00h) except the Auxiliary Equipment (security light) that comes on only for 13hrs (18:00h – 7:00h) as shown in Table 2. It is assumed that it is identical for every day of the year. The annual peak load of 10.67kW was observed between 18:00h and 07:00h, with 254Wh/day energy consumption. The daily average load variation for the Base station site is shown in Table 2.

3. Methodology

3.1. Model Development

The following equations, used in the program, are based on equations used by [5, 13, 14, 15] to derive the power supplied by renewable energies. The potential output power of each of the three sources was evaluated using the following equations:

The PV Power:

$$P_{PV} = G \times A \times \eta \tag{1}$$

The Wind Power:

$$P_{WT} = A_r \times k \times V^3 \times \eta_{ef} \tag{2}$$

The Hydro Power:

$$P_{HT} = K \times Q \times H \times \eta_t \tag{3}$$

Where,

P_{PV} is the Power from solar in kW, G is the Solar irradiance in kW/m^2, A is the Panel area in m^2, η is the efficiency, P_{WT} is the Power from wind turbine generator in kW, A_r is the Area of rotor blades in m^2, V is the wind speed in m/s, η_{ef} is the effective efficiency, P_{HT} is the power from hydro in kW, Q is the flow rate in m^3/s, η_t is the turbine efficiency, H is the effective head in m, K is the constant including water density and the acceleration due to gravity.

3.2. Sizing of the Renewable Hybrid System

The optimal sizing of this renewable energy sources plays a significant role for the energy reliability of the system. In an energy system, 40% of the total energy loss [16] is due to the non-optimal sizing of the system. It is to be recalled that the sizing of the renewable hybrid systems of energy is based on the meteorological data of the implementation area. This requires the development of a computer program for an optimization (Sizing). The developed program requires that the user correctly identify the key variables and then repeatedly run the simulation, adjusting the variables manually to converge on an acceptable sizing. For this study, optimal system was obtained with an assumption of keeping all the different components within the system; i.e. the power of each component is limited to 10kW to be able to accommodate all the renewable energy sources.

3.3. Hybrid Energy System Configuration

The proposed hybrid renewable is consists of solar photovoltaic (PV) panels, hydro and wind turbine with battery added as storage system. This proposed system is shown in Figure 1. To serve the load, electrical energy can be

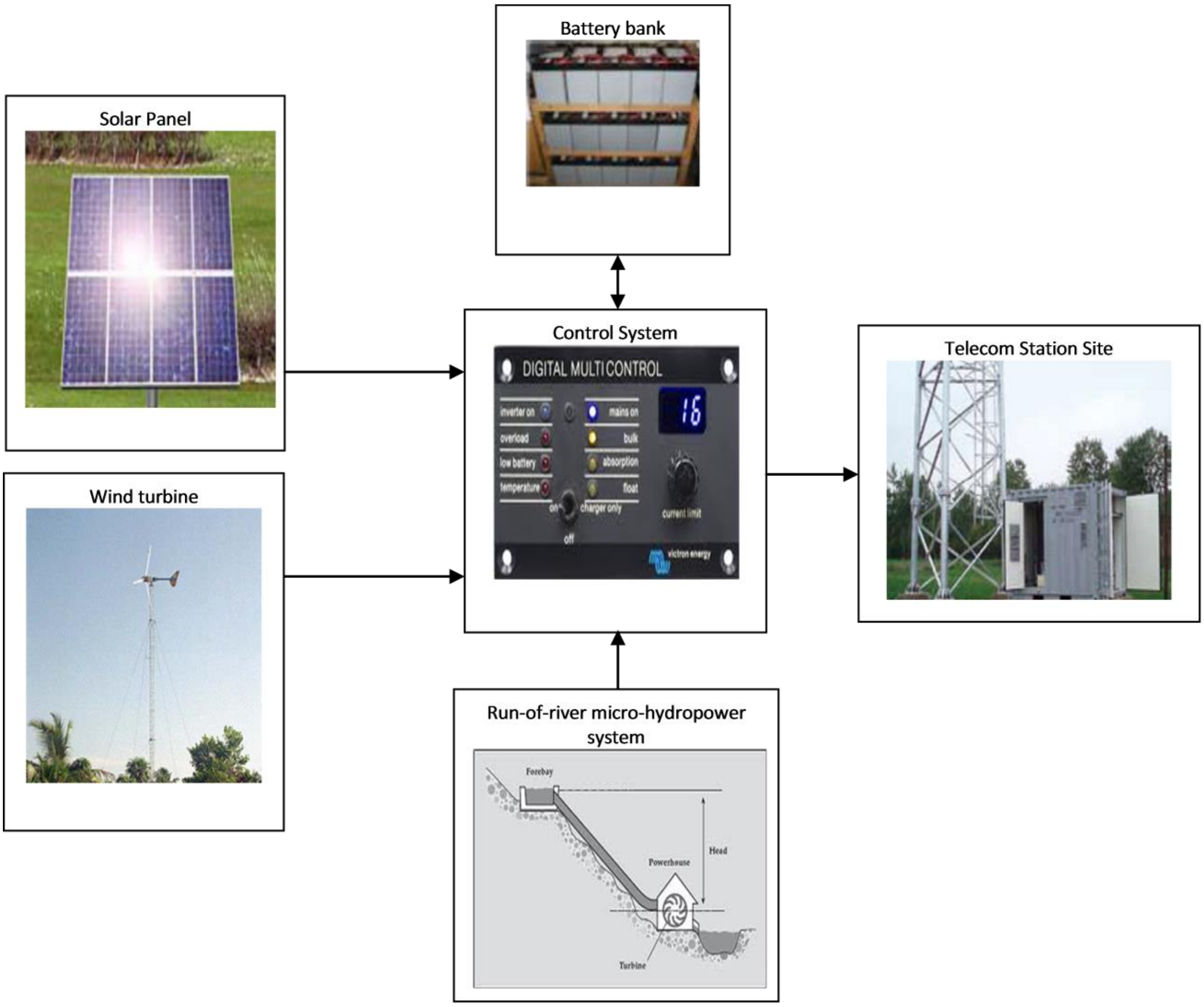

Fig. 1. Architecture of the proposed renewable energy hybrid system

produced either directly from PV, hydro turbine, wind turbine, or indirectly from the battery. A Controller is used to coordinates the generation of renewable energy sources(s) (PV panels, hydro and Wind turbine) and to control the charge and discharge current from the battery.

The study involves a theoretical load demands as shown in Table 2. The load is assumed constant all year. The hybrid renewable is consists of a hydro turbine, wind turbine and solar photovoltaic (PV) panels. The renewable energy supplied is based on hourly basis. The parameters required for the execution of the program were: time for which the user wishes to evaluate power requirement, insolation level (kWh/m^2), average daily wind speed (m/s) and flow rate (m^3/s).

3.4. The Structural Analysis of the Program

This paper mainly deals with renewable energy system design and operation control problem which is non-linear due to non-linear component characteristics and the complexity of the renewable energy system component interaction. The proposed system configuration is composed from PV arrays resulting in a total rated power of 10.7 kW, 10 kW Generic wind turbine, and 10.3 kW hydro turbine. The program starts, and you are required to enter any time. When you enter the time, either the time you entered is within 8:00hr (8am) and 18:00hr (6pm) (PV power available) or out of this range (PV power not available).

3.4.1. The Time is Within 8:00hr and 18:00hr

If the time is between 8:00hr and 18:00hr, then PV power is available, and it loops to the next level where the program will ask you to enter insolation of that particular time and it calculates the PV power. It will also ask you to enter flow rate. When you enter the flow rate, either the flow rate is less than 20 or greater than 20. If the flow rate is greater than 20, then it loops back a step for you to enter another flow rate that is less than 20, but if the flow rate you entered is less than 20, then the program will calculate the hydro power available. Again the program ask you to enter the wind speed, either the wind speed is within the range of 2.5 and 15, or out of the range. If the wind speed is within the range of 2.5 and 15, then the program will calculate the wind power available and check whether there is complete power, if yes it will display suitable combination to use and end or else system unable and end.

But if the wind speed is not within the range of 2.5 and 15, then it means that wind power is not available. If power is greater than the load, then the program displays the available power and end. On the other hand, if power is less than the load, the system is unable and the program end.

3.4.2. When the Time is not Within 8:00hr and 18:00hr

If the time is not between 8:00hr and 18:00hr, then PV power is not available, and it loops to the next level where the program will ask you to enter wind speed. Either the wind speed is within the range of 2.5 and 15, or out of the range. If the wind speed is not between 2.5 and 15, then wind speed is not available and it will loop to another step and ask you to enter flow rate. Either the flow rate is greater than 20 or less than 20. If the flow rate is greater than 20, then it loops back a step for you to enter another flow rate that is less than 20, but if the flow rate you entered is less than 20, then hydro and batteries can be used and the program calculates the hydro and battery power. If power is greater than the load, then the program display the available power and end the program or else, the system is unable and end the program. If the wind speed is between 2.5 and 15, then the program calculates the wind power available and it will loop to another step and ask you to enter flow rate. Either the flow rate is greater than 20 or less than 20. If the flow rate is greater than 20, then it loops back a step for you to enter another flow rate that is less than 20, but if the flow rate you entered is less than 20, then the program calculates the hydro power available. If power is greater than the load, then the program display suitable combination to use and end or else system unable and end.

4. Results and Discussion

Table 3 shows the contributions of the different renewable sources (PV, Wind and Hydro) and it was observed that the variation is not only in the demand but also the availability of sources. The battery compensates the shortage. It is observed that the program allocates the sources optimally according to the demand and availability satisfying the constraints. The entire operations of the program can be seen from Figure 2.

From Table 3, the minimum demand of 10.467kW occurs at 8:00hr till 17:00hr and is met by all the energy sources. It shows that the renewable energy hybrid system is fully utilized to supply the load demand as well as charging the battery during day times (8:00hr to 17:000hr).

From Table 3, the maximum demand of 10.667kW occurs at 18:00hr till 7:00hr and is met by all the energy sources along with the battery bank. During that time no excess power is available from the hybrid energy system and the battery is in discharging mode.

It is observed that during the day when the sun shine is plenty, the excess energy from the sun is stored by the storage components (batteries) of the system and thus

Table 3. Sample program output for the hybrid energy system (pv, wind, and hydro) in 24 hrs.

Time (h)	Global solar (kW/m^2)	Incident solar (kW/m^2)	Wind Speed (m/s)	Stream Flow (L/s)	Dc Load (kW)	PV power (kW)	Wind power (kW)	Hydro power (kW)	Battery power (kWh)	Battery State of Charge (%)
0:00	0.000	0.000	1.164	19.481	10.667	0.000	0.000	7.184	-3.483	93.659
1:00	0.000	0.000	1.231	19.481	10.667	0.000	0.000	7.184	-3.483	93.399
2:00	0.000	0.000	1.253	19.481	10.667	0.000	0.000	7.184	-3.483	93.139
3:00	0.000	0.000	1.036	19.481	10.667	0.000	0.000	7.184	-3.483	92.878
4:00	0.000	0.000	1.477	19.481	10.667	0.000	0.000	7.184	-3.483	92.618
5:00	0.000	0.000	1.741	19.481	10.667	0.000	0.000	7.184	-3.483	92.358
6:00	0.000	0.000	2.087	19.481	10.667	0.000	0.000	7.184	-3.483	92.097
7:00	0.006	0.000	1.309	19.481	10.667	0.000	0.000	7.184	-3.483	91.837
8:00	0.187	0.410	1.518	19.481	10.467	3.952	0.000	7.184	0.668	91.877
9:00	0.415	0.600	2.252	19.481	10.467	5.781	0.000	7.184	2.498	92.026
10:00	0.622	0.783	2.856	19.481	10.467	7.536	0.045	7.184	4.297	92.283
11:00	0.908	1.076	2.431	19.481	10.467	10.358	0.000	7.184	7.075	92.706
12:00	1.087	1.249	1.742	19.481	10.467	12.031	0.000	7.184	8.748	93.229
13:00	1.144	1.301	2.278	19.481	10.467	12.527	0.000	7.184	9.244	93.782
14:00	1.110	1.271	1.694	19.481	10.467	12.243	0.000	7.184	8.959	94.317
15:00	0.972	1.144	2.176	19.481	10.467	11.015	0.000	7.184	7.732	94.779
16:00	0.715	0.890	2.179	19.481	10.467	8.575	0.000	7.184	5.292	95.096
17:00	0.465	0.653	1.807	19.481	10.467	6.284	0.000	7.184	3.001	95.275
18:00	0.196	0.352	2.499	19.481	10.667	3.388	0.000	7.184	-0.095	95.268
19:00	0.016	0.000	3.036	19.481	10.667	0.000	0.083	7.184	-3.400	95.014
20:00	0.000	0.000	3.381	19.481	10.667	0.000	0.158	7.184	-3.326	94.765
21:00	0.000	0.000	2.741	19.481	10.667	0.000	0.020	7.184	-3.463	94.506
22:00	0.000	0.000	2.805	19.481	10.667	0.000	0.034	7.184	-3.450	94.249
23:00	0.000	0.000	2.699	19.481	10.667	0.000	0.011	7.184	-3.472	93.989

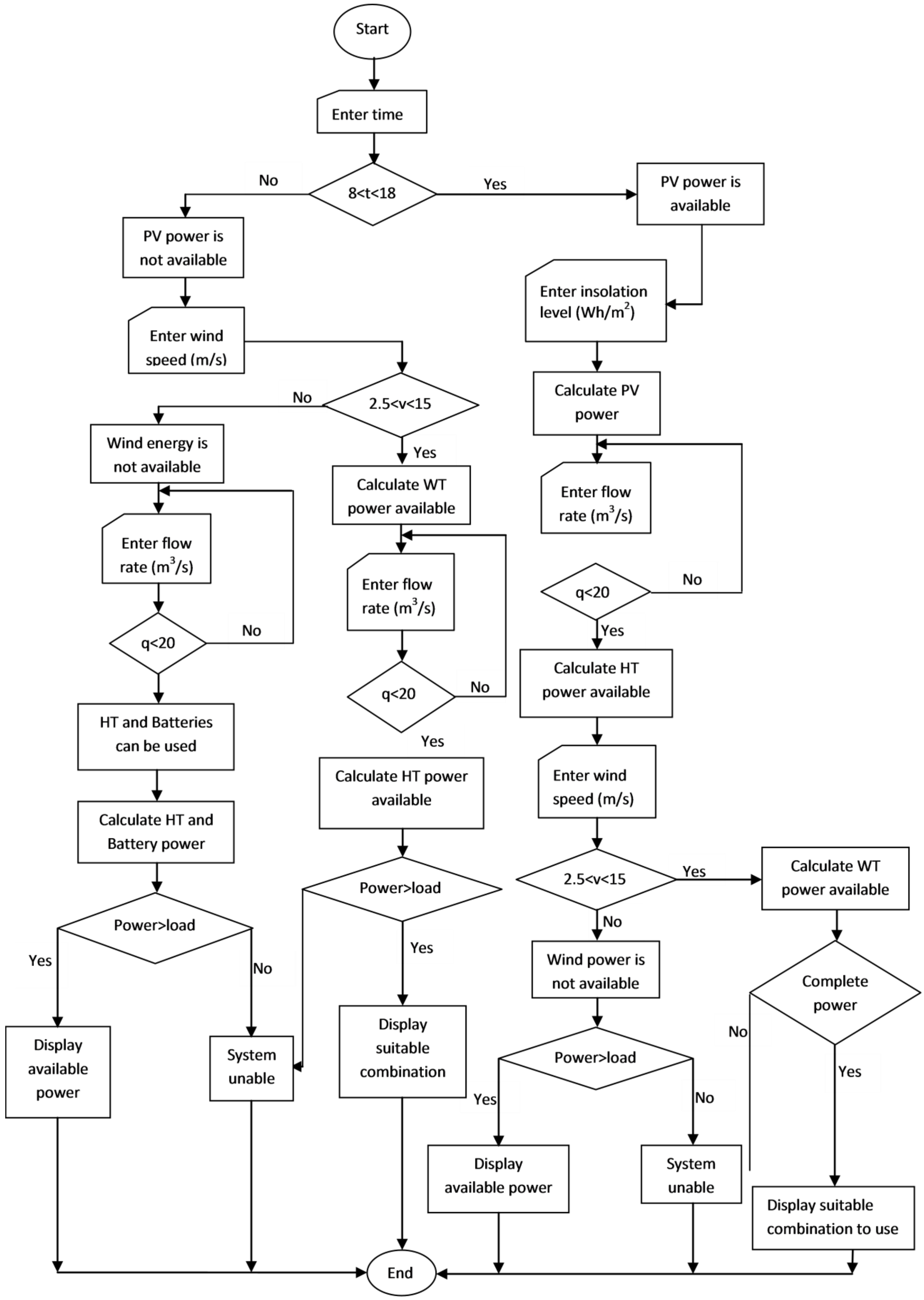

Fig. 2. Program flow chart

compensates for the short fall in solar radiation at night, when the sun shine is quite low.

The charging and discharging of the battery bank is also shown. Battery power indicates the operating strategy of the hybrid system: charging (power positive) or discharging (power negative). The batteries are in charging mode whenever there is excess power available from the sources, and in discharging mode whenever there was a shortage of power from sources. It was observed that the program utilized the battery bank effectively during the optimization.

5. Conclusion

The developed program simplifies the task of determining the most suitable combination of renewable source to supply a given load, and is, therefore, a useful tool in systems load sizing. From the simulation results, it is found that the implemented program allots the sources effectively and the hybrid energy system supplies the demand of the particular site effectively. The Product could be used during the process of design, energy analysis and simulation of electrical power process in renewable hybrid and stand-alone systems for energy supply of daily needs and technological processes in telecommunications (GSM Base station sites). It can be used also as a power monitoring and control system for hybrid systems.

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