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Optimal Energy Management System for PV/Wind/Diesel-Battery Power Systems for Rural Health Clinic

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Abstract: Good operation of a hybrid system can be achieved only by a suitable control of the interaction in the operation of the different devices. This paper presented a supervisory control system that monitors the operations of PV/Wind-Diesel hybrid power generation system with energy storage. The controller was developed in such a way that it coordinates when power should be generated by renewable energy (PV panels and Wind turbine) and when it should be generated by diesel generator and is intended to maximize the use of renewable system while limiting the use of diesel generator. Diesel generator is allocated only when the demand cannot be met by the renewable energy sources including battery bank. The structural analysis of the supervisory control is described in details through data flow diagrams. The developed control system was used to study the operations of the hybrid PV/Wind-Diesel power system for the three hypothetical off-grid remote health clinics at various geographical locations in Nigeria. It was observed that the hybrid controller allocates the sources optimally according to the demand and availability. From the control simulation, we were able to see the performance of the system over the course of the year to see which mode(s) the system spends most time in, the power supplied by each of the energy sources over the year, and the power required by the load over the year. This is a very useful manner to check how the system is being supplied and which source of energy is the most proficient in supplying the load.

Keywords: *Hybrid System, Supervisory control, Power Consumption, Power Supply, Health Clinic.*

1. Introduction

Application of renewable energy for power generation has several benefits (such as clean energy, reduction of electricity cost) but its intermittency has leads to special attention on the mix of renewable energy systems (an electricity production system which consists of a combination of two or more renewable types of electricity generating source) and hybrid systems (an electricity production system which consists of a combination of two or more types of electricity generating source which one of the sources must be diesel generator).

In a mix of renewable energy systems with batteries, the control strategy is simple: the battery charges if the renewable energy exceeds the demand, and the battery discharges if the load exceeds the renewable energy. However, the control strategies of a hybrid system can become very complex if the system includes batteries. Therefore, in a hybrid system it is necessary to determine how the batteries are charged and what element (batteries or diesel generator) have priority to supply energy when the load exceeds the energy generated from renewable sources. A hybrid system uses advanced system control logic (also known as a supervisory control) to coordinate when power should be generated by renewable energy and when it should be generated by sources like battery or diesel generators [1]. Another useful aspect of control system is that it increases renewable energy participation in the load sharing. Without a supervisory controller, it is expected to limit the renewable energy in around 20% [2].

This paper presented a supervisory control system that monitors the operation of the hybrid system with the objective of maximizing renewable energy and limit the use of diesel generator.

2. Hybrid Energy System Configuration

A hybrid power generation system is defined as the interconnection of several power generators (PV panels, wind turbine, and diesel generator) and a set of batteries. The hybrid energy system is based on a generalized three-bus configuration. The three buses are a DC bus, an AC bus, and a load bus. The technologies that generate DC current– PV, wind, and battery – are connected to the DC bus (VDC). Technologies that generate AC current, i.e. diesel generators, are connected to the AC bus (VAC). Only AC appliances are used and are connected to the load bus (IAC). A battery charger is used to convert AC (Ich_AC) current from diesel generator to DC (Ich_DC) current to charge the battery and serve the load. An inverter, or a DC-to-AC converter, is used to convert DC current (Iinv_DC) to AC current (Iinv_AC) (from the DC bus to serve the AC load) as shown in Figure 1.

3. Supervisory Control for PV/Wind-Diesel Hybrid System

As is well-known, a good operation of energy systems can be achieved only by a suitable control of the interaction in the operation of the different devices. A thorough knowledge of the management strategies to be chosen in the preliminary stage is therefore fundamental to optimize the use of the renewable source, thereby, minimize the wear of batteries and use of diesel [3, 4, 5]. In this study, a sliding control was used; using the PV power (PPV) generation as the primary source of energy, wind power (PWT) generation as the secondary source and battery

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(Pchar_max,disch_max) as the supplement and the diesel as the backup. The system moves between different mode depending on the power needed by the load and the power able to be supplied by each of the sources. Fig. 3 outlines the flow between the different modes.

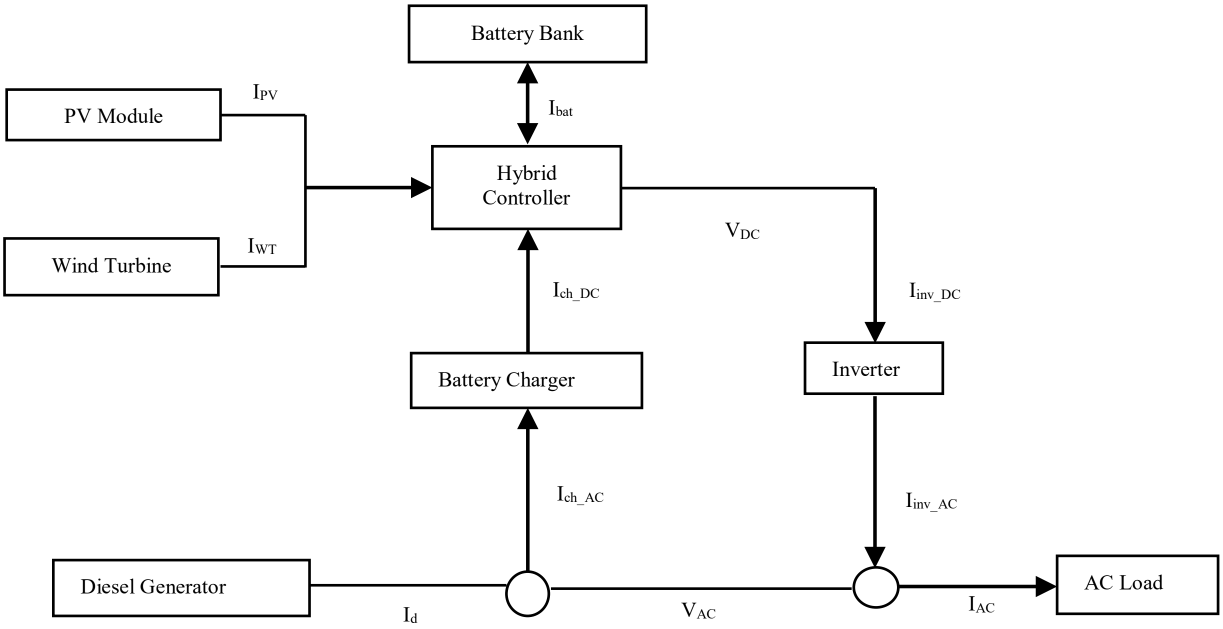

Figure 1. Configuration of the proposed PV/Wind/Diesel Hybrid System

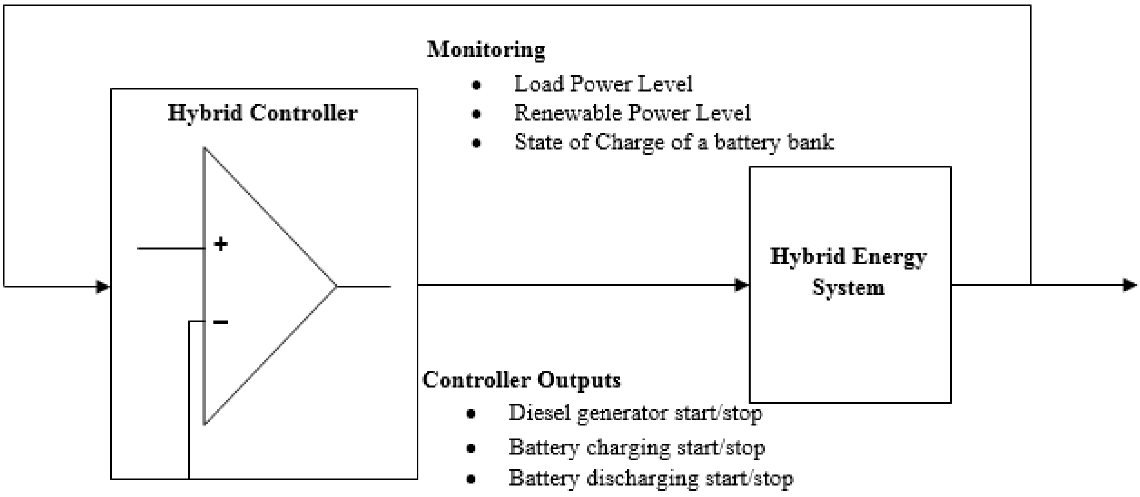

Figure 2. Hybrid System Controller Block Diagram [3].

The controller operates in 4 modes, modes 1-4 according to which of the Hybrid System Components [PV, H, W, DG] is generating the dispatch power to the load. The detailed mode of operational control (sliding) is given below:

3.1.1. Mode 1

Mode 1 uses solely the energy generated by the PV panel to supply the load. When the system is in mode 1, at times, the energy available from the PV panel might be in excess of what is needed by the load and therefore the amount of energy supplied to the load must be matched to the load demand. This is called sliding control. As the wind turbines are connected to the system, but not used to supply the load in this mode, the energy generated by the wind turbine as well as any excess energy from the PV panels can be used to charge the battery. During the charging of the battery, if the SOC of the battery is at its maximum possible SOC value, the excess power is sent to a dump load [Dump load is a device to which power flows when the system batteries are too full to accept more power], which can be defined according to the health clinic's needs, charging of phones, etc. The flowchart inside the dotted line shown in Fig. 3 is the charging control circuit. If the SOC of the battery is less than the maximum SOC, the amount of excess power is checked. Battery-Experts [6] advised not to use a charging current of more than 60A. The power is then checked to make sure that the current used to charge the battery will be less than 60A. If the excess power is less than this maximum charging power, the battery is charged with the full excess power. If the power is above that of maximum charging of the battery, the maximum battery charge power is used to charge the battery and the excess is used for the dump load.

3.1.2. Mode 2

Mode 2 uses the power of the PV panels plus the power of the wind turbine to supply the load. In Mode 2, if the energy available from the PV panel and the wind turbine combined is in excess of what is needed by the load, then the full power available from the PV panels is used to supply the load and the power from the wind turbine is supplied using the sliding control to match the power required by the load. The excess energy from the PV panels and the wind turbine can be used to charge the battery, as in Mode 1.

3.1.3. Mode 3

The system enters Mode 3 when the power generated by the PV panels and wind turbine is not sufficient to supply the load. The full power generated by the PV panels, the wind turbine, and the battery (with the condition that if the SOC of the battery is greater than the SOC minimum amount and the power needed to be discharged by the batteries is below the discharge maximum), then the load is supplied. Battery-Experts [6] also advised that the batteries should not supply more than 80A current, and therefore the amount of power needed to be supplied by the batteries must be checked before it can supply that amount.

There is, however a possibility that the amount of power required by the load is not able to be supplied by the PV panels, wind turbine and the batteries, and when this occurs, it enters mode 4.

3.1.4. Mode 4

When the system is in mode 4, it means that the combined power of the wind turbine and the PV panels is not sufficient to supply the load and the battery is at its minimum SOC and therefore

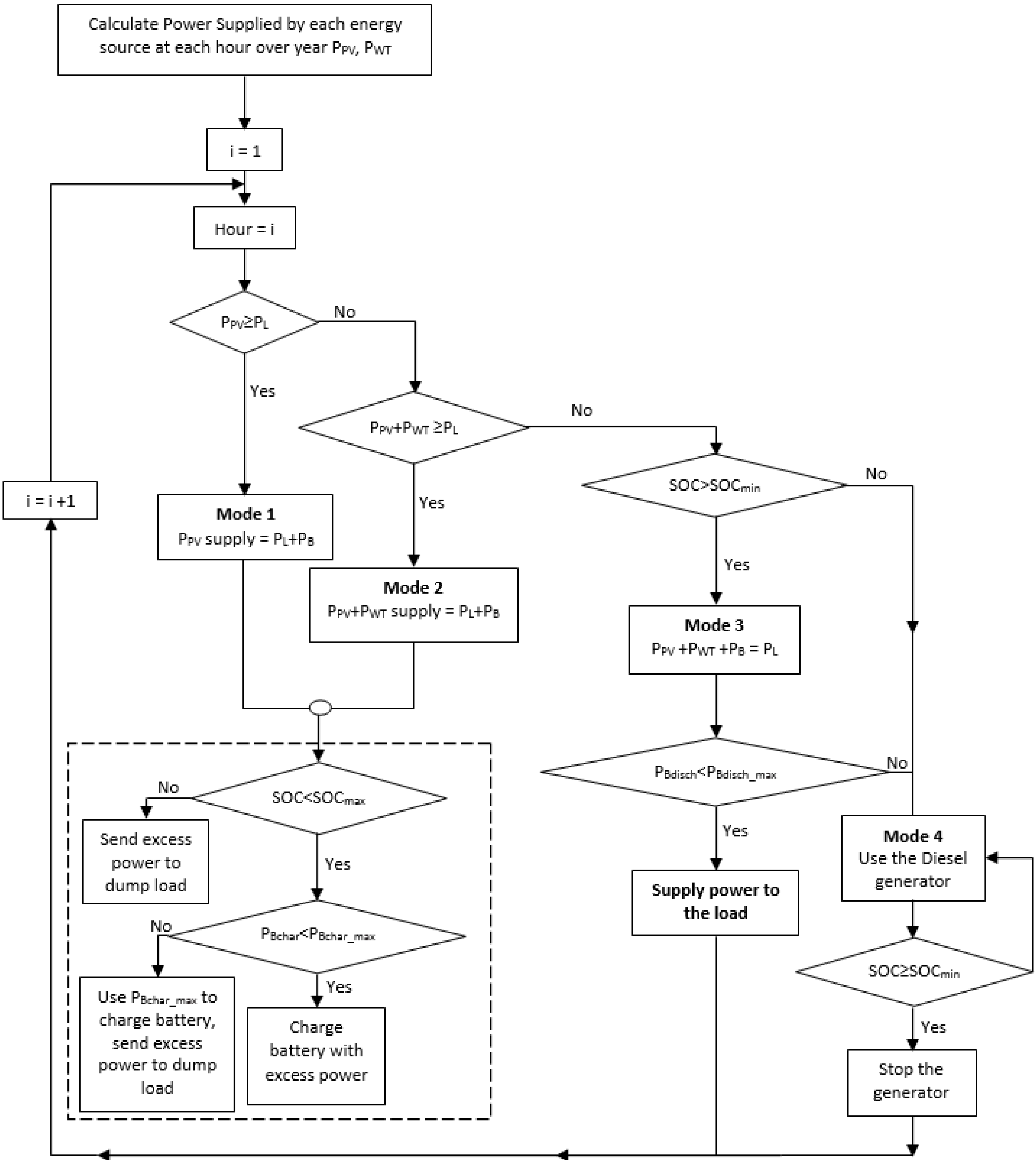

Figure 3. Flowchart of modes of control for PV/Wind/Diesel - Battery Energy System.

cannot be used to supply the deficit of power required, and the hybrid controller connects (starts the generator) to the diesel generator to enable the necessary load to be met.

The operations which activate or deactivate the charging or discharging of the battery, start (ON) and stop (OFF) the diesel generator are managed and done by a hybrid controller unit. The controller unit monitors and manages the load demand and energy supplied as shown in figure 2.

4. Material and Method

The inputs to the control simulator are the technical data of all the components of the hybrid system. These data were: solar insulation (kWh/m2), wind speed (m/s), the load required, and a hypothetical health clinic power configuration, which was gotten from [7]. The tables that contain the parameters are shown in the appendix. The hypothetical health clinic power configuration is composed of hybrid PV (5kW), BWC Excel-R wind turbine (7.5kW), diesel generator (2kW), 24 units Surrete 6CS25P battery and converter (19kW) system.

Initially, the power supplied by the PV panels and the wind turbines is calculated for each hour over the year and stored in matrices, so that power availabi¬lity in each hour can be accessed easily. The control process then begins at hour 1.

5. Results and Discussion

Tables (1, 2, and 3) show the contributions of the different renewable sources (PV and wind) and the diesel generator. These tables (1, 2, and 3) also show how the demand is met by the hybrid energy system (PV, wind, and diesel generator) for the three health clinic locations in the month of July. This month (July) was chosen due to its poor radiation and poor wind speed in Nigeria. The entire operations of the hybrid controller can be seen in figure 3.

Nembe:

The PV power supply is between 8:00h to 19:00h while the radiation peak is at 13:00h as can be seen in table 1. Between 6:00h and 9:00h, and at 17:00h there is no deficit in the system and the renewable energy supplies the load and charges the battery. During these times, there is little or no supply of PV power, but there is good wind power. There is a deficit in other remaining hours due to either higher load that occurs between 10:00h and 15:00h, or due to poor radiation (between 20:00h to 5:00h) and the deficit is being completed by either the battery or the diesel generator. It was mentioned in this paper that the hybrid controller allocates the diesel generator only when the renewable energy with the battery will not meet the load demand. For example in table one, at 21:00h when the renewable energy (no PV supply, the wind power is inadequate, and the battery state of charge is 40.21%) cannot match the load demand then the hybrid controller turns on the diesel generator.

Abaji:

The PV power supply is between 8:00h to 18:00h while the radiation peak is between 12:00h and 14:00h as can be seen in table 2. Between 9:00h and 12:00h there is no deficit in the system and the renewable energy supplies the load and as well charges the battery. During these times, there is an increase in the load demand, but sufficient supply from the PV power and wind power satisfies the load. The demand of the other remaining hours cannot be met by the renewable energy due to either higher load that occurs between 13:00h and 15:00h, or due to poor renewable resources (little or no PV power between 19:00h and 7:00h; poor wind power between 16:00h and 18:00h) and the deficit is being completed by the battery at these very times. Thus, the hybrid controller allots PV, wind, and battery bank to provide the power to the load

Table 1. Contributions and Power demand met by the hybrid energy system (PV, wind, and diesel generator) in Nembe

Time**(h)**	Global solar **(kW/m^2)**	Incident solar **(kW/m^2)**	Wind speed **(m/s)**	AC load **(kW)**	PV power **(kW)**	BWC-Excel-R **(kW)**	Diesel generator **(kW)**	Inverter input (kW)	Inverter output (kW)	Rectifier input **(kW)**	Rectifier output **(kW)**	Battery power **(kWh)**	Battery state of charge **(%)**
0:00	0.000	0.000	3.570	0.503	0.000	0.267	0.000	0.592	0.503	0.000	0.000	-0.325	46.728
1:00	0.000	0.000	3.035	0.503	0.000	0.134	0.000	0.592	0.503	0.000	0.000	-0.458	46.420
2:00	0.000	0.000	3.054	0.503	0.000	0.138	0.000	0.592	0.503	0.000	0.000	-0.453	46.115
3:00	0.000	0.000	2.432	0.503	0.000	0.035	0.000	0.592	0.503	0.000	0.000	-0.557	45.740
4:00	0.000	0.000	2.994	0.503	0.000	0.125	0.000	0.592	0.503	0.000	0.000	-0.467	45.426
5:00	0.000	0.000	3.653	0.503	0.000	0.309	0.000	0.592	0.503	0.000	0.000	-0.282	45.237
6:00	0.000	0.000	4.563	0.503	0.000	0.811	0.000	0.592	0.503	0.000	0.000	0.220	45.355
7:00	0.003	0.003	4.734	0.463	0.013	0.943	0.000	0.544	0.463	0.000	0.000	0.412	45.576
8:00	0.035	0.031	4.685	0.463	0.140	0.906	0.000	0.544	0.463	0.000	0.000	0.502	45.846
9:00	0.029	0.026	4.472	0.463	0.117	0.741	0.000	0.544	0.463	0.000	0.000	0.314	46.015
10:00	0.047	0.042	4.725	0.994	0.191	0.937	0.000	1.169	0.994	0.000	0.000	-0.042	45.987
11:00	0.041	0.037	4.518	1.257	0.167	0.777	0.000	1.479	1.257	0.000	0.000	-0.535	45.627
12:00	0.034	0.031	3.757	1.257	0.138	0.362	0.000	1.479	1.257	0.000	0.000	-0.979	44.969
13:00	0.135	0.123	3.578	3.372	0.552	0.270	0.000	3.967	3.372	0.000	0.000	-3.144	42.855
14:00	0.121	0.110	3.709	1.840	0.494	0.337	0.000	2.165	1.840	0.000	0.000	-1.333	41.958
15:00	0.076	0.069	3.762	1.850	0.310	0.364	0.000	2.177	1.850	0.000	0.000	-1.502	40.948
16:00	0.055	0.049	3.613	0.483	0.223	0.289	0.000	0.568	0.483	0.000	0.000	-0.057	40.910
17:00	0.002	0.002	4.180	0.463	0.008	0.578	0.000	0.544	0.463	0.000	0.000	0.041	40.932
18:00	0.018	0.016	2.177	0.463	0.073	0.021	0.000	0.544	0.463	0.000	0.000	-0.450	40.629
19:00	0.027	0.023	2.713	0.503	0.102	0.061	0.000	0.592	0.503	0.000	0.000	-0.429	40.340
20:00	0.000	0.000	3.819	0.503	0.000	0.393	0.000	0.592	0.503	0.000	0.000	-0.198	40.207
21:00	0.000	0.000	3.444	0.503	0.000	0.227	2.000	0.000	0.000	1.497	1.273	1.500	41.014
22:00	0.000	0.000	3.398	0.503	0.000	0.217	2.000	0.000	0.000	1.497	1.273	1.489	41.815
23:00	0.000	0.000	3.455	0.503	0.000	0.230	2.000	0.000	0.000	1.497	1.273	1.502	42.623

Table 2. Contributions and Power demand met by the hybrid energy system (PV, wind, and diesel generator) in Abaji

Time (h)	Global solar (kW/m^2)	Incident solar (kW/m^2)	Wind speed (m/s)	AC load (kW)	PV power (kW)	BWC-Excel-R (kW)	Diesel generator (kW)	Inverter input (kW)	Inverter output (kW)	Rectifier input (kW)	Rectifier output (kW)	Battery power (kWh)	Battery state of charge (%)
0:00	0.000	0.000	4.687	0.503	0.000	0.908	0.000	0.592	0.503	0.000	0.000	0.316	65.720
1:00	0.000	0.000	4.050	0.503	0.000	0.511	0.000	0.592	0.503	0.000	0.000	-0.080	65.666
2:00	0.000	0.000	4.346	0.503	0.000	0.662	0.000	0.592	0.503	0.000	0.000	0.071	65.704
3:00	0.000	0.000	3.690	0.503	0.000	0.328	0.000	0.592	0.503	0.000	0.000	-0.264	65.527
4:00	0.000	0.000	4.142	0.503	0.000	0.558	0.000	0.592	0.503	0.000	0.000	-0.033	65.505
5:00	0.000	0.000	4.478	0.503	0.000	0.746	0.000	0.592	0.503	0.000	0.000	0.155	65.588
6:00	0.000	0.000	3.274	0.503	0.000	0.188	0.000	0.592	0.503	0.000	0.000	-0.403	65.317
7:00	0.011	0.009	3.646	0.463	0.042	0.305	0.000	0.544	0.463	0.000	0.000	-0.197	65.185
8:00	0.072	0.065	3.229	0.463	0.291	0.178	0.000	0.544	0.463	0.000	0.000	-0.075	65.134
9:00	0.060	0.054	4.813	0.463	0.244	1.005	0.000	0.544	0.463	0.000	0.000	0.704	65.513
10:00	0.102	0.092	4.575	0.994	0.415	0.821	0.000	1.169	0.994	0.000	0.000	0.067	65.549
11:00	0.098	0.089	5.128	1.257	0.399	1.248	0.000	1.479	1.257	0.000	0.000	0.168	65.639
12:00	0.100	0.090	5.778	1.257	0.407	1.815	0.000	1.479	1.257	0.000	0.000	0.743	66.039
13:00	0.281	0.255	4.926	3.372	1.145	1.092	0.000	3.967	3.372	0.000	0.000	-1.729	64.876
14:00	0.248	0.225	4.027	1.840	1.012	0.499	0.000	2.165	1.840	0.000	0.000	-0.654	64.437
15:00	0.157	0.142	2.491	1.850	0.640	0.038	0.000	2.177	1.850	0.000	0.000	-1.499	63.429
16:00	0.109	0.099	2.132	0.483	0.446	0.019	0.000	0.568	0.483	0.000	0.000	-0.103	63.360
17:00	0.007	0.006	2.292	0.463	0.028	0.027	0.000	0.544	0.463	0.000	0.000	-0.489	63.031
18:00	0.036	0.033	2.484	0.463	0.147	0.037	0.000	0.544	0.463	0.000	0.000	-0.360	62.789
19:00	0.018	0.016	1.678	0.503	0.073	0.000	0.000	0.592	0.503	0.000	0.000	-0.519	62.440
20:00	0.000	0.000	2.079	0.503	0.000	0.016	0.000	0.592	0.503	0.000	0.000	-0.575	62.053
21:00	0.000	0.000	1.912	0.503	0.000	0.008	0.000	0.592	0.503	0.000	0.000	-0.584	61.661
22:00	0.000	0.000	2.478	0.503	0.000	0.037	0.000	0.592	0.503	0.000	0.000	-0.554	61.288
23:00	0.000	0.000	2.805	0.503	0.000	0.082	0.000	0.592	0.503	0.000	0.000	-0.510	60.945

Table 3. Contributions and Power demand met by the hybrid energy system (PV, wind, and diesel generator) in Guzamala

Time **(h)**	Global solar **(kW/m^2)**	Incident solar **(kW/m^2)**	Wind speed **(m/s)**	AC load **(kW)**	PV power **(kW)**	BWC-Excel-R **(kW)**	Diesel generator **(kW)**	Inverter input (kW)	Inverter output (kW)	Rectifier input **(kW)**	Rectifier output **(kW)**	Battery power **(kWh)**	Battery state of charge **(%)**
0:00	0.000	0.000	4.243	0.503	0.000	0.610	0.000	0.592	0.503	0.000	0.000	0.018	98.009
1:00	0.000	0.000	3.476	0.503	0.000	0.234	0.000	0.592	0.503	0.000	0.000	-0.357	97.769
2:00	0.000	0.000	3.872	0.503	0.000	0.420	0.000	0.592	0.503	0.000	0.000	-0.171	97.654
3:00	0.000	0.000	3.996	0.503	0.000	0.484	0.000	0.592	0.503	0.000	0.000	-0.108	97.581
4:00	0.000	0.000	4.349	0.503	0.000	0.664	0.000	0.592	0.503	0.000	0.000	0.072	97.620
5:00	0.000	0.000	4.289	0.503	0.000	0.633	0.000	0.592	0.503	0.000	0.000	0.041	97.643
6:00	0.002	0.000	5.245	0.503	0.000	1.338	0.000	0.592	0.503	0.000	0.000	0.747	98.044
7:00	0.042	0.038	4.342	0.463	0.169	0.660	0.000	0.544	0.463	0.000	0.000	0.285	98.197
8:00	0.144	0.127	4.177	0.463	0.570	0.576	0.000	0.544	0.463	0.000	0.000	0.601	98.521
9:00	0.128	0.116	3.342	0.463	0.520	0.204	0.000	0.544	0.463	0.000	0.000	0.180	98.617
10:00	0.210	0.190	3.099	0.994	0.854	0.148	0.000	1.169	0.994	0.000	0.000	-0.166	98.505
11:00	0.213	0.193	4.612	1.257	0.868	0.850	0.000	1.479	1.257	0.000	0.000	0.238	98.634
12:00	0.216	0.196	5.224	1.257	0.882	1.322	0.000	1.479	1.257	0.000	0.000	0.525	98.916
13:00	0.472	0.414	4.452	3.372	1.863	0.726	0.000	3.967	3.372	0.000	0.000	-1.378	97.989
14:00	0.410	0.363	4.869	1.840	1.636	1.048	0.000	2.165	1.840	0.000	0.000	0.519	98.269
15:00	0.265	0.239	6.383	1.850	1.076	2.394	0.000	2.177	1.850	0.000	0.000	1.019	98.817
16:00	0.172	0.156	4.724	0.483	0.700	0.936	0.000	0.568	0.483	0.000	0.000	0.235	98.943
17:00	0.023	0.021	5.500	0.463	0.093	1.563	0.000	0.544	0.463	0.000	0.000	0.210	99.056
18:00	0.042	0.038	5.008	0.463	0.171	1.155	0.000	0.544	0.463	0.000	0.000	0.188	99.157
19:00	0.004	0.000	4.563	0.503	0.000	0.811	0.000	0.592	0.503	0.000	0.000	0.168	99.247
20:00	0.000	0.000	5.659	0.503	0.000	1.707	0.000	0.592	0.503	0.000	0.000	0.150	99.328
21:00	0.000	0.000	4.603	0.503	0.000	0.843	0.000	0.592	0.503	0.000	0.000	0.134	99.400
22:00	0.000	0.000	6.542	0.503	0.000	2.561	0.000	0.592	0.503	0.000	0.000	0.119	99.464
23:00	0.000	0.000	6.252	0.503	0.000	2.256	0.000	0.592	0.503	0.000	0.000	0.107	99.521

without allocating the diesel generator.

Guzamala:

The PV power supply is between 7:00h to 18:00h while the radiation peak is between 12:00h and 14:00h as can be seen in table 3. As from 4:00h to 9:00h, 11:00h to 12:00h, and 14:00h to 0:00h there is no deficit in the system and the renewable energy supplies the load and charges the battery. There are deficit between 1:00h and 3:00h, 10:00h, and 13:00h. These were due to no PV power, low wind power, and increased load, respectively, and this deficit is being completed by the battery.

In summary, the renewable energy were found to be variable as well as the demand in all the three hypothetical health clinic locations studied, but the supervisory control allots the sources optimally and the hybrid energy system supplies the demand of the particular health clinic location effectively.

6. Conclusion

In this study, a supervisory control was developed to satisfy the load demand by optimally allocate the renewable energy sources to the maximum extent while limiting the use of diesel generator. From the control simulation results, it was found that the supervisory control allots the sources optimally and the hybrid energy system supplies the demand of the particular health clinic location effectively. The controller also utilizes the battery bank effectively by switching the batteries into charging mode (power positive) whenever excess power is available from the sources, and switches to discharging mode (power negative) whenever there is a shortage of power from sources. The hybrid controller allocates the diesel generator only when the demand cannot be met by the renewable energy sources (PV+Wind) including the battery bank. This is intended to maximize the use of the renewable energy system while limiting the use of diesel generator which is the aim of the study. This reduces the operational hours of the diesel generator thereby reducing the running cost of the hybrid energy system as well as the pollutant emissions.

From this control simulation, the performance of the system is seen over the course of the year as well as which modes the system spends most time in, the power supplied by each of the energy sources and the power required by the load. This is useful to check how the system is being supplied and which source of energy is the most proficient in supplying the load.

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References

[1] Ani Vincent Anayochukwu and Emetu Alice Nnene, Simulation and Optimization of Photovoltaic/Diesel Hybrid Power Generation System for Health Service Facilities in Rural Environments. Electronic Journal of Energy and Environment (EJEE). Vol 1, No 1 (2013) DOI: 10.7770/ejee-V1N1-art521

[2] Pedro Rosas, Caarem Studzinski, Vicente Simoni, Francisco Neves, Alécio Fernandes, Luiz H. A. Medeiros, Fabricio Bradaschia, Gustavo Azevedo, Felipe Guimaraes, Jimens Lima, André Victor, Lucas Cabral, and Jose Arimateia e Carlos Soares. Developing a Supervisory Controller for Hybrid Power System: Fernando de Noronha Island Case. International Conference on Renewable Energies and Power Quality (ICREPQ'13) Bilbao (Spain), 20th to 22th March, 2013. Renewable Energy and Power Quality Journal (RE&PQJ)

[3] Ani, Vincent Anayochukwu. "Optimal Control of PV/Wind/Hydro-Diesel Hybrid Power Generation System for Off-grid Macro Base Transmitter Station Site."Electronic Journal of Energy & Environment (2013) DOI: 10.7770/ejee-V1N2-art605.

[4] Seeling-Hochmuth, G. "A Combined Optimization Concept for the Design and Operation Strategy of Hybrid PV Energy Systems", Solar Energy, Vol. 61, No. 2, (1997), pp.77-87, Elsevier Science Ltd.

[5] Ani, Vincent Anayochukwu, and Emetu Alice Nnene. "Simulation and optimization of hybrid diesel power generation system for GSM base station site in Nigeria." Electronic Journal of Energy & Environment 1.1 (2013) DOI: 10.7770/ejee-V1N1-art520.

[6] Battery Experts (2012) [Online]. http://www.batteryexperts.co.za/batteries_sealed.html

[7] Ani, Vincent Anayochukwu. "Energy Optimization Map for Off-Grid Health Clinics in Nigeria". International Journal of Renewable Energy Research (IJRER) Vol. 4, No. 1.

Appendix

Table A1: Solar and wind Resources for Nembe (Bayelsa State) [7]

Month	Clearness Index	Average Radiation ($kWh/m^2/d$)	Wind speed (m/s)
Jan	0.547	5.240	2.900
Feb	0.509	5.130	3.000
Mar	0.454	4.730	2.800
Apr	0.434	4.500	2.300
May	0.408	4.090	2.300
Jun	0.354	3.450	3.000
Jul	0.316	3.110	3.900
Aug	0.336	3.420	4.000
Sep	0.311	3.220	3.600
Oct	0.356	3.600	2.800
Nov	0.433	4.180	2.300
Dec	0.520	4.880	2.600
Scaled annual average		**4.124**	**2.960**

Table A2: Solar and wind Resources for Abaji (Abuja, FCT) [7].

Month	Clearness Index	Average Radiation ($kWh/m^2/d$)	Wind speed (m/s)
Jan	0.652	5.880	2.400
Feb	0.630	6.090	2.300
Mar	0.610	6.270	2.500
Apr	0.577	6.060	2.500
May	0.539	5.580	2.500
Jun	0.497	5.060	2.300
Jul	0.434	4.440	2.500
Aug	0.404	4.190	2.500
Sep	0.460	4.730	2.400
Oct	0.542	5.310	2.000
Nov	0.655	5.980	2.400
Dec	0.668	5.860	2.200
Scaled annual average		**5.449**	**2.375**

Table A3: Solar and wind Resources for Guzamala (Borno State) [7].

Month	Clearness Index	Average Radiation ($kWh/m^2/d$)	Wind speed (m/s)
Jan	0.642	5.610	4.100
Feb	0.666	6.300	4.100
Mar	0.658	6.700	4.500
Apr	0.628	6.620	4.600
May	0.606	6.360	4.200
Jun	0.576	5.970	3.500
Jul	0.523	5.430	3.300
Aug	0.492	5.140	3.100
Sep	0.544	5.570	2.900
Oct	0.612	5.890	3.200
Nov	0.658	5.840	3.800
Dec	0.631	5.350	4.300
Scaled annual average		**5.894**	**3.799**

Table A4: Health Facility's Energy Needs [1].

S/no	Power Consumption	Power (Watts)	Qty	Load (watt x qty)	Hours/day	On-Time (Time in Use)
1	Vaccine Refrigerator/Freezer	60	1	60	24	(0.00hr – 23.00hr)
2	Small Refrigerator (non-medical use)	300	1	300	5	(10.00hr – 15.00hr)
3	Centrifuge	575	1	575	2	(12.00hr – 14.00hr)
4	Hematology Mixer	28	1	28	2	(10.00hr – 12.00hr)
5	Microscope	15	1	15	5	(09.00hr – 14.00hr)
6	Security light	10	4	40	12	(18.00hr – 6.00hr)
7	Lighting	10	2	20	7	(09.00hr – 16.00hr)
8	Sterilizer Oven (Laboratory Autoclave)	1,564	1	1,564	1	(12.00hr – 13.00hr)
9	Incubator	400	1	400	24	(0.00hr – 23.00hr)
10	Water Bath	1,000	1	1,000	1	(14.00hr – 15.00hr)
	Communication via VHF Radio		1			
11	Stand-by	2		2	24	(0.00hr – 23.00hr)
12	Transmitting	30		30	4	(09.00hr – 13.00hr)
13	Desktop Computer	200	2	400	5	(09.00hr – 14.00hr)
14	Printer	65	1	65	3	(09.00hr – 10.00hr; 13.00 – 15.00hr)