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SIMULATION OF A PORTABLE CONTAINER HYBRID ENERGY SOURCE

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Abstract

Hybrid energy generation incorporating the renewable energy sources is gaining recognition and importance in the world. Institute of Aviation has thus decided to open a project: construction of a portable energy source container, incorporating modern hybrid solutions. In this article, the basic approach to creating a model of such a hybrid energy source is described: an initial scheme and composition of a portable container hybrid energy source, consisting of a wind turbine, photovoltaic array, battery bank and a backup diesel generator is proposed. A preliminary model of the portable hybrid energy source container, with two separate control system schemes, was created in TRNSYS Simulation Studio software and is presented in this article. The data acquired from the TRNSYS simulations of the hybrid source container are gathered and organized, and then presented and analysed. From a theoretical point of view, it is interesting to see how the renewable based system characteristics differ with changing weather conditions, and how supporting the load is being switched between the renewable system and the diesel generator. From a practical point of view, it will be interesting to see the diesel fuel savings, and related to them lowered exhaust gases emission, coming from reduced diesel generator operation times. A problem of reducing emissions and fuel consumption, and matching the operation of energy generation to consumer need more flexibly that is offered by a hybrid source is particularly important.

Keywords: *hybrid energy generation, renewable energy sources, energy storage, off-grid, portable, simulation*

1. Introduction

In modern times, nearly every piece of equipment we use needs electrical energy to run. This includes complicated equipment belonging to the military or emergency services (firefighters, paramedics). However, sometimes they are forced to conduct prolonged operations in areas without the access to the grid, either in some remote areas, or in the places where some disaster happened, and the power lines were cut off or destroyed. The equipment, military camps, field hospitals, and so on, still needs to be powered somehow. The answer to that problem is a mobile container hybrid energy source – a sort of miniature micro-grid that can be transported to desired location, and placed there to power up any of the mentioned applications. Having several energy sources and energy storage options allows it to excel over simple portable generators in versatility and utility [3, 4]. This article presents the process of constructing a model of said system, and running a simulation based on such model.

2. Assumptions for the model

For the model of the container energy source, a hybrid configuration consisting of a wind turbine, matrix of photovoltaic solar panels, a battery bank and a diesel generator was chosen. The parameters and sizes of the equipment were chosen in such a way, that they could be assembled inside and on the outside of a 1C type ISO freight container and that the total weight of the system does not exceed EU truck road transport limitations, so that the system may be portable. The configuration is presented on Fig. 1.

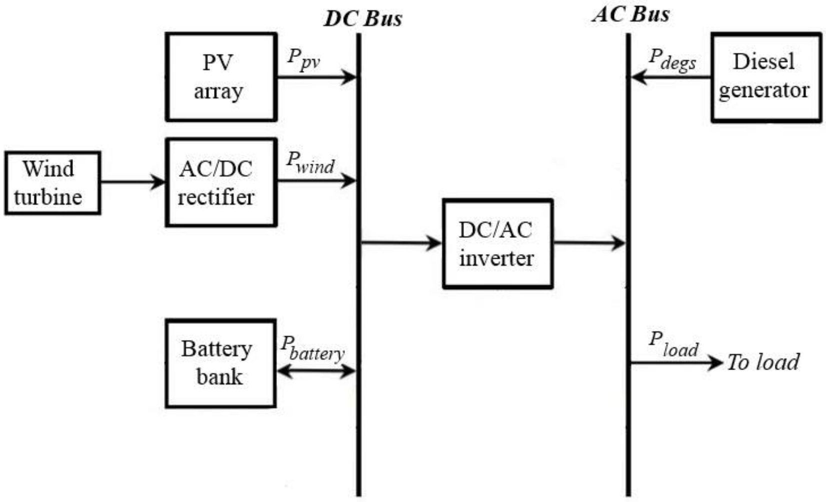

Fig. 1. Schematic of the configuration chosen for the model

The battery bank in such a system is a necessity, as energy storage is essential in the off-grid hybrid systems using the solar or wind energy [2, 6]. Parameters of the chosen components are lead-acid battery bank of 100 kWh capacity, a matrix of monocrystalline solar panels of total power of 4 kW, a 15 kW rated power diesel generator that can operate on variable load. For the wind turbine, a small vertical axis wind turbine of 5 kW rated power was chosen, with a H-type rotor, as it provides advantage over Darrieus and Savonius type rotors in simplicity of assembling and transport [5]. The system was designed to be able to support AC load with peak demand of 15 kW electric power.

The software chosen for simulation is the TRNSYS Transient Simulation Tool, as it is one of the most versatile tools for simulation of hybrid energy sources, and holds a great library of components commonly used in electrical hybrid energy systems [1].

3. Modelling the system

Two similar models were prepared, with the same component structure but with different power control schemes. The models and results of simulations are presented separately for each of the control schemes accordingly. As the models are prepared for the initial testing of the system viability, they are based only on the power flow. The voltages and currents of different components are not being measured and tracked; their changes are covered under the efficiency of the inverter/regulator component. The first control scheme is based on battery state of charge (SOC) and the second control scheme based on available renewable power.

The first control scheme of the model is introduced through TRNSYS equation modules. The main controller is the “Load control signal” equation, which is connected to the load forcing function and to the battery. It collects the information about the batteries state of charge and the direction of energy flow from or to the battery (whether the batteries are loading, unloading or idle), reads the current load value, and directs the load either to the diesel generator (DEGS module) or to the regulator/inverter (renewable sources and batteries).

The second control scheme of the model is similarly introduced through TRNSYS equation modules. The main controller is again the “Load control signal” equation, which this time is connected to the load forcing function and to the renewable sources. It collects the information about the available power output from the renewable sources, reads the current load value, and divides the load between the diesel generator and regulator/inverter (as in this control scheme both work together, and the renewable sources are used to lessen the load on the diesel generator). It also blocks the diesel generator from operating below 25% of its rated power.

4. Simulation results

Simulations were run for a system located in Warsaw, for each quarter of the year, to check performance during different weather (sunlight and wind) conditions. Calculations were started respectively on 1st of January, April, July and October, with simulations running for 24 hours, 7 days and a month each time. A full year calculation was also made for both control scheme models (although it is very unlikely the container would be used for such a prolonged time in real-life application). Fig. 2 presents the annual distribution of power from renewable sources, which is possible to achieve from the PV array and wind turbine simulated in the model.

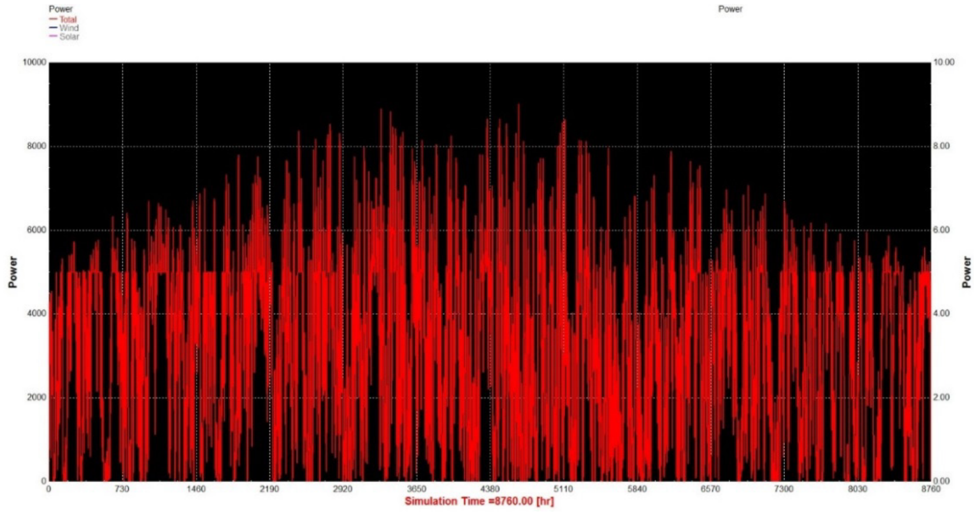

Fig. 2. Distribution of total available power from renewable sources (sum of PV array and wind turbine power) across the year

For the graphic presentation of results, the simulation of 24 hours of system operation on 1st of July was chosen, as the best day concerning renewable sources energy production, to illustrate how the model behaves in favourable weather conditions. Renewable data from that day are presented on Fig. 3.

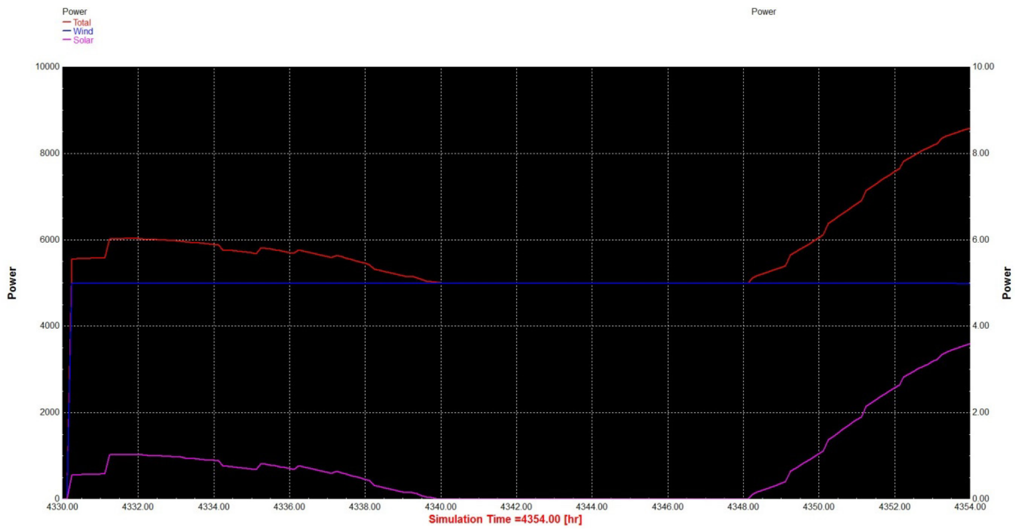

Fig. 3. Renewable data from 24 hours of operation on 1st of July

The simulation was run from 10:00 in the morning on 1st of July to 10:00 in the morning on 2nd of July. The favourable renewable operation comes mostly from the wind turbine, as it operates at rated power for the entire 24 hours of simulation time, with limited support of the solar panels reaching 25% of their rated power (4 kW) on the beginning of simulation, and nearing 100% of their rated power towards the end of simulation.

The system parameters during the 24 hours simulation on 1st of July are presented on Fig. 4 for the battery SOC based control system and on Fig. 5 for the available renewable power based control system.

Fig. 4. System data from 24h simulation on 1st of July in battery SOC based control scheme

On Fig. 4, the red curve on the graph represents the power delivered to the load from the renewable DC bus; yellow curve represents power delivered to the load from diesel generator. Pink curve is the power the batteries delivers to the load, blue curve is the power from the renewable sources (which supports the batteries in sustaining the load parameters). Green curve represents the state of charge of the batteries.

As it can be seen on the graph, the system started at 10:00 being powered from batteries and renewable sources. The system has maintained the load, which was covered partially from the batteries (pink line) and partially from solar panels and wind turbine (blue line). After 6.875 hours, the batteries reached the maximum permissible DoD of 50%, and the diesel generator took over maintaining the load (yellow line). As the renewable energy sources, are producing energy constantly, the batteries starts charging immediately. After it reaches 95% of state of charge (green line), the batteries and renewables take over maintaining the load again – but because renewable sources produce more power than is needed to the load at the moment, the load is fully covered from the renewables, without the need of discharging the batteries.

On Fig. 5, the green curve on the graph represents the total power delivered to the load (from both the renewable DC bus and diesel generator), yellow curve represents power delivered to the load from diesel generator, red curve represents power delivered to the load from renewable DC bus. Blue curve is the available power from the renewable sources (the power delivered from the renewable sources can be lower than the power coming in from generation due to conversion losses), and the pink curve is the power the batteries delivers while supporting the renewable sources. Light blue curve represents the state of charge of the batteries.

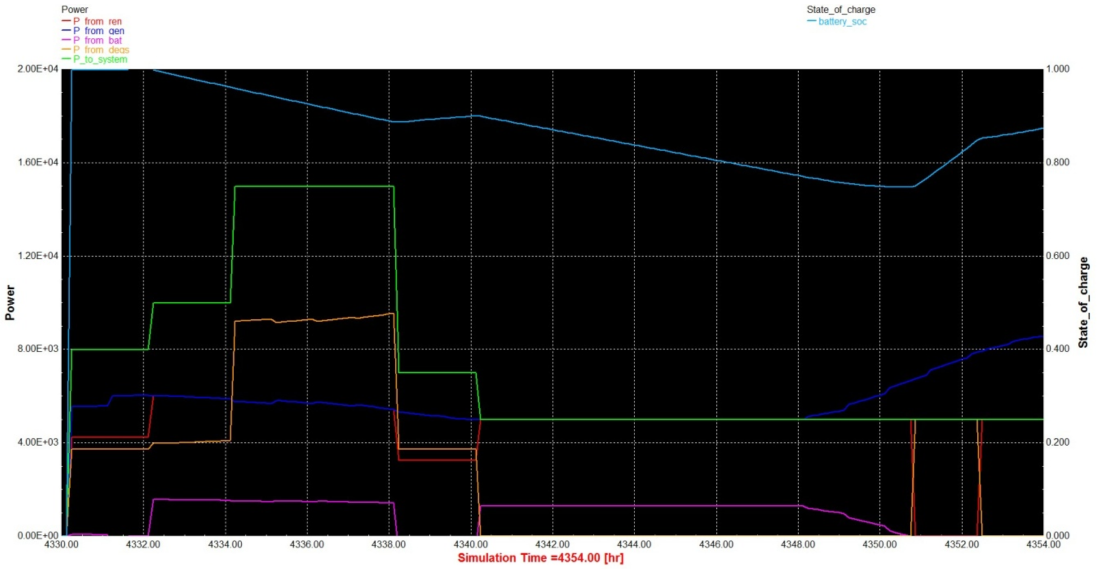

Fig. 5. System data from 24h simulation on 1st of July for available renewable power based control scheme

As it can be seen on the graph, the system started at 10:00 being powered from diesel generator together with renewable sources. The system has maintained the load, which was covered partially also from the batteries (pink line). At 20:00 (4340 h at simulation), the load decreased to the 5 kW level, where the renewable sources were able to maintain it without help of diesel generator, so the generator has shut down. Near the end of simulation, the renewable sources started charging the batteries, and directed all the energy to it, so the diesel generator turned back on again to support the load. This lasted for a little under two hours, when the renewable sources directed the energy back to the load, and the diesel generator shut down again.

Tab. 1. Operating time comparison between two modes of control

Date and time of operation	Working time						
	Control mode 1				Control mode 2		
	Battery [h]	DEGS [h]	Battery [%]		RES only [h]	DEGS [h]	RES only [%]
Jan 1 24 h	5.875	18.375	24.2		0	24	0.0
April 1 24 h	8.5	15.75	35.1		5.5	18.5	22.9
July 1 24 h	10.75	13.375	44.6		14	10	58.3
Oct 1 24 h	5.625	18.5	23.3		0	24	0.0
Jan 1 7 days	33	136.375	19.5		9.25	158.75	5.5
April 1 7 days	39	129.75	23.1		23.25	144.75	13.8
July 1 7 days	49.875	119.375	29.5		40.25	127.75	24.0
Oct 1 7 days	63.25	105.25	37.5		32.375	135.625	19.3
Jan 1 30 days	188.625	538.875	25.9		131.125	588.875	18.2
April 1 30 days	170.875	552.625	23.6		108.875	611.125	15.1
July 1 30 days	158.125	565.75	21.8		80.125	639.875	11.1
Oct 1 30 days	174	548	24.1		95.25	624.75	13.2
Full year	2243.625	6614.125	25.3		1292.625	7467.375	14.8

The results have clearly shown that both modes of control are able to support the given load without power blackouts or power drops. There are however, some differences between parameters of operation in both control modes, due of different circumstances of turning the diesel generator on and off. The differences in running times between both modes of control of a hybrid source are presented in Tab. 1, whereas differences in fuel usage between both modes of control of a hybrid source, as compared to fuel usage of a standalone diesel generator are presented in Tab. 2.

It is noticeable, that the results vary strongly with the weather conditions (and resulting renewable energy sources energy production) during the time of operation. The differences can be as big as 24.2% of time on battery operation on the worst day and 44.6% of time on battery operation on the best day in control mode 1, and 0% time of standalone RES operation on the worst day and 58.3% time of standalone RES operation on the best day in control mode 2. For such heavy differences it is obvious, that the system will have the best results operating in places with favourable weather conditions for the renewable energy systems, and that the addition of backup generation source such as a diesel generator, independent on weather condition, is necessary in such a system.

Tab. 2. Fuel usage comparison between hybrid operation and standalone diesel operation

Simulation time	**Fuel usage [L]**			**Fuel savings [L]**	
	Mode 1	**Mode 2**	**Diesel**	**Mode 1**	**Mode 2**
Jan 1 24 h	42.6	49.1	61.1	18.6	12.1
April 1 24 h	35.6	36.5	61.1	25.5	24.6
July 1 24 h	30.4	25.2	61.1	30.7	35.9
Oct 1 24 h	43.1	55.7	61.1	18.1	5.4
Jan 1 7 days	343.0	361.9	428.0	85.1	66.1
April 1 7 days	318.5	322.7	428.0	109.5	105.3
July 1 7 days	275.8	281.0	428.0	152.2	147.1
Oct 1 7 days	276.2	296.4	428.0	151.8	131.6
Jan 1 30 days	1343.8	1366.4	1834.4	490.6	468.0
April 1 30 days	1288.4	1320.1	1834.4	546.0	514.3
July 1 30 days	1353.9	1390.3	1834.4	480.5	444.1
Oct 1 30 days	1343.2	1387.6	1834.4	491.2	446.8
Full year	16258.3	16569.5	22318.4	6060.1	5748.9

It is noticeable, that the fuel savings are a little higher in the first mode of control. It is due to the fact, that it prioritizes the batteries operation, and the load is supported by the batteries with diesel generator turned off, whenever it is possible (batteries are charged). In the second control mode, batteries and renewable sources only support the diesel generator, and take over the entire load only when renewable power is high enough to support the load standalone. The decreased load on the diesel generator does not result in very high fuel saving, as with the load decrease further from the rated power of the generator, the efficiency of the diesel generator drops. However, the second mode of operation is still more viable economically – batteries are one of the most expensive parts of the system, and regularly discharging them to 50% DoD in mode 1 will significantly lower their lifetime, compared to operation in mode 2.

The first mode of control, battery priority, can still be advantageous in certain conditions. In some of the applications, like the military camp or field hospital, the silence, or the lack of thermal imprint from the diesel generator can be very important. In such cases, we can switch to battery priority control mode, and the diesel generator will shut off, assuming there is sufficient charge left in the batteries to support the system. That is why in the prototype, both modes of control should be implemented, with the possibility for the user to switch between them. The container would be able to run on the second mode of control during normal operation, to not strain the batteries, and be switched to the first mode of battery priority if needed.

5. Conclusions and summary

The needs for portable energy production and storage in applications bigger than powering a single portable device are very high. Hybrid power systems are becoming increasingly important due to energetic safety (having more than one power source) and the possibility to introduce the renewable energy sources. Hybrid systems also allow us to adjust the power and energy production to the level of consumer needs more flexibly.

The ability to build models and numerical simulations is very important, as it allows testing the viability of initial designs and ideas, and properly choosing the hardware and equipment for the real life prototypes and products, without the need of last-minute drastic changes during advanced stages of construction. TRNSYS software is extremely well suited for such modelling, as its libraries include many components found in hybrid energy systems (such as photovoltaics, wind turbines, diesel generators, fuel cells, batteries) and it allows for creation and coding of non-standard own components in several programming languages and external software. Its flexibility, precision of calculation, and easy access to the important simulation data on plots, graphs and raw data sheets makes it useful, powerful tool.

The TRNSYS model proposed in this article turned out to be viable, and able to support the given load profile. The renewable energy sources provide some fuel savings, and an opportunity for clean and quiet operation when needed. Further modifications to the model are planned, with the addition or change of several system components (for example exchanging diesel generator for fuel cells, or adding heat recovery and storage components).

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