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# MODELLING AND SIMULATION OF ALUMINUM-AIR BATTERY

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## ABSTRACT

The technical and scientific challenges to provide reliable sources energy for global economy are enormous tasks and especially when combined with strategic and recent economic concerns of the last ten years. It is clear that as part of the mix of energy sources necessary to deal with these challenges, fuel cells/battery technology will play critical or even a central role. As of today's electrochemical technologies, Aluminum-Air battery has the highest theoretical specific energies (400 Wh/kg). Since aluminum is found in abundant, it'll be the future of energy sources. This paper shows the modelling and simulation of Aluminum-air battery using MATLAB Simulink model which will help to analyze the performance and understand its different applications viz, Reserve power unit, electric vehicle. A major part of the study Al-Air battery with boost converter modelling, and simulations using MATLAB Simulink is presented.

**Keywords:** Fuel cell, Aluminum air battery, Battery Modelling, MATLAB, Simulation.

## I. INTRODUCTION

Aluminum-air technology has been recently a strong alternative to traditional fossil fuels techniques to generate electrical energy. Aluminum-air battery waste by-products are environmentally friendly, making it a cleaner and more sustainable way to generate electricity. The convenient inherent characteristics of fuel cells i.e. Aluminum-air battery such as the capability of fuel cell to produce electrical energy as long as the fuel lasts, makes this alternative a promising technology for the replacement of current environmentally unfriendly ways to generate electricity in the future. Different kind of fuels includes hydrogen, methanol, natural gas and aluminum which have been used as sources of these devices. Each of these fuel sources has its benefits and disadvantages and would be a best fit for particular applications.

In this research endeavor, Aluminum Air Fuel Cells (Al-Air FC) i.e. Aluminum-air battery is investigated. There are several advantages of using Aluminum as fuel for portable applications. This is an abundant material in earth crust, the theoretical inherent limit of energy of aluminum is high and the low cost of aluminum with its full recyclability are really convenient. The Al-Air FC generates electricity by converting the internal energy of aluminum, combined with water and oxygen, by a controlled chemical reaction. The waste byproduct of this reaction is entirely recyclable, which constitutes a great advantage in terms of sustainability and in decreasing the overall cost of the aluminum used as fuel. To create a model for Aluminum-Air battery in an academic level. The model will simulate Al-Air battery to get the SOC characteristics and terminal output voltage. The terminal output voltage is further boosted with boost converter for use as a backup device or in moving cars.

## II. METHODOLOGY

Paradoxically this Fuel-cell technology or more prominently Aluminum-Air technology used in the last decade in electricity generation was invented more than 160 years ago, Sir William Groove, an English scientist published his original experiments on what he called a "gaseous voltaic battery" in 1839 [1].The first real studies about Aluminum as source of electrical energy for batteries are found in the early 1960's. Many researchers have focused their efforts in Aluminum as main fuel source for many applications. The high theoretical ampere hour capacity due to its high enthalpy, the voltage outcome and the potential energy, are one of the most theoretical efficiency of any other metal combined with air kind of batteries [2]. The efforts were focused on material problems at the air electrode, thermal management and different kind of problems associated with the anode [3].

This technology is presented as one of the main candidates for the energy storage devices in the future Smart Cities because, besides the good specific energy, it covers the requirements of the other two main drivers: cost and environment care [4]. This technology has been also used to improve efficiency and autonomy of existing lead acid battery backups of large buildings or telecommunications networks core facilities. AT&T, Bell Canada, among other cellular phones and cable networks operators mainly in Europe have used this technology to increase the reserve back up from lead acid battery to over 60 hours [3].

Some researchers have studied the potentiality in technical and financial terms of Aluminum-Air systems for vehicles, among other applications. Yang and Knickle have concluded "The Al-Air battery system can generate enough energy and power for driving ranges and acceleration similar to gasoline powered cars" [5]. The cost of aluminum as an anode can be as low as US$ 1.1/kg as long as the reaction product is recycled. The total fuel efficiency during the cycle process in Al/air electric vehicles (EVs) can be 15% (present stage) or 20% (projected), comparable to that of internal combustion engine vehicles (ICEs) (13%).

Aluminum-Air Battery work on the principle of Al-Air fuel cell principle and these are devices which converts chemical energy of the reaction between oxygen present in the air with Aluminum as fuel in order to produce electricity.

Aluminum power systems usually are based on some sort of unit cells that uses aluminum as the anode and an air breathing cathode. Because of the solid anode and air cathode, this system is neither a battery (a solid anode and solid cathode) nor a fuel cell (gaseous anode and gaseous cathode) but is often referred to as semi-fuel cell [2] or battery. In this thesis Al-Air system will be considered as a battery. A single Al-Air system is shown in the Figure 1.

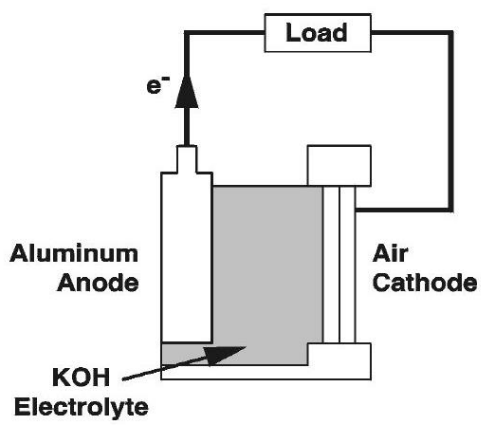


**Figure 1**: Schematic Aluminum-Air battery

Al-air battery has the potential to be used to produce power to operate vehicles and other applications. This fuel cell has a theoretical voltage of 2.7 V, high theoretical energy density (8.1 Kwh/Kg-Al), low cost, environmentally friendly and fully recyclable [5].

The Aluminum fuel cell generates electricity by converting the internal energy of aluminum combined with water and oxygen by a controlled chemical reaction. The chemical reaction is described as follows:

$$4\ Al + 3\ O_2 + 6\ H_2O \rightarrow 4\ Al(OH)_3 + 2.71V$$

Aluminum plates conforms the anode, a gas diffusion electrode supplies the oxygen which is extracted from the air, and additives such water are added to obtain the final reaction.

## III. MODELING AND ANALYSIS

The first step in designing a battery management system (BMS) is to develop a high fidelity battery model. In order for a BMS to estimate the battery critical parameters such as the battery state of charge and state of health, an accurate battery model has to be implemented on board of the BMS along with a robust estimation strategy. So a battery model is a list of mathematical equations that describe what's physically happening inside the battery. In simple terms, as shown in the figure, if we apply the same current profile to the battery and the battery model, both should generate the same voltage profile and the error between the two signals should be close to zero. The model can predict the behavior of the battery in a way that if we applied an estimator, we can predict critical parameters such as the battery SOC and remaining useful life.

**Aluminum-Air battery modelling**

Al/Air FC provides the output voltage as a function of the inputs, aluminum stick weight, aqueous solution volume, temperature, pressures and random changes due to impurities are considered as main inputs. The open circuit voltage is calculated from the electrochemistry reaction between reactants and the interaction with the solute. Two major types of losses are considered when the fuel cell is in operation.

There are two concepts:

(a) First concept is, there is a distinct relationship between the battery state of charge and open circuit voltage. At Zero percent, voltage value will be small, let's say 2.6. If the battery is fully charged, i.e. 100 percent, we actually get a measure higher voltage value of, let's say, 3.6.

(b) The second concept is how state of charge is updated? The increase or decrease in AC depends on charge or discharge of the cell. This is called Coulomb counting technique, which is the state of charge at any time would be equal to the state of charge initial, which is the starting point. And adding or subtracting the amount of current going in or out of the cell. But we have to integrate it first so we can integrate the current going in the cell, which is summing up all the current over a specific period of time that would give the overall AMP hours went in or out of the cell and divided by the overall capacity(C) of the cell. If one knows initial, that will tell him the C update.

Mathematically

$$VT = OCV(SOC) - I * R(T, SOC)$$

$$SOC = SOC|o - 1/Cn \int I(t)dt$$

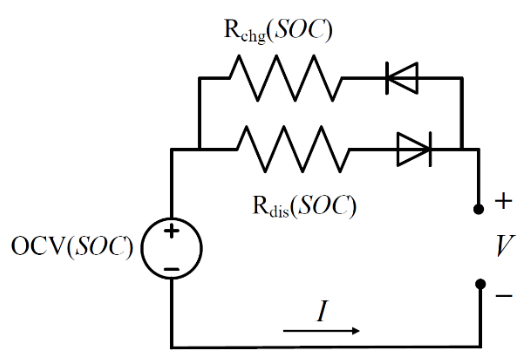


**Figure 2**: Battery Model charging-discharging

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$$Vk=OCV(SOCk)-ik*R$$

$$SOCk+1=SOCk-(\Delta tCn)\ ik$$

Simple model is obtained by combining the two equations

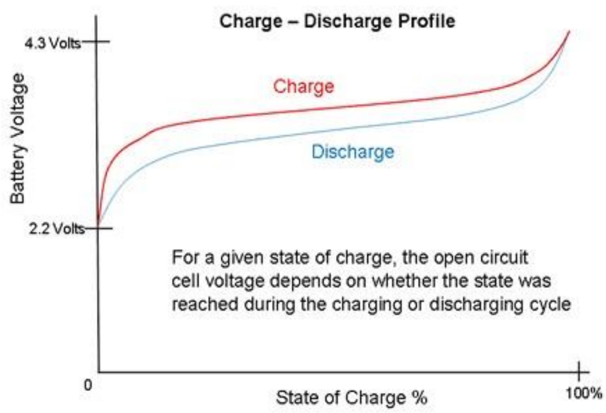


**Figure 3**: Graph of battery charging-discharging

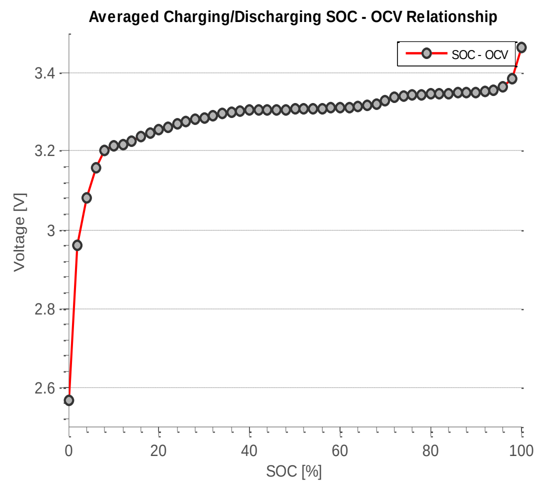


**Figure 4**: Average of charging and discharging SOC-OCV relationship

There is a relationship between the battery Open-circuit voltage (OCV) and State of Charge (SOC). The relationship depends on the battery chemistry and the direction of charging and discharging. If one start with a fully discharged battery and start charging it, the battery OCV starts at let's say 2.2V and keep ramping up following the red line until graph reach the maximum voltage at 4.3V. The battery SOC is set to 100% when the battery is fully charged. As battery starts to discharge it means the battery starts from a fully charged state. Then follow a different path indicated by the blue line until battery is fully discharge at 0% SOC. The difference between the charging and discharging paths is due to hysteresis.

**Simulations**

Based on the concepts explained earlier in this chapter, the Al-Air FC was implemented using Matlab Simulink. In this model Aluminum-Air battery is considered as an Input current which is actually being produced by the reaction of Al-Air battery.

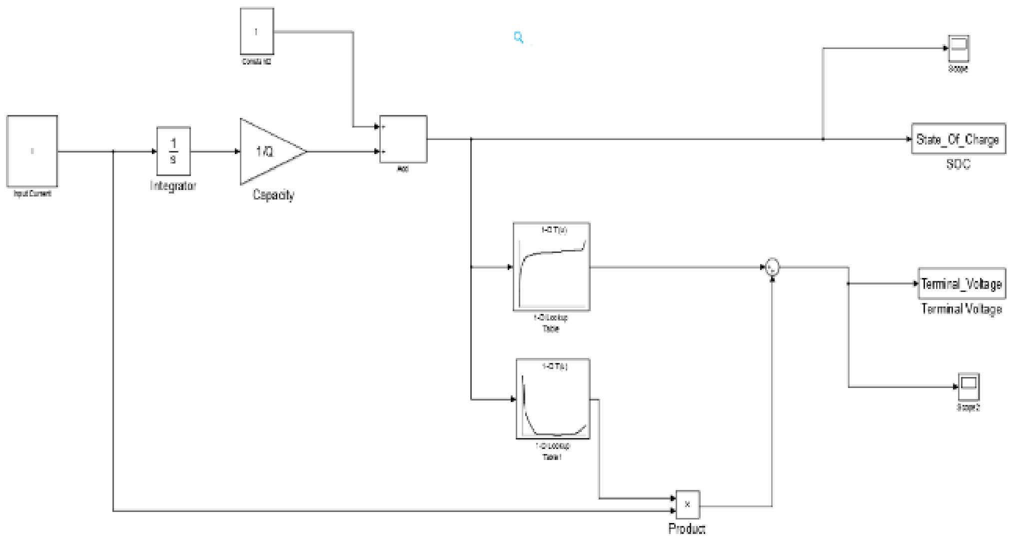


**Figure 5**: Al-Air Battery Model Block Diagram

The concept of Battery modelling discussed above is used here. The Input current is integrated and multiplied by the battery capacity. Since Al-air battery is basically a fuel cell so it only discharges. For discharging purpose a lookup table is used for the value of discharging resistance. The SOC of battery at start is 100% but as time passes it should decrease or decay. The same concept is applicable for terminal voltage output. Below output graph represents the data and results of scope.

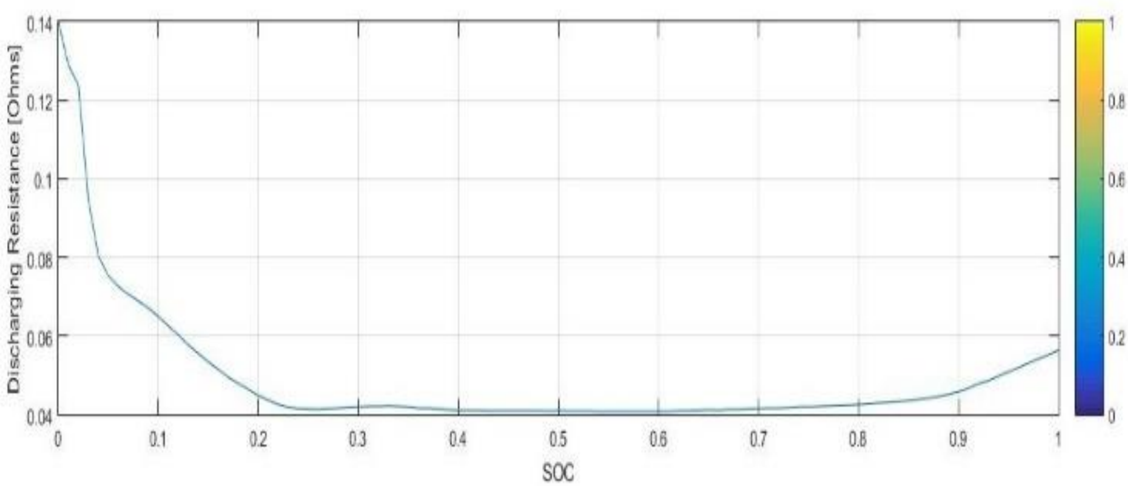


**Figure 6**: Plot of discharging resistance

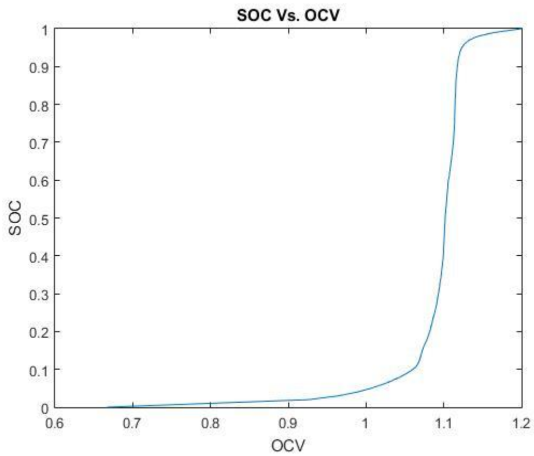


**Figure 7**: SOC vs OCV graph

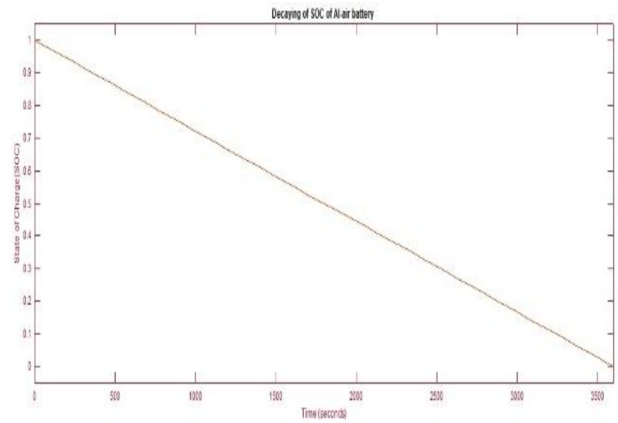

**Figure.8:** Decaying of SOC

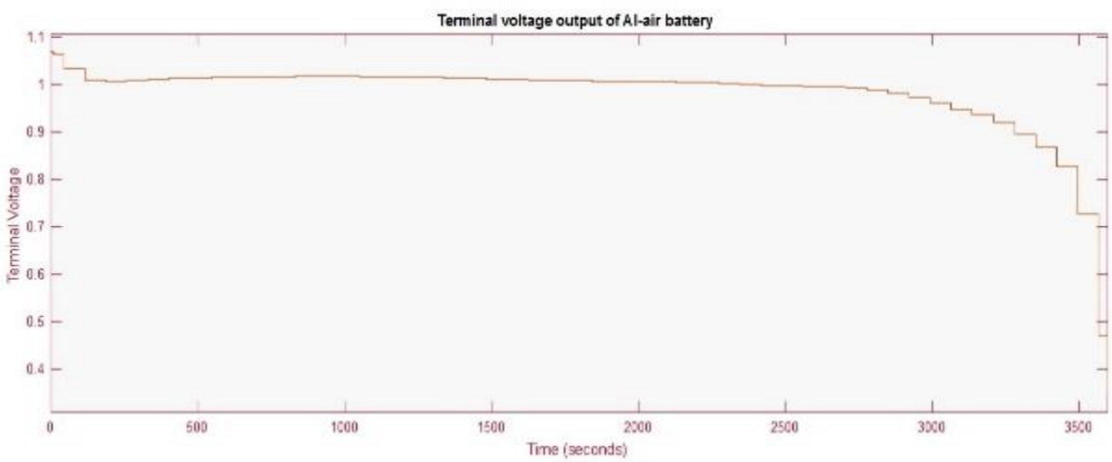


**Figure 9**: Terminal Voltage output of Al-air battery

**AL-AIR BATTERY VOLTAGE IMPROVEMENT WITH BOOST CONVERTER**

Boost converter is used to boost or enhance the input D.C voltage. For this purpose boost converter is used more prominently in D.C systems. The widespread use of portable battery devices such as cell phones and laptops has fabricated the need for electrical power to convert DC to DC as switch mode.

The input voltage source is connected to an inductor. The solid-state device which operates as a switch is connected across the source. The second switch used is a diode. The diode is connected to a capacitor, and the load and the two are connected in parallel. The inductor connected to input source leads to a constant input current, and thus the Boost converter is seen as the constant current input source. And the load can be seen as a constant voltage source. The controlled switch is turned on and off by using Pulse Width Modulation (PWM). PWM can be time-based or frequency based. Frequency-based modulation has disadvantages like a wide range of frequencies to achieve the desired control of the switch which in turn will give the desired output voltage.

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**Simulation And Model of Al-air with Boost Converter**

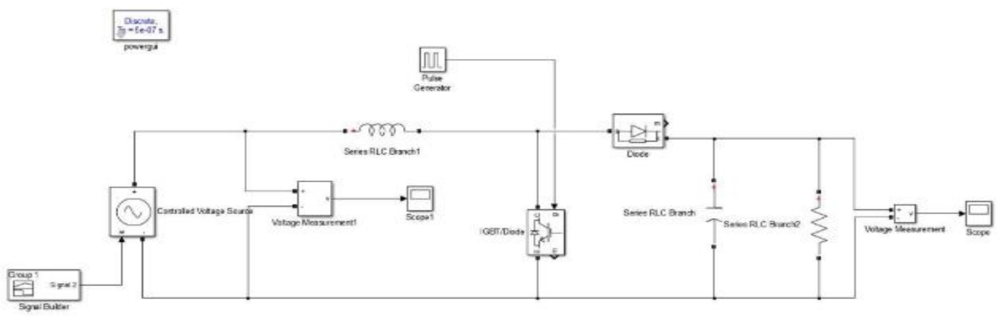


**Figure 10:** Al-Air Boost Converter Block Diagram

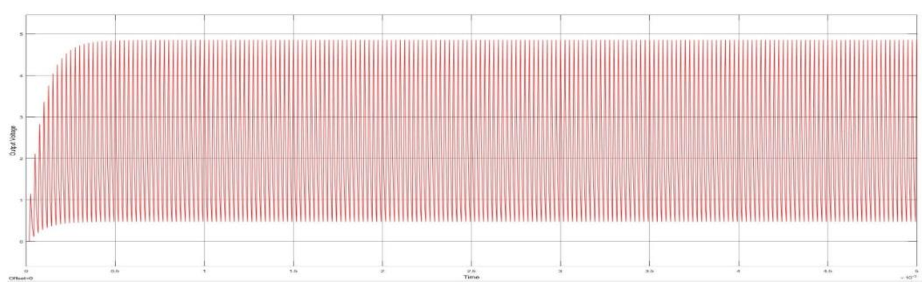

**Figure 11**: Output waveform of Al-Air Boost Converter

In this Model of Al-Air Boost converter Input is the output of Al-Air battery which vary from 1.2 volt to 0.2volt. The Duty cycle is taken as 70%. Inductance value which should be connected in series is 11.28micro Henry. The capacitance value which is in parallel connection so as to obtain a fix and reduce the output frequency is 7.52micro Farad.

The load at the end in this model is considered as 1ohm. Load can vary with the application we want to use. The switching frequency of the IGBT is 40000Hz. The obtained output voltage is 5volt. This voltage used in bulk could be helpful in various applications like backup supply, moving cars, portable and non-portable equipment etc.

## IV. RESULTS AND DISCUSSION

Using the simulations results the following conclusions have been achieved:

- The Al-Air FC model designed tracks the expected output behavior.
- With the time the cell of Al-air battery discharges hence SOC value decreases.
- When the system is required to supply a large amount of power, the model tries to fulfill the demand until it reaches the maximum theoretical set output power value of the model of 2.7 W.
- For the Al-Air battery model, the output is decreasing which is improved by using Boost Converter.
- When the integrated system works together, the output will be stable and can be used for different applications.

## V. CONCLUSION

Matlab Simulink allows the user to design and analyzed a full model of the Al-air Battery. The proposed model started from the SOC and terminal voltage output analysis of Al-Air Battery. This model implementation could lead to further developments of this technology. The Al-Air Battery with boost converter take some time to occur. The optimum time delay response for this model is an open problem to be addressed in future research. The proposed model was successfully tested with different types of converters. The Al-Air FC model simulated by using a Boost converter and adjusting its parameters for optimum behavior. Based on the simulation Boost converter is chosen. Further research is needed in order to make this technology a more viable technology. Particularly, in terms of modeling, control, voltage build up and aluminum alloys that can increase the performance and reliability of these types of battery.

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