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A Novel Approach Towards Introducing Supercapacitor Based Battery Charging Circuit for Off-grid Low Voltage Maglev Verical Axis Wind Turbine

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Abstract

This paper gives performance analysis of a novel Supercap (Superacitor) based energy harvesting battery charging device operated by a Maglev (Magnetic Levitation) VAWT (Vertical Axis Wind Turbine). A 200W PMSG (Permanent Magnet Synchronous Generator) was adopted into the system. A 9 bladed hybrid VAWT, with a radius of 15.5cm and a height of 60cm, was driven at a fixed wind speed of 5m/s. The rated power (W), voltage (V) and diameter (cm) of PMSG were 200, 12 and 16 respectively. Data Acquisition, NIUSB-6009, was used interfacing with Labview software to collect the reading from sensors. 3 cases have been compared for performance analysis. "Case A" showed a battery of 6V, 3.2AH, being charged from 4.2V to 5V through a DC DC converter followed by a series of 4 Supercapacitors (2.7V, 35F). "Case B" and "Case C" demonstrated the direct charging of the battery; where "Case B" was experimented with the converter and "Case C" was without converter. Taking "Case C" as a reference, the result showed an increase of 21% of the charging time while charging through Supercapacitor. Case A, Supercap based charging, was also found to be 133% more efficient than direct battery charging with a converter. For a low voltage small VAWT system, this novel energy harvesting circuit could bring a significant improvement that can help off-grid areas where on-grid system is not approachable.

***Keywords**:*Supercapacitor, Energy Harvesting, Off-grid, Maglev VAWT, Low Voltage.

1. INTRODUCTION

Wind energy is emerging in different number of locations expanding in Africa, Asia, and Latin America [1].Figure 1 gives an idea of total wind power capacity from 2004 to 2014 [2]. Wind energy produces 370GW out of 657 GW from total renewable power at the end of 2014 which is 56% of the total renewable power excluding hydro energy. In addition, total wind energy capacity in the world has increased from 318 GW (end of 2013) to 370 GW (end of 2014) with a boost of 16%. With the increase of wind global power capacity, plentiful researches in the field of wind energy harvesting have been conducted frequently. However, many of the current options have their own limitations such as require wider area to install, difficult to implement in rural area, high costing, real time maintenance and so on. Moreover, for rural areas, there is not ample opportunity to set-up grid turbine. This situation is also true for turbine with low voltage output

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[3] [4]. A need of an alternative way to harvest energy, therefore, is required where it is easily accessible and available. This brings up the idea and interest of harvest energy through Super Capacitor based hybrid system for low voltage output turbines. Current environment demand to have small, autonomous and energy harvesting in wind power for off grid low voltage system.

In order for wind turbines to harvest energy, there is still lack of research being done. Earlier studies showed that Maglev VAWT adapted to a PMSG is a good choice for multi-directional, low wind speed areas [5] and therefore were put into the system. Next, hybrid energy harvesting circuit was brought into the experiment and efficiency was tested in compared with standard system. The objective of this paper is to incorporate a novel design of a Supercap based energy harvesting system that can provide power source from Maglev VAWT for charging batteries for off-grid energy storage.

2. SYSTEMFLOWCHART

The entire system can be divided into four parts. The 1st part consists of the Maglev VAWT and its Permanent Magnet generator. Second part deals with the energy harvesting circuit with the combination of battery and supercap.

The 3rd and 4th parts basically act like a bridge between the first two parts. Figure 2 illustrates the overall system flowchart.

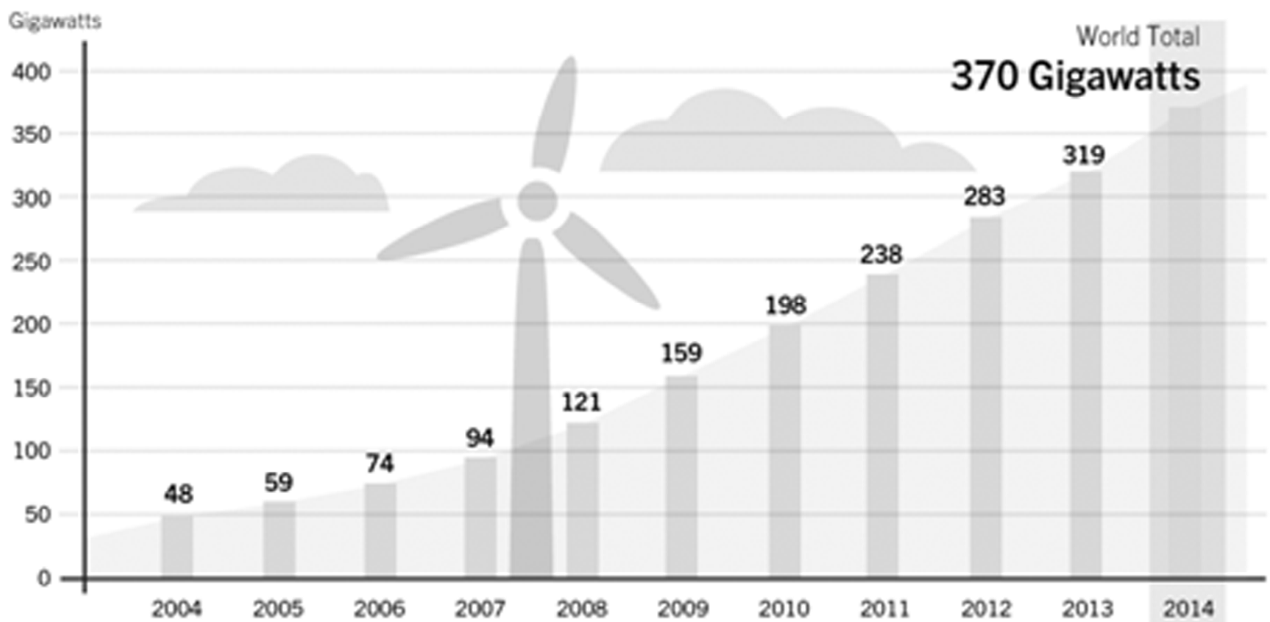

Figure 1: Wind Global Power Capacity from 2004 to 2014[2]

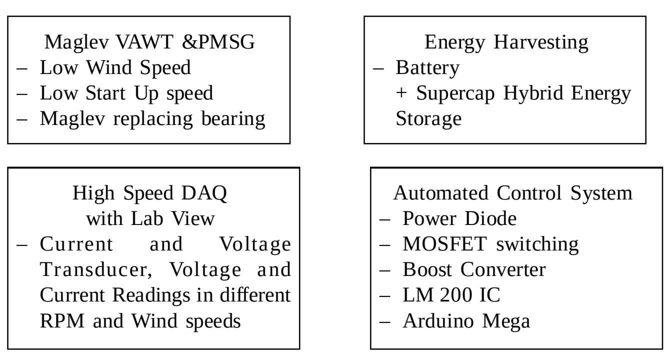

Figure 2: Overall System Flowchart

3. METHODOLOGY

This design of VAWT uses magnetic levitation concept, making it gearless and lightweight resulting in significant reduction in friction and start-up speed. The concept was taken from previous work in the year of 2013, where a 1.5KW PMSG was adopted to a Maglev VAWT for performance analysis for low wind speed [5]. Having taken consideration of the multi-phase, three phase and dual stator, as per the comparative analysis result from 2014 [6], 3 Phase PMSG has been chosen to incorporate with the system [6]. Generated charges are to be stored in a lead acid battery. The charges are not constant as it varies even with a little change of wind [8]. Thus, The DC DC boost converter was applied after the Supercap. This concept was used by *Ottman and Hofman* in 2002[7]. It provides constant current supply to charge the battery lengthening the life cycle of the battery [9] [10]. Since supercapacitors are able to hold charges for a long time; hence, it will not deplete its charges comparing to normal capacitors [11][12]. An efficiency comparison is shown between direct charging and through super capacitor bank charging. “Arduiono Uno” has been implemented to control the charging and discharging circuit through mosfet switches. The pick Supercap charging voltage was fixed as 7.5V whereas the lowest discharging voltage was set as 4V.

When the supercapis being charged by the generator, Mosfet 1 becomes close circuit and Mosfet 2 becomes open. On the contrary, when supercapacitors discharge through battery, Mosfet 2 becomes open

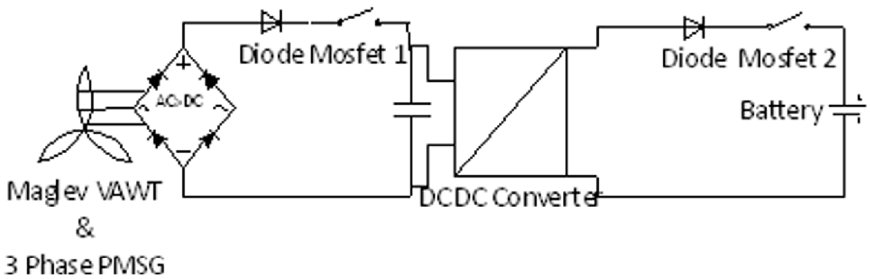

Figure 3: Schematic Diagram of the proposed system

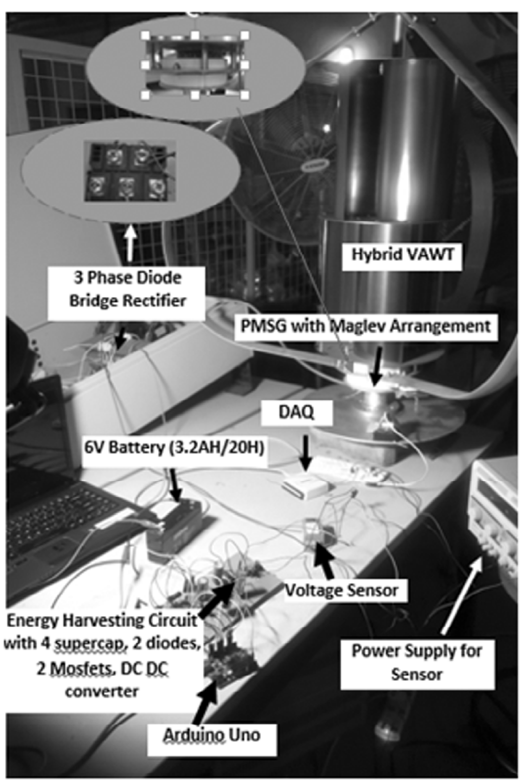

Figure 4: Experimental set-up

and Mosfet 1 becomes close. DAQ was used interfacing with LabVIEW based GUI for data acquisition for data collection. For testing the efficiency of the proposed system, the battery, being charged from 4.2V to 5V through supercapacitor, has been compared with the direct charging.

4. EXPERIMENTAL SET-UP

4.1. Maglev VAWT adopted to PMSG

A 200W PMSG has been attached to a 9 bladed hybrid Maglev VAWT. The turbine is constructed with a combine approach of the Darrieus and Savonius technology.

4.2. Energy Harvesting through Supercapacitor

Four supercapacitors, 2.7V each, have been combined in series to make a total of 10.8V. The turbine is supposed to charge the supercap through a diode. A Mosfet is placed in between as a switch to control charging and discharging time (Figure 5). A 6V battery is supposed to be charged from the supercapacitor (Case A), direct charging via converter (Case B), and direct charging without converter (Case C).

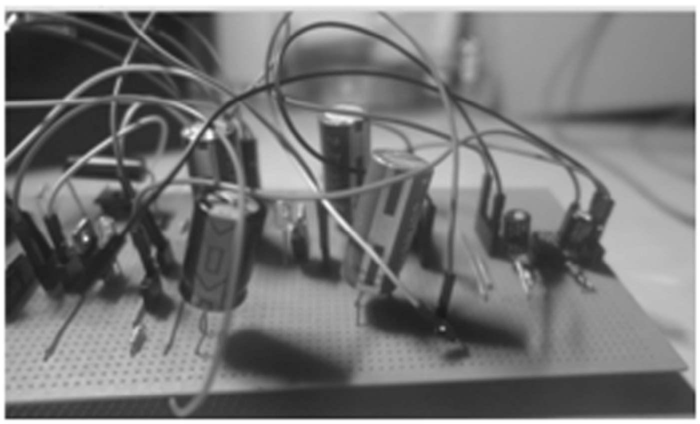

Figure 5: Arrangement of Supercapacitor, DC DC converter. Diodes and Mosfets

4.3. Power Electronics

Two Diodes have been placed in the circuit to prevent back flow of the voltage. One is placed before the supercapacitor and another is after the DC-DC converter. The DC-DC converter has been adjusted to produce an output voltage of 7.3V.

4.4. Data Acquisition (DAQ), Labview and Sensors

DC Voltage sensor is used to measure the voltage across the Supercapacitor and battery whereas DC Current sensor is used for measuring current going into Supercapacitor while charging and coming from the Supercapacitor while discharging. The DAQ, NIUSB-6009, is interfaced with the lab view software. The sensors connected to the DAQ pass the readings to the labview from where the data are collected.

4.5. System Parameter

The experiment has been run with the following system parameters.

5. RESULTS AND DISCUSSIONS

5.1. Case A: Energy Harvesting through Supercap

First, battery was charged through supercapacitor. Supercapacitors being charged by the generator discharged to battery. One entire charging and discharging process was considered as one cycle. For a wind speed of 5

Table 1
System Parameter

VAWT			
	Wind Speed	:	5 m/s
	Height	:	60 cm
	Radius	:	14.5 cm
	Number of blade	:	9
PMSG			
	Phase	:	3-Phase
	Rated Power	:	200W
	Rated Voltage	:	12V
	Diameter	:	16cm
Top net weight		:	12.5kg
Energy Harvesting			
	Battery Details	:	6V, 3.2AH/20H
	Supercap details	:	2.7V,35F
	Number of Supercap	:	4
	Series Voltage	:	10.8V
	Pick Charging Voltage	:	7.5V
	Lowest Discharge Voltage	:	4V
	Battery Charging range	:	4.2V-5V
Power Electronics	DC DC Converter Output	:	7.3V
	Mosfet 1	:	a."Open" when supercap chargingb. "close" when supercap discharging
	Mosfet 2	:	Vice versa

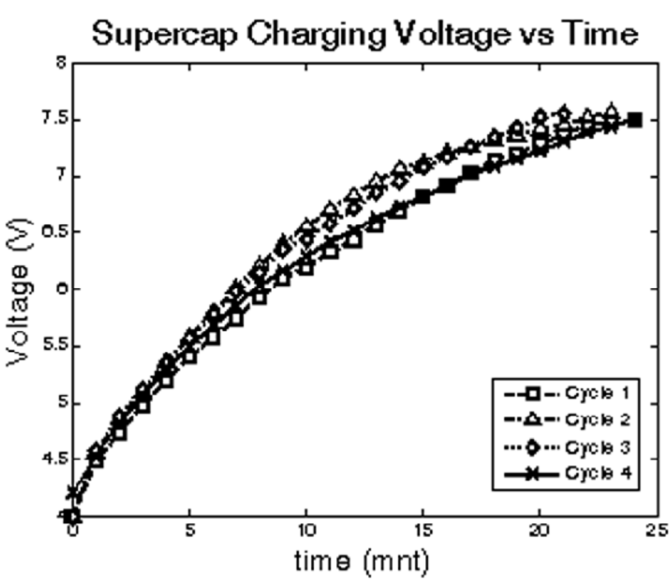

Figure 6: Supercapacitor Charging Voltage with respect to time

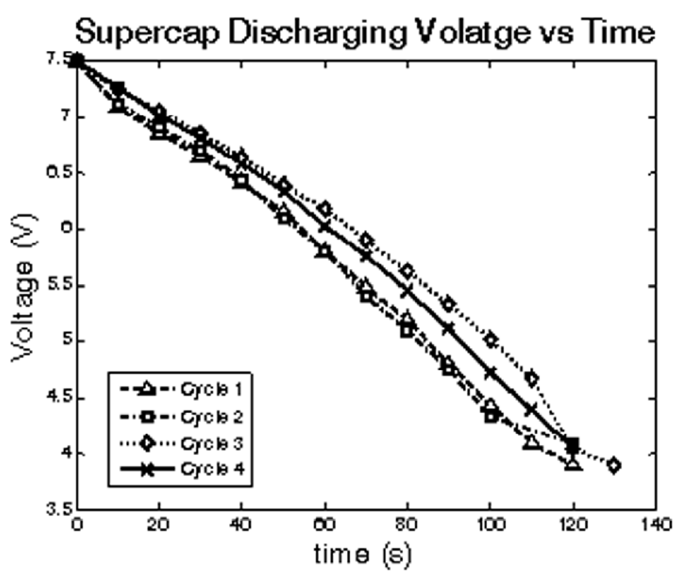

Figure 7: Supercapacitor discharging Voltage with respect to time

m/s, 18 cycle was needed to charge the battery from 4.2V to 5V. Each cycle was for 25mnts in which charging of supercap took 23 minutes on average whereas discharging took only 2minutes.

Figure 6 and 7 show the charging and discharging voltage with respect to time. The increase of the battery voltage per cycle is shown in figure 8. 18 cycles here indicate 7.5 hours of total charging process of the battery.

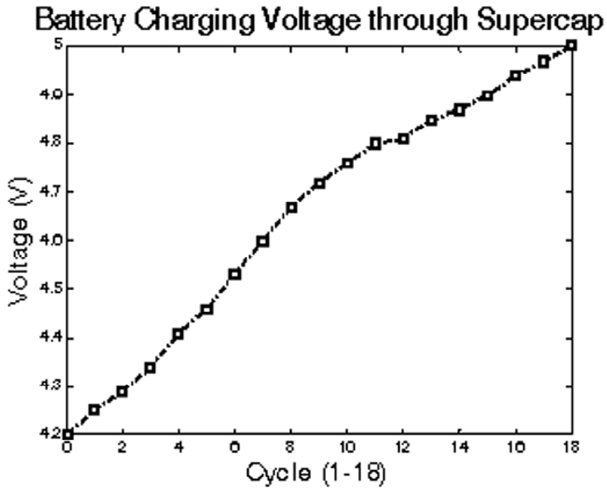

Figure 8: Battery Charging Voltage though supercap for 18 cycle (7.5 hours)

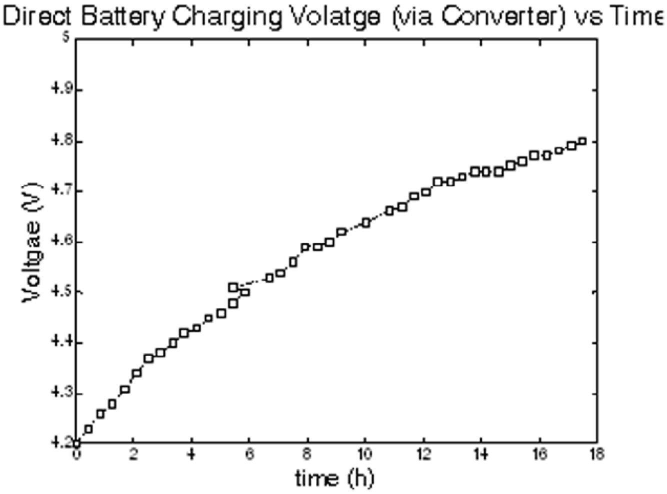

Figure 9: Direct battery charging voltage via converter with respect to time

5.2. Case B: Energy Harvesting without Supercap (with converter)

In this part, without the use of supercapacitors, turbine was fed to charge the battery through the converter. According to figure 9, it took almost 17.5 hours to reach its maximum value of 4.8V. After that the increase of the voltage was so less with respect to time, the value was not taken in consideration.

5.3. Case B: Energy Harvesting without Supercap (without converter)

Last section takes the converter out and connects the turbine directly with the battery. As it can be observed from figure 10, this approach took less time (9.5 hours) than the second approach (direct charging via converter). However, the generator output voltage fluctuates and battery needs a steady constant voltage for charging up. Therefore this method is not recommended and applying this method for a longer period will result damaging of the battery. Still results were gathered for the sake of comparison.

5.4. Efficiency Comparison

Figure 11 indicates the comparison between all the 3 cases. "Case C" was taken as a reference point while comparing. It was found out that charging through supercapacitors was 21% more efficient that direct

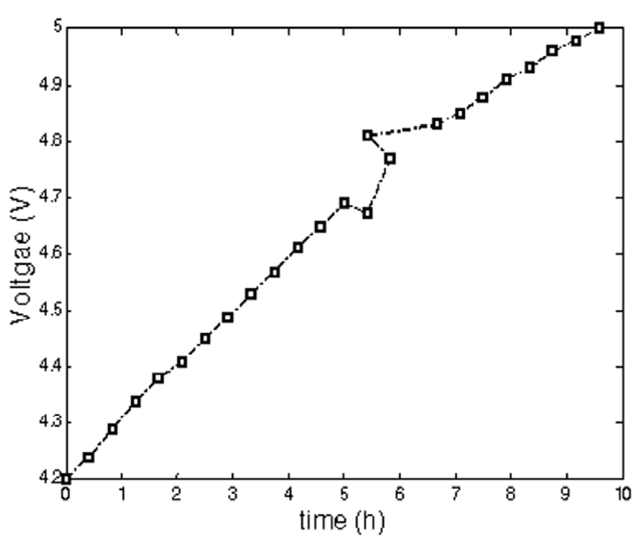

Figure 10: Direct battery charging voltage without convert with respect to time

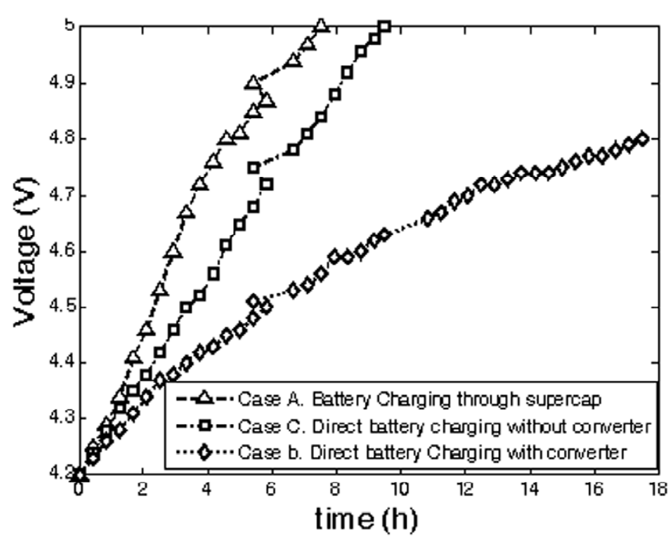

Figure 11: Battery Charging Voltage under 3 cases in respect with time

charging without converter. Supercap battery charging is also 133% more efficient than direct charging with a converter. That makes case 2 being unworthy in low wind speed situation.

6. FUTURE WORK AND CONCLUSION

There is vast scope to extend this work further and come out with potential results. This surely can bring a revolutionary change in low voltage turbine off-grid system. As for example, wind speed can be made lower while experimenting and data should be collected for low wind speed areas. Also, converter and switching configurations should be varied in order to observe the effect on the charging system.To recapitulate, for a low voltage turbine output system, this kind of hybrid supercap based battery charging device could bring a radical change for off-grid technology. With efficiency over 21% than the unconventional direct battery charging, makes the proposed system worthy of consideration. The conventional energy harvesting battery charging circuit through a DC DC converter just failed to catch up the charging speed. To conclude, the supercap based emery harvesting hybrid circuit for battery charging has shown remarkable results with our proposed Maglev PMSG based VAWT and thus more research and further study should be conducted in order for its betterment.

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