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A Review of Research on Small Scale Renewable Energy Sources and the Storage Techniques for off Grid Applications

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Abstract
The paper presents a review of research on various renewable energy sources and storage methods to design and develop an integrated off grid system which can provide continuous and reliable power supply to the Army troops posted in the areas in keeping the equipment powered in extreme temperatures and isolated locations. Harnessing power from the nature using small scale renewable energy generating methods and energy storage devices which are light in weight and could work in extreme temperature is explored here. This paper presents the review of various researches in vertical axis wind turbine and compressed air storage techniques. In addition it discusses the operation difficulties with the storage devices like batteries which could be replaced using super capacitors for critical applications in army. The paper reviews the recent research done in magnetic refrigeration for cooling requirements using the basic principle of magneto caloric effect. Finally the paper presents the scope of research in small scale renewable energy generation using vertical axis wind turbines (VAWT) and its storage using compressed air generator (CAES) and super capacitors for critical applications in extreme temperature applications.

Keywords*: Renewable energy, VAWT, CAES, Magnetic Refrigeration, Super*Capacitor

I. INTRODUCTION

Energy demand of a country explains the growth and development of a country. Ever increasing energy demand pushes the world to look for alternative energy resources which could be long lasting, renewable in nature and expandable. Renewable energy sources like Solar and Wind energy are promising candidates which can be easily expanded to the ever increasing energy demand and to mitigate the risk of climatic change. VAWT generates power in low wind speed and is specifically used in urban and rural areas.Solar power is used along with the vertical axis wind turbine as hybrid power source. An integrated off grid system which can provide continuous and reliable power supply to the Army troops posted in the areas which are cut-off during winters for long durations. Army is deployed in defensive posture along kilometers of Line of Control (LOC) and kilometers of Line of Actual Control (LAC) which present many challenges diverse in nature. One such very important challenge is keeping the equipment powered, in subzero temperatures. The electrical connectivity of these posts is nil and the functionality of generators in long periods of time in treacherous conditions is also questionable. So, it is imperative to come up with a solution that is aptly suitable for such challenging conditions and also reliable.

The renewable energy sources need an energy storage device to provide a continuous power output to the load during the demand period. A battery is the conventional storage device for storing wind and solar energy, but for large energy harvesting stations it is not economical and do not have longer life time. Compressed air generator storage (CAES) is a system using a storage tank to store compressed air generated with the renewable energy source. It uses air compressor to store compressed air into the tank and the stored gas is released as per the need to run an air turbine to generate the electrical power to meet the load demand. The CAES system is a promising technique for large energy backup at very low cost. The challenge is the conversion efficiency and storage sites near the renewable energy sources.

Batteries and Super Capacitors are electrical energy storage devices for renewable energy sources. Batteries are used for various low and high power applications like vehicles, UPS, inverters, laptops and mobile phone applications. Batteries and Super capacitors can be combined to form an advance power source for specialized applications. The battery provides a high energy density but with limited life cycle and poor power density whereas a super capacitor with higher capacitance provides high power density with unlimited cycle but with low energy density. Automotive vehicles need a high discharge current called as cranking current but a high discharge could drain a battery easily. Using a super capacitor added to vehicle could support the initial high current during cranking and avoid battery getting discharged. A switching converter is used to switch power between the super capacitor and the battery by connecting them in parallel. This parallel combination ensures the charging of the super capacitor from the battery normally and the supper capacitor come into the circuit to provide the heavy discharge current during cranking and later the battery comes into the circuit for other electrical power needs of the vehicle. This combination reduces the battery size requirement of the vehicle and helps in prolonging the life of the battery.

Refrigeration is to lower the temperature of a closed space or material by removing the heat by compression / expansion refrigeration cycle. Consumer application includes air-conditioning of closed spaces, preserving perishable items, beverage dispensing and ice making, air dehumidification and equipment cooling. Continued research and development have brought out efficient cooling methods and energy efficient refrigeration systems for various applications, but the refrigerant in these system is a hazardous chemical and threat to the Ozone layer and add to global warming. Magnetic refrigeration is the current research trend and it uses the magnetization and demagnetization instead of compression and expansion cycle of conventional refrigeration. It is based on magneto caloric effect and could achieve extremely low temperature.

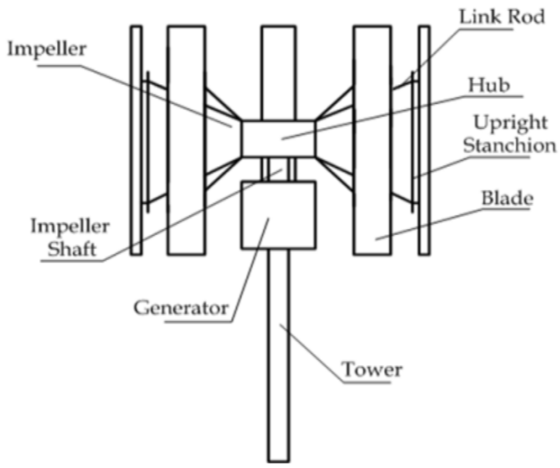

Figure 1.0 VAWT design with component details

A. *Vertical Axis Wind Turbine (VAWT)*

The major components of VAWT are Rotor, Stator (Generator) Battery blades and shaft of tunnel type. Figure 1 shows the hardware components of a VAWT. Wind power generation is proved at low speed levels at 16 m/s to generator power using tunnel Rotor [1]. Matching the rotor design with power generator is a challenge in this design. Optimal power conditioning and controlling work has done for different low speed levels and with less weight. A wind rotor design converts 12 m/s wind speed to 600 rpm for arm generator to generate 24 volt. The design uses horizontal blades built with heavy weight material to generator power at low wind speed for reduced cost but without self starting feature [2]. Hybrid systems use VAWT, solar panel and Pizeo electric generators but when we combine low power generator like pizeo electric generators with high power generators the total average voltage reduces and the performance of high power generator like VAWT and Solar is lost [3].Variation in wind speed creates a torque variation and could affect the hardware for different loading conditions of the turbine. Computational fluid dynamic (CFD) method is used to reduce the impact of torque variation on the hardware [4]. Various blade designs with different materials have been studied using simulation to optimize the efficiency and cost of VAWT [5].The VAWT with permanent magnet using ball bearing increases friction losses and reduces the efficiency. To overcome this Magnetic levitation technique is used with permanent magnet to convert wind energy into electrical energy with reduced losses [6]. VAWT designs demonstrated by directly connecting resistive lighting load without converting pulsating DC to AC to reduce conversion losses but of poor reliability and for low power application [7]. Another novel implementation of VAWT is along the high way placed at the road divider. The moving vehicle along the highway due to its speed produces a wind which is used to rotate the VAWT at the road divider. These VAWTs are integrated with solar panels and the energy is stored in a battery and used for highway lighting and nearby small villages [22]. Studies are done to design a low cost VAWT for houses located at remote locations were no grid connectivity is possible. The simulation study shows a 1.86 units generating unit could be built for 500 USD [23]. To improve the output for a given wind speed the blade length is increased with a two point support one at the top and the other at the bottom of the blade. This provides increased electrical output for a given wind speed and the structure is rigid [24].

B. Hybrid Energy Storage Devices

Lithium ion battery is a common storage options for renewable energy sources. This storage is used for domestic applications. The performance of battery gets affected at extreme operating temperature. The Lithium ion chemical property gets affected due to overcharging and deep discharging and reduces the life of the battery. This could be overcome by battery management system (BMS) and hybrid energy storage system (HESS). The BMS consist of more than one battery and maintain the battery life by monitoring the voltage, current and temperature with proper electronic control and switching systems. SLG battery is a 48 V BMS system used for high discharge capability including cooling, ventilation and electrical system integration [8]. Various mathematical models have been developed to study the state of charge (SoC), state of health (SoH) and the state of function (SoF) [9]. The various components of the BMS system is shown in figure 2. The BMS systems fail to discharge in electrical vehicles for starting at sub-zero temperature which could be overcome by connecting a super-capacitor with the vehicle battery. A working model was demonstrated using a directional chopper using MOSFET to study the effect of temperature (-40 °C to + 50 °C) on the capacitance and series resistance of super-capacitor for using in a hybrid storage system. This study helps in understanding the charging and discharging cycle of super-capacitor in extreme temperature operating conditions [10]. Usage of active carbon to build carbon layers for making a super-capacitor is explored but effect of temperature is not considered in the study [11]. A comparison study with different battery combination was done to study the chemical composition, energy output, charging and discharging cycle. This includes flow battery, Lithium ion battery and atomic battery with Faradaic, non-faradaic and hybrid super-capacitors. For50 to 100 °C temperature operation proton exchange membrane fuel cell (PEMFC) batteries are used for stationary and portable battery application [12]. Figure 3 shows the functional block diagram of PEM fuel cell.

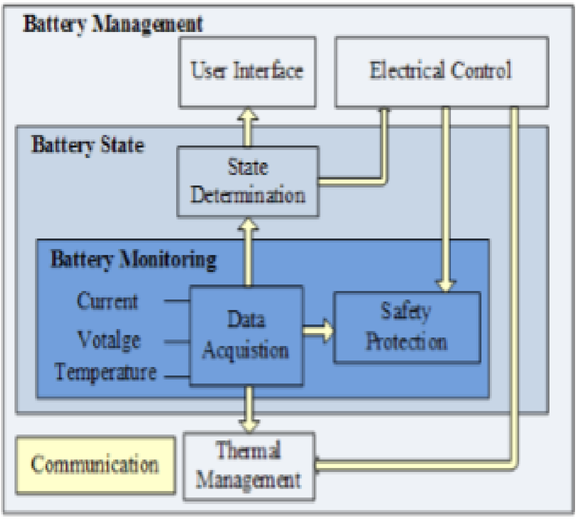

Figure 2. the block diagram of a BMS system [9]

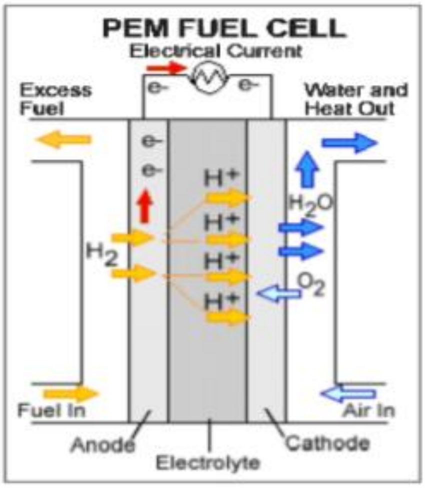

Figure 3. Proton exchange membrane fuel cell [12]

A study was done using super-capacitor with the battery to improve the battery performance during high current discharge and rise in temperature. During heavy discharge the super-capacitor come in parallel with the battery to prevent high current discharge and over loading of the battery [13]. For applications to micro-grid using renewable energy source super-capacitors are used in energy storage system (ESS) with power electronic convertors. Energy management system (EMS) [14] uses HESS for improvement in performance like efficiency, power quality and system stability. System reliability is improved with ESS life span expansion and device protection. The economic feasibility is possible by scheduling proper loading with DG sets and reducing system complexity. Alternatively in an automobile the super-capacitor is charged using re-generative braking system in a vehicle instead of charging it through vehicle battery [25]. Energy management strategy (EMS) system for vehicle using both battery and super-capacitor is optimized using Pontryagin's Minimum Principle (PMP) method to study the real-time driving cycle. This study method has helped in reducing the rms current of the vehicle battery by 50 % compared to the battery with EV system [26]. Super-capacitor is modeled with different materials to improve the electrical characteristics for best performance for practical applications. It studies the electrical self-discharge drawback of the super-capacitor and equivalent capacitance reduction with increase in frequency and suggests graphene as composition for super-capacitor which gives a higher cut-off frequency of few hundred hertz [27-33]. Super-capacitors are used in smart grid connection along with battery along with DC – DC converter to improve energy efficiency, peak demand loading and improved grid frequency [28].

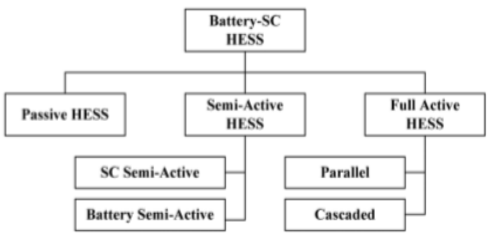

Figure 4. EMS control goals [14]

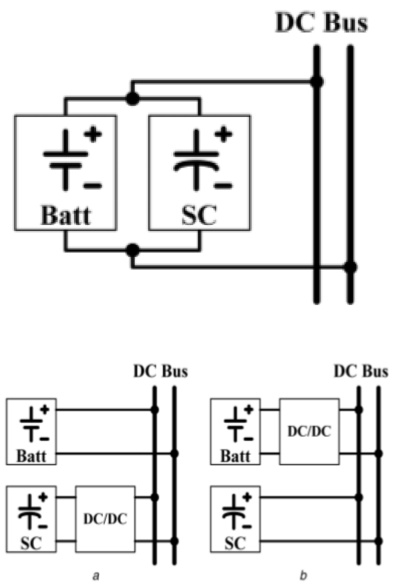

Figure 5. Passive and semi-active HESS topologies [14]

C. Compressed Air Energy Storage System

The energy storage options are flywheel energy storage, electro-chemical energy storage, pumped hydro energy storage and compressed air energy storage (CAES). The pumped hydro and CAES system is preferred due to their scalability and economical. When the load demand on the grid reduces, the renewable energy source is converted into compressed air and stored in a storage tank. When the load demand increases the stored compressed air is released to run a compressed air turbine (CAT) to generate electrical energy to supply the power grid. Figure 6.0 shows a complete CAES system block diagram. The CAES technology is of three types depending on the thermal management in the system. The types are adiabatic, diabatic and isothermal process.

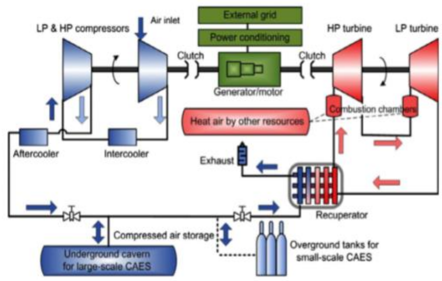

Figure 6. CAES block diagram [15]

A CAES using a combination of air and hydraulic oil is used with pneumatic and hydraulic systems. This is used for small-scale compressed air energy storage (SS-CAES) systems. Compressed air hydro energy storage (CAHES) with repetitive control (RC) discharging cycle improves the efficiency but at higher cost. The effect of temperature and pressure is taken for study [16].

D. Green energy refrigeration system

Magnetic refrigeration is the high energy efficient system used for attaining extremely low temperature using magnetization and demagnetization instead of the age old compression and expansion cycle method. Magnetic refrigeration uses magneto caloric effect and could attain temperature well below a Kelvin. Figure 7.0 shows the working of a magnetic refrigeration system. Special magnetic materials reduce the magnetic entropy by orderly arranging the magnetic moments in the presence of a magnetic field. The phenomenon is reversible for these materials by removing the magnetic field on it. Reversing the magnetic moments to its original state cools the magnetic material. The efficiency of magnetic refrigeration is 50% more than the conventional refrigerator technique.

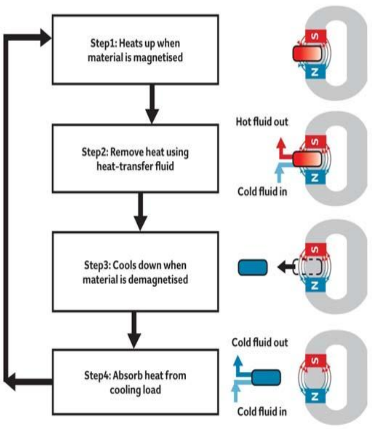

Figure 7. shows the working of magnetic refrigeration system

Energy efficient magnetic caloric Refrigeration system using permanent magnet array was studied to improve flux density and better cooling efficiency. There are two types are magnetic array namely hollow cylindrical permanent magnet Array (HCPMA) and hollow spherical permanent magnet array (HSPMA) [17]. Figure 8 shows regenerative refrigeration with a pneumatic drive which allows the displacement of the whole system in and out of the magnet making the magnetic material Gd (Gadolinium) getting magnetization and demagnetization. It involves four steps in the whole cycle namely Magnetization of Gd, water flow in one direction, demagnetization of Gd and water flow in the reverse direction [18]. The system could demonstrate a 4°C temperature variation but consume higher electrical power. Figure 8.0 shows active magnetic material with thermocouples in regenerative refrigeration.

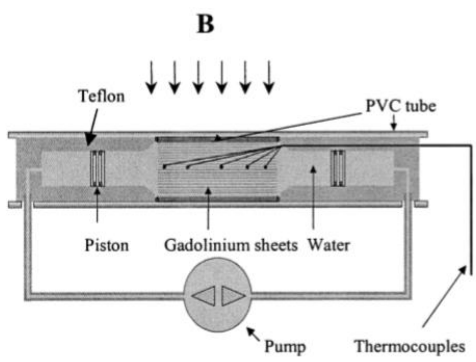

Figure 8. Regenerative refrigeration with pneumatic drive [18].

Rotary magnetic refrigeration systems increase flux density with high power permanent magnet array to achieve 2.6 -3 tesla. The air gap between and the magnet and the Gd is reduced to reduce field loses and water is used as a coolant fluid [19]. Figure 9 shows the magnitude of flux density for different air gap distance.

The various magnetic material combinations with Gd a 2D simulation was done by studying the magnetic calorific value for the magnetic material (MCM) with a flux density of 1 to 1.5 Tesla [20]. Figure 10 shows the reduction in temperature with increase in the number of cycles for different materials. The current research for a power source is Hydrogen cell as a fuel for electrical vehicles. It is limited due to the difficulty in storage of these cells; the voltage output per unit cell is in mV and expensive [21]. Simulations were done for an air-conditioning unit using different magneto caloric effect material as Gadolinium alloys and Praseodymium alloys are used with Nickel for stronger MCE property. Refrigerant with and water and alcohol were tried instead of plain water in the ratio of 80:20 [29]. A hybrid cryogenic refrigerator using magnetic refrigeration at first stage and a Gifford-McMahon (GM) refrigerator as second stage could produce a no load temperature of 3.5 K at 0.5 Hz where as only a GM refrigerator could generate only 4.2 K at no load condition [30].

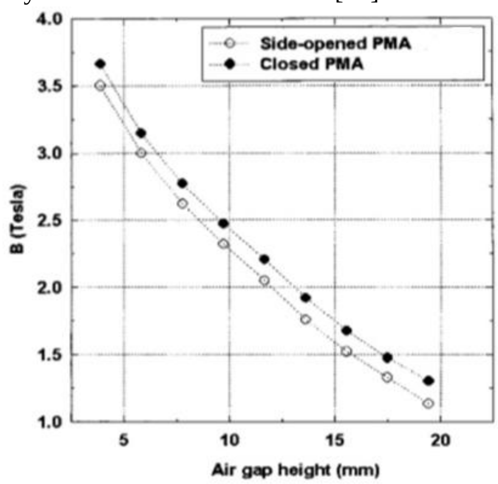

Figure 9: Magnetic flux density with air gap height [19].

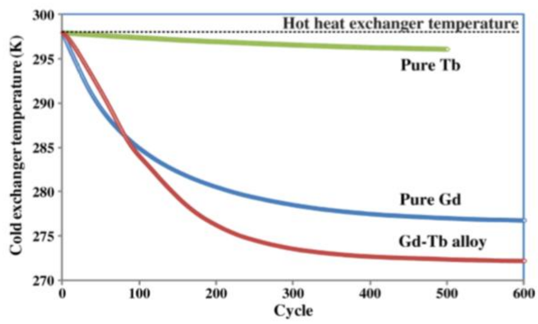

Figure 10 Temperature with number of cycles for different materials [20].

II SCOPE FOR FURTHER RESEARCH

A. Vertical axis wind turbine

There is a scope to optimize the blade design for better wind cutting speed with better aerodynamic designs, optimized blade width and height for a mast height, material selection for reduced weight, without environmental degradation, easy fabrication, installation and serviceability. The number of blades can be increased for better mechanical efficiency of the VAWT. Similarly the VAWTs are designed for a wind speed of 1m/s to 10 m/s but the voltage output is unusable at lower speed and normally it is useful from 9m/s and above. The converter design has been made to harvest this unusable lower voltage which could be optimized for usable voltage range. This also helps in designing the mechanical structures for the usable wind speed. The VAWT at lower wind speed is not compatible with other renewable sources like solar in a hybrid power systems. Braking systems like soft braking could be planned for a wind speed above 12m/s for the mechanical structure protection. Self starting mechanism is one another scope for the design of VAWT. It is also noted that most of the design studies were done using steady state conditions and did not consider the effect of transient conditions which could damage the converters. There is a scope to study the output variations for a transient response of VAWT along with steady state conditions.

B. Hybrid storage systems

In a super-capacitor bank the individual leakage currents create difference in potential between them under load condition and one super-capacitor could damage the other due to the circulate current between them. There is a scope for designing a protection circuit using MOSFET to prevent the failure of super-capacitors under load condition. In a BMS there is a scope to design a monitoring system for the individual cells in a battery and to study the over voltage and over current conditions while charging and discharging cycle and its effect on other cells in a battery. In a hybrid system the super-capacitor gets damaged due to high temperature and a cooling system design could prevent the failure.

C. CAES

Current designs use turbine generators (CAT) to generate Megawatt power but there are no CAT designs for low power requirement. In a CAES system a detail study with the temperature and pressure of the stored gas could done for optimization.

D. Green Energy Refrigeration

In a magnetic refrigeration system most of the design is at experimental stage and have a large scope for research and development. The property of the magnetic material degradation with multiple magnetization and de-magnetization needs to be understood either by experimentation or by simulation. The power conception of the magnetic refrigeration is very high and not energy efficient. Most of the design is with permanent magnet and no study has been made with electromagnet. There is a scope to study the benefits and limitation of using electromagnet for magnetic refrigeration.

CONCLUSION

The detail literature review had given a scope of research for grid cut-off post army locations. A vertical axis wind turbine is a viable solution for providing electrical power along with a hybrid system like solar power panels. Small compressed air generator could be a suitable storage option which is easily portable to high altitudes instead of heavy Lithium ion batteries. At extreme low temperatures a super-capacitor with a Lithium ion battery could help in starting army vehicles with a suitable protection system for super-capacitor bank. Green energy magnet refrigeration is an attractive solution to army tanks and vehicles which operate at high temperature in deserts without proper cooling facility. A low cost design could be suitable for army vehicles at field.

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