

# Energy Management Optimization in a Hybrid Energy Storage System Using Four Leg Three Level NPC Inverter

K.P. Nithya<sup>1</sup>, Aswith Raj.K<sup>2</sup>, Balaji.M.S<sup>3</sup>, Dhanasekaran.K.P<sup>4</sup>, Dis sanjay T<sup>5</sup>

<sup>1</sup>Assistant Professor/Department Of EEE, Panimalar institute of technology, Chennai 600123

<sup>2,3,4,5</sup>UG Student/ Department Of EEE, Panimalar institute of technology, Chennai 60012

**Abstract-** Increasing demand for distributed generation based on Renewable Energy Sources (RES) has led to several issues in the operation of utility grids. The micro grid is a hopeful solution to solve these problems. A dedicated energy storage system could contribute to a better integration of RES into the micro grid by smoothing the renewable resource's intermittency, improving the quality of the injected power and enabling additional services like voltage and frequency regulation. However, due to energy/power technological limitations, it is often necessary to use Hybrid Energy Storage Systems (HESS). In this paper, a second order sliding mode controller is proposed for the power flow control of a HESS, using a Four Leg Three Level Neutral Point Clamped (4-Leg 3LNPC) inverter as the only interface between the RES/HESS and the micro grid. A three-dimensional space vector modulation and a sequence decomposition based AC side control allows the inverter to work in unbalanced load conditions while maintaining a balanced AC voltage at the point of common coupling. DC current harmonics caused by unbalanced load and the NPC floating middle point voltage, together with the power division limits are carefully addressed in this paper. The effectiveness of the proposed technique for the HESS power flow control is compared to a classical PI control scheme and is proven through simulations and experimentally using a 4 Leg 3LNPC prototype on a test bench.

**Index Terms-** DC-AC influence clergy, Exertion repository, Micro bursts, Competency affirmation, Accelerate technique, containment.

## 1. INTRODUCTION

The increasing penetration of DG is changing management of the grid from centralized to decentralized schemes, creating several challenges that must be carefully addressed in order to keep the electrical grid's proper operation. High penetration of

renewable energy can lead to stability and power quality issues due to the stochastic nature of RES, such as wind and solar energy. The microgrid concept, which can be defined as a small scale weak electrical grid that is able to operate both in connected and islanded mode, has been extensively studied as a solution for RES integration. The weak nature of a microgrid implies the use of an Energy Storage System (ESS) to increase RES penetration and insure its stability. Energy storage is the capture of energy produced at one time for use at a later time. A device that stores energy is sometimes called an accumulator or battery. Energy comes in multiple forms including radiation, chemical, gravitational potential, electrical potential, electricity, elevated temperature, latent heat and kinetic. Energy storage involves converting energy from forms that are difficult to store to more conveniently or economically storable forms. Bulk energy storage is currently dominated by hydroelectric dams, both conventional as well as pumped. Some technologies provide short-term energy storage, while others can endure for much longer. A wind-up clock stores potential energy (in this case mechanical, in the spring tension), a rechargeable battery stores readily convertible chemical energy to operate a mobile phone, and a hydroelectric dam stores energy in a reservoir as gravitational potential energy. Fossil fuels such as coal and gasoline store ancient energy derived from sunlight by organisms that later died, became buried and over time were then converted into these fuels. Food (which is made by the same process as fossil fuels) is a form of energy stored in chemical form. Ice storage tanks store ice frozen by cheaper energy at night to meet peak daytime demand for cooling. The energy isn't stored directly,

but the work-product of consuming energy (pumping away heat) is stored, having the equivalent effect on daytime consumption. The largest source and the greatest store of renewable energy is provided by hydroelectric dams. A large reservoir behind a dam can store enough water to average the annual flow of a river between dry and wet seasons. A very large reservoir can store enough water to average the flow of a river between dry and wet years. While a hydroelectric dam does not directly store energy from intermittent sources, it does balance the grid by lowering its output and retaining its water when power is generated by solar or wind. If wind or solar generation exceeds the regions hydroelectric capacity, then some additional source of energy will be needed. Many renewable energy sources (notably solar and wind) produce variable power. Storage systems can level out the imbalances between supply and demand that this causes. Electricity must be used as it is generated or converted immediately into storable forms. The main method of electrical grid storage is pumped-storage hydroelectricity. Areas of the world such as Norway, Wales, Japan and the US have used elevated geographic features for reservoirs, using electrically powered pumps to fill them. When needed, the water passes through generators and converts the gravitational potential of the falling water into electricity. Some forms of storage that produce electricity include pumped-storage hydroelectric dams, rechargeable batteries, thermal storage including molten salts which can efficiently store and release very large quantities of heat energy, and compressed air energy storage, flywheels, cryogenic systems and superconducting magnetic coils.

## 2 RELATED WORKS

Compared with the single-technology ESS, a hybrid ESS (HESS) can combine the advantages of each technology used, thus being more suitable for large-scale renewable energy systems [1]. In [3] the researchers presented that Microgrid (MG) is the indispensable infrastructure of nowadays smart grid, however, fluctuation and intermittence resulted from unstable micro-sources and nonlinear loads will execute considerable impacts on normal operation of the MG. Energy storage technology presents a preferable solution to the above issue. The paper gives a full scope review of the principal energy

storage technologies being developed so far, and the features and benefits of energy storage systems (ESSs). In [2] the authors represented that going beyond 2-D flows, 3-D coupled species/charge/ fluid transport models studying pore scale felt electrodes can be employed to obtain a better understanding of the flow on the pore level. In [4], a unified energy management scheme is proposed for renewable grid integrated systems with battery-super-capacitor hybrid storage. The intermittent nature of renewable-energy resources (RES), coupled with the unpredictable changes in the load, demands high-power and high-energy-density storage systems to coexist in today's microgrid environment. The researchers in [5] presented that the battery voltage and current can be filtered with a capacitor. The capacitor must have sufficient energy storage to deliver the current pulse for the required time, and its equivalent series resistance (ESR) must be small enough to minimize the voltage droop. Super-capacitors meet these requirements. This paper examines performance improvement when a super-capacitor is used with a battery. In [6] the researchers used a dc-coupled structure in order to decouple the grid voltages and frequencies from other sources. All sources are connected to a main dc bus before being connected to the grid through a main inverter. The authors in [7] proposed that Large-scale deployment of intermittent renewable energy (namely wind energy and solar PV) may entail new challenges in power systems and more volatility in power prices in liberalized electricity markets.

An updated review of the state of technology and installations of several energy storage technologies were presented, and their various characteristics were analyzed in [8]. In [9] distributed generation is emerging as a new technology for supplying the increasing demand for electricity. Micro grids are attracting a great deal of attention since they integrate distributed generation in the main grid reliably and cleanly. In [10] they presented the significant benefits associated with micro grids have led to vast efforts to expand their penetration in electric power systems. Although their deployment is rapidly growing, there are still many challenges to efficiently design, control, and operate micro grids when connected to the grid, and also when in islanded mode, where extensive research activities are underway to tackle these issues. A classical wind energy conversion

system is usually a passive generator. Its power does not depend on the grid requirement, but entirely on the fluctuant wind condition [11]. In this paper a DC-coupled wind/hydrogen/super-capacitor hybrid power system is studied Super-capacitors (SCs) have high power density and exceptional durability. Progress has been made in their materials and chemistries, while extensive research has been carried out to address challenges of SC management [12]. Fig 1 shows the Model of the Vanadium Redox Flow Battery (VRB).

The investigated HESS is formed of a Li-Ion battery and a VRB. The VRB technology benefits from the decoupled specific power (which depends on the stack characteristics) and its specific energy (which depends on volume of electrolyte tanks). The Li-Ion battery benefits from a high specific power and moderate self- discharge. This technology has also been developed for high power standalone applications in recent years.

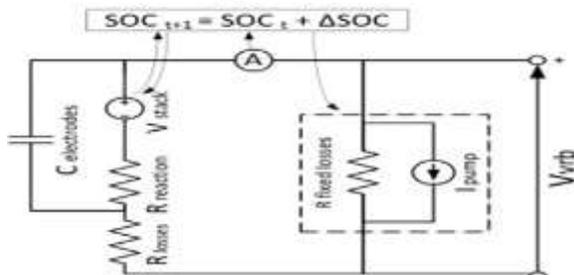


Fig 1: Model of the Vanadium Redox Flow Battery (VRB)

Consequently, the use of these two technologies is complementary and realizes a high specific energy and high specific power HESS. The proposed control method uses a CBPWM approach where each phase is controlled by means of a modulation signal. A zero-sequence voltage is injected aiming to minimize the switching losses, control the current flowing through the NP to regulate the NP voltage, and extend the linear modulation region.

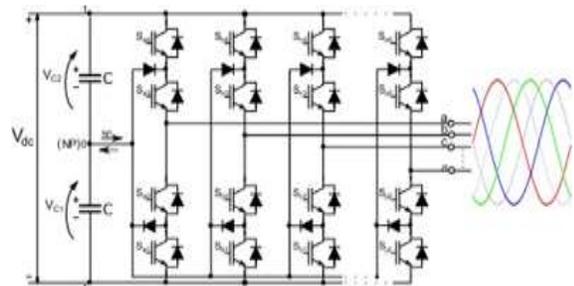


Fig 2: n-phase three-level NPC converter

To fulfill the first requirement, the number of switching events has to be kept as low as possible. This is achieved maintaining one of the converter phases continuously clamped during each switching period. There are several zero-sequence voltage combinations that clamp one phase of the converter to a fixed level.

### 3 SYSTEM MODEL

Systems analysis is a problem solving technique that decomposes a system into its component pieces for the purpose of the studying how well those component parts work and interact to accomplish their purpose. Due to the reduced voltage applied on the switches and an increased number of voltage levels, the 3L-NPC topology becomes more efficient while showing a lower current Total Harmonic Distortion (THD) than an equivalent two level inverter. Several works have been carried out on ESS hybridization using multilevel topologies, including the 3 Leg 3 L-NPC. In, a PI controller is designed to control the power flow of a Vanadium Redox Flow Battery (VRB) whereas a Super Capacitor (SC) provides the fast variation of power with both parallel and 3 Leg 3L-NPC inverters. It is shown that, beyond the limits of the 3L-NPC topology, the efficiency and THD improvement make this topology suitable for ESS hybridization. Another particularity of this topology is the floating DC link middle point voltage which involves voltage ripples at three time the fundamental frequency (i.e. 150 Hz). The harmonic magnitudes are directly linked to the modulation technique used, as well as the DC link filter characteristics. These voltage ripples coupled to highly unbalanced AC loads may cause large DC current harmonics which may increase electromagnetic interference (EMI) and impact ESSs lifetime due to increased thermal losses. This effect could be exacerbated by a degraded DC link filter. Although the 4 Leg 3L-NPC topology shows good specification (low THD, high power capabilities, high efficiency), the power division between the sources has some limits that have to be carefully investigated. The limits of the topology have been investigated considering the DC link capacitor removed and no RES injection on the DC bus.

### 4 PROPOSED SYSTEM

The proposed system model is shown in fig 2. The power flow management of a HESS composed of a Li-Ion battery and a Vanadium Redox Battery (VRB) is investigated in a microgrid context. The 4 Leg 3 LNPC inverter has been chosen to interface the HESS with the microgrid due to its low THD, high efficiency and its ability to manage unbalanced AC loads through the 4th leg. The objective of the paper is to prove that by adding the fourth leg to a 3L-NPC converter and using a new DC side control strategy it is possible to reach both fast and efficient DC power sharing between the two ESSs and the RES, and at the same time improves the AC side power quality. The main contribution of this paper lays in the DC power flow controller which allows HESS power flow control and DC current harmonics suppression. The new model for 4-Leg 3L-NPC structural limits proposed in is assessed. The effectiveness of the proposed system has been tested through simulations and experimental tests using a laboratory prototype.

## 5 CONCLUSION

In this paper the use of a 4-Leg 3L-NPC power converter topology to interface a RES with a HESS (formed by a VRB and a Li-Ion battery) in a microgrid context has been investigated. A new model of the structural limits is presented and implemented to exploit the entire capability of the 4-Leg 3L-NPC converter to insure a maximum power division between the two ESS. A non-linear 2-SMC scheme has been designed and tuned to control the zero sequence injection in the modulating signals in order to control the power flow of the HESS. Furthermore, the fourth leg of the converter allows the unbalanced load issue to be addressed, and thus enable active power filter capabilities. The investigation of the limits of the topology showed a power exchange capability among the HESS. Simulation and experimental results proved the capacity of the proposed control strategy to manage a HESS in order to improve the power quality and stability as well as to control the renewable energy injected into a microgrid. It is able to regulate the NP voltage and to mitigate the low- frequency NPC voltage ripples for balanced and unbalanced load conditions. It exhibits low switching losses for most of the working conditions. It does not rely on the use of external controllers to regulate the NP voltage.

Consequently, no controller tuning is needed and it performs optimally for any operating conditions. All in all, the proposed algorithm represents an interesting alternative to regulate the NP voltage in multiphase NPC converters. It achieves optimal trade-off in terms of NP voltage controllability, power losses and efficiency with regards to other modulation methods and exhibits very low computational burden facilitating its implementation in a digital controller.

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