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POWER QUALITY IMPROVEMENT OF RES/HESS INTEGRATIONTO MICROGRID USING FOUR LEG THREE LEVEL NPC INVERTER AND SECOND ORDER SLIDING MODE CONTROL

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***Abstract*— 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 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.**

***Index Terms*— RESS, DG**

I. INTRODUCTION

The conventional power systems such as hydro, thermal, nuclear, gas and large scale solar power stations are centralized and electrical energy need to be transmitted over long distances. As the power is transmitted over long distances, the overall transmission cost and transmission losses increases and the efficiency of the system reduces. Distributed Generation is emerging as an important option for the future development and restructuring of electricity infrastructure. The benefits of Distributed Generation include lower electricity costs, higher flexibility, improved power quality, higher system efficiency and greater reliability. Hence the demand of distributed generation is rising day-by-day.

A. Distributed Generation:

Distributed Generation, defined as a small scale electricity generation, is the generation of electrical energy at the point of utilization.It is also termed as decentralized generation. The distributed generation typically uses renewable energy sources such as small hydro, biomass, solar, wind and

Geo-thermal power and plays a vital role for the electrical distribution systems. The distributed generation involves the deployment of small, modular generator units much closer to the electricity consumers. The generation units can be operated at the point of use with excess sold to the grid, or by generator units dispersed within the local distribution network.

The benefits of Decentralized generation over conventional centralized systems are discussed as follows:

The problem of high peak load shortages can be effectively solved in Distributed Generation.

The losses during transmission and distribution of electrical power are greatly reduced and hence improve the reliability of the grid network.

The distributed generation plays a vital role in providing power to remote and inaccessible areas, for a country like India.

Easy maintenance of power, voltage and frequency and also has the possibility of combining energy storage and management systems.

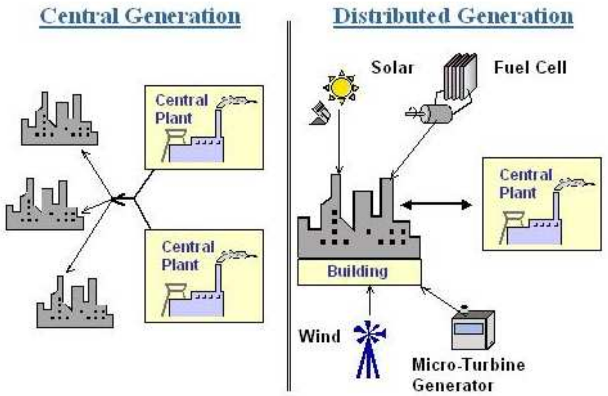


Figure 1.1: Centralized vs. Decentralized Generation

The Centralized and the Decentralized generation is shown in the figure 1.1 above. The distributed generation resources can be interconnected to the same central grid for the sake of reliability, but leads to various technical and economic issues such as power quality, voltage stability, harmonics, reliability, protection and control. Hence the distributed generation is usually connected to the microgrid.

B. Microgrid:

Microgrid is a small scale, weak electrical grid that is able to operate both in connected mode and islanded mode. It is formed by integrating various sources of distributed generation, loads and storage devices. The electrical energy generated is interconnected to the microgrid at low voltages and it can operate in AC, DC or combination of both. A microgrid provides back up for the grid in case of emergencies. A microgrid allows the consumers more energy independent and more environmental friendly. The microgrid is interconnected with different types of energy storage systems to perform multiple functions such as ensuring power quality, frequency and voltage regulation, smoothing the output of renewable energy resources, providing back up power for the system and plays important role in cost optimization.

The microgrid and the renewable energy resources integration may lead to number of operational challenges that are to be addressed in the design of control and protection system. The most significant challenges of microgrid are,

The existing of DG units in the system at low voltages can cause bidirectional power flows that complicate the protection coordination, undesirable power flow patterns, fault current distribution and voltage control.

Interaction of control systems of DG units may create local oscillations.

The microgrid has a low inertia characteristic which leads to severe frequency deviations in stand-alone operation, if a suitable control mechanism is not provided.

The uncertainty in microgrid due to less number of loads and high variations of renewable energy sources.

MicroGrids perform dynamic control over energy sources, enabling autonomous and automatic self-healing operations. During normal or peak usage or at times of the primary power grid failure, a microgrid can operate independently of the larger grid and isolates its generation nodes and power loads from disturbance without affecting the larger grid's integrity. MicroGrids interoperate with existing power systems, information systems, and network infrastructure and are capable of feeding power back to the larger grid during times of grid failure or power outages.

MicroGrids in India:

In Karnataka, the SELCO Solar Light Pvt Ltd is a social enterprise in improving living standards of poor households in rural area. The SELCO foundation has installed solar storage remote DC MicroGrids to provide energy access to Baikampady Mangalore, Neelakantarayanagaddi village, Mendare village and Kalkeri sangeet vidyalaya.

The Indian coast guard operates a microgrid in Andaman island.

C. Hybrid Energy Storage System:

In a traditional electrical power generation system, energy generated has to be utilized immediately, else it will be wasted and leads to economic failure. Further, sporadic Renewable energy such as wind, solar and little of hydro cannot be accumulated in the absence of energy storage systems. The energy storage systems are charged at the time of less energy demand and discharged during the period of high demand from consumers. The Energy storage systems provide load demand services for extended period of time for consumers even when small renewable power generation exists.

The different Energy storage technologies are,

Batteries
Lead Acid Battery
Lithium ion Battery
Nickel cadmium/ Nickel Metal Hydride Battery
Sodium Sulphur Battery
Flow Batteries
Electrochemical Double Layer Capacitors (EDLCs)
Regenerative FCs
Compressed air energy storage (CAES)
Flywheel ESSs
Superconductive Magnetic Energy storage (SMES)
Thermoelectric Energy storage (TEES)

The use of Energy storage systems integrates the limitations such as admissible bandwidth, maximum ratings, current/power maximum gradient, and the number of cycles. If these limitations are not agreed it can lead to a unexpected lifetime reduction of the Energy storage system and leads to its destruction.

The use of Hybrid energy storage system gives the required trade-off for increasing the lifetime of each Energy storage system and also increasing the global specific energy and of the whole system. Hybrid energy storage system is a combination of two energy storage devices with complementary characteristics such as high power density and high energy density.

In our project the hybrid energy storage system is composed of,

A Lithium ion Battery which has high specific power and moderate self-discharge and

A Vanadium Redox Battery (VRB) which has high specific energy and no self-discharge.

D. Power Electronic Converters:

Power electronics mainly deal with efficient conversion, control and conditioning of electric power by static means from its available input form into a desired electrical output from. The electrical power conversion can be realized by power converters built on power semiconductor switching devices and the converters are controlled by control electronics.

Depending on power handling capabilities the converters can be classified as,

High power converters
Medium power converters and
Low power converters

As the power rating increases, to reduce the current rating of the converter, high voltage switching devices have to be used. High voltage switching devices are comparatively costlier and cannot be switched at high frequency. To overcome these problems, several new converter topologies have been used in high voltage applications.

The circuit topologies of converters can be classified into,

Neutral point diode clamped (NPC) converters
Flying capacitor clamped converters and
Cascaded full bridge converters

Neutral point diode clamped and cascaded H-bridge converters are widely used for high power converter applications.

The number of levels in a converter bridge defines the number of voltage steps that are required by the converter bridge in order to achieve a certain voltage level at its output. Because power semiconductor switches have limited voltage capability, the voltage of a converter bridge is divided into number of voltage steps, such that each voltage step can be handled by one power switch.

Depending on voltage levels, converters can be classified as,

Two level converters and

Multi-level converters

The converters with voltage level three or more are referred as multi-level converters. Multilevel converters have been receiving increased attention recently, due to its capability of medium voltage and high power applications. The advantages of multilevel converters are low voltage ratings of power semiconductors, low voltage harmonics and less electromagnetic interference.

The three level Neutral point clamped (3L-NPC) converter is a type of DC-AC power conversion system that uses three DC bus voltage levels. A 3L-NPC converter is considered especially interesting for medium voltage high power applications due to its ability to reduce the voltage ratings of the semiconductor devices to the half in comparison to a typical two level converter. Therefore if the same power conductors are used in the three level and two level converters, the DC bus voltage can be doubled in the three level case, due to the reduction of the voltage applied to each semiconductor device. Assuming that the current is same in both the cases, the power of the three level converters is thus doubled in comparison to the two level converter's case. A 3L-NPC converter has many other advantages in comparison to the two level converter, namely a less distorted AC voltage generation, a reduced dv/dt of the output voltage due to higher amount of DC levels, a smaller DC side current distortion and lower electromagnetic interference. The 3L-NPC converters have been used in large motor drives like conveyers, pumps, fans and mills as well as in back-to-back configurations for regenerative applications like grid interfacing of Renewable energy sources (RES).

II. PROPOSED METHODOLOGY

A. Modeling of HESS:

The HESS is formed of a Li-ion Battery and VRB. The Li-ion battery has advantage of high specific power and moderate self-discharge. The VRB technology has high specific energy and suited for long term storage of energy and no self-discharges. Therefore the use of these two technologies is complementary and achieves a high specific energy and high specific power HESS.

B. Lithium ion Battery:

Lithium ion battery is a type of rechargeable battery, have outstanding applications in both low and high power devices as well as portable electronics and telecommunication gadgets. This battery is highly preferred due to its high energy density and higher efficiency. The anode of this battery is made up of carbon graphite while the cathode consists of lithiated metallic oxide. The electrolyte contains a mixture of lithium salts such as LiBF4, LiClO4 of LiPF6 and organic carbonates ie dimethyl carbonate or diethyl carbonate. In discharging process Li+ ion migrates from negative electrode while carrying current to the positive side with the reverse condition occurring during charging with the following electrochemistry.

Positive electrode half- chemistry

Negative Electrode half-chemistry

Features of Li-ion Battery:

1. Fast charge and discharge ability.
2. High specific energy of 170-300Wh/l and 75-125Wh/Kg
3. Low percentage rate of self-discharge.
4. Availability of different shapes and sizes.
5. Lighter weight with high energy density.
6. High open circuit voltage compared to NiMH, NaS, PbO2 and NaNiCl.
7. Intrinsically secure from environmental perspective due to the absence of free Lithium metal.

Drawbacks:

1. High production cost.

C. Modelling of VRB:

The VRB model to be implemented in SIMULINK is based on the following properties,

The state of charge , which represents the amount of active chemicals in the system, is modeled as a variable that is dynamically updated.

The stack voltage is modeled as a controlled voltage source. The power flow through this source impacts the changes in the SOC .

The variable pump losses are modeled as a controlled current source.

The internal resistances $R_{Reaction}$ and $R_{Resistive}$ account for the losses due to reaction kinetics, mass transport resistance, membrane resistance, solution resistance, electrode resistance and bipolar plate resistance. The parasitic resistance ie $R_{fixed\ losses}$ and the pump losses current ie $I_{pump\ losses}$ account for power consumption by the recirculation pump, the system controller and the power loss from cell stack by-pass currents. The model also accounts for system energy content and transient responses. The model is shown in the figure 4.5 below

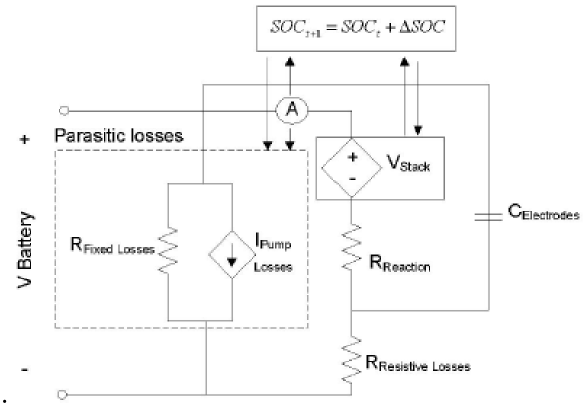


Figure 2.1: VRB simple model

III. Modulation Strategy

A. *Pulse width Modulation (PWM) Strategy:*

Several modulation techniques are used to generate the pulses to control the switches of the inverter. The Carrier Based Sinusoidal pulse width modulation (CB-SPWM) technique has been widely used for multilevel converters as the number of phase's increases. The CB-PWM is less complex and easier to expand to converters with multiple phases and requires less computing time. As there is a neutral point voltage balancing problem in 3 leg NPC converters, the introduction of fourth leg in three phase NPC converters along with CB-PWM technique will regulate the neutral point voltage of the inverter.

In this project as the NPC inverter is a 3level inverter it requires two carrier signals. The modulating signal is compared with the carrier signals to generate the duty pulses of the switches of the inverter. The figure 4.7 below shows two carrier signals with switching frequencies f_s and $f_s/2$, superimposed with the modulating signal whose frequency is 50Hz and is of sinusoidal. This modulating signal is the error signal obtained after the control action of three phase output voltages and currents of the inverter. In the CB-PWM technique, if the magnitude of the modulating signal is greater than the magnitude of the carrier wave ,then the pulse is generated and the switch is turned ON otherwise the switch will be in the OFF state.

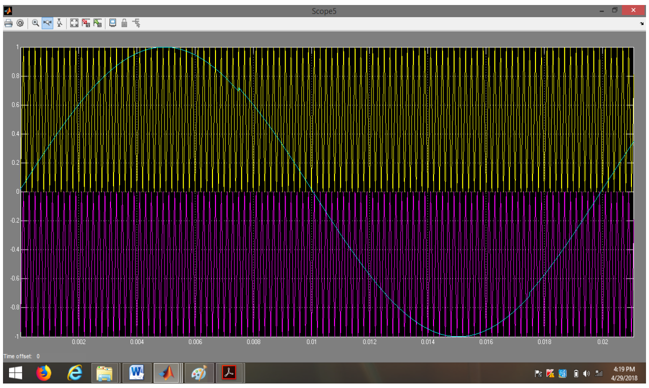


Figure 3.1: CB-PWM technique for the 4 leg 3L NPC inverter.

B. *Block diagram of the controller:*

The block diagram of the control strategy on the Ac side of the inverter is shown in the figure 5.2 below.

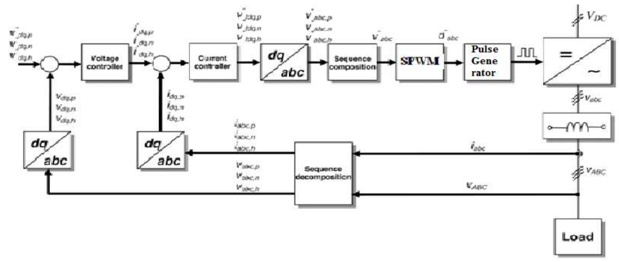
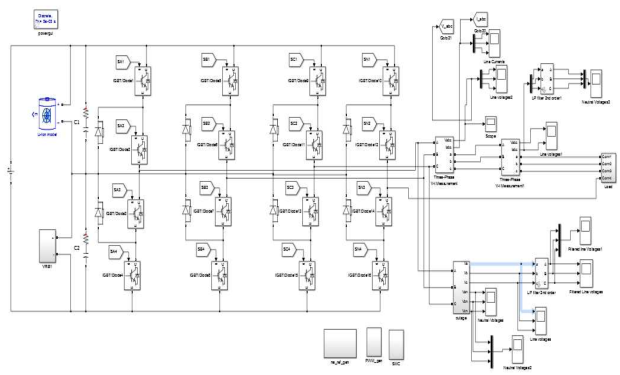


Figure 3.2: Block diagram of the controller

In the controller the three phase output voltages and currents of the inverter are decomposed into positive, negative and zero sequence components. Further they are transformed into dq0 components in the rotating reference frame using park's transformation. The dq0 components of both voltage and current are regulated using PI controllers which are further composed into abc coordinates using inverse park's transformation generating the modulating signal. The control pulses to the inverter switches are generated using carrier based sinusoidal pulse width modulation technique to generate the balanced sinusoidal output voltage even for unbalanced loads.

IV. RESULTS

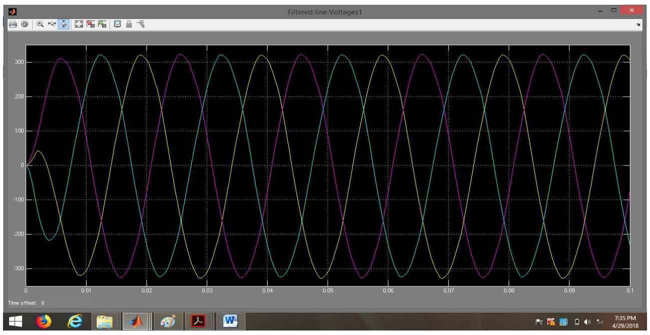


4.1 Simulation circuit of 4 leg 3 Level NPC inverter interfacing RES/HESS to microgrid

The figure 4.1 below shows the main simulation circuit of 4leg 3level NPC inverter used as an interface for the RES/HESS integration to microgrid. The HESS is composed of Li-ion battery and Vanadium Redox battery (VRB). The DC input to the inverter is 440V. The Low Pass (LP) second order filter is used to obtain the sinusoidal voltage and current waveforms.

V. Results for different unbalanced load conditions

Case 1: For unbalanced three phase resistive load of 5kw, 10kw and 20kw in the three phases respectively, the three phase output voltage and current waveforms are shown in the figures6.18 and 6.19 below.



5.1 Three phase output voltage waveform of unbalanced resistive load.

Case 2: For unbalanced three phase RL load of 5kw and 200var in phase A , 10Kw and 400var in phase B and 20kw and 600var in phase C, the three phase output voltage and current waveforms are shown in the figures 6.20 and 6.21 below. It is observed that the three phase output voltage is balanced with constant voltage of 320V and the three phase output current has different magnitudes in all three phases.

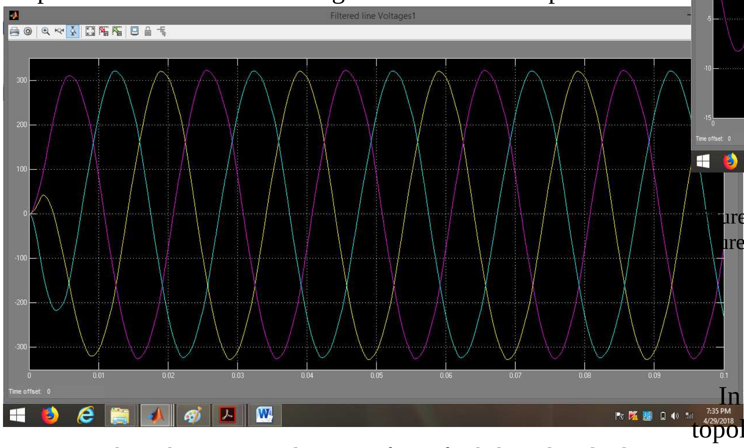


Figure 5.2: Three phase output voltage waveform of unbalanced RL load.

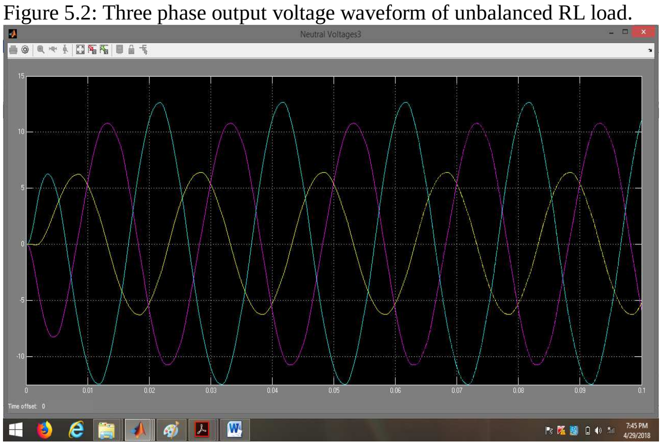


Figure 5.3: Three phase output current waveform of unbalanced RL load.

Case 3: For unbalanced three phase load of RL load in Phase A of 5kw and 200var, R load in Phase B of 10Kw and RC load in Phase C of 20kw and 400var,the three phase output voltage and current waveforms are shown in the figures 6.22 and 6.23 below. It is observed that the three phase output voltage is balanced with constant voltage of 320V and the three phase output current has different magnitudes of current in all the three phases.

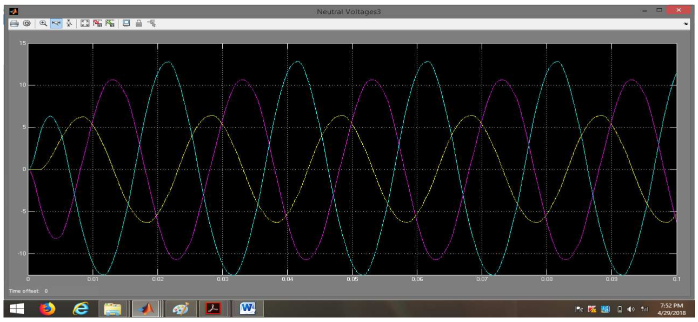
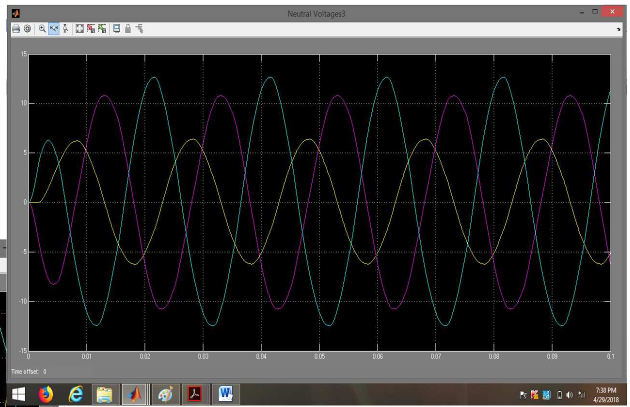


Figure 5.4: Three phase output current waveform of unbalanced and different nature of load in all three phases.



ure 5.5 Three phase output current waveform of unbalanced and different
ure of load in all three phases.

VI. CONCLUSION

In this project 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. The output of the 4 leg 3Level NPC inverter is controlled based on the decomposition of the supply three phase voltage and current into instantaneous positive, negative and zero sequence components using phasor representation. The regulation of three phase unbalanced output voltage and current has been done using classical PI controllers. The duty cycles are generated by using carrier based Sinusoidal Pulse Width Modulation technique. The Simulation results of the three phase output voltage and current are observed for different cases of unbalanced load conditions.

Case 1 : Pure resistive unbalanced load in all the three phases.

Case 2: Unbalanced RL load in all the three phases.

Case 3: Different nature of load in the three phases i.e. RL load in phase A, Pure resistive load in Phase B, RC load in phase C.

It is observed that for all the above cases the three output voltage is sinusoidal, balanced constant amplitude of 320V. The three phase output waveforms are also sinusoidal but their magnitude and phase angle wrt to the voltage depends on the magnitude and nature of load connected. Hence it concludes that the control strategy improves the power quality of the RES/HESS integration to microgrid.

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