Study and simulation of four leg three level NPC inverter for power quality improvement using second order sliding mode

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Abstract: **Theoretical Performance of a bearer based pulsewidth adjustment (SPWM) technique can be enhanced by the consideration of a zero sequence voltage in the regulation reference signal. This paper proposes another PWM procedure for a three-level neutral point- clamped (NPC) converter, which depends on a zero-sequence voltage infusion. By consideration of the zero-sequence voltage, the sinusoidal-balance reference is altered to 1) do the voltage-adjusting assignment of the - link capacitors, with no extra control exertion, 2) decrease the exchanging losses , and 3) diminish the low frequency voltage motions of the unbiased point. Compared with the existing CB-PWM strategies, the proposed strategy offers 1) capability to balance the capacitor voltages and reduce the NP voltage oscillations and 2) reduced switching losses. Performance of the proposed CB-PWM strategy for a three-level NPC converter based on time-domain simulation studies in the /SIMULINK environment is evaluated and also experimentally verified.**

Index Terms **- SPWM, NPC-neutral point clamped, carrier based PWM technique, zero sequence voltage, Renewable Energy (RE), Hybrid energy storage system (HSS), Hybrid power system (HPS).**

I. INTRODUCTION

Efficiency is becoming increasingly important in power electronics. Many applications are driven by the initiatives for reduced energy consumption. The technology leaders are inverter applications in the solar market, but interruptible power supplies and motor drives also have new targets for improved efficiency.

The proposed electric power area is looking forward in expanding the twisted for accessibility, dependability and security of vitality supply to customers. This interest has energetically expanded the expectation for incorporating sustainable power source (RE) into the power division as a methodology to control the issue of vitality inadequacy particularly in separated off-network settlements [1], Notwithstanding, the changeability in the wellsprings of RE supply combined with restrictive changes in the level of vitality utilization as for time has conveyed to center the need for vitality stockpiling frameworks (ESSs)[2]-[3]. Notwithstanding the stochastic idea of RE delivered from sun oriented and wind vitality and to some degree hydro, enthusiasm for their abuse is as yet developing high because of their manageability with respect to natural openness. Along these lines, this paper widely audits the best in class of three various types of vitality stockpiling advances (pumped hydroelectricity stockpiling, batteries and energy units) reasonable for the mix and administration of discontinuity in RE[4]-[5]. Inside the setting of the audit, focal points and burdens of the different innovations are likewise exhibited. Furthermore, it additionally focuses on the diverse zones of uses of ESSs for RE mix and offers survey rundown on variables to be considered for choosing suitable vitality stockpiling innovation for either business or residential applications[6]. Unique consideration is given to the diverse applications, giving a profound portrayal of the framework and tending to the most reasonable stockpiling innovation. The main obstacles of the ensure a maximum power division between the two ESS and to address the unbalanced load issue, and thus enable active power filter capabilities. To design a non-linear 2-SMC scheme to control the zero sequence injection in the modulating signals in order to control the power flow of the HESS [7]-[8].

The main objectives of the paper are ESSs and 4-Leg 3L –NPC inverter are modelled. The design and tuning process of a Second Order Sliding Mode Controller (2-SMC) and a PI classical scheme are developed for the DC power flow control. The AC side control which allows working in unbalance load conditions. To prove the effectiveness of the topology and the ability of the 2-SMC to control the HESS power flow in various conditions.

II. SYSTEM DESCRIPTICTION

The multilevel converters have attracted significant interest for medium- and high-power/voltage applications. Among various well-known multilevel converter configurations, i.e., the neutral-point clamped (NPC), flying capacitor, and cascaded H-bridge, the three-level NPC converter has been widely accepted and investigated for various applications .

Modelling of the 4-Leg 3L-NPC and Control

Several pulsewidth modulation (PWM) strategies have been proposed and extensively investigated for the three level NPC converter to achieve the following main objectives: 1) to carry out the voltage-balancing task of the dc-link capacitors which is the main technical challenge of the NPC converter; 2) to eliminate the low-frequency oscillations of the neutralpoint (NP) voltage, which appear under certain operating conditions and if not mitigated, impose stress on the converter components. The proposed PWM strategies for a three-level NPC converter are mainly classified into the carrier-based PWM (CB-PWM) and the space-vector modulation (SVM) strategies. The CB-PWM strategies are mostly based on pure sinusoidal PWM (SPWM) or a SPWM strategy in conjunction with a zero-sequence voltage injection . Compared with the SPWM strategy, inclusion of a zero-sequence voltage extends the linear-modulation range of the converter. The existing CB-PWM strategies do not provide natural voltage balancing; therefore, additional control effort is required to achieve the voltage balancing. The additional control effort imposes relatively high-switching frequencies in the switching devices and also distorts the ac-side voltage spectra [2]. In the technical literature, a CB-PWM strategy with a proper zerosequence voltage that:

1) autonomously carries out the voltage balancing task, with no requirement for additional control effort;

2) reduces the switching frequency; and

3) mitigates the low-frequency voltage oscillations of the NPC, has been neither proposed nor investigated. This paper proposes a CB-PWM strategy for a three-level NPC converter with a zero-sequence voltage injection. The proposed strategy explores and exploits the duality between the nearest three-vector (NTV)-SVM strategy and the CB-PWM strategy with a zero-sequence voltage injection to:

1)Achieve voltage-balancing task;

2)Reduce the switching frequency and consequently switching losses; and

3) Mitigate the voltage oscillations of the NP. A theoretical basis for the proposed CB-PWM Strategy is developed based on the analysis of the PWM Strategy.

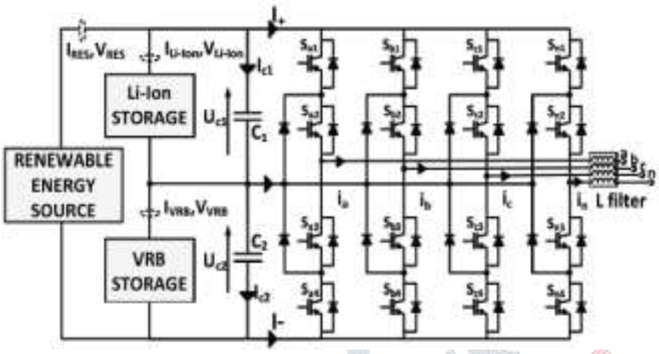

Fig 2.1 Structure of Three level four leg NPC inverter

Fig 2.1 shows the structure of three level four leg NPC inverter, To control independently the phase voltage in a four-wire system,an obvious solution is to use a regulation technique based on an inner current loop and an outer voltage loop with PI regulators in dq0 reference frame rotating at the system fundamental angular frequency ω[8]. Additional control loops for the 0-sequence current and voltage must be implemented to ensure the output voltage balance when the load is unbalanced. If the load is unbalanced, the d-, q-, and 0-component of the output voltages contain additional oscillating quantities. The dq-channels are affected by 2ω voltage and current ripples, and the 0-channel is similarly affected by the oscillations at ω. As a result, the PI regulators will only cause a phase shift and will not be able to cancel the error completely. The additional oscillation in the dq0-channels appears because unbalanced loads create both negative and zero-sequence distortions in three-phase, four-wire systems .

An unconventional control technique based on synchronous frame controllers has been proposed in [1] to eliminate positive- and negative-sequence distortions. An additionally stationary frame controller is employed to attenuate zero-sequence distortion due to nonzero neutral currents. This control strategy seems to achieve good level of performance but it has been tested only in simulation and during a permanent load unbalance. This paper proposes fully digital voltage and current controllers for a four-leg inverter allowing simultaneous balanced voltage supply of three-phase and single-phase ac loads in an HPS application. The controllers are implemented in two differentreference frames rotating at fundamental frequency after the decomposition of the inverter ac voltage and current into positive, negative, and homopolar sequence components. The positive and negative sequences decomposition is often used in three-phase, three-leg converters control strategies for load compensation and sinusoidal currents generation under unbalancevoltage disturbances, or voltage dips mitigation [6]. The strategy presented in this paper has the ability to decompose and to control into *dq* quantities not only the positive and negative current and voltage sequences but also the homopolar sequence. The attention focuses on the transient operation of the improved control strategy.

III. CONTROL STRATEGY WITH SECOND ORDER SLIDING MODE

The sliding mode (SM) and, more recently, the high-order SM (HOSM) control have emerged to be traditionally used in handling bounded perturbations (understood as the ensemble of external disturbances and unmodeled dynamics).

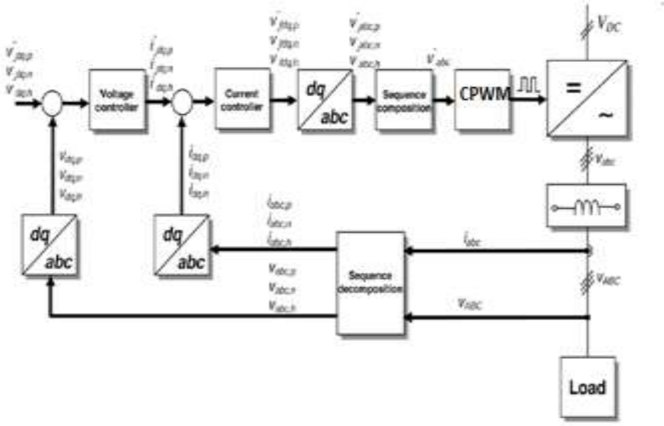

Fig 3.1 Control strategy with Second order sliding mode Block diagram

Fig 3.1 shows control strategy with second order sliding mode. Sliding mode control (SMC) is a nonlinear control technique featuring remarkable properties of accuracy, robustness, and easy tuning and implementation. SMS systems are designed to drive the system states onto a particular surface in the state space, named sliding surface. Once the sliding surface is reached, sliding mode control keeps the states on the close neighbourhood of the sliding surface. Hence the sliding mode control is a two part controller design. The first part involves the design of a sliding surface so that the sliding motion satisfies design specifications. The second is concerned with the selection of a control law that will make the switching surface attractive to the system state [1]. There are two main advantages of sliding mode control. First is that the dynamic behaviour of the system may be tailored by the particular choice of the sliding function. Secondly, the closed loop response becomes totally insensitive to some particular uncertainties. This principle extends to model parameter uncertainties, disturbance and nonlinearity that are bounded. From a practical point of view SMC allows for controlling nonlinear processes subject to external disturbances and heavy model uncertainties.

A.Non linear SISO system

A simple description Consider the nonlinear SISO system

Consider the non linear SISO system

x=f(x,t)+g(x,t)u (1)

y=h(x,t) (2)

x=R

where y and u denote the scalar output and input variable , and

denotes the state vector. The control aim is to make the output variable y to track a desired profile yDES, that is, it is required that the output error variable e=y-yDES tends to some small vicinity of zero after a transient of acceptable duration. As mentioned, SMC synthesis entails two phases

PHASE 1 (“SLIDING SURFACE DESIGN”)

PHASE 2 (“CONTROL INPUT DESIGN ”)

$x \in R^n$ The first phase is the definition of a certain scalar function of the system state, says

σ(x): Rn → R

Often, the sliding surface depends on the tracking error e_y together with a certain number of its derivatives . σ shows the derivative of this function.

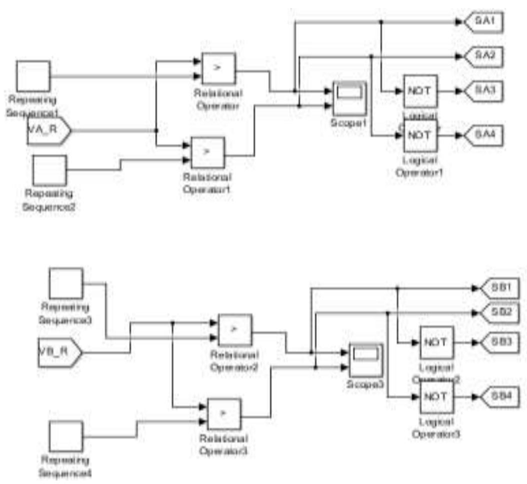

Fig 3.2 SPWM technique applied for the all four legs

Fig 3.2 shows SPWM technique has been applied for getting pulses for each switches for four leg NPC .The VA_R is compared with carrier waves to get pulse for each switch of each leg of NPC.

IV. PERFORMANCE EVALUATION

To assess and verify the effects of the NPC Inverter on the microgrid, a simulation model in Fig.2.1 is built in MATLAB, and simulation parameter listed in Table 4.1.

Table 4.1 Load values given for all four lines with two conditions

For balanced load	For unbalanced load
5e3	5e3
5e3	0.1e3
5e3	1e3
5e3	1e3

Table 4.1 shows the load values applied for each line for Phase load 5e3, for y phase 5e3 KW and b phase also 5e3 and neutral phase 5e3KW.

The unbalance load conditions are for the r phase 5e3, for y phase 0.1e3KW, b phase 1e3 and neutral phase 1e3 is applied.

A. Simulation results

The simulations have been carried out for an inverter rated power of 5kW using MATLAB/Simulink and the Sim PowerSystems library. Simulations are conducted with a 70% initial SOC on both ESSs resulting in an open circuit voltage of approximately 720V for the Li-Ion ESS and 470V for the VRB ESS resulting in a degree of voltage unbalance index A1=1.25 (and thus A2=0.75). The simulation results are shown below.

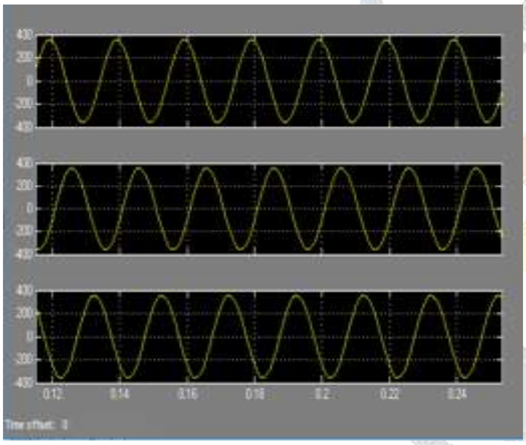

Fig 4.1 Balanced output voltage obtained at load

Fig 4.1 shows that inspite of unbalanced load conditions on the load, the balanced output is achieved at the output. This is due to second order sliding mode control.

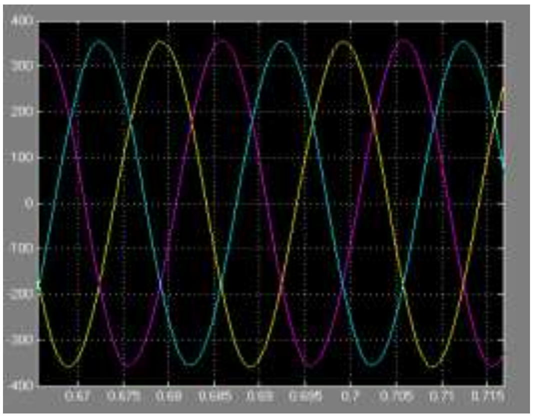

Fig 4.2 Neutral voltage for unbalanced load conditions

Fig 4.2 shows the Neutral voltages for the unbalanced load conditions. The negative-sequence current (id,n,iq,n) the second channel of the control structure is controlled by PI controllers in the negative rotating reference frame.

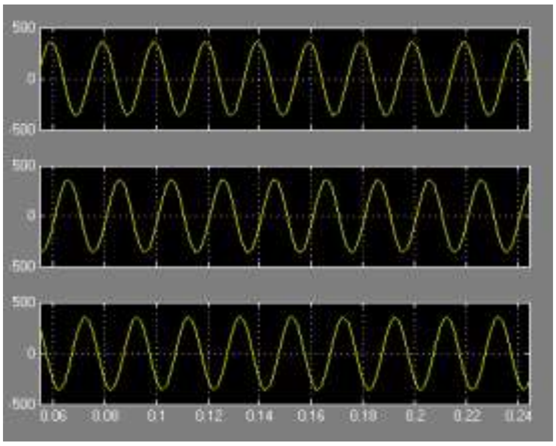

Fig 4.3 Output line voltages for balanced load conditions

Fig 4.3 shows the output for balanced load conditions. The big advantage of this control strategy is its ability to control separately the positive, negative, and homopolar sequences.

The 2-SMC scheme allows a significant improvement of the current harmonics suppression compared to the PI control. Also, the better result of the VRB harmonic suppression compared to the Li-Ion one are due to the fact that only the Venidian Redox Battery(VRB) current is controlled through zero sequence injection. It could be possible to reduce these harmonics even more using a smaller settling time, but the AC side harmonics would increase as a consequence.

IV. RESULTS AND DISCUSSION

In this paper, transient operation of a four-leg inverter under unbalanced load conditions for HPS applications have been investigated. The four-leg inverter is controlled using an innovative control strategy based on the decomposition of the three phase supply voltage and current into instantaneous positive, negative, and zero sequence components using phasor representation. The proposed control strategy has the ability to decompose into *dq DC* quantities not only the positive and negative current and voltage sequences, but also the Zero sequence. The eight duty cycles driving the four legs of the investigated inverter are correctly generated due to a PWM based on *ABC* coordinates. The performance of the proposed control strategy has been confirmed in transient operating conditions as well as in steady-state operations by using both simulations.

V. ACKNOWLEDGMENT

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