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Simulation Study of Power Balancing Technique for Electric Vehicles

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ABSTRACT: The lack of fossil fuels and environmental point of view, the conventional combustion engine vehicles are replaced by electric vehicles on the fourth coming century . The Electric vehicle run by charging and discharging of the power from batteries. Depending on the size/capacity of the vehicle number of batteries and their ampere hours are to be decided. The batteries are built with the number of cells as per the requirement of the vehicle. In electric vehicle there is a need of power balancing among the cells of the batteries. In this paper a study is made in order to implement power balancing technique using simulation method. One of the techniques is Neutral Point Clamped withmulti-level inverters for the electric vehicles is simulated and results are analysed. From the results and analysis, the important conclusions are drawn in terms of voltage balance, current balance and power balance using NPC-MLI Technique under balanced and unbalanced condition.

KEYWORDS: Electric vehicle, NPC-MLI, Power Balancing, Modulation Index (MI).

I.INTRODUCTION

Electric vehicles are the zero emission vehicles andthey are environment friendly because they don't pollute like the other internal combustion engines which produce a lot of pollution to the atmosphere. The electric vehicle's store the energy in the capacitor or battery. Electric Vehicles are the alternate fuel automobiles that uses electric motors and motor controllers for propulsion. As per the History of electric vehicle, the first electric vehicle was developed in Hungary at 1828. Then later the first practical electric vehicle was built in America at 1835. Similarly, France developed an electric car with a rechargeable lead-acid storage battery at 1859. Like this the development of electric vehicle in different scenarios and aspects is still going on all around the world for the better transportability and better environment. With the problem of environmental pollution and fossil energy shortage becoming increasingly serious, the development space of traditional fuel vehicles is getting smaller and smaller because of the waste of energy and environment pollution. As the representative of new energy vehicles electric vehicles have obvious advantages in environmental protection, energy saving, emission-reduction and so on.

The battery management systems and distributed battery cells are being developed by the new energizer strategy in the electric vehicle industry. The three-phase neutral point clamped multi-level inverter is connected to the high voltage DC current source followed by the series connected capacitors and battery bank formed by the series parallel batteries as shown in Fig.1.[1][2]. This layout looks easy in the execution and it is not perfect for the battery balancing aspect. The auxiliary battery balancing circuits are implemented to synchronize the battery charging and discharging cycle due to the different state of charge (SoC) of each battery.

In an EV, the preferable way to arrange the batteries is by dividing them into three blocks, each of them is connected to a separate phase Fig 2. To suggest a new format of power management. So, it is up to the NPC-MLI phase leg to adjust the charging and discharging cycles for the batteries connected to it without the need of auxiliary circuits. However, this design tolerates from a major disadvantage due to the difference in between the total voltage of each battery set in each phase leg even with the type of MLI. This leads to unbalance charging and battery life will be decreased [3].

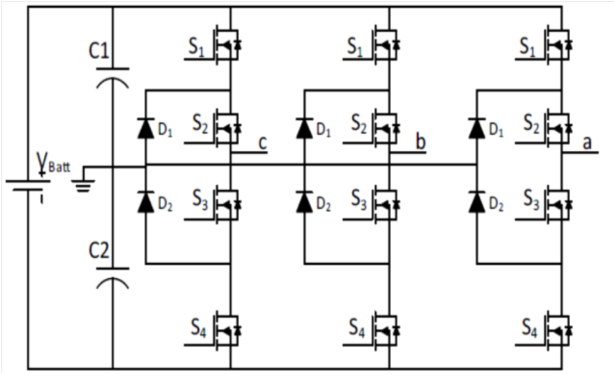

Figure 1: NPC-MLI with individual battery set layout

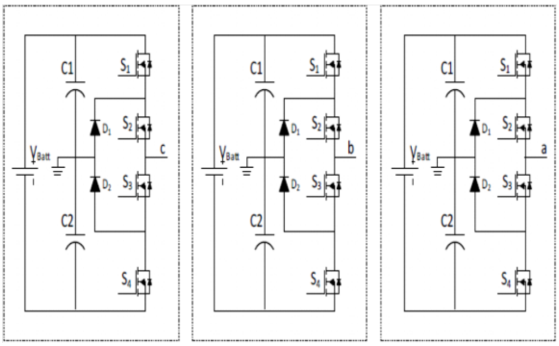

Figure 2: NPC-MLI with distributed battery set design

The three-phase alternating current is drawn from the rotating frame (dq0/abc) which formed by the balanced reference tuned signal from the drive control loop. This results in the imbalance output voltage/current at the machine side. The implementation of phase imbalance technique is used to adjust the modulating three phase sinusoidal signal. It adjusts the fine-tuned signal for each phase as a result of difference in the DC voltage of each phase.

II.POWER BALANCE TECHNIQUE

A three level NPC-MLI topology is depicted in Figure 2.1. The structure comprises of one dc source Vdc, two dc-link capacitors C1 and C2 and twelve semiconductor switching devices. (S1A-S4C) and six clamping diodes (D1A–D2C). The dc bus voltage (Vdc) is distributed on the two capacitors, and their respective voltages are noted as VC1 and VC2 (normally VC1 = −VC2 = Vdc /2). Therefore, the output voltages between any one phase (A, B, or C) and the midpoint of the dc-bus capacitors (N) (VAO, VBO, or VCO) can either be −Vdc /2, 0, or + Vdc /2 according to the configuration of the switches.

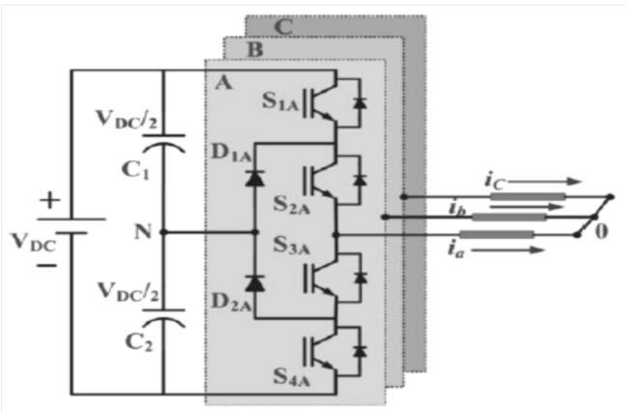

Figure 2.1: Three Level Neutral-Point Clamped Technology

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2.1 **Basic Operation of the Three-Level NPC Inverter**

A three-level NPC-MLI is shown in Figure 4.3 The three legs of the inverter share a common dc bus, which is divided by the two capacitors into three levels. The voltage stress across each switching device is limited to Vdc/2 through the clamping diodes and the voltage across each capacitor is Vdc/2. The operation of the switching is explained as follows: State 1 means the switch is ON, and 0 means the switch is OFF. Each phase has two complementary switch pairs such that turning on one of the switches needs the other switch should be turned off.

The output of the rotating frame of the machine dqo/abc has been employed in the three-phase AC drive control loop of the gating signal generator. It is primarily revised by the phase difference compensator which is proportional to the voltage difference of each phase. Then the final result of the periodic waveform signal carrier is connected to the gating signal generator to regulate the NPC-MLI power switches. The voltage difference is first weighted as follows

$$\eta = (V_{dc,av}) \,/\, V_{det}$$

where Vdet is the DC voltage level of each phase,

t=(a,b,c) and Vdc,av is the average DC voltage of overall batteries in all phases

The phase imbalance correcting value do isthen calculated as follows:

$$d_o = 0.3(\min(r_a,r_b,r_c) - \max(r_a,r_b,r_c))$$

where ,d_j is the primary modulating signal of each generated by rotating frame (dqo/abc).Then the new modulating signal d_j is revised to d_j' as follows:

$$d_j' = d_j(1 \pm d_o)$$

To meet the desired values of the output voltage and as well as current of the overall modulation index, the motor controller is employed to decrease or increase the original modulation signal. Then the phase imbalance factor is either increases or decreases the modulation index of each phase of NPC-MLI depend of its deviation from the average value.

The below figure 2.2 depicts the complete block diagram of the overall system. Individual component of the overall multi-level inverter's independently operating parallel fed circuits are exhibited. Furthermore, a modification of control loop is also shown with the methodology of changing the modulation signal index by adding the power imbalance signal measured from power circuit at the input stage of front end of the multi-level inverter.

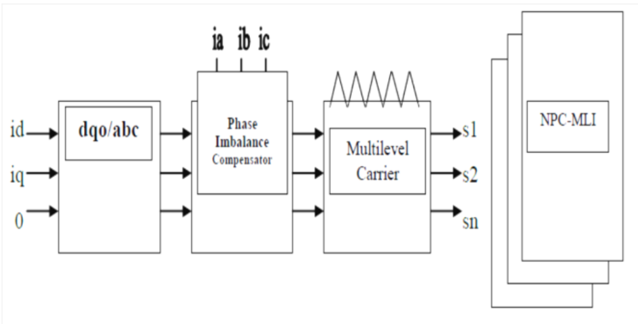

Figure 2.2: Block Diagram of the phase imbalance compensator within system control loop

The earlier recommended phase imbalance technique depends on the voltage of the input DC connected to each phase. Consequently, it requires a greater number of voltage sensors and that hikes the overall system cost. Though the motor constitutes a balanced impedance which allow to detect the voltage imbalance in terms of the motor phase current ij. In balanced input DC voltage, the balanced modulating signal that generated by the rotating frame (dq0/ABC) generates a balanced output current to each motor phase. On the other hand, imbalance input DC voltage will result in imbalance output current in each phase with regard to the balanced reference of the rotating frame. Hence, the phase current carries the imbalance factor among the phases which allows to eliminate the need for added voltage sensors

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III.SIMULATION MODEL AND RESULTS

The simulation model is established using the MATLAB/Simulink to verify the validity of the phase imbalance technique recommended in this paper. The figure shows the value of the DC Voltage of each battery set connected to each phase of 3 level NPC-MLI. The whole simulation process in shown in the below figure.3.1.

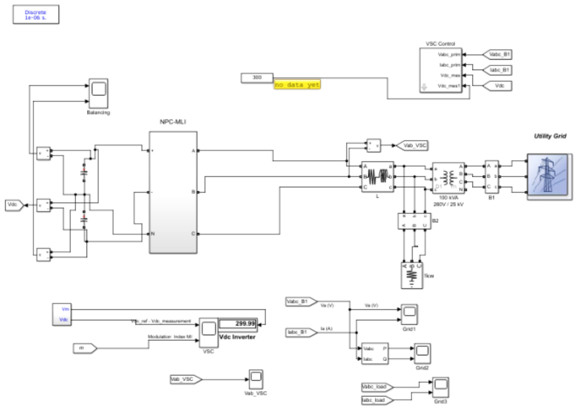

Figure 3.1: Simulation Model of 3 Level NPC-MLI

The above figure shows the overall system setup. The utility grid consists of 5, 14 km feeders with 2 MW load and 30 MW load respectively to provide the same effect of transferring the power to the respective KMs and it is shown in the above figure. The VSC Controller is employed to balance the power when the imbalance had been occurred in the load end. The VSC controller block is as shown in the below figure 3.1

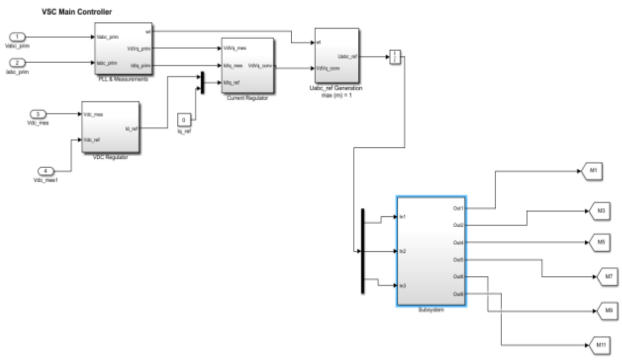

Figure 3.2: Voltage Source Controller Block

In order to validate the efficiency of the described control systems as described, simulations have been carried out in MATLAB®/Simulink. The results from the simulation are presented and discussed. Simulations have been carried out in only one phase due to the controller in each phase is independent. The ratings used for the simulations are not large-scale converter ratings and they are not a target application for a Modular Multilevel Converter. In order to have a good overview of the gain's orders of magnitude in the experimental verification, simulations parameter was chosen accordingly.

The Balanced Condition:

The voltage reference Vref for the steady state operation was set to 300V, which corresponds to the modulation index of 0.7. Table shows the parameters that were used in the simulations,

Rated Power =10kW, Frequency=50Hz,Vdc = 300V

The performance of the proposed NPC-MLI has simulated and reviewed. The simulation model is constructed using MATLAB/Simulink to confirm the phase imbalance technique discussed/initiated in this paper. The Fig.1 shows the value of the DC Voltage of each battery set connected to each phase of three level NPC-MLI. It shows the voltage balance in each phase is exactly half of the supplied voltage.

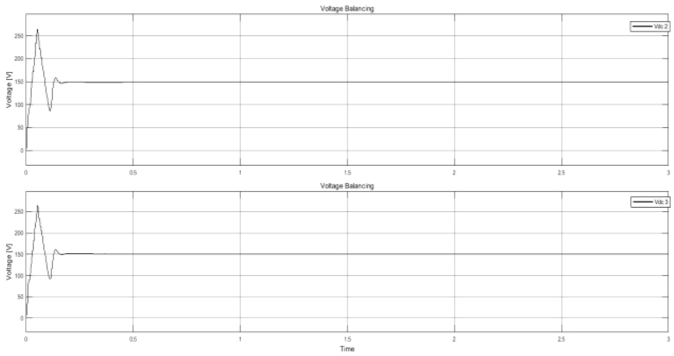

Figure 3.3: Voltage Balancing

For the DC voltage value Vdc = 300V, the balancing of the voltage in each battery set is exactly half of the supplied voltage i.e.Vdc1=150V, Vdc2=150V. This can be seen in the Figure 3.3. The voltage magnitude is exactly 150V and the corresponding phase is 0. Similarly, the other magnitude & phases also perform the same value. The time period t=0.28sec for the voltage of the battery set connected in the phase-a to phase-b changes without operating the phase imbalance compensation, it means it won't damage the whole configuration which is operating in changing the phases.

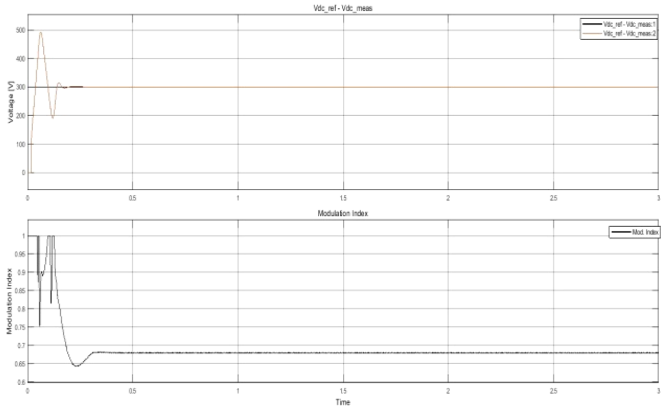

Figure3.4: Voltage Reference Value and Measured Value, Modulation Index - MI

In Figure3.4 the VdcRef and VdcMeas of the voltage source converter.The given VdcRef = 300V and the VdcMeas = 300V, the phase is zero for the DC Voltage and Magnitude is 300V respectively. So, the reference and the measured voltage is same for the time period t=0.28sec, the measured value will take the time period of 0.28sec for matching with the magnitude of the DC voltage. Then the Modulation index [MI], it is the ratio of the fundamental component amplitude of the line-to-neutral inverter output voltage to one half of the available DC bus voltage. In this simulation the MI is calculated for one phase, that means when the Vdc voltage is found balancing with the employed batteries. The MI is always less than 1(<1)., in this simulation the Vdc = 300V and with respect to this value the MI=0.68 and the time period for this value is t=0.28sec that can be observed in the figure. The before and after values of the step change in the battery voltage, when the phase imbalance compensator is bypassed, the reference value of Vdc and Vmeas are measured to 150V, the phases for Vmea and MI is completely 0.

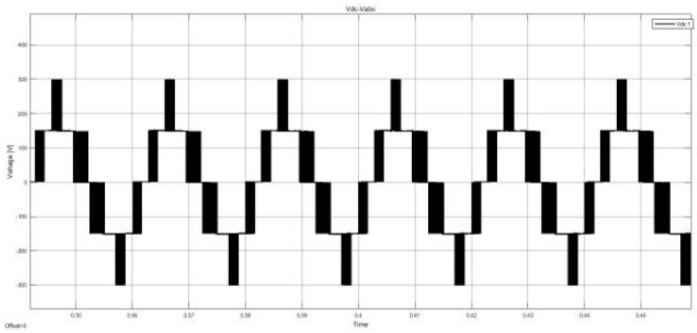

Figure 3.5 Vdc value of the 300V.

The Voltage Source Converter [V_{ab},V_{bc},V_{ca}] and [I_{ab}, I_{bc}, I_{ca}] are the three phase voltages and currents. The magnitude of the $V_{ab}$of the VSC in the step wave V_{dc}=300V, and the phase of the voltage is measured 180°. Similarly,V_{ba},V_{ca}assumed. The currents will be Zero in phase and magnitude. The phase and line voltages of each phase of NPC-MLI. It shows the effect of the change of the modulating signal to restore the phase imbalance.

The instantaneous voltage [V_{abc}] and currents [I_{abc}] values which are flowing from the utility grid, shows the phase angle of 180° for time period of t=0.19s and the magnitude is equal to zero for the one phase of the three phases. The current and the phase angle is switching frequently on and off, then the magnitude results zero. Figure 3.6 and 3.7 shows the Load voltage V_{Labc} and current $I_{Labc}$of the 10kW rated power, magnitude of the voltage gives the result of 100V for Vdc=300V. The phase angle is maintained at 180° for all the three phases. Similarly, the I_{Labc}current measures the value 60A for the specified V_{dc} voltage. These values are verified for the Balanced State of the voltages for each different set which are operating at three phase grids

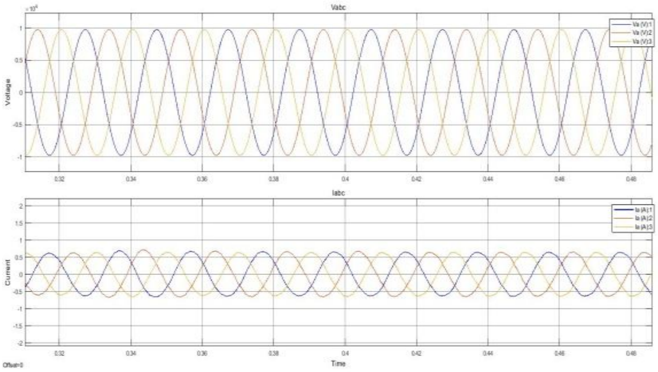

Figure 3.6:Voltage& current values of the V_{abc}

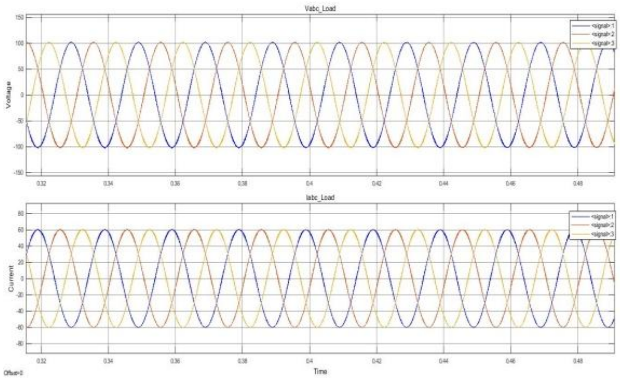

Figure 3.7:Load Voltage and Current V_{Labc} , I_{Labc}

The Unbalanced Condition:

The unbalanced Condition can be observed by changing the value of the Vdc = 170 for the Power 10kW, when we simulate these values in the MATLAB/Simulink, the results did not balance the voltages in each phase of the batteries. Instead they reached the value of 100V in each phase without balancing for 85V. The time period for the unbalancing condition is t=0.3 for the steady state value. This can be clearly seen in the Figure3.8.

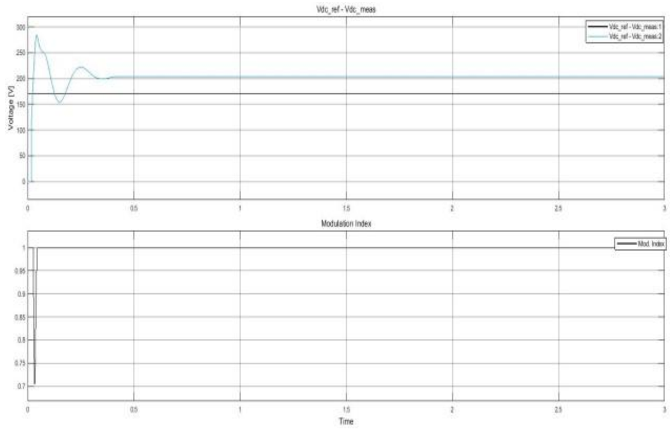

Figure 3.9: V_{dcref} value and V_{dcmeas} values of the DC voltage and Modulation Index [MI

The figure3.9 will be displaying the measured values of the unbalanced battery phase voltages. The given value Vdc=170V and the measured value is Vdc=200V, and the modulation index is MI=1, this states that the phase voltages have failed to balance the given DC voltage.

The phase and magnitude values of Va, Vb, Vc of voltages and Ia, Ib, Ic currents with the same values of the rated power 10kW and the phase angle is 180° can be seen. Similarly, the currents of all the phases is resulted in 0.6A and less current is flowing when we compared to the balancing of voltages with a power loss of 4kW.

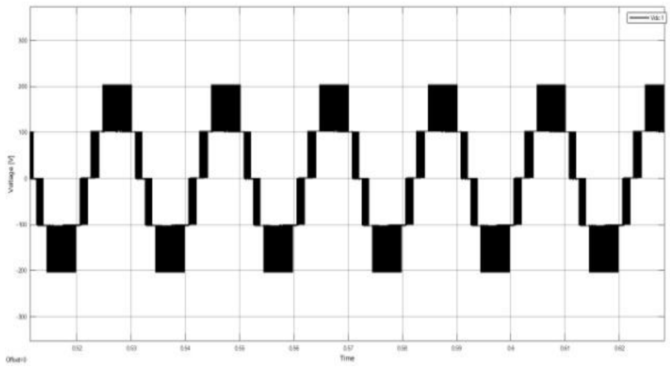

Figure 3.10: V_{dc} voltage V_{dc} =170V but showing V_{dc} = 200V in unbalanced condition

IV.CONCLUSION

In this paper, an attempt has been made to implement Neutral Point Clamping with Multi Level Inverter in the Electric Vehicle for power balancing requirement. The Neutral Point Clamped with Multi level Inverter technique is simulated using the simulation package for the study of power source of the vehicle. The obtained results from the simulation study are analysed in terms of power balance and imbalance along with modulation index. Based on the analysis the following specific conclusions are drawn.

- For the balanced condition, the reference value of power source is set to 300V, the voltage is supplied from the battery is 300V with the current supply of 60A, with a current output of 9kW with a loss of power about 1kW. The modulation index is 0.68.
- For the unbalanced condition, the reference value of the power source is set to 170V, the voltage supplied from the battery is 170V with the current supply of 60A with a power output of 6kW and with a loss of 4kW. The Modulation Index is 1. (very high)
- By Implementing the Neutral Point Clamped technique, the vehicle is made to run under the power balanced condition only.
- By the implementation of NPC-MLI technique the charging and discharging cycle of the battery are improved which in turn enhances the life of the batteries.
- The electric vehicle can be analysed in terms of energy efficient usage and better power management of the attached batteries.

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