A SCHEMATIC STUDY AND APPROACH TO SOLVE VOLTAGE UNBALANCE OF THE DC SUPPLY IN MULTILEVEL H-BRIDGES BASED SOLID STATE MOTOR

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ABSTRACT:

As the expansion of the dc distribution machine and the increase of the penetration of dispensed generations a wise motor with the capability to actively supervise the strength and taking into account the easy connection of the distribution assets is becoming critical. The cascaded H-bridge multilevel inverter (CHMI)-based totally strong kingdom motor (SST) has the functions of immediate voltage regulation, voltage sag repayment, fault isolation, energy aspect correction, harmonic isolation and dc output. Acting very just like an strength router, each SST has bidirectional energy float manage ability permitting it to control energetic and reactive strength float and to deal with the fault currents on each low- and high-voltage aspects. Its massive manipulate bandwidth offers the plug-and-play characteristic for dispensed sources to promptly recognize and reply to adjustments within the system. This paper proposes a 20-kVA cascaded H-Bridge multilevel converter-based totally SST to without delay interface with 7.2-kV single-segment distribution voltage degree. The SST includes a cascaded multilevel ac/dc rectifier, dual active bridge (DAB) converters with excessive-frequency motors. The DAB converter regulates the four hundred-V-low-voltage dc bus and introduced dc/ac inverters can be introduced to present a 60 Hz one hundred twenty/240-V ac residential voltage.

Keywords: *Cascaded H-Bridge converter, dq vector control, solid-state motor (SST), voltage and power balance.*

I. INTRODUCTION

Permanent the proliferation of disbursed generation and renewable power resources has stimulated the researchers to investigate the feasibility of a new micro grid operation mode future renewable electric powered energy shipping and management (FREEDM) gadget. The FREEDM system is a brand new medium-voltage micro grid composed of several strong-country motors (SST), high bandwidth virtual communication, and distributed manipulate. As the fundamental element of modern clever micro grid machine, SST is meant to update the traditional line-frequency vehicles and plays the electricity drift control. Conventional cars own many unwanted houses such as cumbersome and electricity nice susceptibility. In evaluation, the SST is a shrewd power electronics gadget with abilities together with managing power waft, presenting strength great improvement, and permitting smooth connection of the distribution resources.

Fig. 1 shows a standard FREEDM gadget which consists of three parts. The first part is the person-stage interface that consists of both a 400-V dc distribution bus and occasional-voltage 220-V ac bus. The second part is a smart power management (IEM) device, which is related to 10-kV ac distribution bus and helps the regulated buses. The IEM is genuinely formed by means of the SST that manages bidirectional energy glide control to all devices linked to the low-voltage (four hundred and 220 V ac) buses and masses. It additionally has many additional features which include voltage law, voltage sag reimbursement, fault isolation, and harmonic isolation. The third component is known as the disbursed grid intelligence working device, that's embedded into the IEM device and utilizes the communiqué community to coordinate the device electricity control with other power routers. Furthermore, an shrewd fault management device is used to prevent capability faults in the 10-kV ac circuit and reconfiguration capability and uninterrupted power pleasant to the person [6]–[8].

An important objective of using the SST within the FREEDM system is to reap compatibility and flexibility. It can adjust the low-voltage buses and provide lively and reactive energy manage or energy/frequency manipulate for the grid-side port. Fig. 2 indicates the proposed 20-kV•A SST based totally on the cascaded H bridge multilevel inverter (CHMI). The SST consists of a twin active bridge (DAB) dc/dc degree to step up the four hundred-V dc enter to the excessive-voltage dc link, a cascade H-Bridge multilevel dc/ac inverter stage to offer active energy and reactive energy for the ten-kV ac grid, and a dc/ac degree to produce a 220-V ac residential voltage for masses. In China, the utility structures and home voltage are 10 kV and 220 V, respectively.

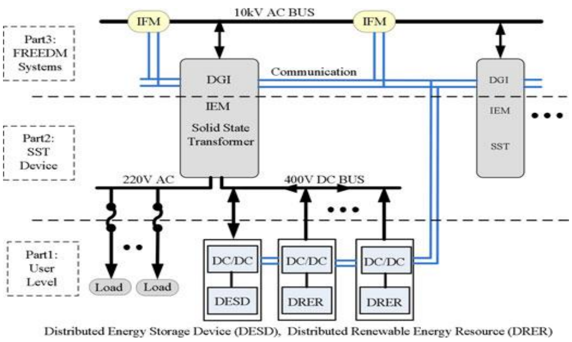


Fig. 1 Microgrid interface of the FREEDM system

Despite cascaded H-bridge topology has been extensively used inside the SST tool due to its modularity to gain medium voltage output and good electricity fine, it also has several drawbacks [9]–[15]. One of the primary drawbacks is the strength unbalance at one of a kind levels and the dc voltage unbalance at distinctive modules. Various configurations for cascaded H-bridge multilevel converter had been pronounced in [16]–[22], maximum of preceding research specifically makes a speciality of programs in static synchronous compensator, EV traction drive, and medium-voltage industrial drives for improving power first-rate and reliability of a energy distribution device. In [20] and [21], the proposed system is applied primarily based on impartial PV sun resources with independent MPPT control set of rules for each PV string. The PV input is connected immediately to the cascaded H-bridge dc/ac module and the dc–dc DAB degree has been eliminated to lessen the size of the converter. However, it calls for 3 person PI controllers for every PV cell to balance the inverter output and there is no isolation among the low- and high-voltage sides due to the removal of the DAB degree and its excessive-frequency motor. A single-phase SST to interface with the 7.2-kV distribution machine has been stated in [22]. It consists of a cascaded H-bridge ac–dc rectifier, a dc–dc converter (DAB), and an ac–dc inverter tiers. Through the interaction of the DAB controller with the rectifier controller, the rectifier dc-link voltages and DAB level powers can be balanced via choosing the voltage feed-forward and remarks coefficients in DAB modules.

Nevertheless, the most suitable selection of these coefficients is not given and it calls for three-character controllers for each DAB module. Furthermore, the electricity waft from distributed renewable electricity source to utility for 3-section gadget isn't always discussed. Different topologies aside from DAB dc–dc converter to reinforce the PV source voltage are also proposed for SST in [23] and [24] however the concept is based on motorless SST in which there's no isolation motor among input and output.

This venture extends a number of the control strategies advanced formerly [20]–[22] for exclusive packages and validates the concept through numerical simulations, validation accomplished on a ten-kV•A laboratory prototype. The project investigates the software of the three-segment SST and its controller with the energy float from the distributed renewable electricity sources to the grid underneath unbalanced situations. The manage scheme remedy the energy and voltage unbalanced issues of 3-section SST together with the unbalanced of different modules (DAB+CHMI) in each segment and sooner or later inject a simply sinusoidal balanced three-section modern-day into the ac grid. The controller employs the moving floating neutral point manage algorithm to balance the power on the three phase ac aspect and the dynamic reference voltage technique (feed-ahead repayment) to stability the dc-link voltage of various modules in each section. A grasp–slave manage (MSC) is used to control the output of the DAB level. Compared with the preceding strategies [20]–[22], the proposed method has the following capabilities: 1) This project investigates the application of the SST converter in FREEDOM device and its control with energy flowing from the allotted renewable electricity resources to the grid under unbalanced conditions. 2) The DAB stage is used to boost the low input voltage of renewable electricity sources to medium voltage stage of the ac grid distribution. Therefore, a couple of renewable strength resources can be utilized in parallel to increase the energy score of the gadget. 3) The dc-link voltage float is managed by unbiased controllers. The DAB grasp–slave and the extra feed ahead voltage balance mechanism embedded in the CHMI modulation level. Four) It simplifies the controller of the DAB ranges the usage of the grasp–slave technique and presents high-frequency galvanic isolation among the input and output.

II. THREE-PHASE SST MODELING AND CONTROL

The topology and control strategy of a 3-phase SST (see Fig. 2) are advanced in this section. The prototype of the SST is rated as enter dc-link voltage of 400 V, output ac-voltage of 10 kV, and output energy of 20 kVA. The first degree of SST is high-frequency DAB converter which boosts low-voltage dc enter to excessive-voltage dc link. The second level is CHMI, which converts the dc-link voltage to medium voltage ac grid, and controls lively and reactive power introduced to grid.

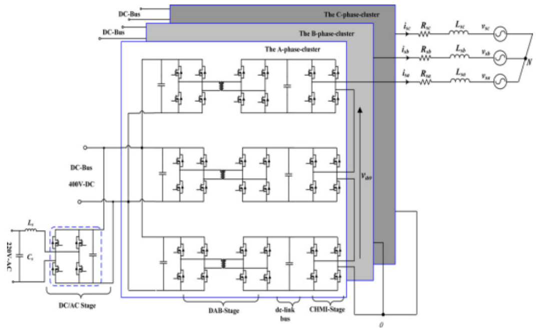


Fig. 2 Topology of the proposed 20-kVA three-phase SST

Fig. 3 shows structure of the DAB tiers and their control circuit. The DAB stage steps up the four hundred-V dc input to four-kV dc output that is fed to CHMI stage. In the proposed manage circuit, handiest one DAB converter is utilized as the grasp proportional-indispensable (PI) voltage controller, which executes all control and modulation calculations and sends the ensuing converter riding command signals to other DAB slave controllers via excessive-velocity fiber optic. Typically, DAB slave controllers most effective manipulate gadgets switching and safety. Also, to calculate the power transferred with the aid of every module and implement the protection of overvoltage and over present day, the voltage and modern of input facet and output aspect are all sensed. Since circuit structure is absolutely same, the output voltage amplitude of every DAB converter should be equal to the reference voltage with the equal driving alerts assuming that the components (switches and automobiles) of every DAB level are ideal.

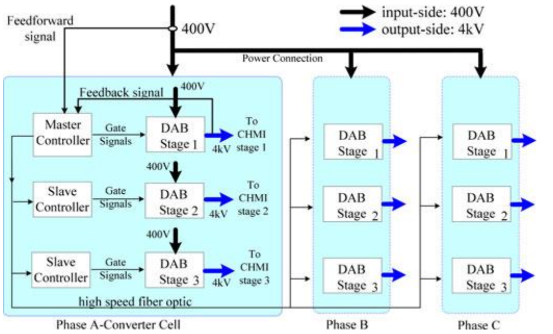


Fig. 3 MSC diagram of the DAB converter stages

However, it's miles unlikely to have one hundred% equal switching gadgets and motor parameters for every DAB, resulting in barely unbalanced of energy transferred through DAB modules. Nevertheless, this unbalanced may be also compensated by means of the CHMI controller degree, as a way to be discussed in Section III. Therefore, the proposed grasp–slave controller inside the DAB level now not most effective gives the high-frequency galvanic isolation, however also simplifies the complex algorithm and improves the dynamic performance. The function of CHMI stage is to produce sinusoidal 3 phase output voltage/modern and manage the lively/reactive power injected into the grid. Fig. Four indicates the block diagram of a 3-section decoupled modern-day controller advanced for the CHMI degree.

The common of all the dc-hyperlink voltages is used to determine command of the total actual electricity references P∗ had to control the output of the 3-section gadget. The controller of CHMI degree in Fig. Four carries loops 1) outer voltage loop and a couple of) internal current loop. The outer voltage loop regulates the common dc-hyperlink voltages in order to determine the general energetic electricity P needed to manipulate the device. Therefore, the dc-link voltage go with the flow is not directly handled by modulating the voltage reference amplitude of every phase according to the respective imbalance proportion which causes unbalanced strength drawn by every module until the balance is carried out. In addition, the reactive power reference may be managed at specific values depending at the system necessities. According to the three-section dq transformation, the ac-voltage instructions (v∗d and v∗q) inside the d-axis and q-axis is expressed with the aid of

$$\begin{bmatrix} v_d^* \\ v_q^* \end{bmatrix} = \frac{1}{N}\left(\begin{bmatrix} v_{Sd} \\ 0 \end{bmatrix} - \begin{bmatrix} 0 & -\omega L_{AC} \\ \omega L_{AC} & 0 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} - K_P \begin{bmatrix} i_d^* - i_d \\ i_q^* - i_q \end{bmatrix} - K_I \int \begin{bmatrix} i_d^* - i_d \\ i_q^* - i_q \end{bmatrix} dt \right) \quad (1)$$

In which identification is the d-axis current, iq is the q-axis current, i∗d is the d-axis current reference, i∗q is the q-axis contemporary reference, ω is the frequency of rotation of the reference body in rad/sec, vSd is the d-axis aspect corresponding to the three-segment grid voltage, and LAC is the ac line inductor. Note that the coefficient 1/N in Fig. 4 represents the wide variety of cascaded converters, which is N = 3in this case. The command voltages are transformed returned to the three-phase reference signals v∗ao , v∗bo , and v∗co via applying the inverse dq transformation, wherein they'll be used because the phase-shifted pulse width modulation (PS-PWM) modulator signals in CHMI stage. Then, (1) can be rearranged as

$$\frac{d}{dt}\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \frac{1}{L_{AC}}\begin{bmatrix} K_P(i_d^* - i_d) + K_I\int(i_d^* - i_d)dt \\ K_P(i_q^* - i_q) + K_I\int(i_q^* - i_q)dt \end{bmatrix}. \quad (2)$$

Equation (2) signifies that identity and iq can be controlled independently from each other, because of this that the SST can offer energetic and reactive electricity manipulate for the ten-kV ac grid independently. Meanwhile, so as to properly deal with the inherent power and voltage unbalance problems due to the distinction of module parameters, an extra manipulate strategy is introduced into the modulation level, that is the second one consciousness of this studies.

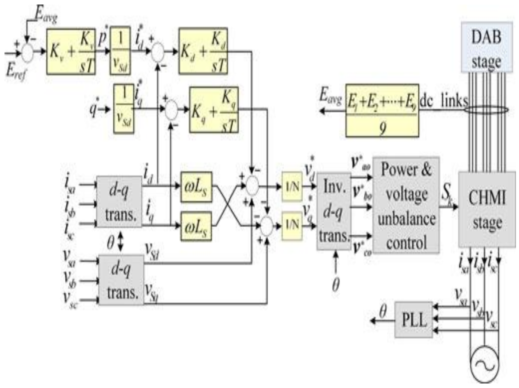


Fig. 4 Control scheme of the three-phase grid currents

Due to the modularity of topology, PS-PWM is the top-quality modulation technique for CHMI degree. The switching kingdom of one H-bridge-module Sk is decided by means of the logical cost of two indicators (Sk1, Sk2), which may be "1" and "zero" representing the "ON" and "OFF" nation of each switch, respectively. This ends in four distinct binary combinations that generate three unique output voltage +Vdc, 0, and −Vdc. Since these H bridge- modules are related in series, the overall output voltage of one phase m (m = a, b, c) is given by

$$v_{mN} = \sum_{y=1}^{k} v_{my} = \sum_{y=1}^{k} V_{dc}(S_{y1} - S_{y2}) \qquad (3)$$

Wherein k is the quantity of power modules according to segment and Vdc is the dc-link voltage of every module. The collection connection of okay modules will produce 2k + 1voltage tiers within the total converter output voltage. The PS-PWM modulation precept with 3 modules in step with segment is shown in Fig. 5. Due to the modularity of the topology, every module can be modulated independently using unipolar PWM with the same reference signal [25]. In this undertaking, 3 modules provider indicators are managed on the identical frequency 1 kHz and shifted by2π/three rad from every different. Since the section shift introduces a multiplicative effect, the CMHI line-to-impartial voltage has a switching pattern with three times the frequency the switching devices of every module. Hence, this converter can without difficulty reach medium voltage without the low-frequency motor and the entire harmonic distortion is lower.

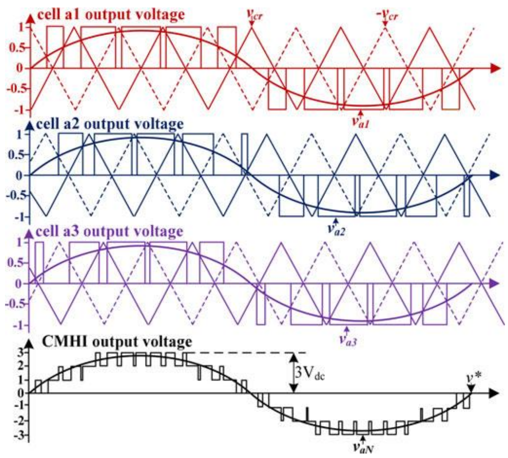


Fig. 5 Phase-shifted PWM waveforms for a three-module CHMI

Fig. 6 Indicates the virtual control structure of the CHMI based on DSP and FPGA. The sampled data consists of dc-excessive side voltage/present day and three-section grid voltage/present day. The synchronization of the dq transformation is done via a segment-locked loop to regulate the active and reactive electricity within the DSP controller. Meanwhile, the electricity and voltage unbalance reimbursement calculation have additionally been introduced into the controller. Since the frequency of the switching gadgets of every module is 1 kHz, the sampling frequency is 6 kHz and the reference replace length is 1 ms. Therefore, the digital manage gadget has to execute a chain of voltage/cutting-edge signal acquisition and voltage reference computation inside the sampling duration of 167 μs(1 s/6k). The DSP sends voltage references every 167 μs to FPGA, which plays an crucial function in the use of section shifted clock to generate 36 corresponding PWM indicators. The trouble description and answer of the inherent unbalance among 3 levels and exceptional modules of one section are mentioned inside the subsequent section.

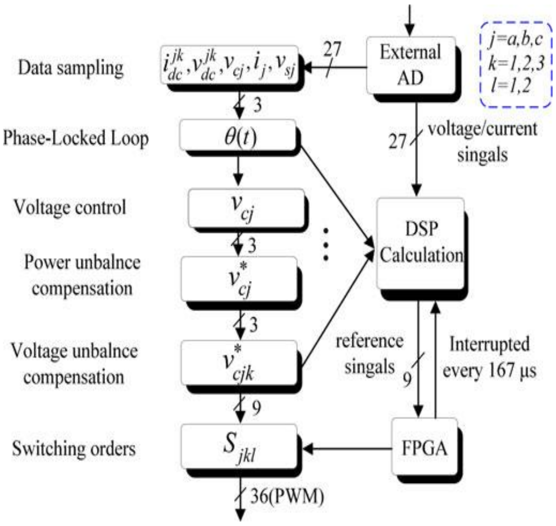


Fig. 6 Software block diagram for the CHMI stage

III. MATLAB/ SIMULATION RESULTS

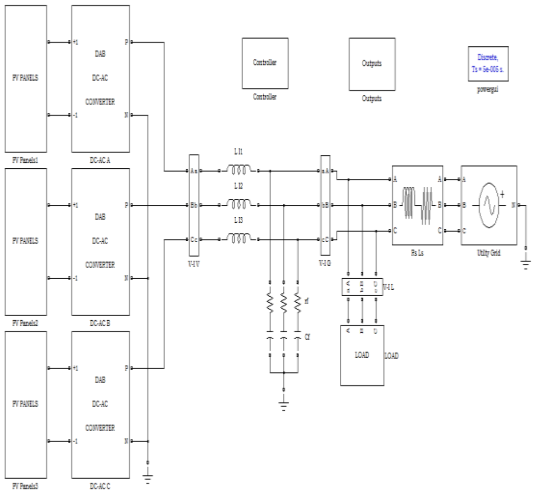


Fig 7 Simulation diagram of proposed system

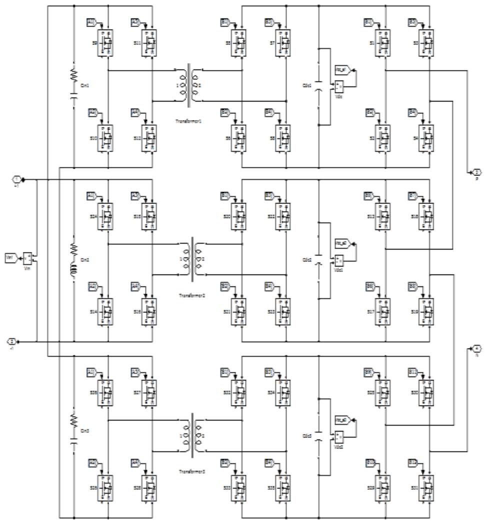


Fig 8 Simulation block diagram of EMF signals to Pulse signals

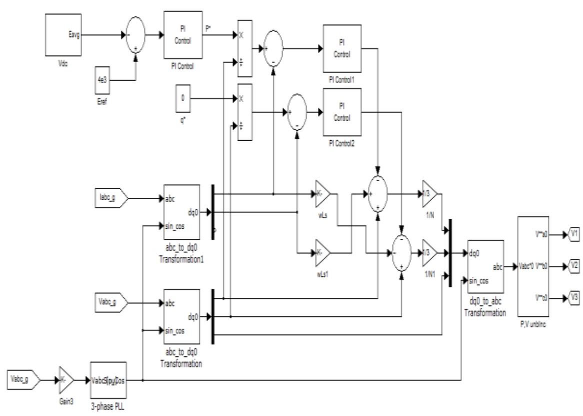


Fig 9 control scheme of grid current Simulation block

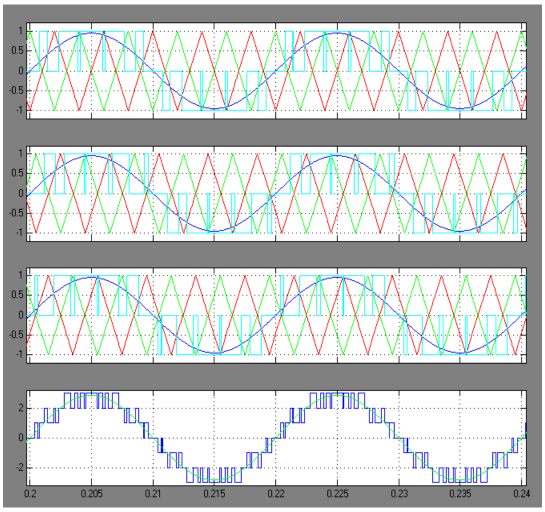


Fig.10. Simulation Phase-shifted PWM waveforms implementation

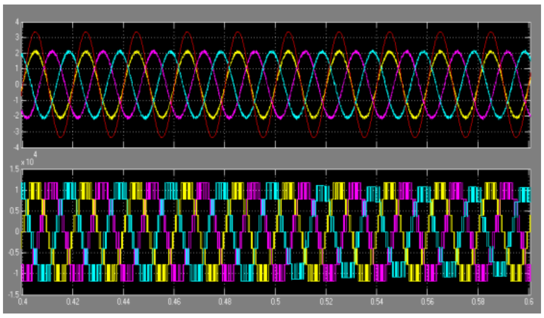


Fig.11 Dynamic performance without power balance control results

The 3-segment delivered currents to the grid are unbalanced and the road-to-impartial voltage in section A additionally turns into distorted. Meanwhile, the unbalanced circumstance additionally effects in a pulsating strength on the gird aspect because the lively power and reactive electricity are respectively proportional to the dq synchronous frame components of the grid modern isd and isq . Fig. 12 shows three-segment output currents with the strength balance manipulate. With the energy stability control, three-section grid currents are absolutely balanced despite the modules are running at unique energy levels. This is due to the fact the injection of 0-series voltage does not have an effect on the road-to-line voltage. To validate the voltage stability manipulates, the dc-link voltages of three modules of phase B are given in Fig. 15. Fig. 15(a) indicates that the 3 dc-hyperlink voltages cannot maintain on the reference value with out voltage unbalance manage. The reason is that the CHMI modulation level imposes the identical voltage reference for every module, while their voltages go with the flow while power transferred is special by means of DAB modules. The module that supplies greater electricity has better dc-link voltage. Fig. 15(b) shows the three dc-link voltages of segment B with the proposed voltage balance manipulate. The output voltage values of the three modules are identical primarily based on the voltage balance manipulate. The controller modifies the amplitude of each module voltage reference in step with their respective unbalance deviation to redistribute the switching gadgets ON/OFF instances. This discount at the voltage reference reasons a reduction at the ON time of the module for creating a rise on the corresponding dc-link voltage

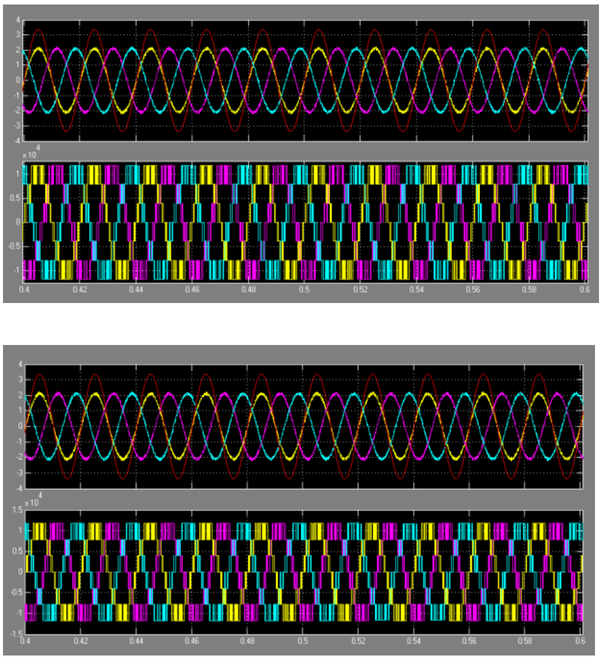


Fig.12 Dynamic performance with power balance control results (a) with control 1 (b) With control 2

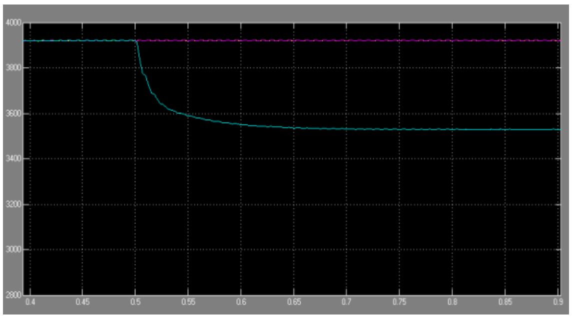
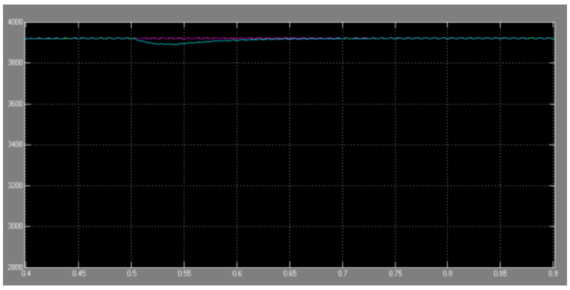


Fig 13 Dynamic performance of three dc-link voltages of phase B. (a) without voltage balance control.



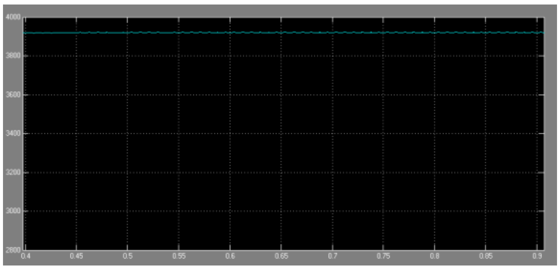


Fig 14 Dynamic performance of three dc-link voltages of phase -C output with voltage balance control.

CONCLUSIONS

In this venture, a cascaded H-Bridge converter-based totally SST is schemed to interconnection among 7.2-kV ac grid and a four hundred-V dc distribution in smart grid systems. The single-phase dq vector designing and restrain of the SST, inclusive of ac/dc rectifier, DAB converter is developed. A new voltage stability restrain manner is schemed to resolve the voltage unbalance of the dc MOTOR in exceptional H-bridges. The power intrinsic unbalance constraints of the voltage balance restrain for the cascaded H-Bridge rectifier is derived and proven through simulations. Mean-at the same time as, a strength stability restrain process is schemed to adjust the actual power moving thru the parallel modules. Finally, the switching version simulation and SST scale-down prototype are instigated with the schemed controller. The results affirm the performance of the SST, which include energy issue correction, real and reactive strength restrain, voltage sag reimbursement, and the schemed voltage balance restrain.

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