A DC–DC Quad Active Bridge Converter Based Hybrid Energy Storage Systems

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Abstract— The Solid-state transformer (SST) has been proposed in this paper to replace the regular distribution transformer in the future smart grid. The SST provides ports for the integration of storage and distributed generation. This paper proposes a SST topology based on a quad-active-bridge (QAB) converter which not only provides isolation for the load, but also for DG and storage. A gyrator-based average model is developed for a general multi active-bridge (MAB) converter, and expressions to determine the power rating of the MAB ports are derived. These results are then applied to analyze the QAB converter. For the control of the dc–dc stage of the proposed QAB-based SST integrating PV and battery, a technique that accounts for the cross-coupling characteristics of the QAB converter in order to improve the regulation of the high-voltage-dc link is introduced. This is done by transferring the disturbances onto the battery. The control loops are designed using single-input single-output techniques with different bandwidths. The dynamic performance of the control strategy is verified through extensive simulation results by MATLAB/SIMULINK Environment.

Keywords— Solid State Transformer, Quad active bridge, Multi active bridge, MATLAB, solar panel.

I. Introduction

The power-electronics-based transformer, or so-called SST, is one of the key components of the distribution system. In addition to serving as a regular distribution transformer, the SST provides ports for the proper integration of distributed energy resources and distributed energy storage, thus enhancing the reliability of the distribution system. Besides the advantage of its reduced size and weight due to its high frequency (HF) transformer, the SST makes use of state-of-the-art Power Electronics devices that allows it to provide additional functionalities such as on-demand reactive power support to grid, power quality, current limiting, storage management and a DC bus for end use. Poor load power factor and harmonics are isolated from the distribution system, thus improving the overall system efficiency. Additionally, the selection of new generation materials for semiconductors and magnetic may help improve its efficiency when compared to a regular transformer of the same ratings. It shows the SST interfacing photovoltaic (PV) generation, storage, electric loads as well as plug-in hybrid electric Vehicles.

DC-DC converters are electronic devices used whenever we want to change DC electrical power efficiently from one voltage level to another. They are needed because unlike AC, DC can't simply be stepped up or down using a transformer. In many ways, a DC-DC converter is the DC equivalent of a transformer. In all of these applications, want to change the DC energy from one voltage level to another, while wasting as little as possible in the process. In other words, it is to perform the conversion with the highest possible efficiency.

The first section gives the introduction about the paper. The second section of the paper discuss about the basics of DC-DC converter. Proposed technique is discussed in the third section. The fourth section deal with the simulation work carried through MATLAB environment. The fifth section is about the results and discussions. The final section presents the conclusion.

II. Basics of DC-DC Converter

DC-DC converters are like a transformer, they essentially just change the input energy into a different impedance level. So whatever the output voltage level, the output power all comes from the input; there is no energy manufactured inside the converter. Therefore represent the basic power flow in a converter with this equation

$$P_{in} = P_{out} + P_{loss} \qquad (1)$$

Where Pin is the power fed into the converter, Pout is the output power and P_{loss} are the power wasted inside the converter. If a perfect converter, it would behave in the same way as a perfect transformer. There would be no losses, and Pout would be exactly the same as Pin. There are many different types of DC-DC converter, each of which tends to be more suitable for some types of application than for others. For convenience they can be classified into various groups, however. For example some converters are only suitable for stepping down the voltage, while others are only suitable for stepping it up; a third group can be used for either. DC-DC conversion is important in electronic circuit applications and is becoming increasingly important in a much wider range of applications. Many circuits use power at several different voltage levels. Modern fixed-output DC power supplies find their way into products ranging from, home appliances to industrial controllers. Today most supplies are built with DC – DC converters. The incoming AC is rectified directly with a simple diode circuit, and then the high level DC is converted to desired levels. Power MOSFETs are used for drive applications where wide range at low power levels required. Since it is a voltage controlled device, the gate terminal is electrically isolated from the source by a silicon oxide layer. The gate circuit impedance is very high and the device power gain is very high. These have low switching losses.

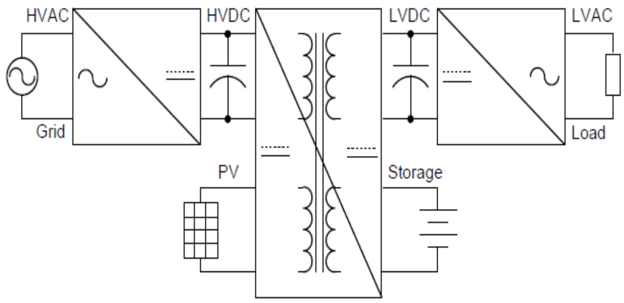


Fig.1. QAB-based SST with storage and PV

The control design for the SST AC-DC stage introduces a technique to deal with the interactions that result when the above two SST stages are interconnected. The performance of the controls is verified through extensive simulation of both switching and average models of the SST. The thee-stage DAB-based SST with the integration of PV and storage through separate non-isolated converters is shown in Fig.1 The proposed SST topology, presented herein, replaces the DAB with a QAB. The two remaining ports are reserved for PV and storage integration.

III. BLOCK DIAGRAM OF PROPOSED SCHEME

The proposed block diagram shown in fig.2.This scheme consists of inverter, filter, battery, rectifier and corresponding load. Rectification is a process of converting the alternate current or voltage into a direct current or voltage. This conversion can be achieved by circuits, based on switching devices.

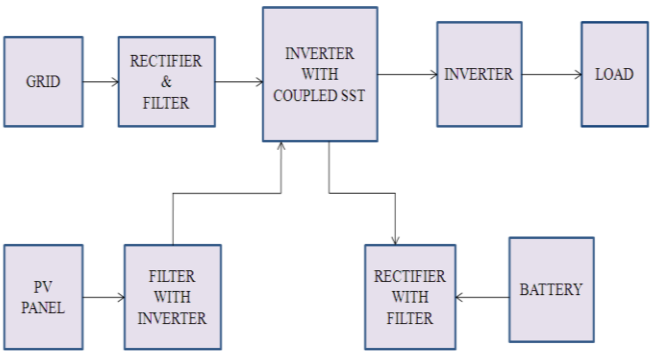


Fig.2. Block diagram for the proposed scheme

The function of an inverter is to change a DC input voltage to a symmetrical AC output voltage of desired magnitude and frequency. A variable output voltage can be obtained by varying the input DC voltage and maintaining the gain of the inverter constant. Inverter converts DC into high frequency AC. This high frequency AC is required to reduce the size of the transformer and filter. The transformer used in this circuit is used to step down the voltage to require at the output.

IV. SIMULATION OF PROPOSED SCHEME

A model for the proposed scheme was designed using MATLAB/SIMULINK software as shown in fig.4 and fig.6.The data of the QAB based SST used for simulation is given in table-1.

TABLE I: PARAMETERS

Description	Values
High voltage DC link voltage	48 V
Low voltage DC link voltage	48 V
PV voltage	48 V
Battery voltage	48 V
Ports Current Rating	5 A
Phase shift angle	90◦
Switching Frequency	20 KHz

Simulation is done for both load and without load conditions, from the results it was observed that it provides the smooth isolation for the corresponding load and storage action for particular voltage conditions.

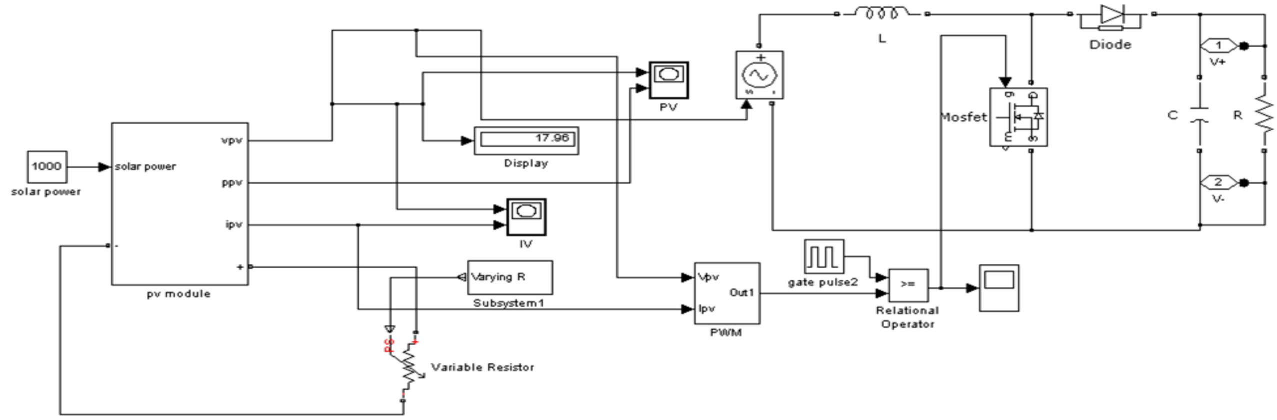


Fig.4. Simulink Model of proposed solar module

V. RESULTS AND DISCUSSIONS

The results of the proposed scheme were depicted for various cases such as, speed change, solar output response, bump transferring condition.

A. *Supply voltage response*

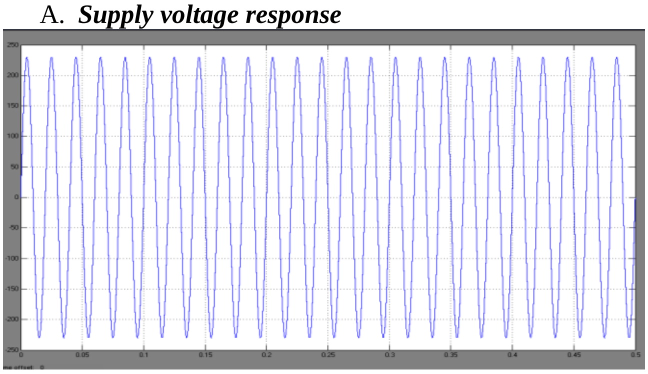
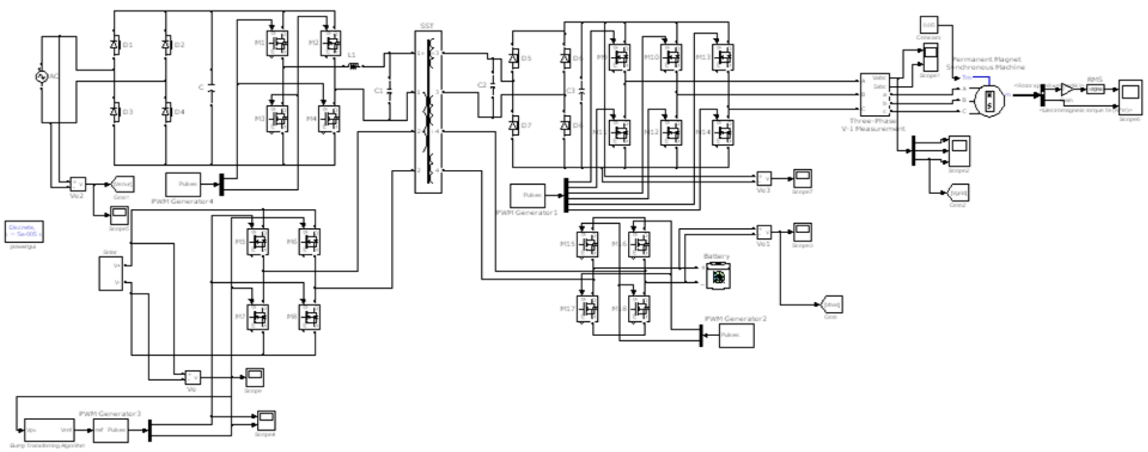


Fig.3 Supply Voltage Waveform

Figure.3 shows the supply voltage waveform for the proposed scheme. Here the input voltage is applied as 230v. Fig.5. shows PWM output the waveform for the proposed scheme. Here the waveform gets settled at the period of 0.15 sec. The corresponding voltage



and current waveforms are depicted in fig.7.depends upon the pulse width of the voltage the corresponding signals will be generated. A photovoltaic system is a system which uses one or more solar panels to convert solar energy into electricity. It consists of multiple components, including the photovoltaic modules, mechanical and electrical connections and mountings and means of regulating and/or modifying th electrical output which is shown in fig.4.

Fig.6. Simulink model of proposed work

B. *PWM Response*

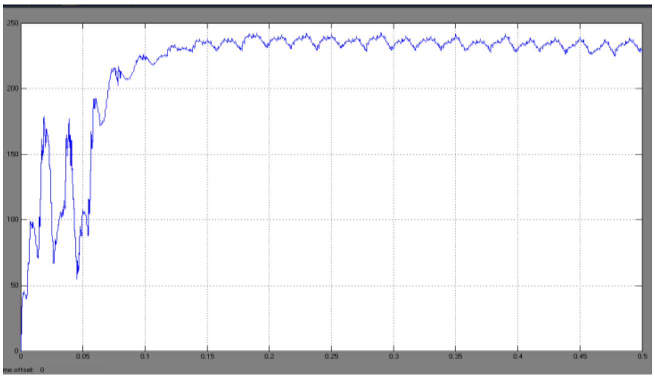


Fig.5. PWM Waveform

C.Voltage and current Response

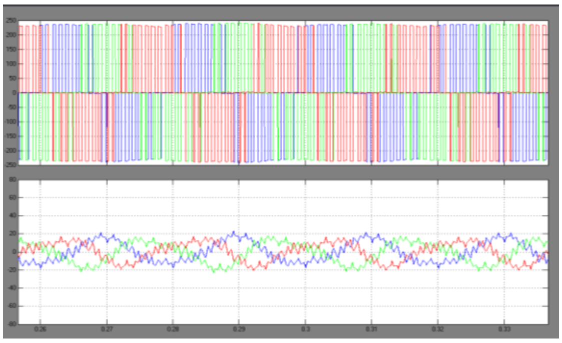


Fig.7 Voltage and current Waveform

D. Speed and Torque Response

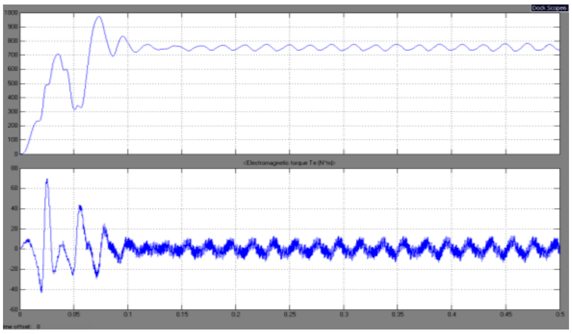


Fig.8. Speed & Torque Output Waveform

The corresponding speed and torque waveforms are depicted in fig.8.after 0.1 sec the speed of the system gets settled. The second plot describes about the electromagnetic torque.

E. Solar Output Response

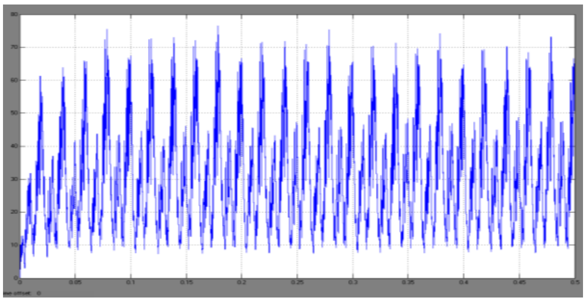


Fig.9. Solar Output Waveform

Fig.9 shows about the solar panel output of the corresponding system. Depend upon the irradiation level the output of the PV gets generated.

F. Battery Output Response

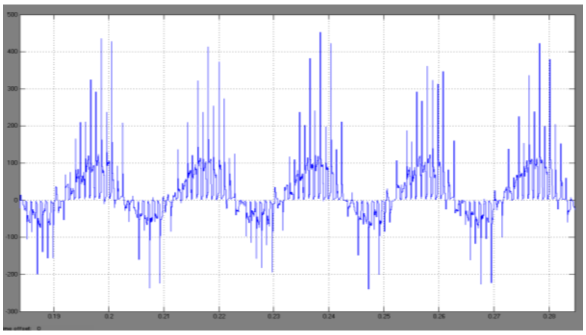


Fig.10. Battery Output

G. Bump Transferring Response

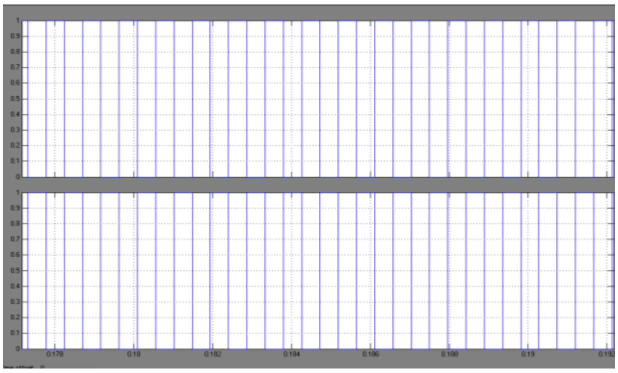


Fig.11. Bump transferring Output

Several results were simulated to evaluate the performance of the proposed QAB Converter based Hybrid drive system.

VI. CONCLUSION

A SST topology based on a quad-active-bridge (QAB) converter which provides isolation for the load, as well as DG and storage has been proposed here in. A gyrator type large-signal average model has been developed for a general multi-active-bridge (MAB) converter and used to significantly speed up the simulation of the DC-DC stage of the QAB-based SST. Additionally, the expressions to determine the power rating of an MAB port have been derived and used to determine the power rating of the QAB ports considering the operating characteristics of the SST application based hybrid drive system. The power demanded by the QAB is estimated and fed into the AC-DC stage controller. This is a simple yet effective approach that helps minimize the interaction between the two SST stages. This technique was simulated through solar PV module by using MATLAB Environment.

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