Modelling & Analysis of Solid-State Transformer for Integration of Renewable Energy Sources to the Grid

Aditya Kadam and Vishal Dake

Modelling & Analysis of Solid-State Transformer for Integration of Renewable Energy Sources To The Grid

Aditya Santosh Kadam, Mtech,
PEPS Student,Department Of
ElectricalEngineering.
Sardar Patel College Of
Engineering,Andheri,Mumbai,India
e2055010@spce.ac.in

Vishal Dake
Assistant Professor,Department Of
ElectricalEngineering.
Sardar Patel College Of
Engineering,Andheri,Mumbai,India
vishal_dake@spce.ac.in

Abstract— **The solid-state transformer is an emerging technology for the efficient and adaptable integration of distributed and renewable energy sources into the power grid (SST). This work develops and implements an SST-based power electronic converter to integrate renewable energy systems into the grid. SST is built with an LCL filter, an inverter, and two active bridges (DAB). Matlab/Simpower is used to design the proposed SST-based system and associated controls. Utilizing SST and a medium-frequency transformer expands the control options for a high-power converter by decreasing transformer size and expense.**

Keywords— Solid State Transformer, Dual Active Bridge, LCL Filter, Inverter.

I. INTRODUCTION

Power generation, transmission and distribution are the three key components of a typical power generation network. A power transformer is one of the most important part of this network. Power transformers efficiently step-up voltages on the generation side and offer long-distance transmissions. At the substation, the voltages are reduced and used for both home and industrial uses via a distribution system. To boost a typical power transformer's performance, numerous improvements have been made. However, a conventional power transformer (CPT) still has several flaws, such as its size, weight, cost, de-rating caused by harmonics, poor power quality and inability to regulate voltage. Use of renewable energy sources for generation of electricity has grown popularly in recent years. Reactive power regulation, storage integration, and DC distribution are difficult aspects of a CPT's integration into a smart grid. A solid-state transformer (SST), which is also known as a power electronic transformer, may provide an answer to all these problems and downsides. Compared to conventional power transformers, the solid-state transformer provides the following advantages: Lighter weight and smaller in size, Harmonic elimination, Active and reactive power control, Voltage regulation and voltage Sag compensation, Power factor correction.

SST Represents The power electronic interface of High-frequency (HF) or medium-frequency (MF) transformers, control circuits, and power converters. . Traction systems, EV charging infrastructure, offshore wind farms, and tidal power plants are examples of applications for SSTs. The Fundamental notion is to replace the typical 50/60 Hz transformer with an HF or MF transformer, which permits a

Substantial reduction in volume and weight.

Generic SST Configuration

Fig: illustrates a general arrangement to implement an SST. The three stages of this structure are an active-front-end rectifier stage (AC-DC), a dual-active bridge (DAB) stage (DC-DC) with an HF or MF transformer, and a back-end inverter stage (DC-AC). The rectifier is required for the high voltage (HV) DC link and input current regulation.

The DAB stage controls power flow, steps up or down a voltage from one level to another, and regulates the LV DC link. Energy is stored and transferred using the leakage inductance of a transformer. In order to connect the AC loads, the inverter step finally transforms the voltage back to 50/60 Hz.
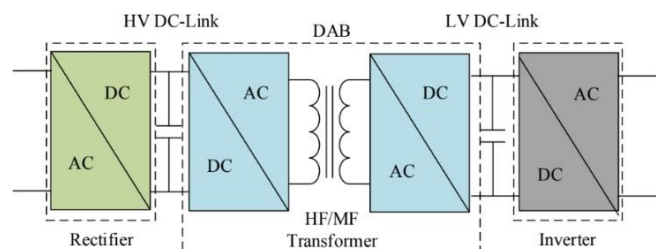

Figure -1: Three-stage SST configuration

II. PROPOSED SST SYSTEM STRUCTURE

The proposed two-stage SST-based system, depicted in Fig.2, includes a Dual Active Bridge (DAB), a grid-side inverter, and an LCL filter. The grid-side inverter is controlled by a synchronous reference frame control scheme. Controlling the d-axis and q-axis currents, respectively, changes the flow of active and reactive power. The shape of the current and the voltage will be determined by the phase angle between the primary and secondary. Harmonics can be taken out of the inverter's output by using an LCL filter. The output voltage is 415V at 50Hz, and it can be fed to load or into a grid. Since this is a single DAB module, there is no need to balance the power across multiple modules.

DAB operate all the switches at a 50% duty ratio and concurrently turn the diagonal switches to produce square waves from the primary and secondary bridges. S3 and S2 are
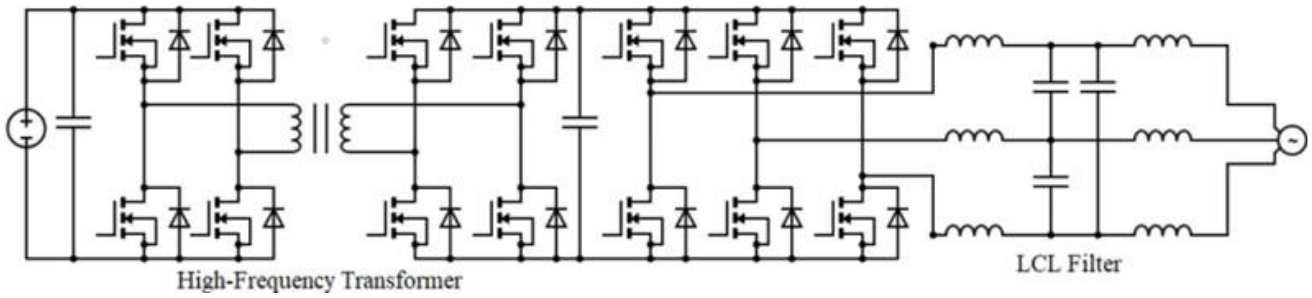
Figure 2 Topology of two stage SST

also turned on at the same time as S1 and S4, respectively. As a result, the primary bridge's output is produced as a square wave. Now that the square waves at the primary and secondary are phase-shifted by an angle φ , this can be done easily by turning on S1 and S5 with the same phase-shift angle.

A three-phase DC-AC inverter is the final stage of SST. This stage will either be linked to a low-voltage distribution grid or will operate independently. Because distribution grids are inherently asymmetrical, it should be capable of handling asymmetrical loads in both scenarios. The output of an inverter should ideally be sinusoidal; nevertheless, usually, the output is not only non-sinusoidal but also contains harmonics. Square wave voltages are suitable for low and medium power applications. In higher power applications, low distorted sinusoidal voltages are preferred. The square wave voltage inverter has certain downsides, such as the constant size of the fundamental voltage and the output consisting of low order harmonics. Because of the enormous size of inductor and capacitor necessary to reduce harmonics, they are complex and expensive. SPWM, or sinusoidal pulse width modulation, can be used to overcome both problems.

The control strategy for the inverter largely consists of two loops that are cascaded together. The rapid inner current control loop is what's responsible for regulating the grid current. A voltage control loop located externally is responsible for regulating the dc-output link's voltage.. The current control loop is the root cause of power quality issues as well as problems with current protection. The function of the dc-link voltage controller is to maintain a consistent flow of power throughout the system. A control for a synchronous reference frame is utilised here In some circles, it is also referred to as "dq control". We have utilised the abc to dq transformation in order to successfully convert the voltage and current waveforms of the grid into a reference frame that rotates in time with the grid voltage. As a direct consequence of this, filtering and controlling can be accomplished with relative ease.

The dc-link voltage is adjusted in accordance with the Supply energy systems in the inverter control structure shown in Fig.3. The active current controller uses its output as a reference, the reference for the reactive current controller is set to zero since only active electricity is anticipated to be delivered by the energy system connected to the low voltage distribution network in a typical circumstance. The grid voltage and current vector are thus always in phase. K factor controllers are linked to the dq control structure because they have a satisfying performance while controlling dc factors. The Phase-Locked Loop is used to determine the phase angle for the abc to dq transformation module (PLL).

By reducing the harmonics in the generated current, the output filter lowers the effects of semiconductor switching. Filters come in a variety of forms. Filter inductors attached to the inverter's output are the most basic variation. However,

combinations like LC or LCL can also be employed. Lower switching frequencies for the converter can be used because the LCL-filter attenuates at frequencies above its resonant frequency by 60 dB/decade. It also provides greater decoupling between the filter and the grid impedance and reduces current ripple across the grid inductor. LCL-filter is hence appropriate for our purpose.

The LCL filter has good current ripple attenuation even with small inductance values. However, it can also introduce unstable states and resonances into the system. As a result, the filter needs to be precisely created using the parameters of the converter. The primary goal of the LCL filter is to lower high-order harmonics on the output side; nevertheless, a poordesign could result in an increase in distortion. As a result, thefilter needs to be properly and sensibly built. The transfer function of LCL filter (neglecting damping) is:

$$H_{LCL}(s) = \frac{1}{L_1 C_f L_2 s^3 + (L_1 + L_2)s}$$

III. DESIGN SPECIFICATIONS

The designed SST-based power converter system, as shown in Fig., is implemented in MATLAB/Simpower System. A constant DC source powers the DAB SST module, which then feeds a DC link capacitor into a 3-phase full bridge inverter module before exiting into a load via an LCL filter.
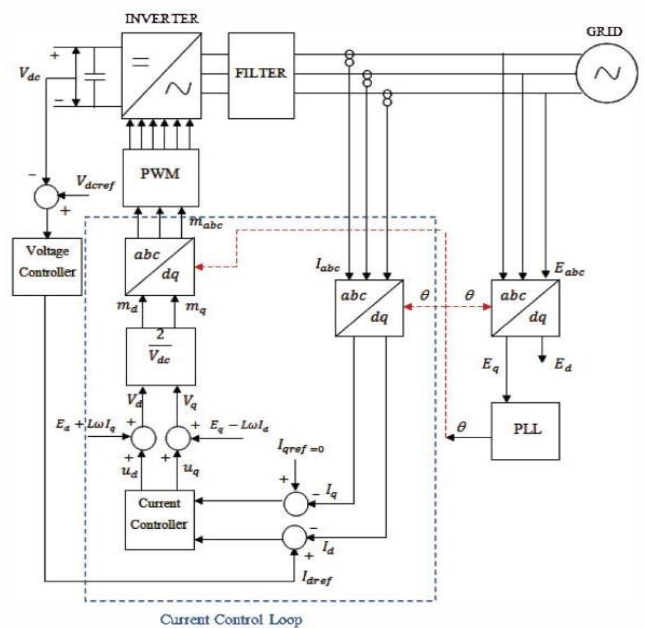

Figure 3 INVERTER CONTROL MODEL

The Control Model of Inverter. A synchronous reference frame control is used. Which consists of abc to dq transformation, The Phase-Locked Loop, current control for both d-axis and q-axis currents and the relationship between the modulation index, m, the DC link voltage, Vdc, and the inverter output voltage are also being considered.

Table 1

Vin	Vout	Operating frequency	Output current
400 V	800 V	10 khz	7.9 A
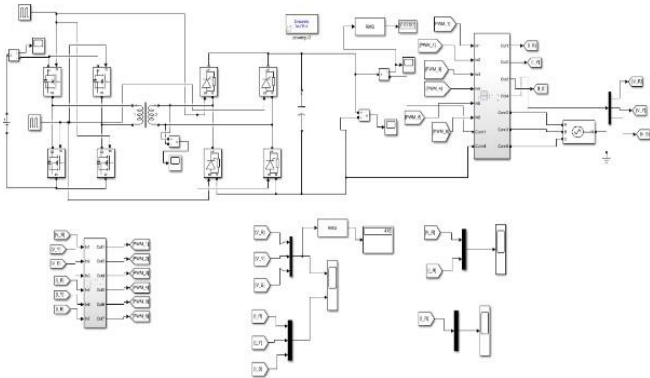
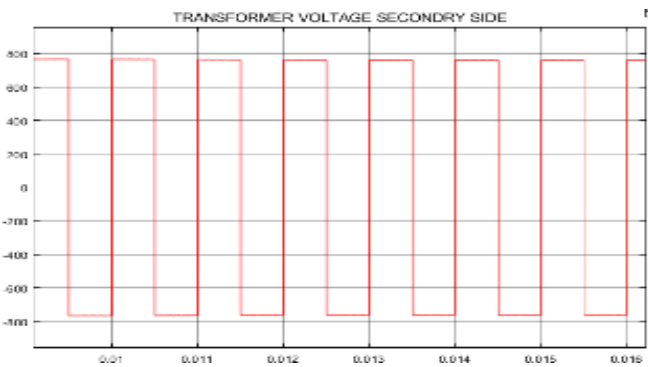**Figure 4: MATLAB Simulation of Two Stage SST**

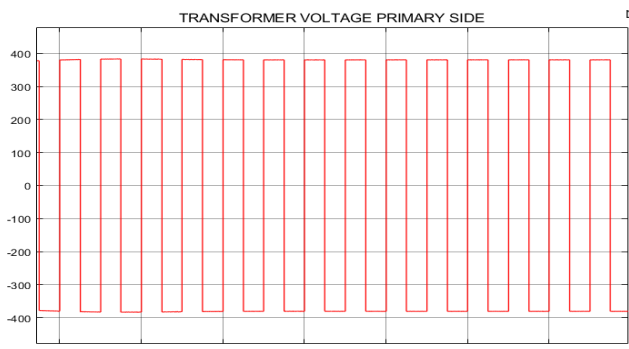**Figure 5:Output Voltage of Secondary of Transformer**
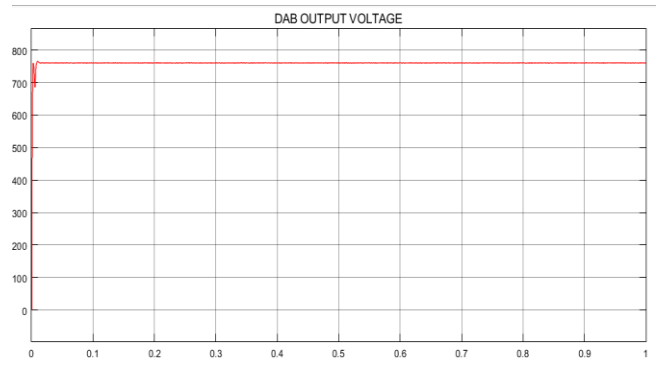

Figure 6:Output Voltages of Primary of Transformer
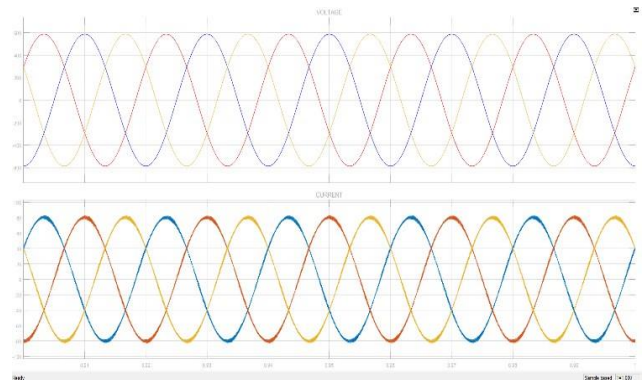

Figure 7:DAB Output Voltage

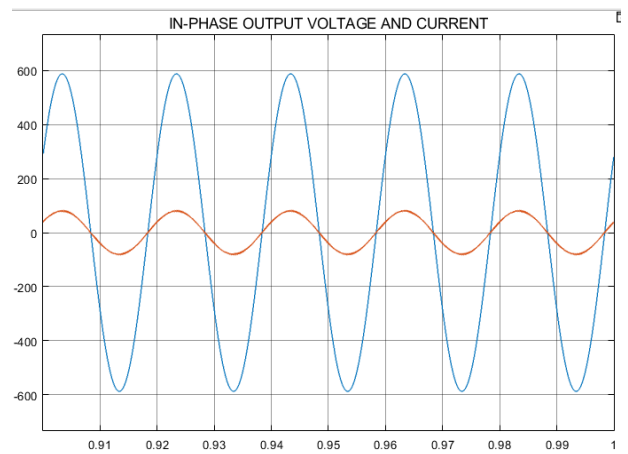**Figure 8: Output of Inverter**

Figure 9: In Phase Output Voltage and Current With L-C-L Filter

IV. CONCLUSION

In this thesis, a power electronic interface for the integration of renewable energy sources into the grid has been devised using the MATLAB / Simpower System. The interface is based on solid-state transformers and was implemented. According to the results of simulations and experiments, the proposed SST-based converter system is able to integrate renewable energy sources into the grid and the load in an effective manner. Furthermore, the LCL filter demonstrates an excellent reduction of undesirable harmonics in the system. The utilization of high-frequency transformers and SST opens up new avenues of control for high-power converters. This is made possible as a result of a reduction in both the size and cost of the transformer. The SST configuration with dual active bridges improves both efficiency and power transfer, with the degree to which these improvements being dependent on the relative phase angle between each Active Bridge switching. A grid-tie inverter's SST concept offers a potential middle ground between transformer-less and line frequency transformer solutions. Power transfer across the high frequency transformer can be regulated using a variation of DAB phase angle shifting.

V. FUTURE SCOPE

Hardware Implementation of SST Topology can be done to verify the results obtained in MATLAB simulations. The Bidirectional Flow of Power Can Be Introduced to the system. Grid quality management of the rectifier/inverter pack with the necessary control method. The Study of impact of using various switching devices can be seen on a converter's performance.

VI. REFERENCES

[1] X. She, X. Yu, F. Wang and A. Q. Huang, "Design and Demonstration of a 3.6-kV-120-V/10-kVA Solid-State Transformer for Smart Grid Application," Transactions on Power Electronics, vol. 29, no. 8, pp. 3982-3997, 2014. Eason, B. Noble, and I. N. Sneddon, "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions," Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955.

[2] J. W. van der Merwe and H. d. T. Mouton, "the Solid-State Transformer Concept: A New Era in Power Distribution," in AFRICON 2009, Nairobi, 2009.

[3] R. Gao, X. She, I. Husain and A. Q. Huang, "Solid-State-Transformer Interfaced Permanent Magnet Wind Turbine Distributed Generation System with Power Management Functions," IEEE Transactions on Industry Applications, vol. 53, no. 4, pp. 3849-3861, 2017.

[4] M. A. Hannah and e. al, "State of the Art of Solid-State Transformers: Advanced Topologies, Implementation Issues, Recent Progress and Improvements," IEEE Access, vol. 8, pp. 19113-13132, 2020.

[5] Electronic converters with de-coupled control",National Power Systems Conference (NPSC) - 2018, December 14-16, NIT Tiruchirappalli, India