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Design & Simulation of High Voltage Solid State Transformer for Smart Grid Application

Swapnil Bhuskute[1] , Mr. V. S. Pawar[2]

[1] PG Scholar, SSBT's College of Engineering, Bambori, MS, India.

[2]Associate Professor, SSBT's College of Engineering, Bambori, MS, India.

ABSTRACT: In recent years the grid system are becoming more complex and has grown due to the increased insertion power from renewable sources. Due to the increased complexity new methods are required to manage the changing loads and sources. A solid-state transformer is the solution and it provide the efficient functioning as a conventional transformer and also provide other benefits, particularly on-demand reactive power maintenance for smart grid, power quality and voltage conversion. Recently, another high-frequency link power conversion system, the solid-state transformer, has garnered a great deal of attention and has been extensively investigated for use in distribution systems with the development of the high-voltage power device technologies. Solid-state transformer has been proposed as for the traction system, distribution and smart grid application.

Keywords: Solid State Transformer (SST), High Frequency (HF) Transformer, SST topology, HV/MV/LV Link.

I. INTRODUCTION

In present power grids, large power stations generate energy and it is transmitted over HV lines. Medium (MV) and low-voltage (LV) lines are used to deliver this energy to consumers. In these grid layouts, the power flow goes only in one direction: from central power stations to consumers [1]. In the last few years, European countries have started to open their electricity market due to this there is an increased penetration of renewable energy and other distributed generation sources in the grid. These developments cause the network layout and operation to become much more complex, new technologies are required that allow better control, bi-directional power flow and increased number of power inputs.

The SST gives way to control the routing of electricity and provides easy methods for interfacing distributed generation with the grid. The solid-state transformer also controls power flow, which is required to ensure a stable and safe operation of the grid. However, this comes at the cost of a more complex and expensive system.A typical SST made up of an AC/DC rectifier, a DC/DC converter with HF transformer and a DC/AC inverter. SST has a similar function to that of a traditional line frequency transformer (LFT), namely increasing/decreasing the voltage.

Previous research that attempted to introduce solid-state transformer concept can be found in the reference [3][7]. The solid-state switching technologies allow power conversion between different formats such as dc/dc, ac/ac, ac/dc, and dc/ac with any desired frequencies. This paper provides an overview of the basic concepts of SST. Also the brief review of SST's configuration is also discussed including converter topologies& application in the grid.

II. SOLID STATE TRANSFORMER CONCEPT

The basic structure of a SST is shown in Fig. 1. The HF transformer is used as a isolator. The grid voltage is converted into a HF AC voltage through the use of power-electronics converters before applied to the primary of the HF transformer. The opposite process is performed on the High Frequency transformer secondary to get an AC and/or DC voltage for the load [4].

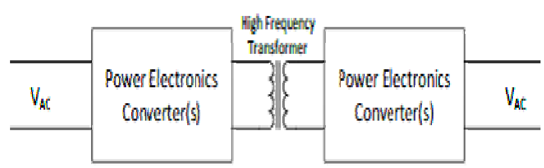

Fig. 1 Basic structure of SST

The traditional Line Frequency Transformer (LFT) has been used since the introduction of AC systems for voltage conversion and isolation. The widespread use of this device has resulted in a cheap, efficient, reliable and mature technology and any increase in performance are marginal and come at great cost [9] Additional features of the SST not found in Line frequency transformer are as below [2]:

1. Reduced size and weight.
2. Instantaneous voltage regulation.
3. Fault isolation.
4. Power factor correction.
5. Control of active and reactive power flow.
6. Fault current management on low-voltage and high voltage side.
7. Active power filtering of harmonic content on the input.
8. Good voltage regulating capabilities

9. The output can have a different frequency and number of phases than the input
10. Possibility of a DC input or output
11. Voltage dip and sag ride though capability (with enough energy storage)

III. SOLID STATE TRANSFORMER CONFIGURATIONS

The SST architectures developed in the last 10 years can be categorized as [10]:

1) SST based on their topologies:
2) SST based on their application:
3) SST architectures with focus on switching devices

Different research teams used different topologies and architectures for the Solid State Transformer.

Schematic Overview of SST based on topologies

The Solid State Transformer made up of one or more power electronics converters with an integrated high-frequency transformer. Based on the topologies, SST can be classified in four categories [11].

1) Single-stage with no DC link(Figure 2.a)
2) Two-stage with a DC link on the secondary side (Figure 2.b)
3) Two-stage with a DC link on the primary side (Figure 2.c)
4) Three-stage with a DC link on both the primary and secondary side(Figure 2.d)

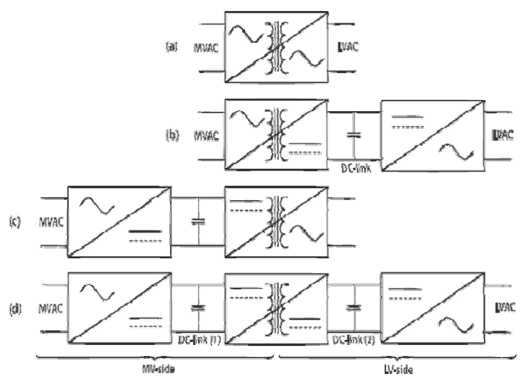

Fig. 2: SST architectures

Out of these four possible classifications, architecture from fig.2 .d, with two DCs, is the feasible because it has high flexibility and control performance. The DC links decouple the MV-from the LV-side, allowing for independent reactive power control and input voltage sag ride-though. This topology also allows better control of voltages and currents on both primary and secondary side[11][12][13].It consists of an AC-DC conversion stage at the MV-side, a DC-DC conversion stage with high-frequency transformer for isolation and a DC-AC conversion stage at the LV-side.

IV. DESIGN AND SIMULATION

AC-DC Conversion Step:-

The first step in the design of solid state transformer is AC-DC conversion; in this MV/HV ac is converted in the LV Dc voltage in this stage we used three level NPC conversions topology as shown in figure below[3][8].

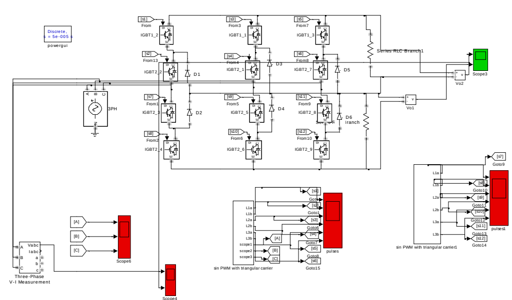

Fig. 3 Three level Neutral point clamped power circuit

It consist of two level VSI's theoretically it is extended upto several levels but practically is can extend upto only five level.

Due to additional advantages, that all phases share same DC source ultimately it reduces capacitor requirement, and reactive power control can be established, its simple to design.[1][12][13]:

The following figure 4 shows the simulation result of three phase AC-DC conversion three level neutral point topology.

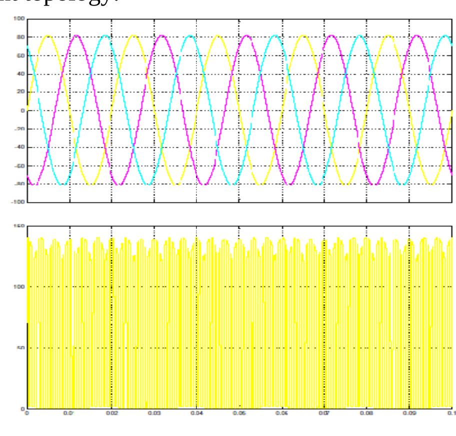

Fig. 4 Simulation result (a) AC input source (b) converted DC output

DC-DC Conversion Step:-

The second stage in the design of solid state transformer is DC-DC conversion stage in this stage a high frequency transformer is used for electric isolation it's mainly used for reduction of size of SST This stage will receive input from first stage i.e. AC-DC conversion. There are several topologies which we can use for DC-DC conversion stage here in this we are using the three phase dual active bridge converter [8].

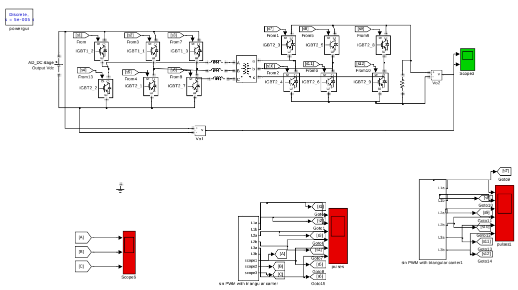

Fig. 5 DC-DC Conversion stage model

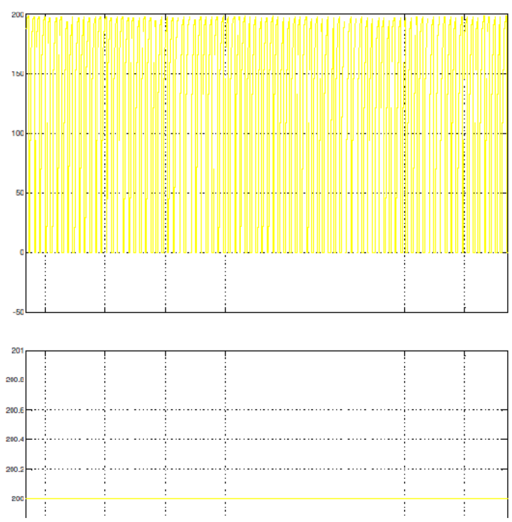

Fig.6 input output waveform of DC-DC Conversion (a) output (b) input from AC-DC stage

here in the three phase DAB conversion model three half bridges are used in both the side of transformer due to use of one single three phase transformer it can achieve good efficiency and low rating transformer.

DC-AC Conversion Step:-

This is the third and final stage for SST design in this stage output from DC-DC conversion stage is converted into AC voltage. Here in the design we have used a conventional three phase to DC conversion model is used as shown in the figure 7. This is simple for designing but there are several topologies for designing this stage. The output of this stage is shown in the figure 8.

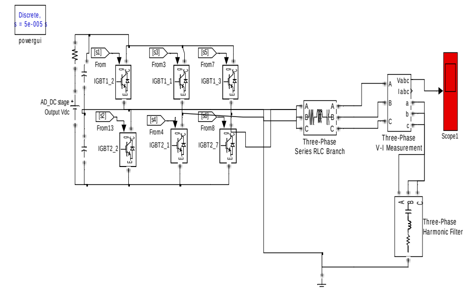

Fig. 7 DC-AC Conversion stage

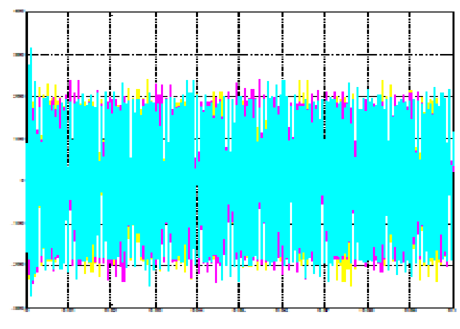

Fig. 8 output waveform of three phase AC from DC-AC conversion stage

As from the three stages of SST design this will be very useful for future distribution and renewable generation system and has an advantage of compact design too. It has the ability to manage the source and load too. There are so many architectures and topologies have been investigated by researchers and everyone has its unique features therefore for grid system it is very much suitable [3][8].

V. APPLICATIONS OF SST:-

There are lots of applications where it can be used the following schematic will give a brief idea about the uses of application of SST.

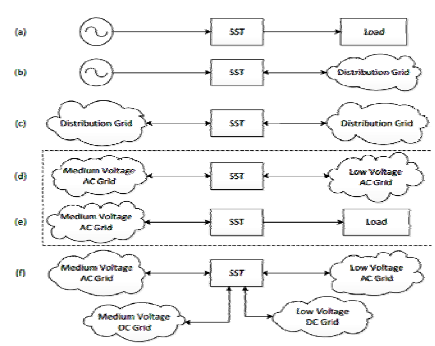

Fig. 9: Schematic overview of the SST applications

Future Benefits of solid state transformer

Integration with other systems The LV DC link in the SST topology provides a good and flexible integration point for renewable energy systems in the distribution grid. When the load demand is higher than the renewable energy source capabilities then a unidirectional converter could be used. Where the highest generation capabilities exceed the load demand during certain periods, then the excess power could be fed back to the grid by using a bidirectional converter.

DC as a Means of Power Delivery

The Solid state transformer concept is ideally suited to extend the use of DC, both in MV and LV applications. The difficulty in interrupting a DC feeder under fault conditions is often cited as a major hurdle in the acceptance of DC distribution in MV applications. The use of the SST to generate the DC is a means of controlling the system and interrupting fault currents. [13]

CONCLUSION

In this paper the concepts and developments in field of SST has been shown. Also various topologies and configuration implemented has been briefly reviewed and the model for the same is designed and the results are observed with graphs. The comparison between this various topologies of SST has been summarized. Finally it is concluded that the conventional transformer having disadvantages like bulkiness, poor voltage regulation saturation of core for non linear load, Majority of these problems can be eliminated by solid state power electronic transformer. Also it has the ability to work as energy router for smart grid energy internet.Therefore application of power electronic based SST now a day's not limited up to distribution level but research work suggested that SST are having ability to replace the conventional transformer too in near future.

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