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Study of Various Design for SST Implementation

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Abstract:

The Solid State Transformers (SST) are studied in the present paper with five descriptive designs.For future smart grid systems the solid state transformer (SST) is expected to play an important role.

In comparison to conventional magnetic transformers, SST is versatile enough to be modular in nature, allowing bi-directional power flow and can be used for both AC and DC grids.The aim of the paper is to study the most appropriate designs compared to a regular transformer.The distinction is based on switching failure, number of switches, control properties and features enabled. It was concluded that the most convenient implementation was a three-stage configuration comprising separate AC-DC, DC-DC and DC-AC steps.To illustrate the desired SST, a Simulink Model is designed to describe this three stage configuration.

Keywords **—HF Transformers, Solid State Transformers, Pulse Width Modulation(PWM), Dual-Active Bridge, Power Transformers .**

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I. INTRODUCTION

The up-gradation of the power distribution network is an important step for a future Smart Grid.Transformers, as we know, are the basic eleme nts of the power grid; they transform the high-voltage electricity supplied by power lines to the level need ed for consumers and vice versa at generating statio ns.[1]Transformers are widely used in electric power system to perform the primary functions, such as voltage transformation and isolation. They are one of the heaviest and most expensive devices in an electrical system because of the large iron cores and heavy copper windings in the composition. This classical transformer has to be replaced with a solid state transformer (SST) which is a reduced size high frequency transformer[3] forvoltagelevel control, and avarietyof switching to ol forinput and output power shape and controlthatcan enable bi-directional power flow. SSTs have the potential to provide additional power quality andcontrollability benefits compared to a conventional transformer, such as output voltage control, reactive power compensation, voltage regulation and power factor correction[4].

In addition to the benefit of a smaller size and weight due to the high frequency (HF) transformer, the SST utilizes modern Power Electronic devices that can attain an efficiency that is roughly equivalent to the standard transformer with the same ratings. Furthermore, the SST offers additional features such as on-demand reactive power support to grid, the power quality, current limitation, storage management and a DC bus.

Since the selection of the suitable topology for the application of the SST is a crucial aspect, this paper tackles that issue by comparing some potential designs which at least meets the bidirectional power flow requirement.

II. SST CONFIGURATIONS

For the purpose of comparing of the various topologies, a number of various topologies for SST and general AC-AC power conversionsis listed herein[4]-[10]. Many of those SST topologies available are not bidirectional. The SST topology classification method and suitable parameters according to specific requirements was presented in [5]. Four SST configurations, which includes all the possible topologies of SST, are described in the description as shown in Fig. 1:

a) single-staged with no DC link,
b) two-staged with a low voltage DC (LVDC) link,
c) two-staged high voltage DC (HVDC) link,
d) three-staged with both the HVDC and LVDC links.

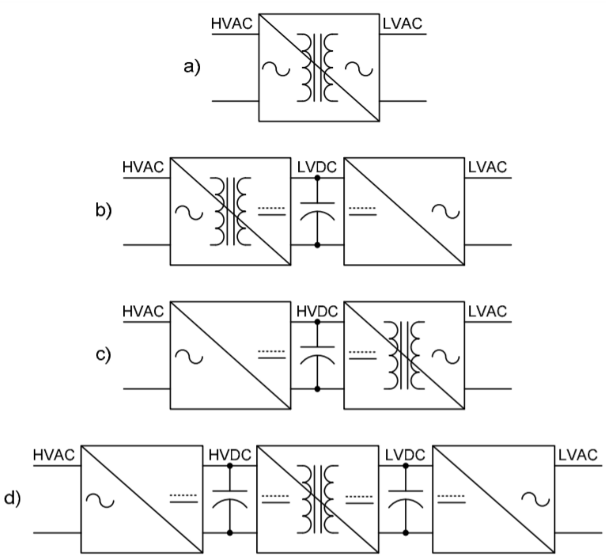

Fig.1. SST configurations: (a) single-staged with no DC link,(b) two-staged with LVDC link, (c) two-staged with HVDC link, and (d) three-staged with LVDC and HVDC links.

There are currently no readily available HF transformers with distribution voltage ratings. To solve this issue, it is possible to use a modular approach to meet this requirement.[11] Also, the ripple currents may be minimized by using smaller filter sizes.

Fig. 2 demonstrates a modular two-stage configuration, where a modular implementation is needed only for the AC-DC stage. As in the previous case, voltage and current sharing may not be intrinsic in this configuration, because it depends on the type of AC-DC converter.

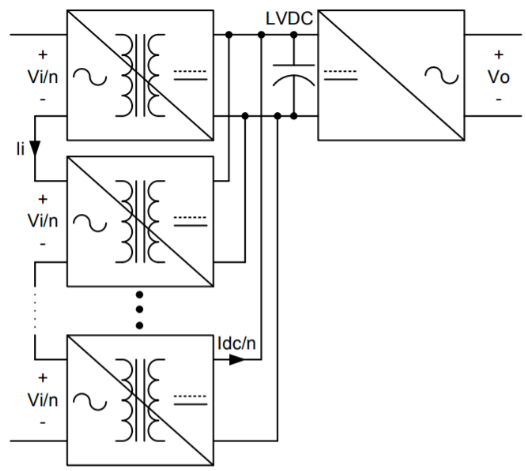

Fig. 2. Modular two-stage SST.

Fig. 3 demonstrates a three-staged modular configuration Here, a multilevel converter is implemented in the input stage; thus, it may not require a modular implementation. The isolated DC-DC stage must, however, be modular. Depending on the selected topology, current and/or voltage control is required in this configuration to ensure voltage and current sharing.

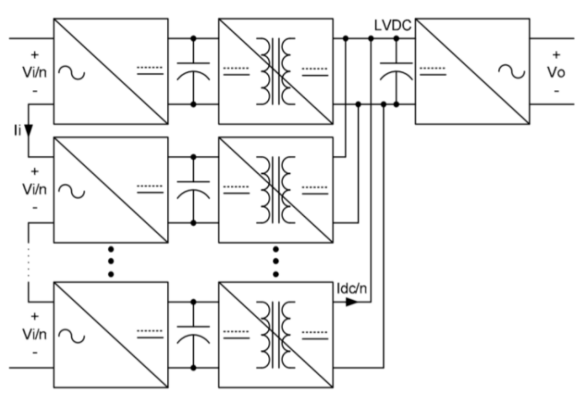

Fig. 3. Modular three-stage SST.

III. SELECTED SST TOPOLOGIES

The SST topologies can replace a regular transformer. Five typical SST topologies have been chosen for detailed analysis and comparison:

A. modular single-staged AC-AC Full-bridge converters,
B. modular single-staged AC-AC Flyback Converters,
C. modular two-staged consisting of AC-DC isolated Boost converters and a pulse width modulated (PWM) dual-phase inverter,
D. modular two-staged AC-DC Dual Active Bridges (DAB) and PWM dual-phase inverter.
E. three-stageDC-DC DAB modules and a PWM dual-phase inverter.

A. Single-stage: AC-AC Full-bridge Converter

In single-stage SST topologies, simple control is required. A simplistic version of this converter is presented in [12]. In this case, before going through the HF transformer, the input voltage is converted into a high-frequency square wave with a 50% duty cycle. The voltage is rectified back to its original

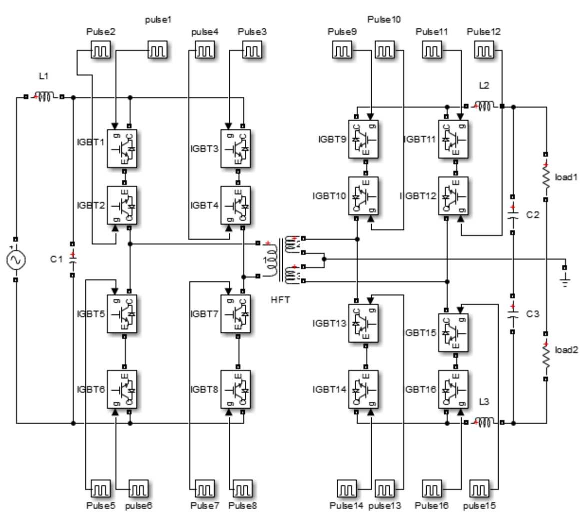

Fig. 4..Single-stage SST based on an AC-AC Full-bridge converter

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sinusoidal form, on the low voltage side. This simple approach eliminates the need for input and output inductive filters.

The duty cycle can be modulated to provide the output voltage control. However, to allow the buck mode and another one to the input to filter the generated ripple current, an inductive filter must be added to the output. Fig. 7 shows one module to implement this SST topology. The main drawback of this method is that the increased filter size that affects the input power factor.

B. Single-stage: AC-AC Flyback

There are some DC-DC converter topologies that can be converted into AC-AC converters by swapping some or all of the switches with four-

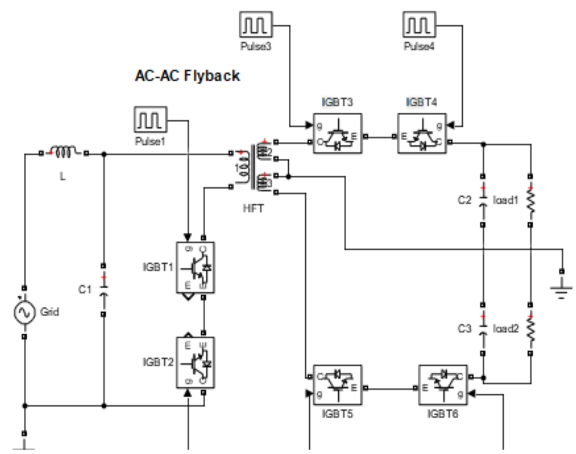

Fig. 5.Single-stage SST based on an AC-AC Flyback converter.

quadrant. It is derived from the simplest discrete topology of the DC-DC converter, the Flyback, as shown on Fig 8. There is the least amount of module switches[13]. The modulation of the duty cycle enables the voltage adjustment of the output. Apart from the lack of a DC linkage, the primary disadvantage is that the filters required are large in size because of their large ripple currents.

C. Two-stage: AC-DC Isolated Boost + PWM Inverter

This topology is based on the AC-DC model of the isolated Boost converter, and is the same as the isolated DC-DC version [14]. The PWM voltage duty cycle at the input terminals has to be modulated correctly in order to obtain a sinusoidal input current. To withstand bi-polar voltage and current, the switches on the high side must be four-quadrant. The Fig. 6 shows only one AC-DC module for this topology.

The DC-AC stage is a double-phase inverter that gives a bi-directional power flow between the LVDC link and the ±120 V AC buses. The extra leg is driven by a gate signal with a constant duty cycle of 50% and offers a ground level output, as compared to a regular H-bridge converter. For the rest of the SST topologies this DC-AC implementation phase is common.

The use of two different controls depending on the power flow path is a drawback, as in the DC-DC version. Furthermore, because of the absence of a HVDC link, the LVDC link voltage shall have a larger 120Hz ripple, as the connector capacitor to the LVDC will have to absorb the 120Hz ripple currents from both AC sides. The voltage regulation is thus not tight as its bandwidth is significantly lower than that of the input current due to the cascade control.

D. Two-stage: AC-DC DAB + PWM Inverter

This topology for the SST is based on AC-DC version of DAB. The typical large signal average model is same as that of the DC-DC version.[15] The phase shift angle can be modulated to get a sinusoidal input current. The dual AC Bridge provides smooth power control in both directions and zero voltage switching for a wide range. Two disadvantages of this converter are the high sensitivity of the typical active power flow to the variability in inductance of the leakage and the highest ripple current. As the phase shift is the main control variable, the LVDC connection voltage and the input current must be regulated.The Fig. 7shows this topology with only one AC-DC module. In addition, the architecture of the control is very constrained due to the presence of the second order filter at the input and results in low bandwidth.

E. Three-stage: PWM Rectifier + DC-DC DAB + PWM Inverter

This SST topology has very good controllability, which allows multiple functions suitable for an SST [16].This topology is shown in Fig8, showing single module in both the AC-DC and isolated DC-DC stages. The AC-DC stage is a full-bridge rectifier which will introduce a cascaded mul tilevel rectifier in the modular configuration. The isolated DC-DC is based on DAB modules which interface the HVDC link to the LVDC linkage. The DC-AC stage is again implemented by a double-phase inverter. Since this topology consist of a large efficiency and reliability. This is a major drawback of this topology.

IV. COMPARISON OF VARIOUS DESIGN OF SST

The five topologies selected are compared here to determine their suitability for SST applications. The comparison is based on switch count, switch tension, switch losses, control properties. The switch count is based on the number of switches on high voltage side, and the number of switches on low voltage side provided by each topology. This also takes into account the characteristics of the switching stress. Also, the frequency used for the HF transformer is related to the maximum switching frequency of the high voltage side IGBTs. Based on this, all SST topologies require 3 modules, with the exception of the topology based on Flyback which requires 6 modules because of its higher voltage stress.

This comparison is performed through extensive simulationof each switching model using the software MATLAB Simulink®.

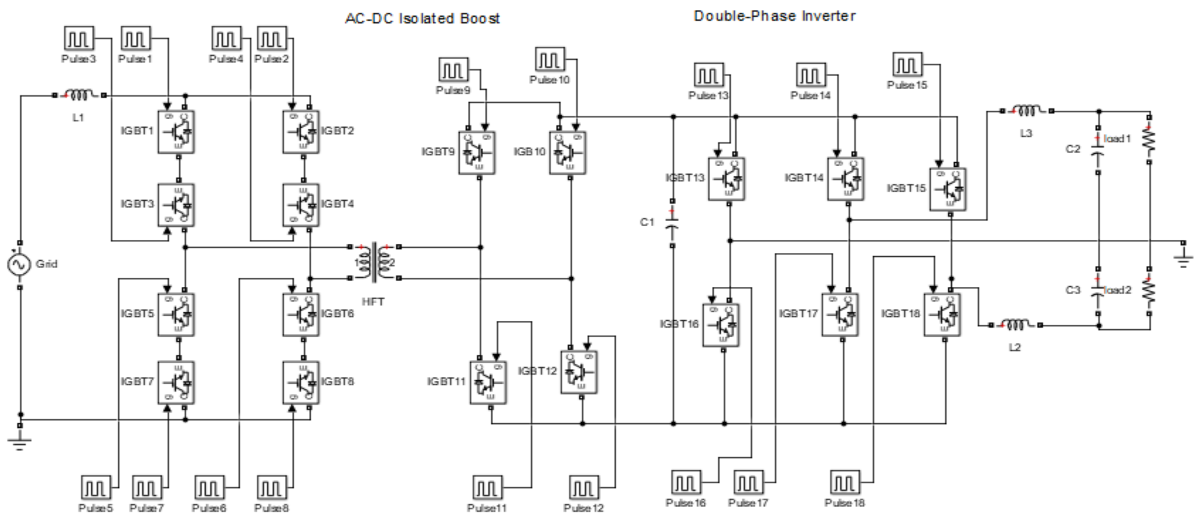

Fig.6.:Two-stage SST based on an AC-DC Isolated Boost converter

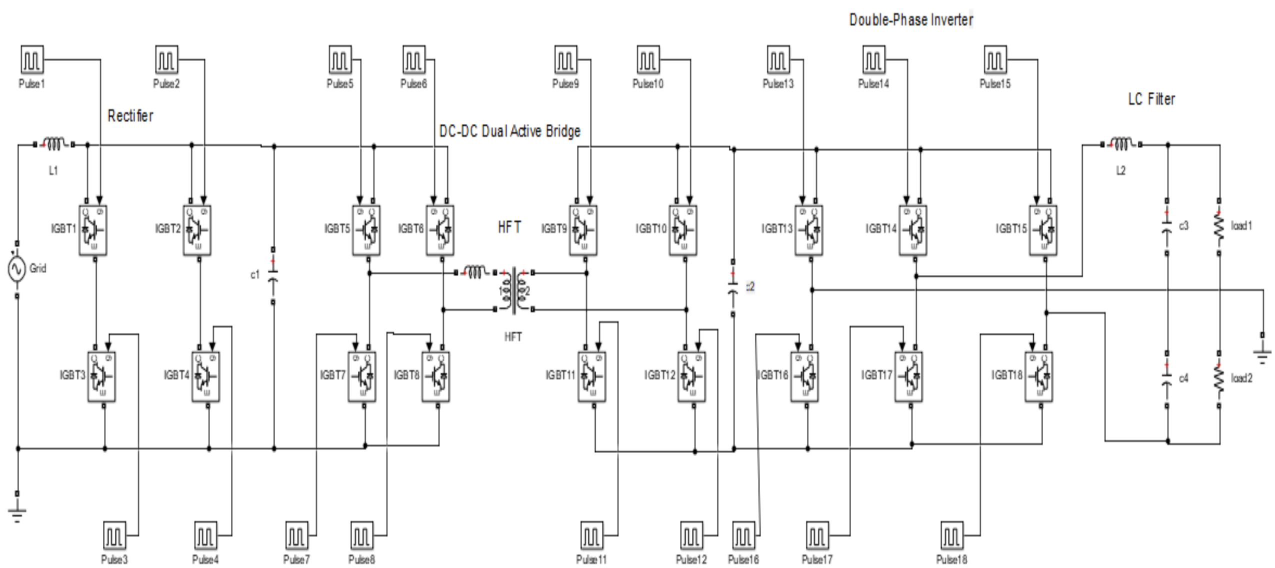

Fig.7.: Two-stage SST based on an AC-DC DAB.

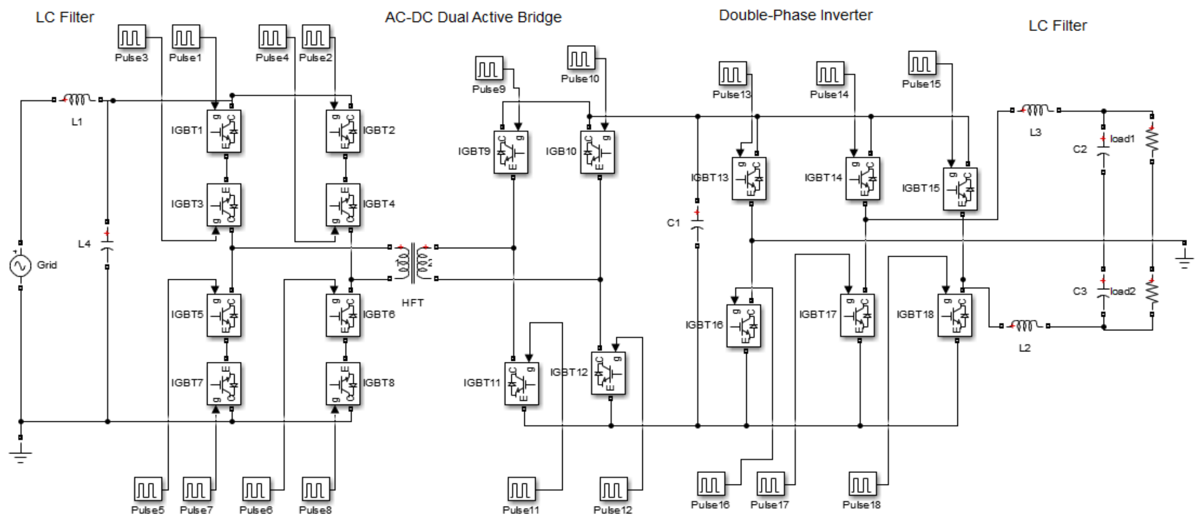

Fig.8.: Three-stage SST based on a DC-DC DAB.

V. SIMULATION RESULTS

A Simulink® block-set with an SST was developed based on the three-stage average model. This model implements all the functionalities needed as the ideal SST. Fig. 9 shows the simulation output from running the switching model of the three-stage DAB based SST.

VI. CONCLUSION

A topology comparison of fiverepresentative SST topologies has been presented herein.The main challenges posed by existing power grid systems are the proliferation of renewable sources, distributed generation, distributed storage, and bi-directional power flow.SSTs can be the key to the future grid topologies..Although SSTs are on the track of commercialisation, a number of technical problems still need to be developed and controlled, such as efficiency size and reliability.Because of many advantages and feasible high voltage levels the wind integration and locomotive applications are expected to be the first to implement SSTs.

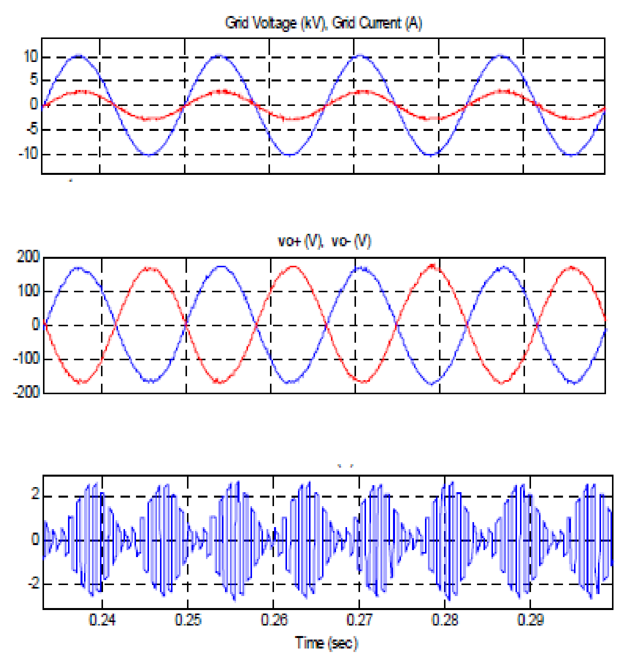

Fig.9.:Three-stage DAB based SST switching model waveforms

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