A Research In AC-AC/DC-DC DAB Based Solid State Transformers

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ABSTRACT:

This dissertation gives the investigation in the area of AC/AC power conversion and DC/DC with solid state transformer. The proposed single phase solid state transformer with bidirectional flow capability may find application in compact isolated PWM AC drives. This topology along with the proposed control has the following advantages. A)input power factor correction b) Common mode voltage suppression at the load end , c) high quality output voltage waveform (compared to the conventional space vector PWM) and d)minimizing output voltage losses, And lossless commutation for soft switching .

KEYWORDS: *Solid State Transformer, Bridge converters, Fly back converters, DAB converter Module*

INTRODUCTION:

Replacement of a line frequency transformer with a high frequency transformer results in the considerable reduction in size and cost. With the advancement of power semiconductor devices it is possible to apply high frequency PWM converter as distribution transformers[1], and the development of high voltage and high current devices capable of switching at a high frequency and have a relatively low conduction loss [2]. These development have enabled the possible realization of HFT link AC/AC power converters known as power electronic converters (PET) or solid state transformers (SST). SSTs can be employed in modern power distribution systems due to advanced features like voltage and frequency control, reactive power support etc. Another major area of application is high power density electric motor drives for example in Electric Traction [3] [4[5], Wind Power [6] [7].

Extensive classification of different types of SSTs found in [8].Two stage SSTs (AC-DC-AC) are of two kinds: high voltage DC link (HVDC) [9] and low voltage DC link (LVDC) [3] [4] [5].

SST TOPOLOGIES :

The selection of the appropriate topology for the SST is a key aspect. In [10] the issue is addressed by comparing some of the potential topologies that support bidirectional power flow as a minimum requirement. In order to select these potential topologies for comparison, a number of topologies proposed for SST as well as for general AC-AC power conversion have been surveyed there in.

An approach to classify the SST topologies and select the appropriate configuration according to the specific needs was introduced.

In this classification, as seen in Fig.1 four SST configurations that cover all the possible SST topologies are identified: a)single stage with no DC link, b)two-stage with low voltage DC (lvdc) link, c) two –stage with high voltage DC (HVDC) link, and d)three-stage with both HVDC AND LVDC links. The DC link of the third configuration is not appropriate for DES and DER integration since it is high voltage and no isolation from the grid : therefore, topologies under that classification are not practical for SST implementation.

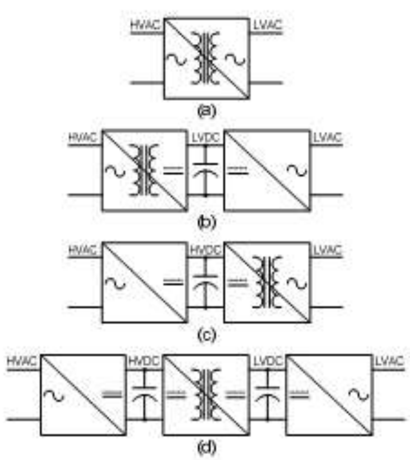

Fig.1. SST configurations: (a) single-stage, (b) two-stage with LVDC link (c) two-stage with HVDC link, and (d) three-stage.

Presently, Insulated Gate Bipolar Transistors (IGBT) and HF transformers with distribution voltage ratings are not readily available. In order to solve this problem, a modular approach can be used to meet this requirement in which the high voltage AC (HVAC) sides of several modules are series connected[10]. Additionally by using the interleaving approach, the ripple currents may be reduced which translated into smaller filter size. Fig.2 shows a fully modular single-stage configuration a modular two-stage configuration is shown in Fig.3 where only AC-AC stage is modular. Fig.4 shows a modular three stage configuration.

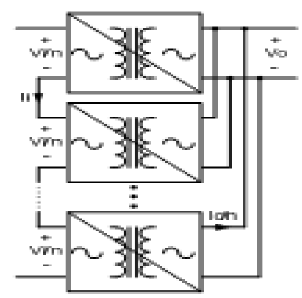

Fig.2 modular single-stage SST

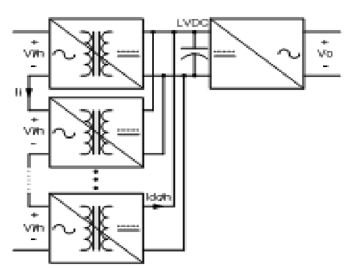

Fig.3 modular two-stage SST

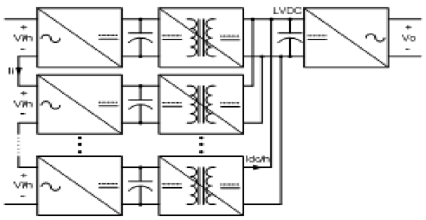

Fig.4 modular three-stage SST

Six representative SST topologies have been identified in [11].

a) A single-stage SST comprising AC-AC Full-bridge converter modules.
b) A single-stage SST comprising AC-AC Fly back converter modules.
c) A two-stage SST comprising AC-DC isolated boost converter modules and a pulse with modulated PWM dual-phase inverter.
d) A two-stage SST comprising AC-DC dual active bridge (DAB) converter modules and a PWM dual-phase inverter.
e) A three-stage SST comprising a cascaded-full-bridge rectifier, DC-DC DAB modules and a PWM dual-phase inverter.
f) A three-stage SST comprising a diode-clamped multilevel rectifier, DC-DC full-bridge converters and a PWM dual-phase inverter.

The single-stage SST topologies require simple control. Their main drawback is the lack of capabilities that the presence of a DC link offers, e.g. Input Power Factor correction. Fig.5 and Fig.6 show the AC-AC Full bridge SST and the AC-AC Fly back based SST, respectively. For simplicity, both SST topologies are implemented with a single AC-AC module. The two-stage SST topologies offer a LVDC link for DER and DES integration. However, due to their lack of HVDC link, the LVDC link voltage may have a larger 120Hz ripple, caused by the 120Hz ripple currents generated by both AC sides

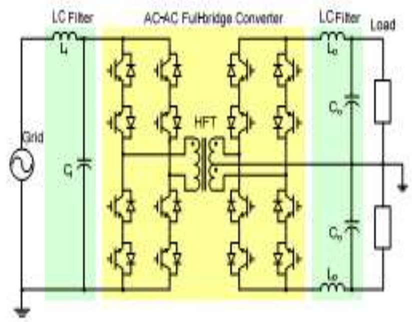

Fig.5 Single-stage SST based on an AC-AC Full-bridge converter.

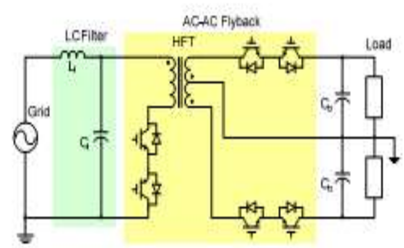

Fig.6 Single-stage SST based on AC-AC Fly back converter.

The selection of a larger capacitance leads to lower bandwidth voltage regulation. Fig.6 and Fig.7 show the AC-DC isolated Boost based SST and the AC-DC DAB based SST, respectively. Both are also implemented with a single AC-DC module. The three-stage SST topologies offer superior controllability that enables all of the functions that are desirable for an SST. The main drawback of this SST topology is large number of components which translates into possibly lower efficiency and reliability.

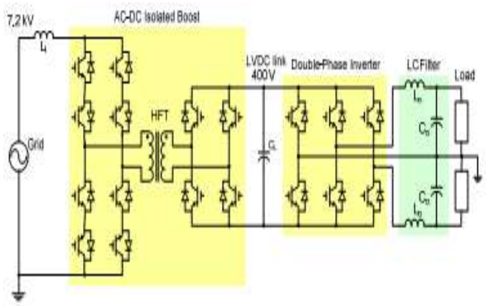

Fig.7 Two-stage SST based on an AC-DC Isolated Boost converter

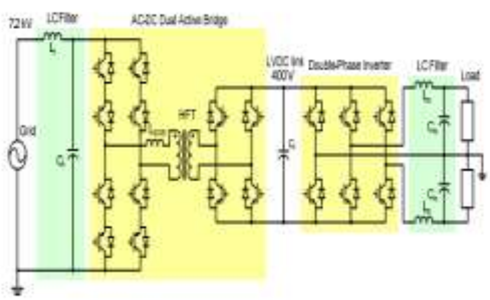

Fig.8 Two-stage SST based on an AC-DC DAB

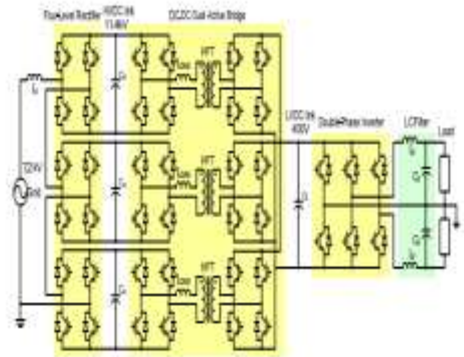

Fig.9. Modular three-stage SST based on a Four-level Rectifier and three DC-DC DAB converters

Fig.9 and Fig.10 shows the fully modular versions of DC-DC DAB based SST and the DC-DC Full-bridge SST, respectively.

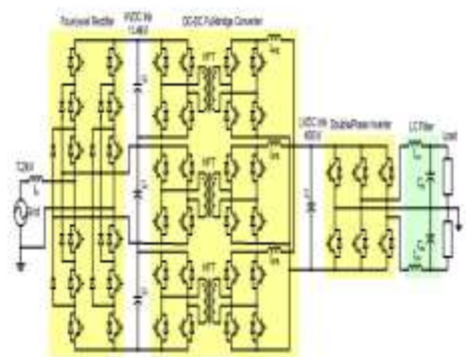

Fig.10. Modular three-stage SST based on a Four-level Rectifier and three DC-DC Full-bridge converters.

Hence the Fig 11. Shows the functional capabilities supported by the SST topologies

Functionality	Single-stage		Two-stage		Three-stage	
	AC-AC Flyback	AC-AC Full Bridge	AC-DC Boost + Inverter	AC-DC DAB + Inverter	Cascaded Full-bridge Multilevel Rectifier + DAB + Inverter	Diode-clamped Multilevel Rectifier + Full-bridge + Inverter
Bidirectional power	Yes	Yes	Yes	Yes	Yes	Yes
LVDC for DES and DER	No	No	Yes	Yes	Yes	Yes
DES management	No	No	Yes	Yes	Yes	Yes
Reactive power support to grid	No	No	Yes	Yes	Yes	Yes
HVDC link regulation	N/A	N/A	N/A	N/A	Good	Good
LVDC link regulation	N/A	N/A	Good	Poor	Very good	Very Good
Output voltage regulation	Poor	Poor	Good	Good	Good	Good
Input current regulation	No	No	Very good	Good	Very good	Very good
Input voltage sag ride through	Poor	Poor	Good	Good	Very good	Very good
Input current limiting	No	No	Yes	Yes	Yes	Yes
Output current limiting	No	No	Yes	Yes	Yes	Yes
HVDC undervoltage protection	N/A	N/A	N/A	N/A	Yes	Yes
HVDC overvoltage protection	N/A	N/A	N/A	N/A	Yes	Yes
LVDC undervoltage protection	N/A	N/A	Yes	Yes	Yes	Yes
LVDC overvoltage protection	N/A	N/A	Yes	Yes	Yes	Yes
independent frequency	No	No	Yes	Yes	Yes	Yes
independent power factor	No	No	Yes	Yes	Yes	Yes
Modularity Inplementation	Simple	Simple	Simple	Hard	Simple	Simple

* N/A = Not applicable

Fig.11. Functional capabilities supported by the SST topologies

LOSSLESS COMMUTATION :

Commutation refers to the change in the direction of the current in each of the primary windings and transfer of the current from one half of the secondary winding to the other half when the modulation is changing from one state to another. Transformer windings have leakage inductances. In Fig ,L_1 refers to the primary leakage inductance.L21 and L22 represent the leakage inductances present in the upper and lower half of the secondary winding respectively.

In order to change the current through these leakage inductances a proper voltage needs to be applied Hereto he input converter is switched to provide the required voltage from the input ac source. Note that at any instant of time, at least 0.5 times the peak of the input line to neutral voltage is available (in both directions: positive or negative), to be applied across the transformer primary winding of any phase.

Depending on the direction of the output current and the type of change in the modulation state (either upper to lower or otherwise) the commutation process can be classified into four cases. Tables I and II provide the details of the switching schemes for all of these four cases. As the commutation process is similar for all the three phases, commutation of only one phase (phase-R) misanalysed here. Details of one of the four cases of com-mutation are presented. Figs. 5-9 show the different configurations during commutation when the modulation state is changing from lower to upper state and the load current is negative. Since the commutation period is much smaller than the time period (To =2π/ωo) of the output load current, the load is modeled as a dc current source.

TABLE I
$i_o > 0$

	Q_1	Q_2	Q_3	Q_4	Q	D_1	D_2	D_3	D_4
P	1	1	0	0	0	0	1	0	0
PN1a	1	0	0	0	1	0	1	0	0
PN1b	1	0	1	0	1	0	1	0	1
N	0	0	1	1	0	0	0	0	1
NP1a	0	0	1	0	1	0	0	0	1
NP1b	1	0	1	0	1	0	1	0	1

TABLE II
$i_o < 0$

	Q_1	Q_2	Q_3	Q_4	Q	D_1	D_2	D_3	D_4
P	1	1	0	0	0	1	0	0	0
PN1a	0	1	0	0	1	1	0	0	0
PN1b	0	1	0	1	1	1	0	1	0
N	0	0	1	1	0	0	0	1	0
NP1a	0	0	0	1	1	0	0	1	0
NP1b	0	1	0	1	1	1	0	1	0

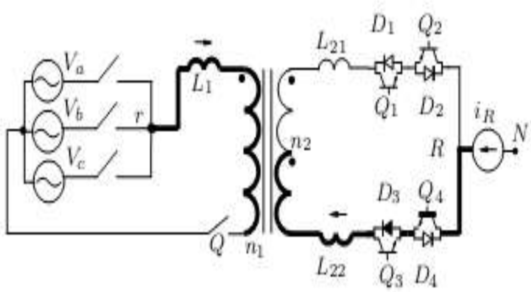

Fig.12. Power transfer through lower half of the secondary winding

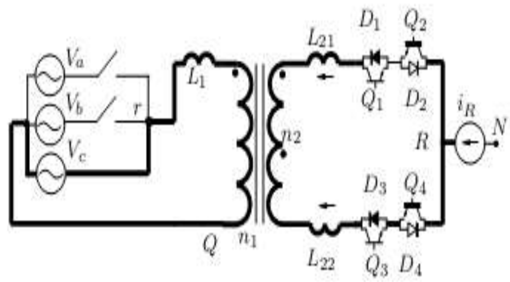

Fig.12. NP1 is high

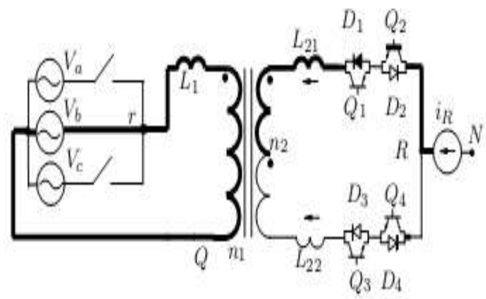

Fig.13.NP2 is high

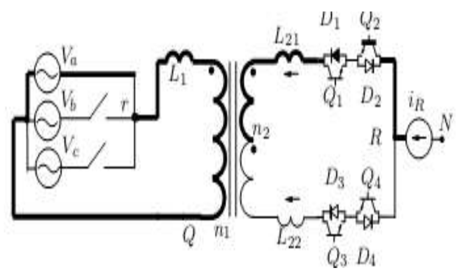

Fig.14.NP2 is high

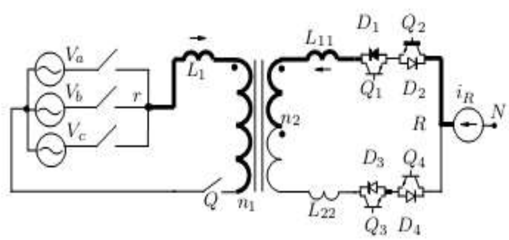

Fig.15.Powertransferthroughthe upper half of the secondary winding

Fig. 12 shows power transfer to the load through the lower half of the secondary winding. Switch Q4and diodeD3are conducting. Switch Q is open during the power transfer mode. The commutation is done on a phase-by-phase basis. A proper voltage needs to be applied to the primary of each phase that is independent of other phases. This is the reason why switch Q is turned ON during commutation. Commutation starts when signal NP1 goes high .The first stage of NP1 is referred to as NP1ain the Tables I and II. At this stage, switch Q3is turned OFF and Q is turned ON. This particular commutation requires a negative voltage to be applied transformer primary. Say that at this instant of time v

Cn is most negative input voltage. So the switch S cris turned ON. During the second stage of NP1 (NP1b), switch Q2isturned ON. This forward biases the diode D1(Fig. 13)and current i21starts building in the upper half of the primary winding. The equivalent circuit of this stage is given in Fig. 16.

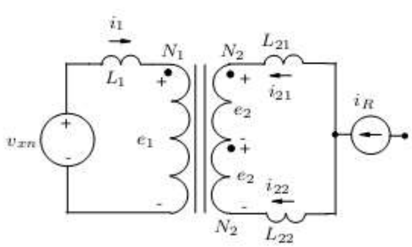

Fig.16 equivalent circuit during commutation

And Fig.17, 18 shows the output waveforms for commutation process.

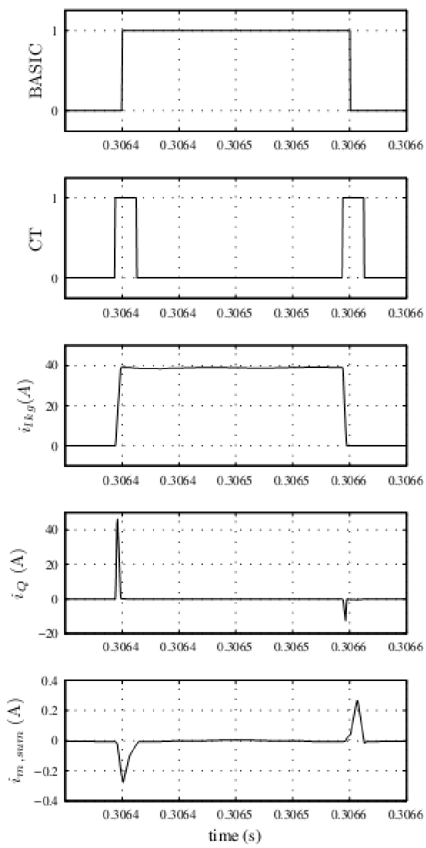

Fig.17Output Waveforms for Commutation

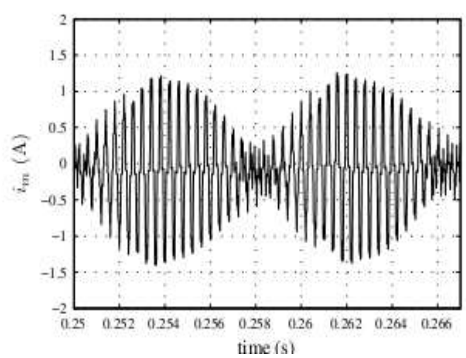

Fig.18. Magnetizing Currents

CONCLUSION:

In this work , a naval ac-ac and dc-dc dual active bridge converter is proposed for solid state transformer application. A high frequency transformer is used to minimize the bulk of passive components. Hence all possible topologies were discussed along with the inherent capability of output power factor and the input power factor is control and loss less commutation for leakage inductances.

Compared to the state-of-the-art approach with LFT and three-phase PWM rectifiers, the AC/DC SST achieves 40% lower losses while also providing full galvanic isolation and the characteristic increased functionalities provided in general by AC/DC SST technology. As a consequence, unidirectional SST structures are a promising solution for supplying high-power DC loads directly from the MV AC grid.

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