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ORIGINAL ARTICLE

Mitigation of voltage sag, swell and power factor correction using solid-state transformer based matrix converter in output stage

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Abstract This paper presents a novel topology of solid-state transformer (SST). In the design process, the AC/DC, DC/AC and AC/AC converters have been integrated to achieve higher efficiency. To obtain higher efficiency from other SST with DC-link topologies, the AC/DC and DC/AC converters have been integrated in one matrix converter. The proposed SST performs typical functions and has advantages such as power factor correction, voltage sag and swell elimination, voltage flicker reduction and protection capability in fault situations. In addition, it has other benefits such as light weight, low volume and elimination of hazardous liquid dielectrics because it uses medium frequency transformer. The operation and some performances of the proposed SST have been verified by the simulation results.

1. Introduction

Transformers are widely used in electric power system to perform the primary functions, such as voltage transformation and isolation. Transformers 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 [1]. A new type of transformers based on power electronic converters has been introduced, which realizes voltage transformation, galvanic isolation, and power quality improvements in a single device. The SST provides a fundamentally different and more complete approach in transformer design by using power electronics on the primary and secondary sides of the transformer. Several features such as instantaneous voltage regulation, voltage sag compensation and power factor correction can be combined into SST.

Different topologies have been presented for realizing the SST, in the recent years [2–13]. These topologies are called as PET or EPT. In [2] the AC/AC buck converter has been proposed to transform the voltage level directly and without any isolation transformer. This method would cause the semiconductor devices to carry very high stress.

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Nomenclature

DC	direct current	V_i	primary voltage in MF transformer
AC	alternative current	V_S	secondary voltage in MF transformer
SST	solid-state transformer	N_i	primary turn winding in MF transformer
PET	power electronic transformer	N_S	secondary turn winding in MF transformer
EPT	electronic power transformer	IGBT	insulated gate bipolar transistor
MF	medium frequency	f	frequency
VSC	voltage source converter	m	modulation index
PWM	pulse width modulation	f_S	frequency of the main supply in AC/AC converter
SPWM	sinusoidal pulse width modulation	f_T	frequency of the triangular carrier
V_{in}	input voltage	Vo	output voltage
I_{in}	input current	Io	output current
V_{dc}	DC link voltage		

In second type, the line side AC waveform is modulated into a MF square wave, coupled to the secondary of MF transformer, and again is demodulated to AC form by a converter in second side of MF transformer. This method however does not provide any benefits such as instantaneous voltage regulation and voltage sag compensation due to lack of energy storage system [3–6].

Another type is a three-part design that utilizes an input stage, an isolation stage, and an output stage [7–13]. These types enhance the flexibility and functionality of the electronic transformers owing to the available DC links.

In the recent years, increasing attention has been drawn to the matrix converters as a variable voltage variable frequency AC/AC power processing system with applications to the fields that require smaller size, higher power density and easier maintenance [14–16].

This paper investigates the SST that includes three parts input stage, isolation stage, and output stage. Proposed SST includes AC/AC converter. The proposed AC/AC converter can generate desired output voltage from square input voltage. The main purpose of this paper is reduction in the stage and components of the three-part SSTs.

The proposed SST includes only one DC-link capacitor and in output stage, rectifier and inverter have been integrated to reduce the power losses and increase the efficiency. The proposed topology performs input power factor correction, eliminates voltage sag and swells, reduces the voltage flicker and does not utilize mineral oil or other liquid dielectrics.

Many different algorithms are presented to switching in power electronic converters. A very popular method is classic carrier based SPWM that is used in this paper.

To verify the performance of the proposed SST, computer-aided simulations are carried out using MATLAB/SIMULINK.

2. Conventional SST

In the SST using MF AC-link without DC-link capacitor, the line side AC waveform is modulated with a converter to a medium-frequency square-wave and passed through a MF transformer and again with a converter; it is demodulated to AC form power-frequency. Since the transformer size is inversely proportional to the frequency, the MF transformer will be much smaller than the power-frequency transformer. So, the transformer size, weight and stress factor are reduced considerably [3]. This converter does not provide any benefits in terms of control or power-factor improvement, and may not protect the critical loads from the instantaneous power interruptions due to lack of energy storage system. In addition, another drawback is the inability to prevent primary voltage harmonics from propagating into the load side.

The SST with DC-link capacitor includes three stages. First stage is an AC/DC converter which is utilized to shape the input current, to correct the input power factor, and to regulate the voltage of primary DC bus. Second stage is an isolation stage which provides the galvanic isolation between the primary and secondary side. In the isolation stage, the DC voltage is converted to a medium-frequency square wave voltage, coupled to the secondary of the MF transformer and is rectified to form the DC link voltage. The output stage is a voltage source inverter which produces the desired AC waveforms [4–8]. In comparison with first SST, the voltage or current of SST can be flexibly controlled in either side of MF transformer. It is possible to add energy storage to enhance the ride-through capability of the SST or to prepare integrated interface for distributed resources due to the available DC links. It prevents the voltage or current harmonics to propagate in either side of the transformer, even if the input voltage has low order harmonic content or the load is not linear but they need too many AC/DC links, large bulky magnetic components or DC-link electrolytic capacitors. Thus they are resulted in a rather cumbersome solution and multiple power conversion stages can lower the transformer efficiency.

3. Proposed SST

The block diagram of the proposed SST is shown in Fig. 1. As can be seen from the Fig. 1, this is a three-stage design that

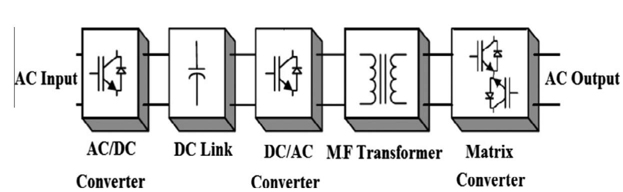

Figure 1 Block diagram of proposed SST with DC link.