

## Simulation Study of a Power Electronic Transformer Based on Matrix Converter

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**Abstract**— A power electronic transformer (PET) is a direct AC/AC converter with a high frequency isolation. Various topologies of electronic PETs have been discussed in recent literatures. This paper is concentrated on the simulation study of an electronic transformer adopting matrix converter on either side of the high frequency isolation transformer. The industrial standard power system simulation package PSAD/EMTDC is used for the modeling of the PET. The PET described can convert a sinusoidal AC to a lower or higher voltage and/or to a lower or higher frequency without DC link. Both the steady state and transient performance of the converter are carried out to assess the performance. The simulation results of the converter shows that the PET accomplishes high frequency isolation, bidirectional power flow, two stage power conversion, higher power density, controllable input source displacement power factor, and lower harmonic distortion on both input and output sides.

**Keywords**— *electronic transformer, AC-AC converter; high frequency link; matrix converter; PSCAD/EMTDC*

### I. INTRODUCTION

Electronic converters have wide application such as electrical drives, regulated power supplies, and variable voltage sources. Power electronic converter can be divided as isolated and non-isolated. Isolated converters are preferred over non-isolated because an unwanted effect in the load side will not affect the source side. Transformers are generally used for isolation of input from the load. Apart from isolation, transformer provides voltage transformation, noise decoupling etc. Conventional isolation transformer is operated at line frequency of 50Hz or 60Hz. Line frequency transformers have lower flux utilization. This makes it heavy, bulky and very expensive part of an electrical converter system. The size and weight of the transformer can be reduced by increasing the saturation flux density of the core material and the maximum allowable temperature rise

in the core and windings. Since the saturation flux density is inversely related to frequency, higher frequency of operation reduces the magnetic core size by increasing the flux utilization [1]. So a high frequency isolated power electronic converter provides overall size and cost advantage over a line frequency transformer. This kind of small high frequency isolated power converters are called PETs.

A number of PETs have been discussed in recent literatures [1]-[4]. The cheap and easily available ferrite cores are used as core for high frequency transformers. This makes the high frequency transformer implementation easy. Higher frequency of operation makes the transformer, energy storage, and passive components smaller and lighter. The system response is faster and less acoustic noise at higher frequencies. These advantages of high-frequency link power converters gives it increasing attention as an alternative to more conventional DC link power conversion systems. High frequency DC/DC converters have been employed successfully in recent decades. This demonstrated the benefits of operation at high frequency. Lots of research have been carried out on high frequency link AC/DC converters, the high-frequency link DC/AC converters (switching mode rectifiers), and the high frequency link DC/AC inverters [5]. Few researches happened on direct AC/AC power converters. Most of the research on AC/AC converters were mainly limited to non-isolated AC/AC converters such as direct matrix converter [6], the pulse width modulated (PWM) AC choppers [7], and the soft switched AC link buck-boost AC/AC converter [8]. These converters have the features such as single or two stages of power conversion, low voltage transmission ratio, no need of intermediate dc-energy storage components etc.

A number of research have been taken place on thyristor phase controlled cycloconverters [9] and matrix converters [10] without electrical isolation. Therefore AC/AC converter

with high frequency isolation are a leading research content of power electronics, and a key technical foundation on new type Power Electronic Transformers (PET), regulated sinusoidal ac power supplies and ac regulators.

PET is a new concept and a few literatures have been reported on three-phase PETs [3][4]. But, they need too many ac/dc links, large bulky magnetic components or dc-link electrolytic capacitors. So they are more complex and all the output loads are assumed to be balanced. First high frequency AC link AC/AC converter was proposed in [5]. It has two cycloconverters with a high-frequency AC link in between. Literature [11] and [12] has proposed H-bridge and push-pull circuits respectively.

This paper is intended to study the simulation of a high-frequency link direct ac/ac three phase matrix type PET. The steady state and transient analysis of PET based on matrix converter using PSCAD/EMTDC software is discussed. The simulation results are shown to verify the performance.

## II. CONVERTER CONFIGURATION

The main components of the three phase PET considered here are three-phase to single phase matrix converter, single phase high frequency transformer, load side single-phase to three-phase matrix converter and output filters. The converter on the primary side converts the input source line frequency voltage to high frequency square wave pulse. An efficient high frequency transformer is used to transfer the square wave pulse to the secondary side converter. The utility side matrix converter is realized using ten unidirectional switches instead of six bidirectional IGBT switches with unfiltered DC link. The real implementation of the PET based on dual bridge matrix converter is shown in Fig. 1. The load side converter consists of a full bridge active rectifier (R1-R4) and conventional voltage source inverter (VSI) structure (T1-T6). The high frequency square wave signal is rectified to dc using the rectifier. By the dc link voltage  $V_{dc}$  is maintained at a desired magnitude by proper selection of transformer turns ratio. The three phase voltage source inverter is modulated using well known space vector PWM (SVPWM).

### A. Primary Side Converter Modulation Strategy

Three phase to single phase converter on the primary side of the transformer is used to generate the high-frequency ac voltage denoted as  $V_p$  from the balanced three-phase input voltage. This high frequency square wave pulses are then transferred to the utility side single-phase to three-phase converter part through an single phase HF transformer.

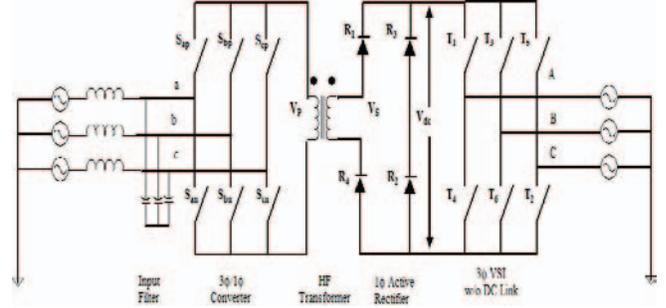


Fig. 1 Circuit diagram of the high-frequency link PET

The expanded form of PWM scheme discussed in [13] is used for the modulation of the primary side converter. The three phase input source voltage is assumed to be balanced and is given by.

$$V_a = V_{im} \cos\theta_a = V_{im} \cos(\omega_{in} t) \quad (1)$$

$$V_b = V_{im} \cos\theta_b = V_{im} \cos(\omega_{in} t - 2\pi/3) \quad (2)$$

$$V_c = V_{im} \cos\theta_c = V_{im} \cos(\omega_{in} t + 2\pi/3) \quad (3)$$

Where,  $\omega_{in}$  is the source voltage angular frequency.

Only one of the three phase input voltages has the maximum absolute value and the other two phase voltages have opposite polarity between successive zero crossing of the input phase voltages. In mode 1 as shown in Fig. 2 phase a has maximum positive voltage and the other two phases b and c have negative value and it can be shown that,  $|V_a| = |V_b| + |V_c|$ .

In mode-1, switch  $S_{ap}$  remains turned on and switches  $S_{bp}$ ,  $S_{cp}$  are modulated within one switching period  $T_s$ . For achieving full utilization of input voltage and to get unity power factor at input source side, the duty ratios  $d_b$ ,  $d_c$  of switches  $S_{bp}$  and  $S_{cp}$  are given as

$$d_b = \cos\theta_b / \cos\theta_c \quad d_c = \cos\theta_c / \cos\theta_a \quad (4)$$

The duty ratios for all the six modes can be derived in the same way. The dc link voltage of the load side converter is given by

$$V_{dc} = n (d_b (v_a - v_b) + d_c (v_a - v_c)) \quad (5)$$

Where n is the transformer turns ratio,  $n = N_s / N_p$ . Averaged  $V_{dc}$  within a switching period  $T_s$  using trigonometric transformation is given by

$$V_{dc} = 3nV_{im}/2 |\cos\theta_a| \quad (6)$$

The PWM method can be chosen synchronous or asynchronous based on the source frequency for source side

converter control. The PWM method is decided using the modulation ratio given by

$$m_f = f_{sp}/f_i \quad (7)$$

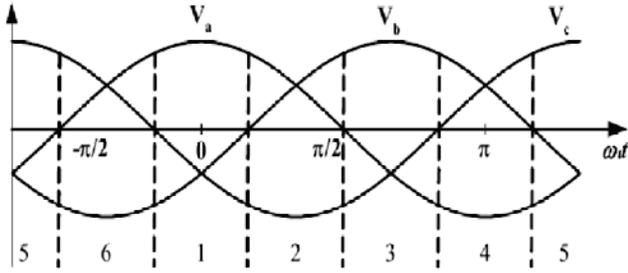


Fig. 2 Six modes of input phase voltages

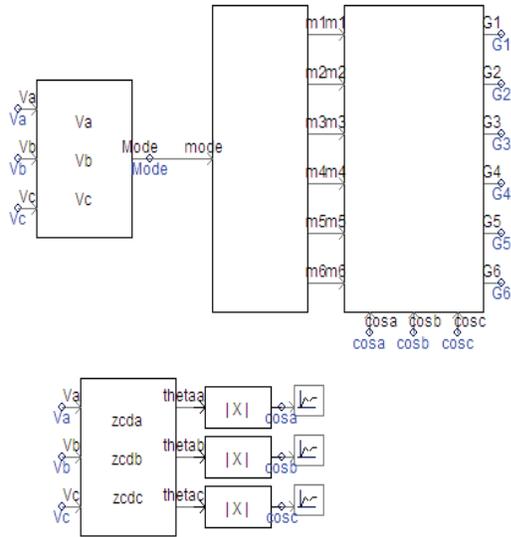


Fig. 3 Switching pulse generation of primary side converter

Where  $f_i$  is source frequency and  $f_{sp}$  is the switching frequency of source side converter. If the value of  $m_f$  is small the full utilization of the input voltage is possible only if the source side converter is synchronized to the source. This also improves the current waveform. Since the whole range input phase is divided into six modes, the value of  $m_f$  should be a multiple of six. This can distribute square wave pulse train to be quarter wave symmetric about each centre of modes and maintain the magnetic flux balance of the HF transformer. Simulation block for the modulation of the primary converter is shown in Fig.3. The first block is used to find out the mode of the phase voltages. The first block is shown in detail in Fig.4. The second block is to find the duty ratios and the third block generates the gate signals for the switches.

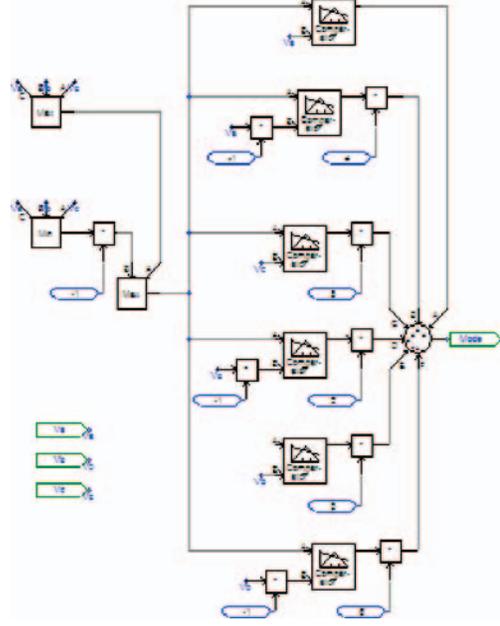


Fig. 4 Simulation block for finding the mode of the phase voltages

### B. Secondary Side Converter Modulation Strategy

The secondary side converter works like a conventional AC/DC/AC converter without DC capacitors [14]. The rectifier stage ( $R_1$ - $R_4$ ) is used to rectify the 50% square wave  $V_s$  into fluctuated dc-link voltage  $V_{dc}$  and active switches are used to provide bidirectional power flow. The four active switches can be replaced by four diodes when output power factor is more than 0.87 and bidirectional power flow is no longer required.

The VSI is used is a conventional one for converting the fluctuated dc-link voltage to sinusoidal ac. SVPWM is used for the modulation. In SVPWM, any three-phase system can be represented by a vector rotating with a synchronous speed with respect to the stationary orthogonal  $\alpha$ - $\beta$  axes where the  $\alpha$ -axis coincides with phase A phasor [15]. The magnitude of this vector is the vector sum of all the three phase voltages at any instant. This can be projected to the stationary axes  $\alpha$ - $\beta$  to give  $V_\alpha$  and  $V_\beta$ . In SVM approach, a space vector is defined as

$$\mathbf{V} = \frac{2}{3} (V_a(t) + V_b(t)e^{j2\pi/3} + V_c(t)e^{-j2\pi/3}) \quad (8)$$

The implementation of the SVM in PSCAD is shown in Fig.5. The first block generates the control signal. The second block is used to find the magnitude and the angle of the space vector and the corresponding sector in which it belongs. The third block is used to calculate the adjacent vectors time duration. Vector transition time is calculated in the fourth block. Calculation of the duty cycle is done in fifth



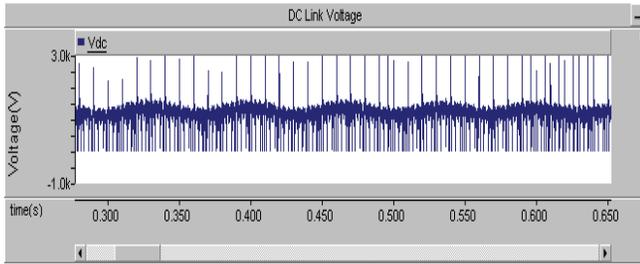


Fig.10 Load side converter dc-link voltage waveform

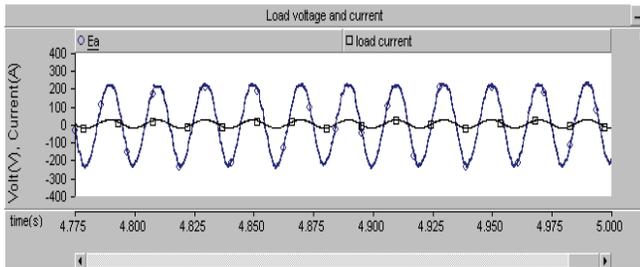


Fig.11 Load voltage and current waveforms

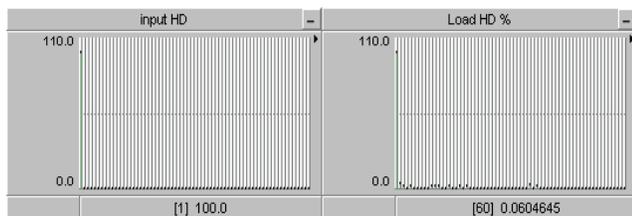


Fig.12 Harmonic distortions on source and load side

## V. CONCLUSION

The simulation aspect of a three-phase to three-phase PET is carried out and its characteristics are studied. The simulation of the PET is carried out in PSCAD/EMTDC and the results are analyzed. The simulation results show that the PET maintains low harmonic distortion in both the load and the source side with controllable input source displacement power factor. The HF transformer used into the intermediate stage of the dual bridge matrix converter gives electrical galvanic isolation and flexible voltage transfer ratio. This makes the PET feasible to connect to any commercial utility voltage. The simulation study is also shows that the PET is able to maintain the characteristics of a conventional matrix

converter such as bidirectional power flow without dc-link capacitors.

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