

Modeling of Modular Based Flexible Power Electronic Transformer

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Abstract — In this paper, a new topology proposes power electronic transformer. The power electronic transformer is a solid state transformer which replace conventional transformer. The conventional transformer has a many disadvantages such as heavy weight, large size, require toxic dielectric coolant, voltage drop under load, sensitivity to harmonics. These disadvantages are becoming compulsory for power quality improvement. To overcome the disadvantages power electronics transformer is good option for reduce it. Power electronic transformer provides a fundamentally different and more complete approach in transformer desine by using power electronics on primary and secondary side of transformer. It has a bidirectional power flow capability and voltage regulation. The main feature of this PET is the independent operation of modules each of which contains one port. Each port can be considered as input or output, because bidirectional power flow is provided. The modules are connected to common dc link that facilitates to energy transfer among modules as well as port.

Keywords - DC link, power electronic transformer, HFIT, Phase shift modulation.

I. INTRODUCTION

Distribution transformers are fundamental components in power distribution systems. They are relatively inexpensive, highly reliable, and fairly efficient. However, they have some disadvantages such as heavy weight, large size, sensitivity to harmonics, voltage drop under load, protection from system disruptions and overload, protection of the system from problems arising at or beyond the transformer and environmental concerns regarding mineral oil. These disadvantages are becoming increasingly important as power quality becomes more of a concern. In this case, power electronic based transformer is a good option for solving above problems [1-4]. Power electronic transformers (PETs) are proposed to replace conventional transformers and perform voltage regulation and power exchange between generation and consumption by electrical conversion [1]–[5]. The previous researches show that PETs have a great capacity to receive much more attention due to their merits such as high frequency link transformation and flexible regulation of

the voltage and power. Although many studies have been conducted on application and control of PET in power systems [1]–[8], less attention is paid to the areas of the circuit topologies [7] and [8]. The topology of PET can be developed in such a way to achieve multiport electrical system that converts variable input waveform to the desired output waveform. In addition, for higher voltage applications or three phase systems, the topology is expandable as it is modular

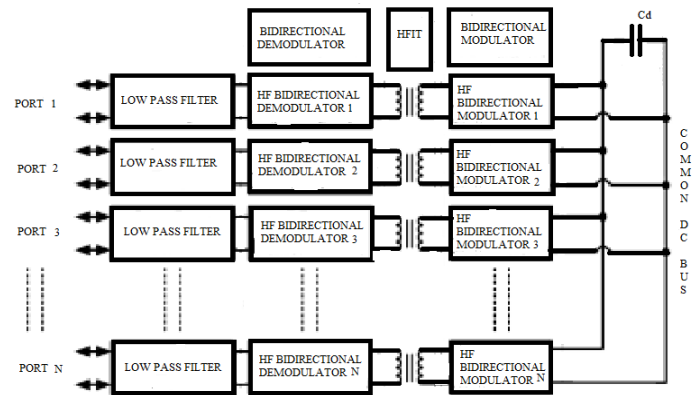


Fig .1 Main concept of the FPET

As shown in Fig. 1, it is constructed based on modules and a common dc link, which is used to transfer energy between ports and isolate all ports from each other. In this bidirectional topology, each port can be considered as an input or output. Each module consists of three main parts.[9]

1. Modulator,
2. Demodulator,
3. High Frequency Isolation Transformer (HFIT).

The modulator is a dc–ac converter and the demodulator is an ac–ac converter both with bidirectional power flow capability. Each module operates independently and can transfer power between ports.

II. PROPOSED CIRCUIT OF FPET

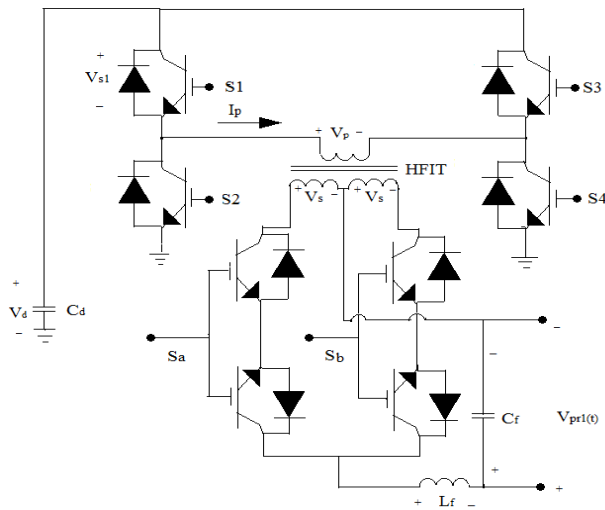


Fig.2 Proposed circuit of the FPET

The proposed circuit is shown in Fig. 2. It should be mentioned that the proposed topology can be expanded by connecting modules in series or parallel to obtain higher voltage or current ratings, and to form star/delta connections for three phase applications. As shown in Fig.2 each port is composed of a fullbridge dc-link inverter (FBDCI), HFIT, and a cycloconverter. This topology consists of independent and similar modules and each port can work independently. Thus, the analysis of one port is sufficient to introduce whole topology. The FBDCI (modulator) can operate as an inverter when it converts the dc-link voltage to an ac waveform at the HFIT side. It can operate as an active rectifier when it converts the ac waveform of the HFIT to the dc-link voltage. The FBDCI is used to achieve zero-voltage level, adjustable pulsewidth, and symmetrical switching. In addition, the number of switches can be reduced to obtain simpler

The modulator can be described as follows

- 1) Bidirectional power flow capability
- 2) Adjustable switching frequency that feet voltage pulses Frequency into the pass band of HFIT; and
- 3) Stored energy in the dc link

For cycloconverters, several circuit topologies can be proposed using unidirectional or bidirectional switches. In this paper, a typical cycloconverter with two bidirectional switches operates as the demodulator. The demodulator converts high frequency voltage to low frequency voltage and vice versa. The specifications of the demodulator are listed as follows:

- 1) Bidirectional power flow capability; and

- 2) Providing zero voltage switching by turning the switches of cycloconverter ON/OFF, while voltage of HFIT riches to zero.

III. MODULATION AND DEMODULATION PRINCIPLE

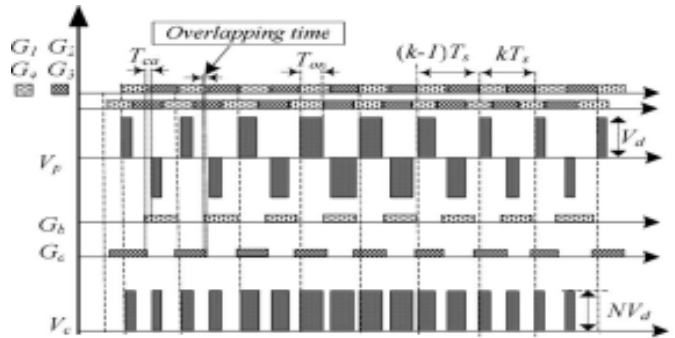


Fig.3 Principle of the PSM method

The well-known phase shift modulation (PSM) method is shown in Fig. 3. The voltage regulation is performed by the FBDCI using PSM method [9]. The cycloconverter chooses the PSM pulses in such a way to provide positive or negative voltage polarity at the output. In this figure, the cycloconverter provides positive output voltage polarity as an example. On one hand, the switches of cycloconverter turn ON/OFF with a time delay respect to those of FBDCI, so they operate under zero voltage condition

IV. TABLE
DEFINITION OF PARAMETERS

SYMBOL	DEFINITION
Gi	Gate driving signal of Si where i=1,2,3,4
Ga and Gb	Gate driving signal of Sa and Sb
Ts	Switching period
Ton	Turn on duration time in Ts/2
Tcd	Cycloconverter switches delay time
Vp	Primary side voltage of HFIT
Vs	Secondary side voltage of HFIT
Vc	Cycloconverter output voltage
N	Transformer winding ratio Ns/Np

In practice, snubber circuits must be used to damp the stored energy in the leakage inductance of HFIT. According to Fig. 3, the duty cycle of FBDCI is defined as Follows

$$D(kT_s) = 2T_{on}(kT_s)/T_s \quad k=1,2,3,\dots \quad (1)$$

The modulated voltage at the secondary side for one duty cycle is expressed by

$$V_s = NV_p. \quad (2)$$

The modulated voltage at the output of cycloconverter (V_c) is Determined as follows:

$$V_c(t) = \text{sign}(t) |NV_p(t)| = \text{sign}(t) NV_d(t)$$

$$\text{Sign}(t) = 1 \text{ or } -1, (k-1)T_s < t < kT_s, k=1, 2, 3, \dots (3)$$

where $\text{sign}(tk)$ function determines the polarity of V_c that can be positive or negative according to the desired output voltage and presented by (4), as shown at the bottom of the page.

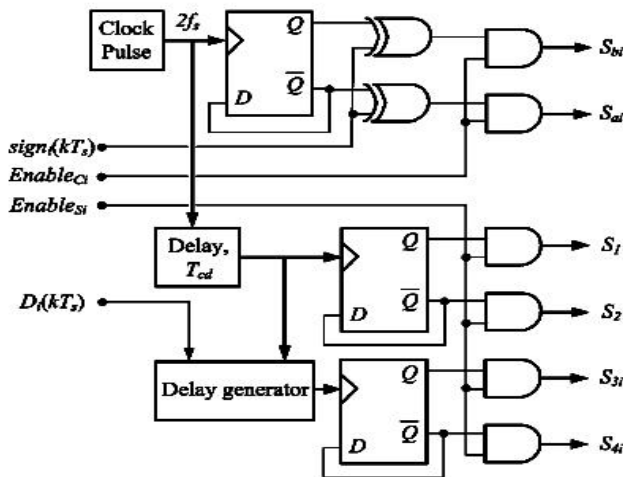


Fig.4 Schematic diagram of psm controller

A .PSM CONTROL CIRCUIT

The control circuit is responsible for providing pulse gate of dc link switch and cycloconverter. There are four input address line. The first line is polarity of output voltage sign_i . The second line is switch-enabled of cycloconverter (Enable_{Ci}). The third line is switch-enabled of dc link (Enable_{Si}). The fourth line provides the duty cycle data of the i th port. The enabled lines are provided by the startup and protection circuits.[9] Controllable voltage at the output of cycloconverter can be obtained and it is given by

$$v_{ci}(t) = v_{Refi}(t) \quad (4)$$

B.ENERGY BALANCE IN FPET

In every system, there is a balance among losses, input energy and output energy. This balance for FPET is presented as follows

$$\sum_{i=1}^n W_i + W_{Cd} + W_{loss} = 0 \quad (5)$$

where W_i , W_{Cd} , and W_{loss} are the input/output energy, stored energy at dc link and losses, respectively. Neglecting the power losses, can be approximated by

$$\Delta \sum_{i=1}^n P_i \approx -\Delta P_{Cd}. \quad (6)$$

To achieve power equilibrium in Cd and have constant dclink voltage, some of the ports should absorb and inject desired active power.

The algorithm for regulation of dc-link voltage is as follows:

(1): At the start-up instant, following two methods can be used to charge the dc-link capacitor to the desired value.

- 1) The dc-link capacitor can be charged by an extra dc source. As the desired dc-link voltage achieved, the dc source
- 2) The cycloconverter can provide a high frequency voltage across HFIT. When the voltage passes through HFIT, it changes to a dc voltage across dc-link capacitor by the body diodes of FBDCl switches. The dc voltage can charge the capacitor considering the winding ratio of HFIT. The startup current is limited by L_f .

(2): dc-link voltage checking.

- 1) If $V_{d,Ref} - \Delta V_{d,Ref} < v_d(t) < V_{d,Ref} + \Delta V_{d,Ref}$, then there is no need for adjustments. The $\Delta V_{d,Ref}$ is a fraction of $V_{d,Ref}$ that is required to provide Hysteresis band.
- 2) If $V_{d,Ref} - \Delta V_{d,Ref} > v_d(t)$ or $v_d(t) > V_{d,Ref} + \Delta V_{d,Ref}$, then voltage should be regulated and the port powers should be adjusted.

(3): Return to the second step

C. COMPARISION BETWEEN POWER ELECTRONIC TRANSFORMER [PET] AND CONVENTIONAL TRANSFORMER

DEFINITION	PET	CONVENTIONAL
Transformer designed	Semiconductor devices	Metal
Bidirectional power flow capability	Yes	Not possible
No of storage capacitor	1	0
Desine simplicity and expandability to achieve higher	Yes, modular structure to any	Not possible

ratings	stage	
Reliability regarding independent operation capability of phases	Port, independently	Phases are dependent to each other

D. ADVANTAGES

- 1) Reduce the volume. [9]-[10]
- 2) No toxic dielectric coolant.
- 3) Bidirectional power flow capability of ports .
- 4) Module-based topology, which can be used in different forms.
- 5) Independent operation of ports, flexibility in power amount and direction in all ports.
- 6) Double galvanic isolation between each port.
- 7) Control the reactive power and power factor .
- 8) Light weight.
- 9) Flexible power amount and direction in all ports

E. SIMULATION OF MODULATOR AND DEMODULATOR

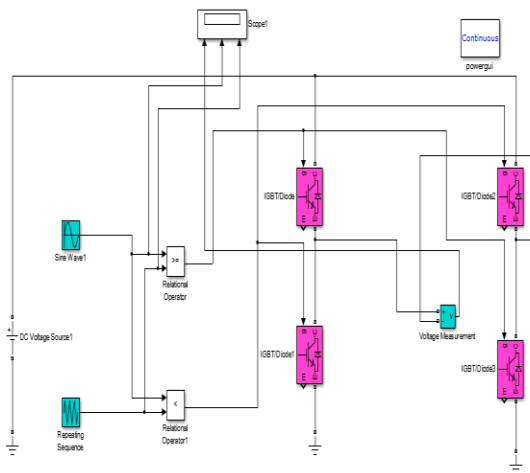


Fig..5 Simulation of single phase inverter

WAVEFORM'S OF MODULATOR

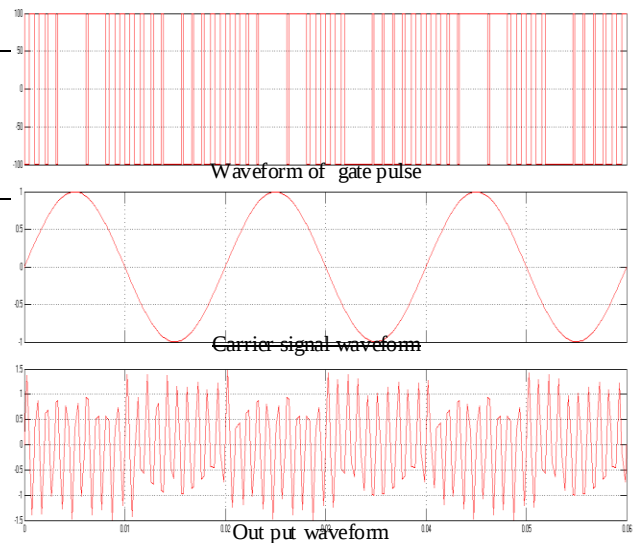


Fig..6 Output waveform of single phase open loop inverter

SIMULATION OF DEMODULATOR

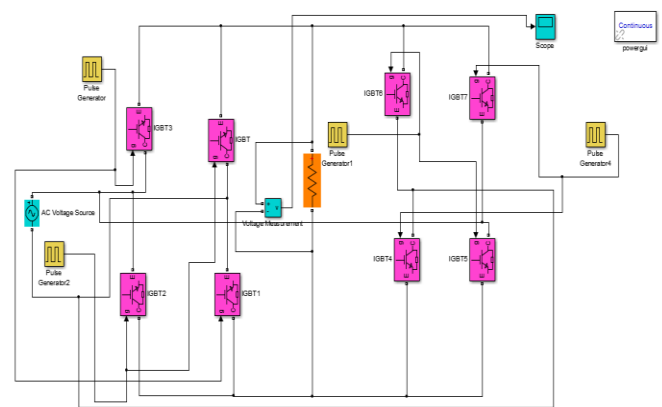


Fig..7 Simulation of open loop cycloconverter

WAVEFORM'S OF DEMODULATOR

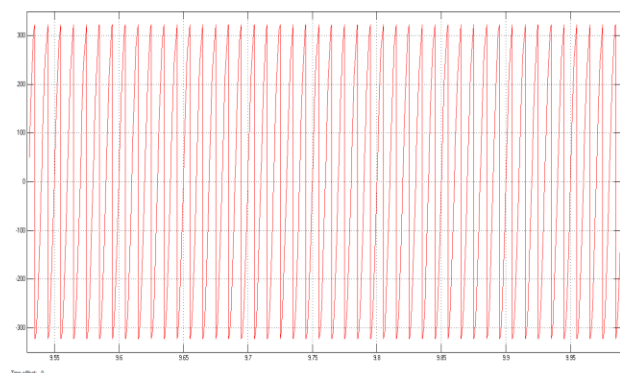


Fig.8 output waveform of openloop cycloconverter

WAVEFORM'S OF DEMODULATOR

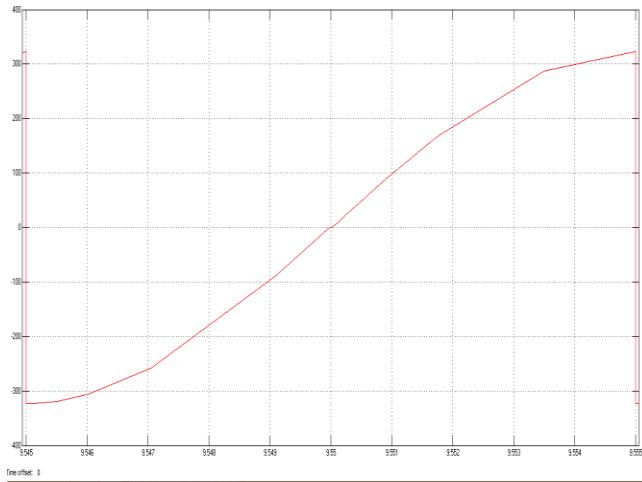


Fig.9 Output waveform of cycloconverter for one cycle

CONCLUSION

By this paper we can conclude that the power electronic transformer is replacing the conventional transformer and reduce the disadvantages of conventional transformer. It facilitates many requirements which we want in power electronic and electrical system. It has bidirectional power flow capability and voltage regulation. The PET has an independent operation of ports and module. The topology of PET can be developed in such a way to achieve multiport electrical system that converts variable input waveform to the desired output waveform. The dc link plays a significant role to provide energy balance, power management in the circuit and independent operation of ports.

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