

# Function of Distribution Power Electronic Transformer for Medium Voltage

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**Abstract:** In this paper a distribution power electronic transformer (DPET) for feeding critical loads is presented. The PE based transformer is a multi-port converter that can connect to medium voltage levels on the primary side. Bidirectional power flow is provided to the each module. The presented structure consists of three stages: an input stage, an isolation stage, and an output stage. The input current is sinusoidal, and it converts the high AC input voltage to low DC voltages. The isolated DC/DC converters are then connected to the DC links and provide galvanic isolation between the HV and LV sides. Finally, a three-phase inverter generates the AC output with the desired amplitude and frequency. The proposed DPET is extremely modular and can be extended for different voltage and power levels. It performs typical functions and has advantages such as power factor correction, elimination of voltage sag and swell, and reduction of voltage flicker in load side.

**Keywords:** Flexible Power Electronic Transformer (FPET), Matrix Converter, Bidirectional Power Flow Control.

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## 1. INTRODUCTION

Distribution power transformers are used in the power grid to implement the voltage conversion, isolation and noise decoupling. They are very reliable and sensitive to harmonics. On the other hand, due to their large iron cores, they are bulky, massive and expensive devices. Their oil threatens the environment [1-4]. The power electronic transformers have introduced to carry out voltage transformation, isolate the loads from grid and improve the power quality. High frequency transformer used in FPET to makes the system lighter and smaller. Since flux density is inversely proportional to frequency, the frequency has increased to reduce the transformer size. Some of FPET qualities and applications are voltage sag compensation, instantaneous voltage regulation, high reliability, power factor correction and power quality improvement of distribution system [5]-[18]. In recent years, several structures of FPET presented [6-9].

A transformer less AC/AC buck converter, which is capable of voltage level conversion, has been proposed in [2]. The high voltage stress on semiconductor devices is its main drawback. The second topology [9, 14, 5] are three fundamentals stages: an input, an isolation and an output. This topology achieves high power quality and desired output voltage with a DC link and several power electronic converters [5, 15, 19]. In another topology of PET, AC waveform side of utility network modulated with a PWM strategy in to a High Frequency (HF) square wave. This square wave demodulated to AC waveform by switching of matrix converter at secondary of transformer. The FPET consist of matrix converter that contributed to the high frequency operation.

## 2. PROPOSED POWER CIRCUIT OF 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. 1(a), each port is composed of a full bridge dc-link inverter (FBDCI), HFIT, and a Cyclo-converter. 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 dclink voltage. The FBDCI is used to achieve zero voltage level, adjustable pulse width, and symmetrical switching. In addition, the number of switches can be reduced to obtain simpler circuit than the latter, shown in Fig. 1(b). In this case, one of the half-bridge circuits can be considered as the reference or master leg. Once gate pulses for the master leg (i.e., switches  $S_{11}$  and  $S_{21}$ ) are provided, the gate pulses of the other legs (slave legs) have a phase shift respect to the master leg. Using this control strategy, the number of switches can be reduced to half [10]-[12].

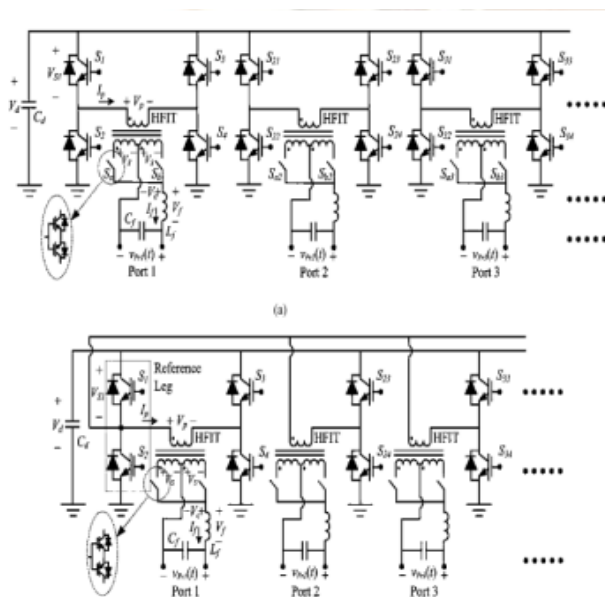


Fig1. Proposed circuit of the FPET (a) Basic topology and (b) reduced switch topology

The modulator can be described as follows:

- 1) Bi directional power flow capability;
- 2) Adjustable switching frequency that feet voltage pulses frequency into the pass band of HFIT;
- 3) Stored energy in the dc link (if the modulator is in active rectifier mode). For cyclo-converters, several circuit topologies can be proposed using unidirectional or bidirectional switches. In this paper, a typical cyclo-converter with two bidirectional switches operates as the demodulator. The demodulator converts high frequency voltage (i.e.) to low frequency voltage (i.e.,  $V_{pr1}$ ) 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 cyclo-converter ON/OFF, while voltage of HFIT riches to zero.

**BALANCING PORTS:**

For another solution to regulate voltage of dc link, some ports are considered as “balancing ports” that provide energy to balance dc-link voltage in FPET. One of the main objectives of these kinds of ports is to control voltage level in the dc-link voltage, particularly when over voltage or voltage drop occurs in the dc link. Assuming the  $I$  th port is chosen as the balancing port, the main component of the cycloconverter voltage, and output of the port are given as follows:

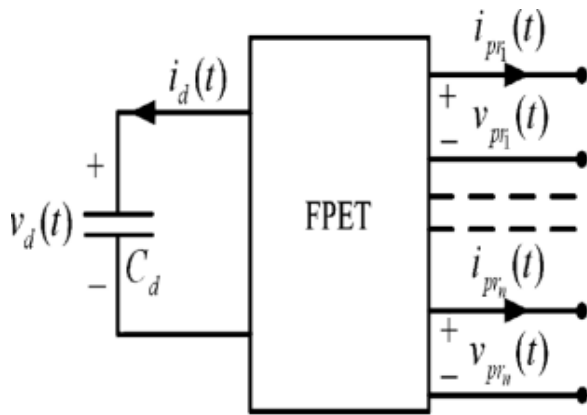


Fig.2. Simplified diagram of FPET

### 3. SYSTEM CONFIGURATION

A new DPET topology is proposed. As shown in Figure 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, including modulator, demodulator, and 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. These ports can have many different characteristics, such as voltage level, frequency, phase angle, and waveform. As a result, PET can satisfy almost any kind of application, which are desired in power electronic conversion systems and meet future needs of electricity networks.

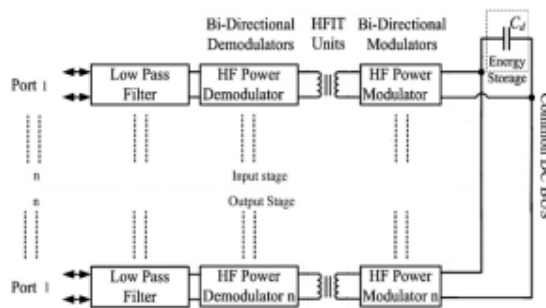


Figure 3. Proposed DPET

In this paper, a modular structure based on the classification system given in [11] is proposed (Figure 3). The main AC/DC converter is placed in switch shown in Figure 4 is composed of “N” Half-bridge (HB) cells connected in series on the primary side and “N” DC/DC converters connected in series on the secondary side. The DPET structure can also be rearranged to supply different types of electric loads simultaneously.

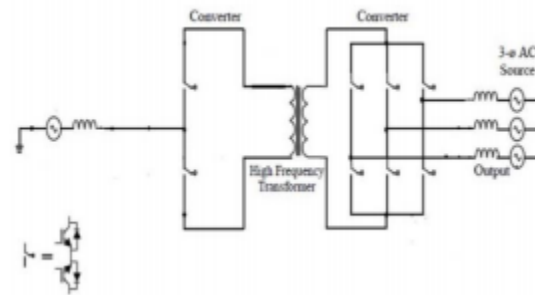


Figure 4. DPET schematic diagram

This capability is shown in Figure 2 where 3 series-output cells will supply a three-phase voltage source inverter and the remaining cells will supply individual loads. In this case, the input power fed to the series Half-bridges in switch would be different. Therefore, the HB rectifier should maintain voltage balance among the primary DC links and correct the input power factor. Another challenging issue is related to the equal load-current sharing among the series cells. A very small mismatch among the series cells can cause a large current deviation among them. This problem, in practice, is intensified by the non-ideality of series cells

#### 3.1. Input Stage Power

The input stage is a multilevel HB rectifier, which is particularly attractive in high voltage applications. This structure is extremely modular, it has a simple physical layout, and it needs the lowest number of components in comparison with other multilevel converters. This paper focuses only on the single-phase HB rectifier. The three-phase structure is obtained by association of three Single-phase HB converters connected in a star configuration. Furthermore, bidirectional power flow

can be realized from the bidirectional rectifier by turning off the top switches in all Half-bridges. In this work, a single-phase bidirectional HB converter is analyzed, and the results can be used either in a bidirectional converter or a three-phase system. In Figure 2, there are "N" series-connected Half-bridge cells and each cell can generate three voltage levels on the AC side: 0, +VC and -VC, where VC is the desired DC-link voltage. Thus, using "N" Half-bridge cells, a maximum of  $2N+1$  different voltage levels are obtained to synthesize Van or V1 (AC terminal voltage):

### 3.2. Isolation Stage

The second part of the DPET structure (Figure 2) contains the isolated DC/DC converters. These converters are connected to the HB converter links and provide a highly stable DC interface on the LV side. In the above topology, several isolated converters can be series on the LV side to increase the power capacity. However, the series cells should share the load-current equally and uniformly, in order to achieve identical operating conditions. This fact is also important from a thermal viewpoint. In the isolation stage, different kinds of DC/DC converters can be utilized. Nevertheless, we use a bridge converter, which is the best in terms of efficiency and voltage stress. Among the bridge topologies, the zero voltage switched converter has a better performance than alternative topologies. All switches, in this topology, are turned on in the ZVS condition, and the turnoff losses are controlled by the series capacitors. Furthermore, in this DPET application, we need good voltage isolation between the HV and LV sides, which corresponds to high leakage inductance. Therefore it appears more reasonable to use a zero voltage switched converter as opposed to other alternatives that require a low leakage inductance transformer.

### 3.3. Output Stage

The output stage usually contains a single-phase or three-phase voltage source inverter that is connected to the DC bus and generates the AC output with the

desired amplitude and frequency. The DC bus may also connect directly to a DC load or to a combination of AC and DC loads.

## 4. CONCLUSION

Based on the requirement of a power conversion system, PET is proposed to facilitate many requirements that are expected in power electronic and distribution systems. The proposed topology is flexible enough to provide bidirectional power flow and has as many ports as it is required. For low-voltage application, PET can correct power factor and can adjust the waveform and frequency of the output voltage. The proposed topology can be expanded for high voltage and high current applications. The dc link plays a significant role to provide energy balance, power management in the circuit and independent operation of ports. The PET is extremely modular and can be extended for different voltage levels and power levels. It performs typical functions and has advantages such as power factor correction and double galvanic isolation between each port, as well as using only one storage element.

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