

# A Novel Cycloconverter Based Power Electronic Transformer Approach for Power System

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**Abstract:** A power electronics transformer with a cycloconverter on the grid side is being proposed in this chapter for integrating several renewable energy sources to the grid. a single phase multi winding high frequency transformer connects multiple wind energy conversion systems and solar photo voltaic arrays to the cycloconverters using separate H bridge PWM converters .The current is smooth and continuous due to the leakage inductance of the transformer, this results in the reduction of losses and also the use of thyristor ensures natural commutations of the leakage energy. The grid side current and voltage have THDs within the limits as stipulated by the IEEE 519 standards. The principle of operations control and modulation of the proposed PETs topology is validated by simulations in MATLAB/SIMULINK environment.

## I. INTRODUCTION

A power transformer is an indispensable part of any transmission systems. Not only does it transform voltage levels it also performs several other function such as galvanic isolation and noise decoupling. However conventional transformers operating at low frequencies (50/60 Hz) are quite bulky and are increasingly becoming more and more expensive to buy and maintain due a steady rise in the cost of core material and land. This has led to surge in the research and development of power electronic transformers (PET) operating at much higher frequencies(1-10KHz) than the line frequency transformers, PETS requires a smaller core which drastically bring down the size and weight of the transformer. Moreover PETs gives several benefits such as voltage regulations, reactive power support, power factor control and current limiting and therefore become an attractive choice for integrating renewable energy sources to the grid and in uninterrupted power supplies.

speed. These topologies also face the problem of communication of the transformer leakage energy due to the absence of natural freewheel paths and also due to the use of self commutating devices. Conventional topologies of multilevel inverters and converters integration to the grid are reviewed in [5-7]. All the topologies considered require multiple capacitances to serve as non ideal DC voltage sources. Depending on the topology these capacitances may be isolated or connected in series. The mere presence of these introduces a host of problems, the most prominent being the problem of voltage balancing, moreover scaling these topologies to increase the number of voltage levels is not very feasible due to the bulk of these capacitances. Also these topologies are not specifically designed for use in PETs. In PETs having a transmission level power rating it is not feasible to use these multilevel topologies due to the requirement for huge and expensive capacitors. Three stage PETs using a multilevel topology such as in [8] having a modular configuration generates the grid level AC from DC. Other than the presence of capacitors the topology detailed in [8] require a large number of switches thereby increasing the complexity of the control logic circuitry and condition and conversion losses.

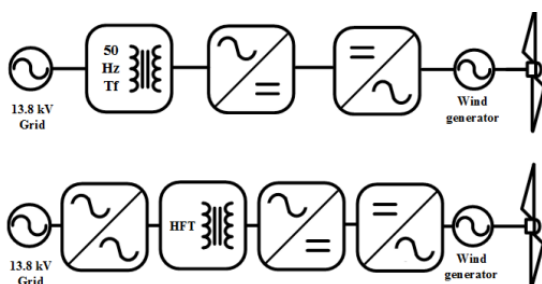


Fig 1: (top) conventional wind generation system and (bottom)PET using HFT

Since the commencement of research into PET topologies many single stage and multistage topologies have been proposed. However single stage topologies proposed in [3].These are the most suitable when the input frequency is equal to the output frequency which minimizes the harmonic distortion. So there are not suitable for integrating a wind energy conversion system to the grid as the putput frequency of a WECS generator varies continuously depending on the wind

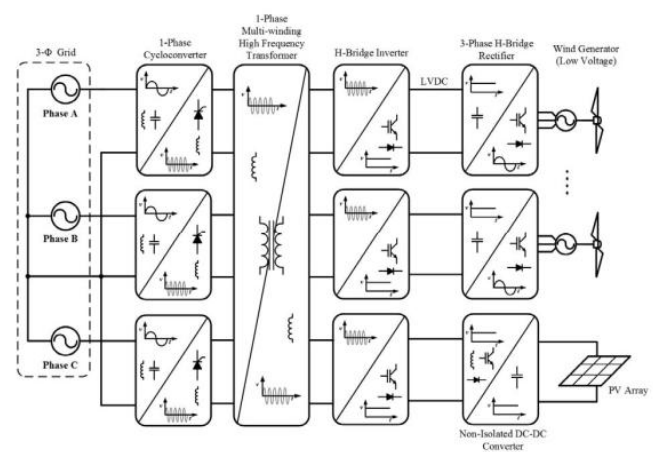


Fig 2 Simplified block diagram of proposed PET topology

Another significant advantage of the topology detailed in [8] is the requirement for only a single transformer. The transformer used is a single phase multi-winding high frequency transformer. Each source voltage i.e variable frequency and variable amplitude AC in case of WECS and variable amplitude DC in case of SPV array is individually rectified and stabilized into a constant DC voltage Link. These link voltages are then inverted into high frequency AC by separate H bridges (which are modulated by the unipolar PWM technique.) and then fed to the transformer using separate isolated windings. The proposed topology uses the exact same design for the HFT and the secondary side converters Due to the obvious advantages of self commutating devices(IGBTs) over the line commutated devices, the advantages of the later such as natural

commutation of the power which results in zero turn off losses and their higher power handling capacity are often overlooked. The higher power rating of Thyristors and lower switching frequencies go hand in hand if used for high power applications such as the inversion of the power output of a wind or solar form. Using thyristor also simplifies the firing logic as the continuous gating signal is not necessary which allows the use of pulse transformer for isolating the power and control circuit. Due to these advantages offer by Thyristors one of the most common thyristor based AC to AC converter topologies namely cycloconverter is being used in the proposed configuration. The proposed PET topology which uses thyristor based phase controlled cycloconverters as the grid side converters as shown in fig4.2. It has a single phase multi-winding high frequency transformer to integrate multiple renewable energy sources to the grid through the grid side converters. Some of the main advantages of the proposed topology are:

1. The grid side converter is a thyristor based cycloconverter. As a single thyristor can handle a very high amount of power, series and parallel operation of the devices is not needed resulting in lower number of devices and simpler logic circuitry.
2. The cycloconverter operates in circulating current mode resulting in a continuous current supply and therefore decreased harmonic content in the output voltage.
3. The frequency conversion is achieved in a single stage, resulting in lower conversion losses.
4. The HFT is a multi-winding transformer having multiple secondary windings to interface multiple renewable energy sources and three primary windings which serve as the input supplies to the cycloconverters. The use of a single HFT as opposed to multiple line frequency transformers results in a substantial reduction in size and weight.
5. The leakage inductance of the transformer acts as a low pass filter for the current through it resulting in smooth and continuous current which assist the natural commutation of the leakage energy of the transformer.

The proposed PET topology along with the principle of operation is explained in below section they presents the analysis of the HFT and source side converters and the cycloconverters respectively.

## II. TOPOLOGY

In the proposed topology multiple source side converters are used one fed from each of the renewable sources. The sources Side converter used are IGBT/diode module based single phase H bridge which are modulated by using the unipolar PWM technique.

The transformer used is a single phase multiwinding high frequency transformer with a turns ratio of  $N:1$ . This transformer has three primary windings and numerous secondary windings. Every secondary winding interfaces a single WECS and SPV array. Each WECS requires two dedicated H bridge : one acts as rectifier and the other a high frequency inverter. SPV arrays require only a single H bridge converter but may also employ an additional DC-DC boost converter. The transformer has leakage inductance  $L_p$  on its primary side and  $L_s$  on its secondary. To account for non-idealities  $R_p$  and  $R_s$  are taken to be leakage resistances.

The three high voltage primaries are connected to the cycloconverters. This PET has smooth and continuous current through the transformers resulting in lower core losses. For the integration of SPV arrays a DC-DC converter is also made use of which is modulated either by maximum power point tracking algorithm or by schemes which ensures voltage regulation. For the integration of wind generators a 3-phase bridge converter rectifies the 3 phase variable magnitude variable frequency AC voltage to a fixed DC voltage at the LVDC link. Finally the LVDC links are connected to the secondary windings of the HFT through separate but synchronized 1-phase PWM h bridge converters.

The voltage appearing across the output terminals of the transformer still have a frequency which is much higher than the line frequency and has to be converted to the line frequency (50Hz) before interfacing with the grid. This frequency conversion is achieved by the grid side converter. In this proposed topology the grid side converter is cycloconverter. A simplified block diagram of the topology is illustrated in fig4.2. To interface the high voltage grid to the low voltage renewable through the HFT three single phase to single phase cycloconverter (in fig4.3) are being used on the grid side as shown in fig4.2, 4.3 in detail.

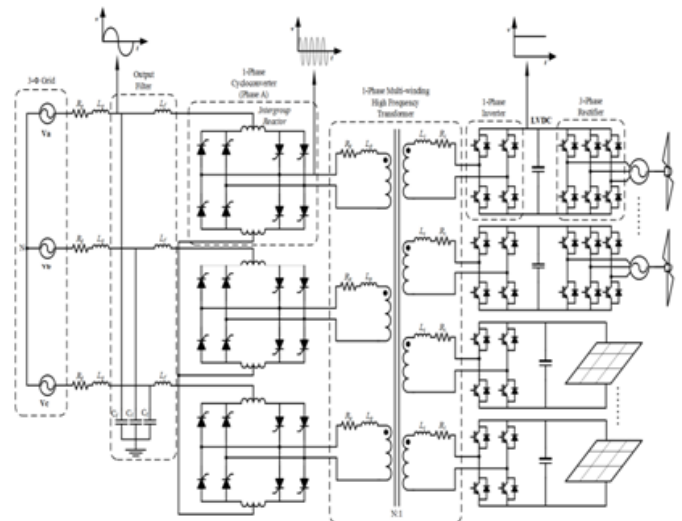


Fig 3. Detailed circuit diagram of PET topology for integrating multiple renewable energy sources to the grid.

### A. Analysis of HFT and Secondary Side Converters

One single phase multi-winding high frequency transformer is used in the proposed PET to interface multiple renewable energy sources. The HFT has the turn ratio of  $N:1$ . It has three winding on its high voltage Side and numerous secondary windings. Due to all the winding being wound on a single core as shown in fig4.3, the transformer has lower volume and weight. The transmission lines between the wind generators and the high frequency transformers carry high frequency voltages. Therefore when interfacing multiple wind generators or solar photovoltaic array spread out across a large area, a significant amount of impedance is encountered. Hence the proposed PET is suitable only when the renewable sources are closer together and also on land. The use of single HFT for interfacing numerous wind generators to the grid makes this topology more compact as opposed to those having separate HFT for each generators.

A 1 phase 3 level PWM H bridge converter inverts the LVDC link voltage and synthesizes a sinusoidal PWM voltage at the secondary of the HFT. The LVDC buses are charged by 3 phase 2 level H bridge converters in case of a wind generator

which rectify the variable magnitude and frequency AC waveform (in fig4.3) or in case of SPV arrays they are charged by DC-DC converters which maintain the output voltage levels and also ensures maximum power evacuation. The transformer has leakage resistance and inductance in its windings. The leakage inductance smoothens and also ensures a continuous current through the HFT. This leakage inductance,  $L_{lkg}$  is the sum of leakage inductances on the secondary windings,  $L_s$  and the leakage inductances on the primary windings  $L_p$  which are transferred to the secondary side. Because of smoothly varying continuous current through the transformer a natural commutation of the leakage energy is obtained.

**B. Analysis of Cycloconverters**

The three high voltage windings of the HFT serve as the input voltage supplies to the three 1 phase to 1 phase cycloconverters that function as the grid side converters. The cycloconverters is essentially two thyristor based H Bridge connected back to back. Both these bridges are gated simultaneously albeit with different timing pulses. There is also an intergroup reactor on each arm of the link between the two converters as shown in fig4.3 to limit the amplitude as well as the rate of change of the circulating current which flows due to the different instantaneous voltage at the output terminals of the two bridges. The lower terminals of all the three terminals are shorted to form the neutral point. The upper terminals are then interfaced with the three phases of the grid as shown in fig4.3. The HFT operates at the much higher frequency than the grid frequency. The cycloconverters convert these 1 phase high frequency sinusoidal PWM AC voltage waveforms into 3 phase AC voltages at grid frequency. As the frequency ratio between the input and output is usually quite large the output voltage waveform synthesized by the cycloconverters is near sinusoidal. By controlling the timing and the frequency of the firing angles of the converters it is possible to control the frequency and amplitude of the fundamental components of the output voltage. Thus both the magnitude and the frequency can be continuously and independently controlled. A cycloconverter has the inherent property of being able to handle loads of any power factor and also provides 4 quadrant operations i.e power is free to flow in either direction through the cycloconverter. It is thus able to handle both passive as well as regenerative loads However this topology only unidirectional net power flow is of interest.(from LVDC to the grid).

The output voltage waveform contains harmonic component in addition to the fundamental component. These harmonics are produced as a results of the working principle of the cycloconverter and their production cannot be avoided. These distortion components can be filtered off to obtain a near sinusoidal output voltage waveform. These distortion decreases with the increasing in frequency ratio. This is because there is provision for changing the firing angle, "input to output frequency ratio" times per half cycle of the reference output voltage waveform. Also by increasing the pulse number (the number of pulses occurring per time period) or  $360^\circ$  of the original input AC waveform of the circuit, the distortion of the output decreases.

In the proposed topology a pulse number of 2 is used. The relative distortion of the output voltage will be large as compared to those obtained from three pulse (3 phase half bridge) or six pulse (3 phase full bridge) cycloconverters. Nevertheless a pulse number of 2 is still being used in this topology as the benefit of using the 1 phase HFT far offset the benefits of having a higher pulse number

consequently a multi-phase high frequency transformer or multiple 1 phase high frequency transformer.

**III. KEY SIMULATION RESULTS**

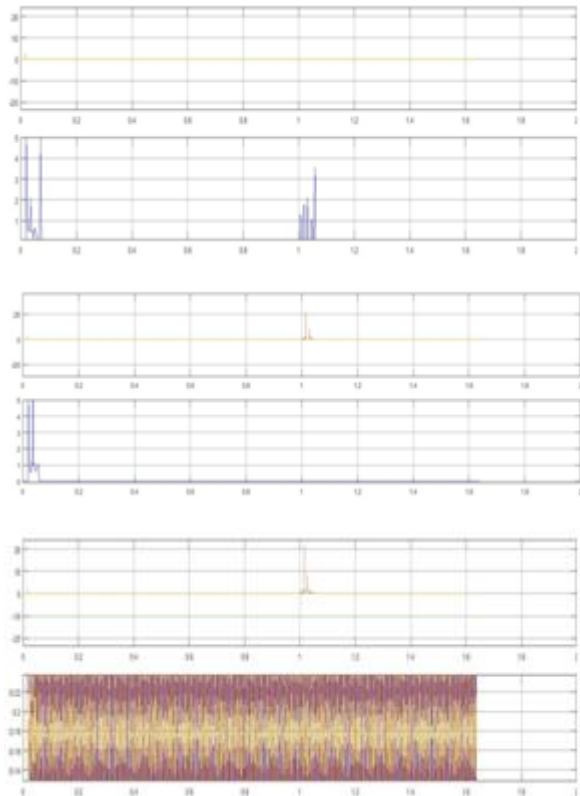


Fig 4: THD waveforms

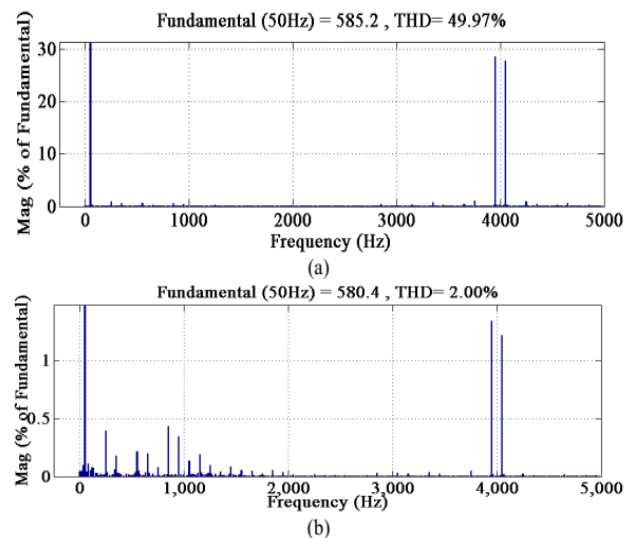
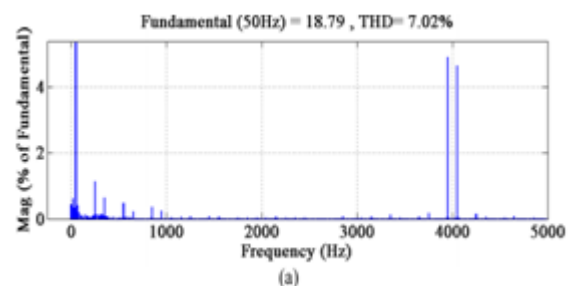


Fig5 (a) Harmonic spectrum of grid side voltage before the addition of filter (b) after addition of filter



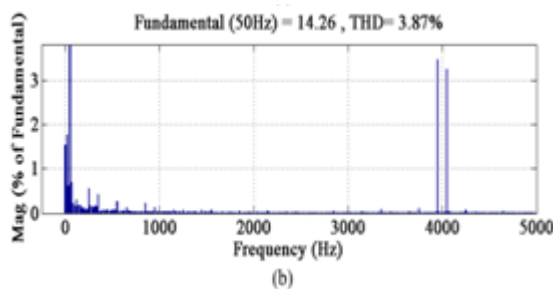


Fig 6: (a) Harmonic spectrum of grid side current before the addition of filter (b) after addition of filter

### CONCLUSION

In this paper a thyristorized phase controlled cycloconverter based power electronics transformer topology has been implemented. One single phase multiwinding high frequency transformer is used to interface multiple renewable energy sources to the AC grid. There is natural commutation of the transformer leakage energy due to the principle of operation of thyristors. THDs of current and voltages has been found in the specified limits and this topology is given better results as compared to conventional approaches.

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