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Mitigation of Power Quality Issues Using Single Stage and Multi Stage Converters

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***Abstract*—this paper presents a novel topology of power electronic transformer. In the design process, the AC/DC, DC/AC, AC/AC converters and high frequency transformer have been used. One matrix converter operates as AC/AC converter in power electronic transformer. The proposed power electronic transformer 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. Power quality improvement with proposed power electronic transformer has been verified by the simulation results.**

***Keywords:*--Power quality; Voltage sag and swell; Power electronic transformer; AC/AC converter.**

I. 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 Electronics (PET) has been introduced, which realizes voltage transformation, galvanic isolation, and power quality improvements in a single device. The PET 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 PET.

Different topologies have been presented for realizing the PET, in recent years [2]-[7]. 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. In second type, the line side AC waveform is modulated into a High or medium Frequency (HF or MF) square wave, coupled to the secondary of HF (MF) transformer, and again is demodulated to AC form by a converter in second side of HF (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. In second type matrix converter is a direct AC-AC power converter employing bidirectional switches. In addition to the basic ability of power converter providing a sinusoidal variable voltage variable frequency to the load, matrix converter has many attractive features: no bulky DC-link Capacitor, ability to make sinusoidal input current, high efficiency, compact circuit design and regeneration capability [3]-[5].

Another type is a three-part design that utilizes an input stage, an isolation stage, and an output stage [6]-[10]. These types enhance the flexibility and functionality of the electronic transformers owing to the available DC links. This approach can perform different power quality functions and provide galvanic isolation but they need whether too many power electronic converters and DC-link electrolytic capacitors. Thus they result in a rather cumbersome solution.

Custom power devices are introduced in the distribution system to deal with various power quality problems faced by industrial and commercial customers due to increase in sensitive loads such as computer and adjustable speed drives and use of programmable logic control in the industrial process [11], [12].

This paper proposed the PET that includes three parts: input stage, an isolation stage, and an output stage. Proposed PET includes AC/AC matrix converter. The proposed AC/AC converter can generate desired output voltage from square input voltage. The main point of proposed PET is reduction of the stage and components of the three-part PETs. The reliability and power quality of distribution system can be significantly improved by using proposed PET. To verify the performance of the proposed PET, computer-aided simulations are carried out using Mat lab/Simulink.

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II. CONVENTIONAL PETS

Fig. 1 shows the basic block diagram of the PET using HF (MF) AC-link without DC-link capacitor. In this system, the line side AC waveform is modulated with a converter to a high-frequency square-wave and passed through a HF (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 HF (MF) transformer will be much smaller than the power-frequency transformer. So, the transformer size, weight and stress factor is reduced considerably [3].

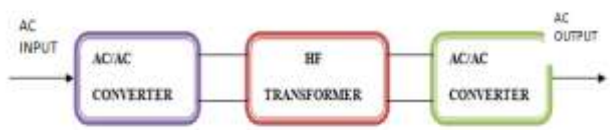

Fig1. Block Diagram of electronic transformer using HF (MF) AC link.

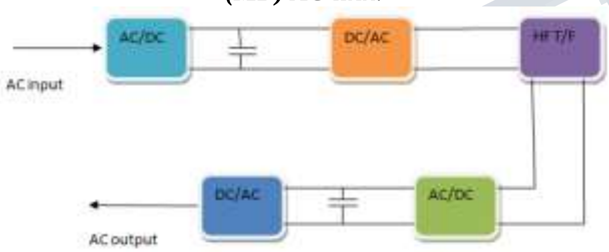

Fig 2. Block Diagram of Power Electronic based Transformer (PET) with DC link.

This converter does not provide any benefits in terms of protect the critical loads from the instantaneous power interruptions due to lack of energy storage system [7]. Fig. 2 shows the basic block diagram of a PET with DClink capacitor which 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 high-frequency square wave voltage, coupled to the secondary of the HF (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]-[10]. In comparison to first PET, the voltage or current of PET can be flexibly controlled in either side of HF (MF) transformer. It is possible to add energy storage to enhance the ride-through capability of the PET 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 converters (AC/DC or DC/AC) and DC-link electrolytic capacitors. Thus they are resulted in a rather cumbersome solution and multiple power conversion stages can lower the transformer efficiency.

III. PROPOSED PET

The block diagram of the proposed PET is shown in Fig. 3. As can be seen from the Fig. 3, this is a three-stage design that includes an input stage, an isolation stage and an output stage. In the input stage, there is a converter, which converts the input AC voltage to DC voltage. The second part of the converter is formed by a DC/AC converter. This part of the converter contains the MF transformer with the high insulation capability. In the output part, the high frequency voltage is revealed as a power-frequency voltage. In this paper, a three-part design is introduced. It is a new configuration based on the matrix converter with new function shown in Fig. 3.

It can provide desired output voltage. In addition, it performs power quality functions, such as sag correction, reactive power compensation and is capable to provide three-phase power from a single phase system. The PET has three stages and each stage can be controlled independently from the other one. Many advantages of the PET such as output power quality and power factor correction depend on appropriate close-loop control, and correlative research is necessary. The reliability of a system is indirectly proportional to the number of its components. The main purpose of proposed PET is reduction of the power delivery stage (AC/DC and DC/AC links) in PET with DC-link.

The input stage is a three or single phase PWM rectifier, which is used to convert the primary low frequency voltage into the DC voltage. The main functions associated with the rectifier control are shaping the input current, controlling the input power factor, and keeping the DC-link voltage at the desired reference value. Many control methods are presented for control of input stage in conventional PET, which could be used in proposed PET. Fig. 4 shows three phase rectifier with input inductances. A

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three phase PWM rectifier is used in this paper, which operates same as input stage of conventional PET [8]-[10]. Fig. 5 shows input stage control diagram.

To realize constant DC voltage and keep input current sinusoidal, the double control loops, a DC voltage outer loop and an AC current inner loop, are adopted. For most description refer to [8]-[10]. As can be seen from Fig. 5, the reference for the active current is derived from the DC voltage outer loop. The reference for the reactive current is set to zero to get unity power factor.

The current error signals are input the current regulators and then form the modulation signals. If the d axis of the reference frame is aligned to the grid voltage, we obtain Vinq =0.Isolation stage is contained a single-phase high frequency voltage source converter (VSC), which converts the input DC voltage to AC square voltage with high (or medium) frequency and HF (MF) transformer. The main functions of the HF (MF) transformer are such as: voltage transformation and isolation between source and load.

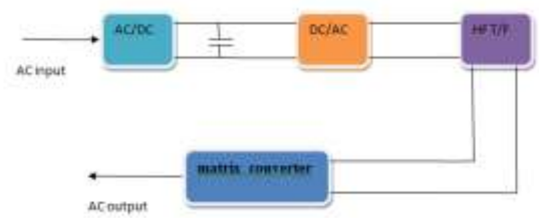

Fig 3. Block Diagram of proposed PET with DC link.

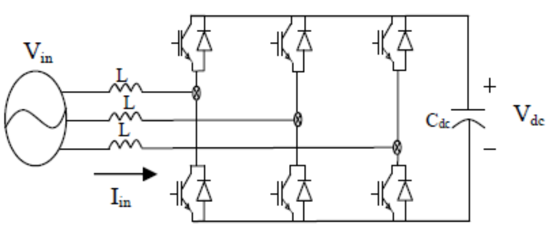

Fig 4. Structure of the proposed input stage

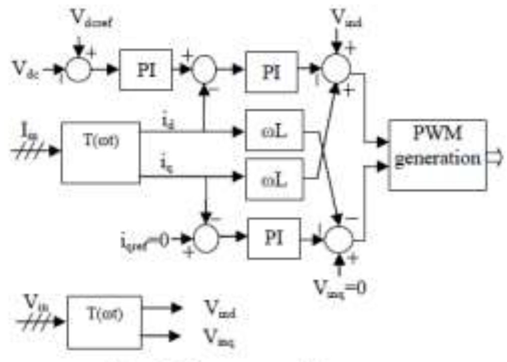

Figure 5. Input stage control diagram.

Fig 5. Input stage control diagram.

Structure of the proposed isolation stage is shown in Fig. 6.Circuit diagram of VSC is the same as H-bridge cell. To simplify the design of the control system, open loop control is applied for the VSC. The principle of modulation is based on a comparison of a sinusoidal reference waveform with zero carrier waveform. The principle of switching H-bridge is described with Conditions bellow:

Condition 1: if sin wave ≥ 0, then H1 and H2 are turned on.
Condition 2: if sin wave < 0, then H3 and H4 are turned on.

If sine reference wave has a frequency fr and an amplitude Ar then output voltage of VSC has a frequency fr. By neglecting the losses of HF (MF) transformer, the HF (MF) transformer can be treated as a proportional amplifier. The simplified model of the MF transformer is presented as: Vi, Vs. are the primary and secondary voltage in HF (MF) transformer, respectively and N points to turn ratio. A square voltage source can be generated by isolation stage.

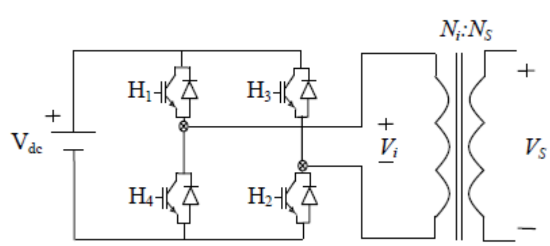

Fig 6. Structure of the proposed isolation stage.

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Fig. 7 shows a matrix converter with novel function for square to sinusoidal voltage converter. Matrix converter topology employs six bidirectional switches to convert high frequency single-phase input directly to a power frequency (50/60 Hz) three- phase output. The proposed converter generates desired output voltage with suitable shape and frequency. Operation of proposed converter is the same as three levels voltage source inverter but here voltage source has two polarities. Several modulation strategies have been proposed for traditional inverters. Among these methods, the most common used is the pulse widths modulation (PWM). The principle of the PWM is based on a comparison of a sinusoidal reference waveform, with triangular carrier waveform. At each instant, the result of the comparison is decoded in order to generate the correct switching function corresponding to a given output voltage level. In proposed PET, PWM modulation technique applied to a matrix converter is employed. The main point of switching is this point that with changing of polarity in input sources on switches are turned off and other switches in arms are turned on. In this method, there are two important parameters to define: the amplitude modulation ratio, or modulation index m, and the

$$M = \frac{V_{ref\ max}}{V_{carrier\ max}} \qquad (2)$$

$$P = \frac{f_r}{f_s} \qquad (3)$$

frequency modulation ratio p. Definitions are given by

Vref max and Vcarrier max are the amplitudes of reference voltage and carrier voltage, respectively. On the other hand, Fs is the frequency of the main supply and fT the frequency of the triangular carrier. As it can be seen in Fig. 8, the matrix converter is controlled by PWM method. In this case, the direct axis, quadratic axis, and zero sequence quantities for three-phase sinusoidal signal is computed by Park transformation. Then the dq voltage terms are compared by reference signals Vdref and Vqref and error signals enter to PI controllers. Next the PI controller outputs are transformed to three-phase sinusoidal abc voltage terms and used to generate appropriate matrix gate pulses.

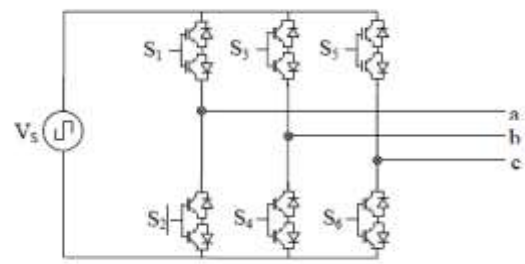


Fig 7. Proposed matrix converter

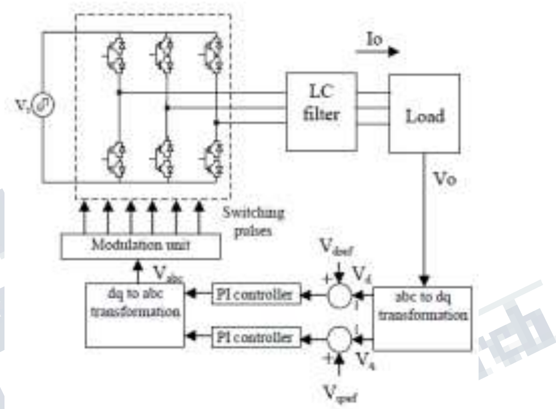
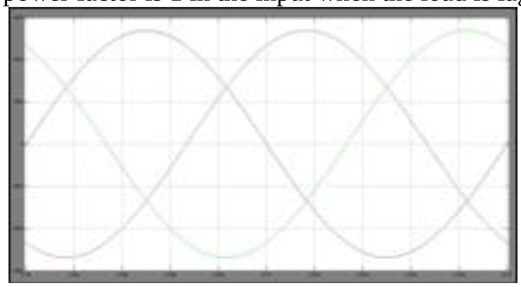


Fig 8. Circuit control of output stage.

In comparison with conventional PET with DC-link, in proposed converter power delivery stages and power electronic converters have been reduced and AC/AC matrix converter is used replaced by two converters (rectifier and inverter). This idea leads to the loss reduction, by processing the power in one stage instead of two stages. Operation of proposed PET is described by Fig. 9. In this case the line voltage is 3.8 kV and the PET power is 30 kVA. Fig. 9(a) shows input line voltage of PET. As it can be seen in Fig. 9(b), the DC-link voltage of input stage is 7800 V. The voltage controller in Fig. 5 acts so that the DC-link voltage is regulated in reference value. Fig. 9(c) depicts the output voltage of VSC in isolation stage that transforms DC voltage to medium frequency AC voltage as the transformer primary voltage. The level of medium frequency AC voltage in secondary side is changed by MF transformer in Fig. 9(d). In the output stage, the medium frequency voltage is revealed as a 50 Hz waveform by AC/AC matrix converter. Fig. 9(e) shows load voltage between phase (a) and phase (b) before LC filter and load output voltage is shown in Fig. 9(f). Fig. 10 shows the PET input power factor correction ability. In these simulations the active load is assumed to be 20 kW and the reactive power is assumed to be 10 kVAR inductive. Fig. 10(a) and Fig. 10(b) show phase voltages and currents of the load.

Voltage and current for one phase together are shown in Fig.10(c). It is considered the power factor is 0.5 lag. Fig. 10(d) show input phase voltage and current. As it can be seen, power factor is 1 in the input when the load is lag.



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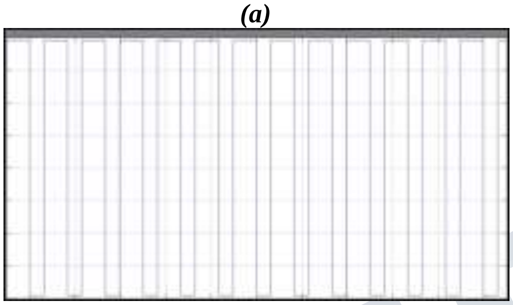

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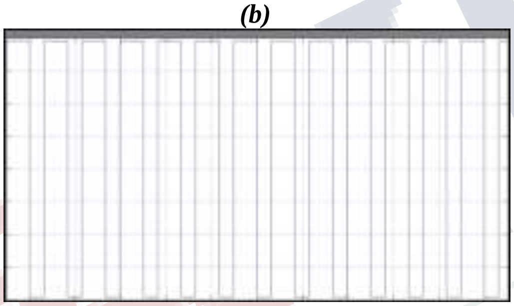

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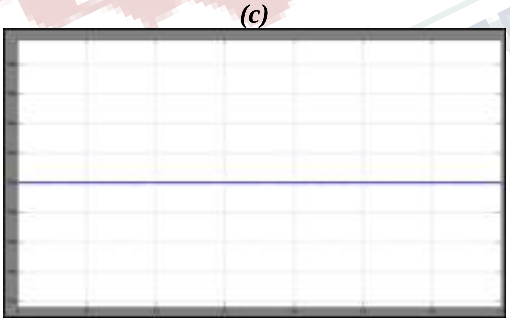

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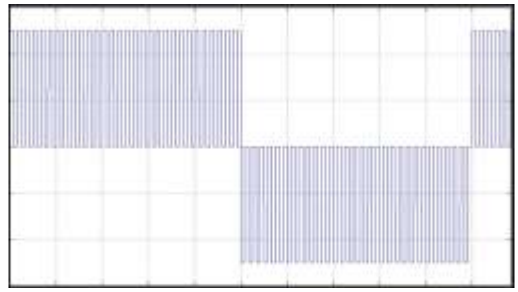

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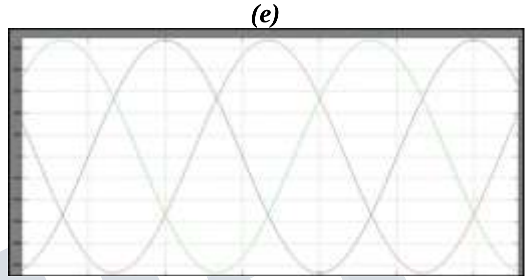

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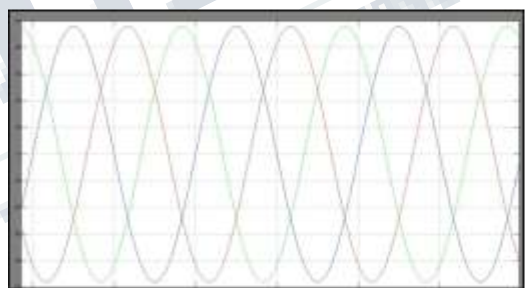
Fig 9. (a) Input voltage (b) DC-link voltage (c) MF transformer primary voltage (d) MF transformer secondary voltage (e) output voltage before filter and (f) output voltage



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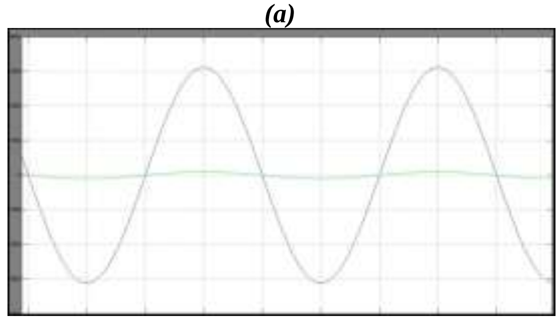

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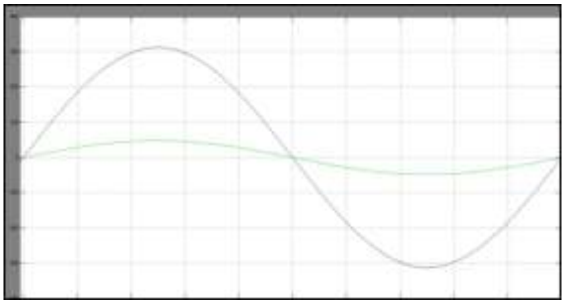

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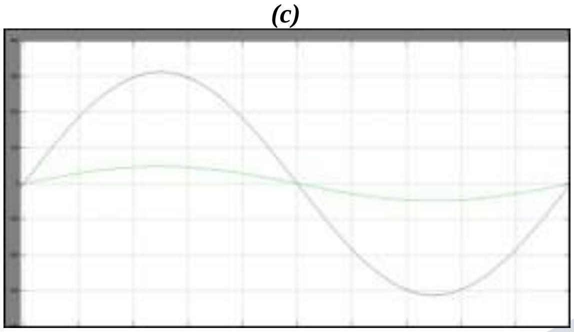
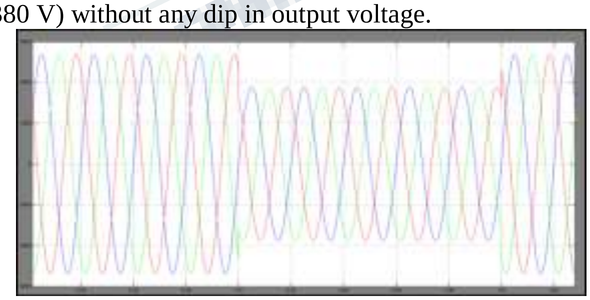


(d)

Fig 10. PET current and voltage waveforms in inductive load (a) phase output voltages (b) load currents (c) one phase output voltage and current and (d) one phase output voltage and current

IV. SIMULATION RESULTS

To evaluate the expected performance of the PET, the design was simulated to predict steady state performance. A prototype based on the proposed topology is simulated using MATLAB/SIMULINK. Also the parameters value used for simulations has been shown in Table I. Fig. 11 shows how the PET handles the voltage sag conditions. In Fig. 11(a), input voltage reduces 30 percent from t=0.4 s to t=0.5 s. As it can be seen, the PET acts properly and adjusts the output voltage to desired level (380 V) without any dip in output voltage.



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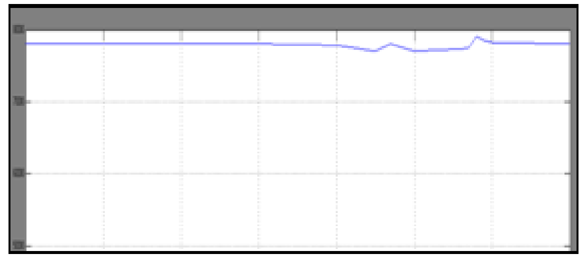

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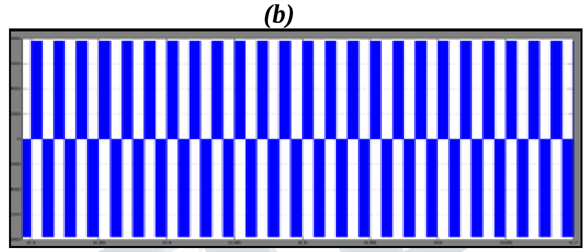

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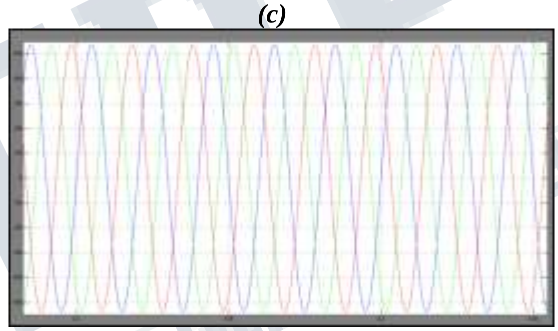
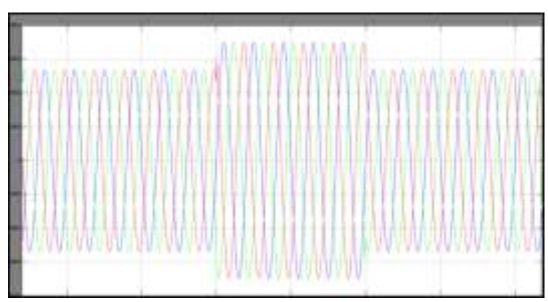


(d)

Fig 11. (a) Input voltage (b) DC-link voltage (c) load voltage before filter and (d) load voltage.

Fig. 12 shows response of PET to swell voltage in input voltage. Fig. 12 (a), shows That the fault starts at t = 0.4s and cleared at t = 0.5s. During the fault, the voltage of supply (grid) increase to 1.3 rated value. Fig. 12(b) shows the DC-link voltage. During the voltage swell, the grid voltage increases but DC-link voltage almost is constant and the output converter keeps the load voltage at rated value as in normal operation conditions. Fig. 12(c) shows the load voltage (Vab) before LC filter. Output line voltage is shown in Fig. 12(d).



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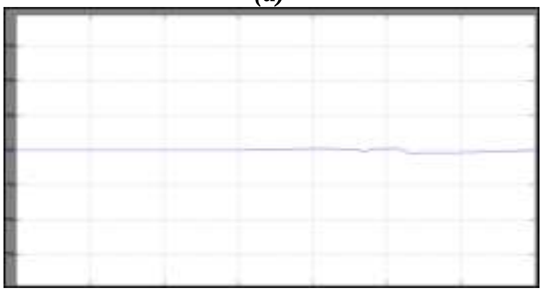

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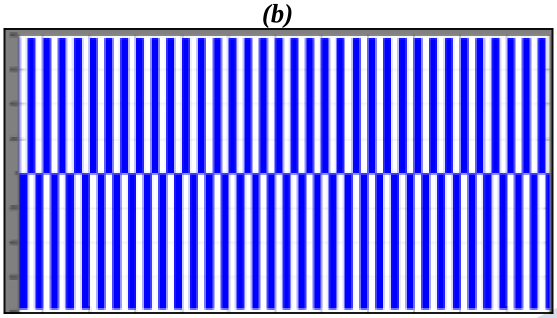

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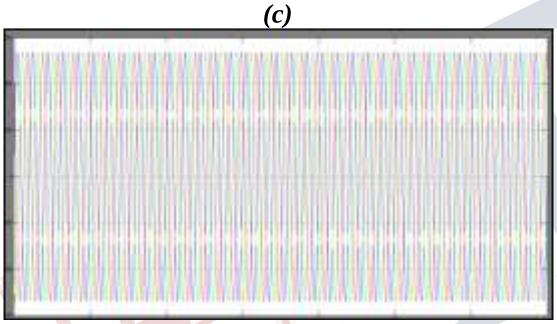

(d)

Fig 12. (a) Input voltage (b) DC-link voltage (c) load voltage before filter and (d) load voltage.

V. CONCLUSION

In this paper a new configuration of power electronic transformer with DC-Link capacitor has been proposed. To obtain higher efficiency, the AC/DC and DC/AC converters have been integrated in one converter. The topology described in this paper has many advantages such as power factor correction, voltage regulation, voltage sag and swell elimination, voltage flicker reduction. In proposed PET one AC/AC matrix converter is used to replace two converters and switching of matrix converter is easy and not complex. Simulation results showed some of advantages in proposed PET.

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