Modeling and Simulation of AC/AC Matrix Converter based Power Electronic Transformer for Power Quality Improvement

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Abstract: A new type of transformer based on Power Electronics (PET) has been proposed in this paper, 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.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 designed 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. The proposed power electronic transformer has been modeled using MATLAB/ SIMULINK and Power quality improvement with proposed model has been verified by the simulation results.

Keywords- Power electronic transformer; AC/AC Matrix converter; Power Quality; High Frequency Transformer; PWM Technique

I. INRODUCTION

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 intoPET.

Different topologies have been presented for realizing thePET, 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 modulatedinto 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 aconverter 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 inputstage, an isolation stage, and an output stage [6]-[9]. Thesetypes enhance the flexibility and functionality of the electronic transformers owing to the available DC links. This approachcan perform different power quality functions and providegalvanic isolation but they need whether too many powerelectronic converters and DC-link electrolytic capacitors. Thusthey result in a rather cumbersome solution.

Custom power devices are introduced in the distribution system to deal with various power quality problems faced byindustrial and

commercial customers due to increase insensitive loads such as computer and adjustable speed drivesand use of programmable logic control in the industrial process.

This paper investigates the PET that includes three parts: input stage, an isolation stage, and an output stage. ProposedPET includes AC/AC matrix converter. The proposed AC/ACconverter can generate desired output voltage from squareinput voltage. The main point of proposed PET is reduction ofthe stage and components of the three-part PETs. Thereliability and power quality of distribution system can besignificantly improved by using proposed PET. To verify theperformance of the proposed PET, computer-aided simulationsare carried out using MATLAB/SIMULINK.

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, theline side AC waveform is modulated with a converter to ahigh-frequency square-wave and passed through a HF (MF)transformer and again with a converter, it is demodulated toAC form power-frequency. Since the transformer size isinversely proportional to the frequency, the HF (MF)transformer will be much smaller than the power-frequencytransformer. So, the transformer size, weight and stress factoris reduced considerably [3].
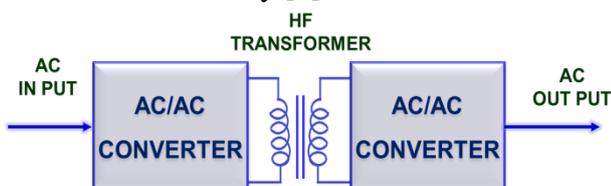
Figure 1 Block Diagram of electronic transformer using High Frequency AC link
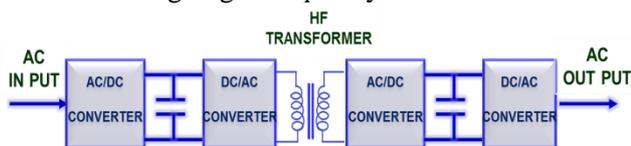
Figure 2 Block Diagram of Power Electronic based Transformer (PET) with DC link

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 DC link 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]-[9].

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 voltageinto the DC voltage. The main functions associated with therectifier control are shaping the input current, controlling theinput power factor, and keeping the DC-link voltage at thedesired reference value. Many control methods are presentedfor control of input stage in conventional PET, which could beused in proposed PET. Fig. 4 shows three phase rectifier withinput inductances. A three phase PWM rectifier is used in thispaper, which operates same as input stage of conventional PET[8]-[9]. Fig. 5 shows input stage control diagram. To realizeconstant DC voltage and keep input current sinusoidal, thedouble control loops, a DC voltage outer loop and an ACcurrent inner loop, are adopted. For most description refer to[8]-[9]. As can be seen from Fig. 5, the reference for theactive current is derived from the DC voltage outer loop. Thereference for the reactive current is set to zero to get unitypower factor. The current error signals are input the currentregulators and then form the modulation signals. If the d axis ofthe reference frame is aligned to the grid voltage, we obtainV_{inq} =0.
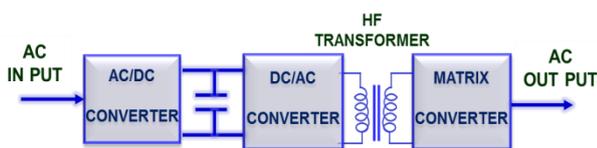
Figure 3 Block Diagram of proposed PET with DC link

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.
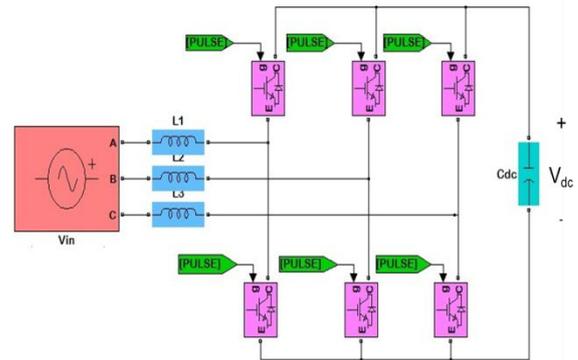
Figure 4 Structure of the proposed input stage
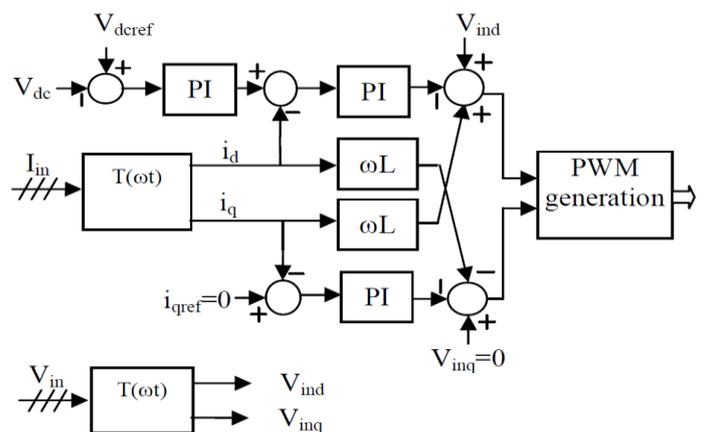
Figure 5 Input stage control diagram

Structure of the proposed isolation stage is shown in Fig. 6. Circuit diagram of VSC is the same as H-bridge cell. 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 $\geq$ 0, then H1 and H2 are turned on.
Condition 2: if sin wave < 0, then H3 and H4 are turned on.
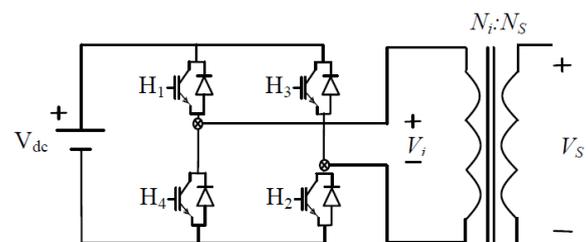
Figure 6 Structure of the proposed isolation stage

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. 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.
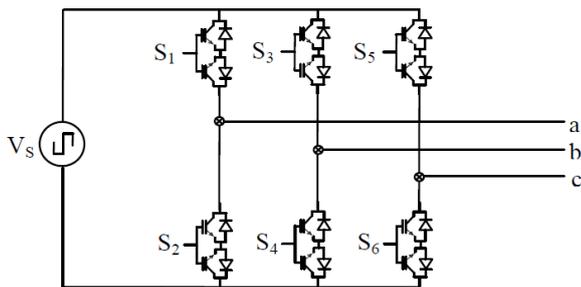
Figure 7 Proposed matrix converter

In comparison with conventional PET with DC-link, inproposed 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.
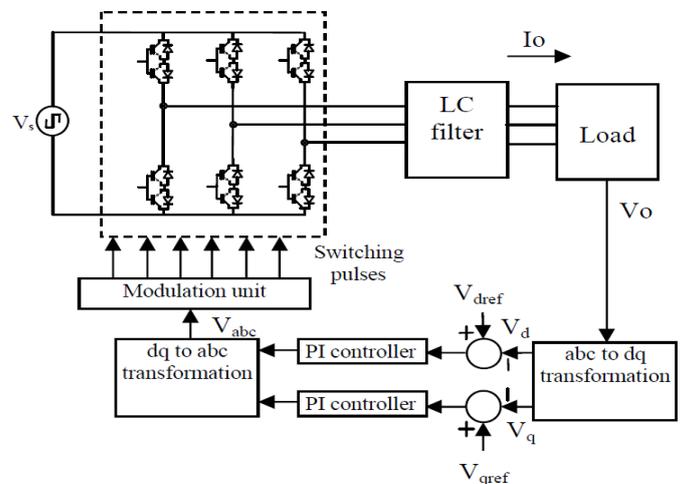
Figure 8 Circuit control of output stage

IV. SIMULATION RESULTS

To evaluate the expected performance of the PET, thedesign was simulated to predict steady state performance. A prototype based on the proposed topology is simulated using MATLAB/SIMULINK.Operation of proposed PET is described by Fig. 10. Fig. 10(a) shows input line voltage of PET. As it can be seen in Fig. 10(b), the DC-link voltage of input stage is 7800 V. Fig. 10(c) depicts the output voltage of VSC in isolation stage that transforms DC voltage to medium frequency AC voltage as the transformer primary voltage.In the output stage, the medium frequency voltage is revealed as a 50 Hz waveform by AC/AC matrix converter.
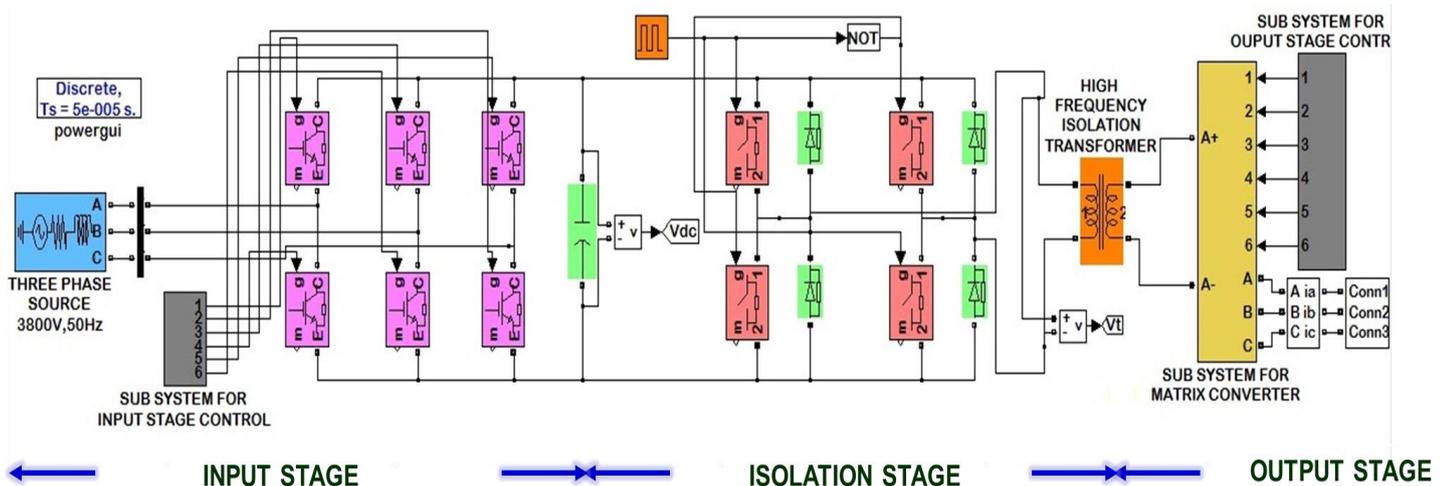
Fig 9. MATLAB / SIMULINK MODELING OF PROPOSED POWER ELECTRONIC TRANSFORMER

(a)

(b)

(c)

(d)

(e)

(f)
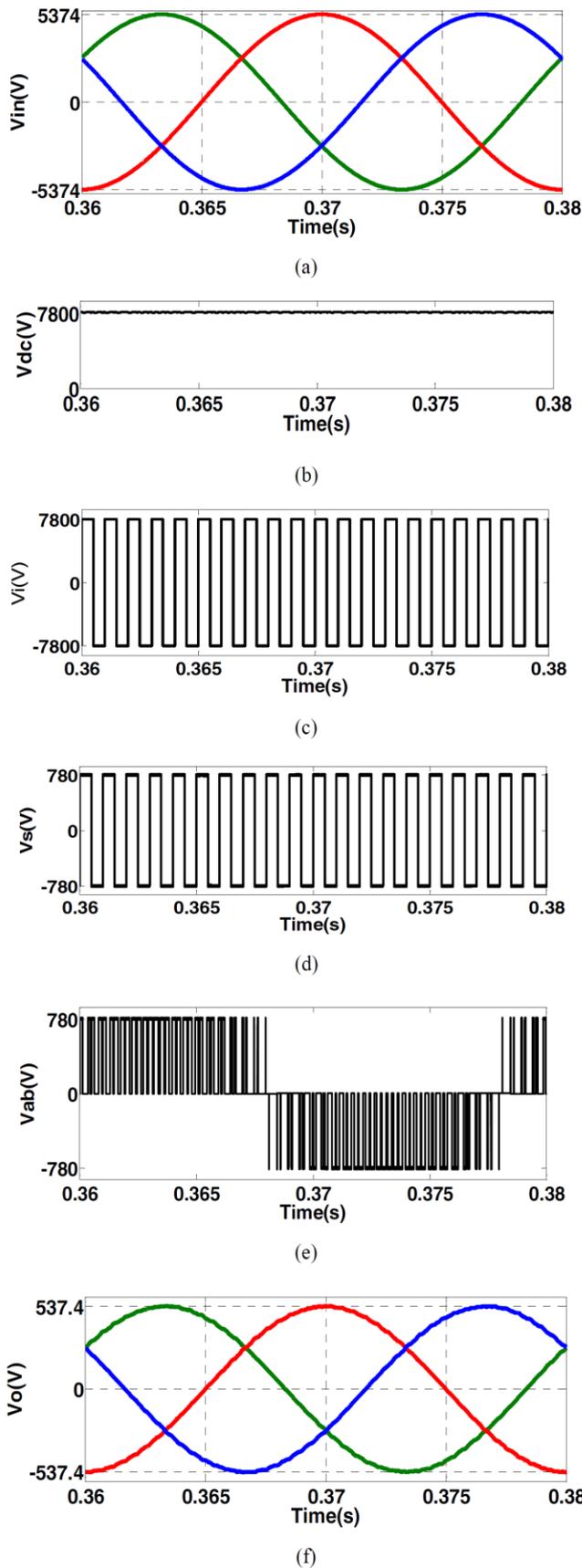
Figure 10. (a) Input voltage (b) DC-link voltage (c) MF transformer primaryvoltage (d) MF transformer secondary voltage (e) output voltage before filter and (f) output voltage.

(a)

(b)

(c)

(d)
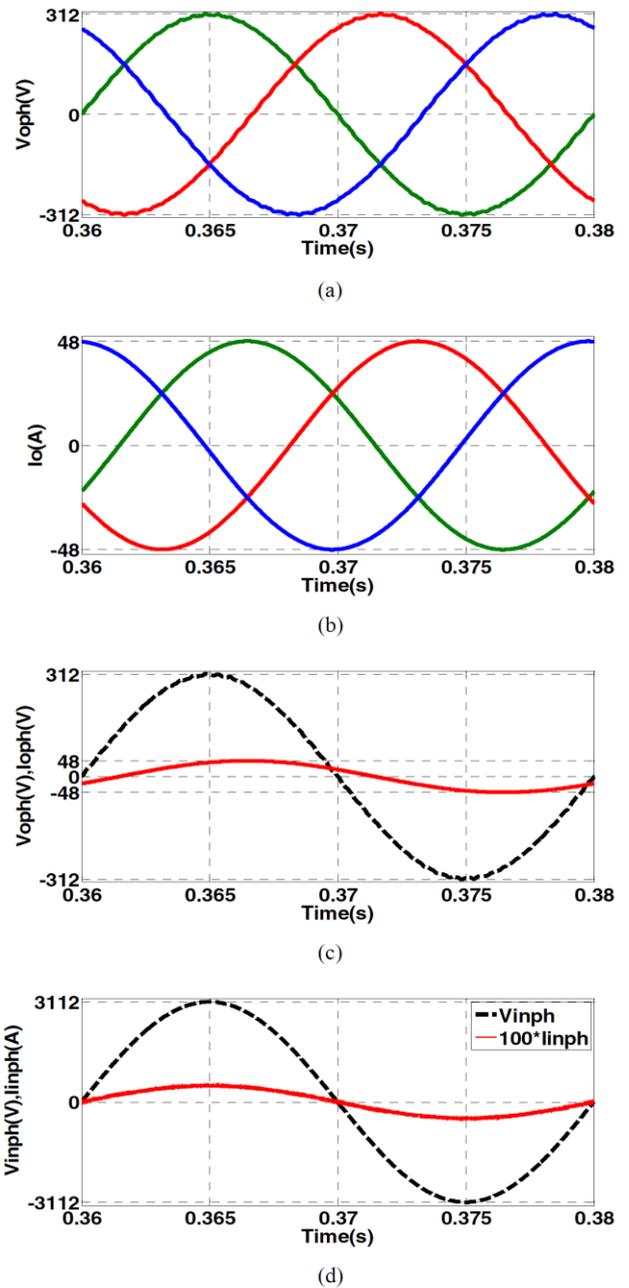
Figure11 PET current and voltage waveforms in inductive load (a) phaseoutput voltages (b) load currents (c)& (d) one phase output voltage and current

TABLE-I

Parameters	Value
Input phase-phase voltage	3800V
Power frequency	50Hz
MF transformer	10:1, 1000 Hz,30 kVA
Output phase-phase voltage	380V
Matrix converter switching frequency	2050Hz
Load	20 kW+j10 kVAR
LC filter	2 mH, 220 μF
L, Cdc	3 mH, 2000 μF
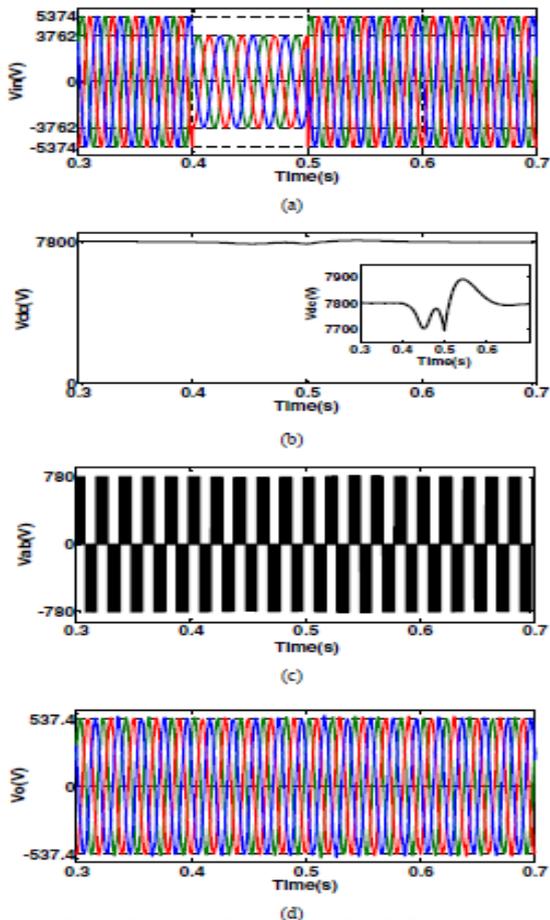
Figure 12. (a) Input voltage sag (b) DC-link voltage
(c) load voltage before filter and (d) load voltage.

Figure 13. (a) Input voltage swell (b) DC-link voltage
(c) load voltage before filter and (d) load voltage.

V. CONCLUSION

In this paper a new configuration of power electronictransformer 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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