PET USING MATRIX CONVERTER

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Abstract : Matrix converters have wide application such as electrical drives, regulated power supplies and variable voltage sources. Transformers are generally used for isolation of input from the load. Apart from isolation, transformer provides voltage transformation, noise decoupling etc. Conventional isolation transformer is operated at line frequency of 50Hz or 60Hz. Line frequency transformers have lower flux utilization. This makes it heavy, bulky and very expensive part of an electrical converter system. The size and weight of the transformer can be reduced by increasing the saturation flux density of the core material and the maximum allowable temperature rise in the core and windings. Since the saturation flux density is inversely related to frequency, higher frequency of operation reduces the magnetic core size by increasing the flux utilization. So a high frequency isolated power electronic converter provides overall size and cost advantage over a line frequency transformer. This kind of small high frequency isolated power converters are called PETs. 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 .

I. INTRODUCTION

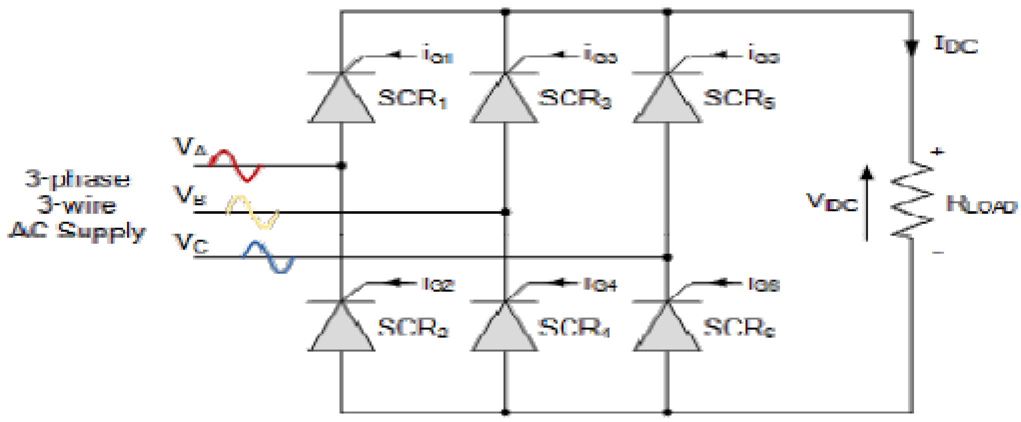
A new type of transformer based on Power electronics known as the power electronics transformer (PET) which has galvanic isolation also allows voltage transformation and power quality improvements in a single device. The PET provides a complete and fundamentally different approach in transformer design by using power electronics devices. Several advantages such as instantaneous voltage regulation, voltage sag compensation and power factor correction can be combined into PET. The design process involves the AC/DC (rectifier), DC/AC (inverter), AC/AC (matrix converter) converters and high frequency transformer have been used. The matrix converter has several advantages over traditional rectifier-inverter type power frequency converters. It provides sinusoidal input and output waveforms, with minimal higher order harmonics and no sub harmonics; it has inherent bi-directional energy flow capability; the input power factor can be fully controlled. Finally, it has minimal energy storage requirements, which allows to get rid of bulky and lifetime-limited energy-storing capacitors. The main advantage of PET using matrix converter is that it improves the power quality of distribution system. The proposed power electronic transformer has been modeled using MATLAB/ Simulink.

II. CONVERTERS

2.1 RECTIFIER

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as rectification, since it "straightens" the direction of current. Rectifiers have many uses, but are often found serving as components of DC power supplies and high-voltage direct current power transmission systems. Rectification may serve in roles other than to generate direct current for use as a source of power. As noted, detectors of radio signals serve as rectifiers. In gas heating systems flame rectification is used to detect presence of a flame. Many applications of rectifiers, such as power supplies for radio, television and computer equipment, require a steady constant DC voltage (as would be produced by a battery). In these applications the output of the rectifier is smoothed by an electronic filter, which may be a capacitor, choke, or set of capacitors, chokes and resistors, possibly followed by a voltage regulator to produce a steady voltage.

Working and operation



THREE PHASE FULL WAVE RECTIFIER

Three phase full converters can operate in 2 quadrants. The output voltage of three phase full converter can be positive as well as negative. It uses 6 thyristors as shown in figure . For 6 thyristors, there are 6 gate drives. In the first cycle gate drives are given to thyristors T6 and T1, hence line voltage VRY is applied across the load. Now T6 and T1 conduct. Output current Io and R-phase current IR flows in same direction hence, IR= IO

Similarly, Y-phase current IY and output current IO are in opposite direction, hence

IY = - IO

The SCR pair T6 and T1 conducts from (π/6+α) to (π/2+α) where α is the firing angle. Line voltage VRY is applied during this period. At (π/2 + α) thyristor T2 is triggered. Then, T6 turns off and T2 is triggered. Hence T1- T2 starts conducting and this is second cycle. In this cycle line voltage VRB is applied across the load. At (5π/6 +α), T3 is triggered. Then T1 turns off and T2-T3 starts conducting. Therefore, line voltage VYB is applied across the load and this is third cycle. Thyristors are triggered in following sequence T1-T2-T3-T4-T5-T6 and the cycle repeats, the triggering delay between individual thyristors is 60°. Each thyristor conducts for 120° and each thyristor pair conducts for a cycle of 60°

The waveform shows the supply line voltages. These supply voltages are drawn according to the Phasor diagram shown in figure 2.3. The above waveform shows the gate drives triggered for α =30°. For six thyristors, there are 6 gate drives. In first interval gate drives are given to T6 and T1. Hence line voltage VRY is applied across the load.When T6 and T1 conduct Vo =VRY. The output current Io and IR flows in the same direction. Hence Io = IR

Similarly Y phase current IY and the output current Io are in opposite directions.

Hence IY = - Io

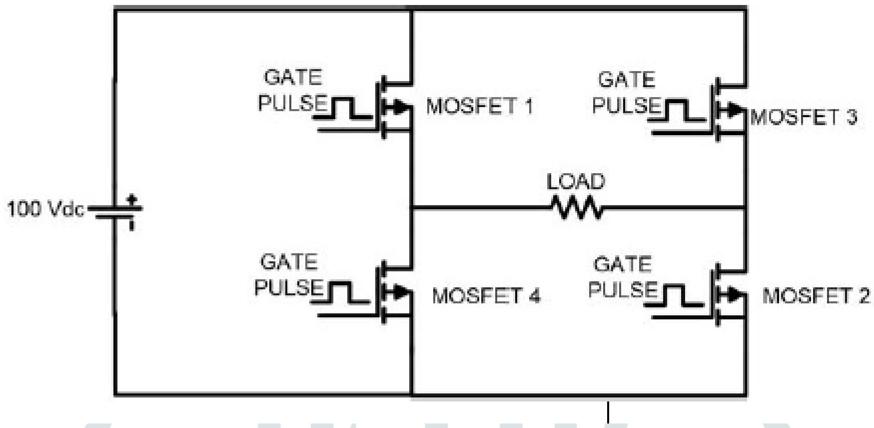
The SCR pair T6-T1 conduct from (π/6+α) to (π/2+α). Line voltage VRY is applied during this period. At (π/2+α) SCR T2 is triggered and now T6 turns off, since T2 is triggered T1-T2 starts conducting and it is marked as interval 2.In this interval supply line voltage VRB is applied across the load. At (5π/6+α), T3 is triggered. Hence T1 turns off and T2-T3 starts conducting. Therefore line voltage VYB is applied across the load.

2.2 INVERTER

An Inverter is basically a single stage converter device that converts DC signal to AC signal. The word “inverter” in the context of power electronics denotes a class of power conversion circuits that operates from a dc voltage source or a dc current source and converts it into ac voltage or current. Even though input to an inverter circuit is a dc source, it not uncommon to have this dc derived from an ac source such as utility ac supply. Thus, for example, the primary source of input power may be utility ac voltage supply that is converted, to dc by an ac to dc converter and then inverted back to ac using an inverter. Here, the final output may be of a different frequency and magnitude than the input ac of the utility supply. Typical Applications such as Uninterruptible Power Supply (UPS), Industrial (induction motor) drives, Traction, HVDC.

Working of Full Bridge Inverter

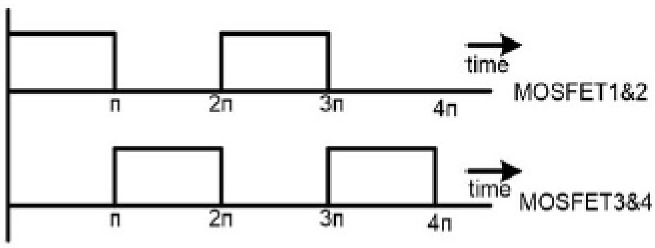
In this type of inverter, four switches are used. The main difference between half bridge and full bridge inverter is the maximum value of output voltage. In half bridge inverter, peak voltage is half of the DC supply voltage. In full bridge inverter, peak voltage is same as the DC supply voltage. The circuit diagram of full bridge inverter is as shown in below figure.



FULL BRIDGE INVERTER

The gate pulse for MOSFET 1 and 2 are same. Both switches are operating at same time. Similarly, MOSFET 3 and 4 has same gate pulses and operating at same time. But, MOSFET 1 and 4 (vertical arm) never operate at same time. If this happens, then DC voltage source will be short circuited. For upper half cycle ($0 < t < \pi$), MOSFET 1 and 2 get triggered and current will flow as shown in figure below. In this time period, the current flow from left to right direction.

For lower half cycle ($\pi < t < 2\pi$), MOSFET 3 and 4 get triggered and current will flow as shown in figure. In this time period, the current flow from right to left direction. The peak load voltage is same as DC supply voltage Vdc in both cases.



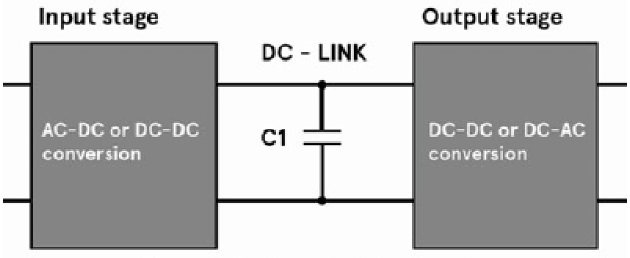
VOLTAGE WAVEFORM MOSFET

The below figure depicts the voltage waveform and current conduction of the four MOSFETs .This shows that the MOSFET 1 and 2 conducts during the duration ($0 < t < \pi$) and MOSFET 3 and 4 conducts during the duration ($\pi < t < 2\pi$).

2.3 DC LINK CAPACITOR AND ISOLATION TRANSFORMER

The DC Link capacitor

A DC-link voltage ripple analysis is essential for determining harmonics and for DC-link capacitor design and selection in single and three phase inverters. DC-link capacitors are used in order to provide a stable DC voltage, limiting its fluctuations even under heavy current absorption by the inverter: in practice they act as filters. In inverters the supply current is highly distorted due to commutation. It also acts as a filter to reduce the ripple in the DC link voltage and also as a DC link support so that for abrupt changes at the output we have a stabilized operation of inverter. Inverter operation demands pulsed currents from the DC link side. DC link capacitors are required to deliver these currents so that they do not reflect on the source side.In particular, the dc-link capacitance is calculated considering requirements or restrictions referred to in the switching frequency and/or double-fundamental frequency voltage ripple components The capacitor must be sized to meet specifications for ripple voltage at the DC-link and energy storage between mains cycles or when input power is lost. This means it should have a low equivalent series resistance (ESR) and a minimum capacitance and ripple current rating. These specifications must be met at the required operating voltage, temperature, power output, line and switching frequencies, and target lifetime.



DC LINK CAPACITOR

For low power AC-DC converters with no PFC stage, minimum capacitance is normally set by the allowed mains ripple voltage on the DC-link. For higher power AC-DC converters with PFC, the value is set by 'hold-up' or 'ride-through' time on input power loss and a much lower capacitance is possible with energy stored at high voltage, values of less than 1 µF/watt being normal.

Capacitance required for hold-up is simply calculated by equating the energy required by the load during hold-up:

th* Po/η (hold-up time times output power divided by efficiency) with the energy difference in the capacitor between its starting voltage and final voltage at which the converter stops operating to specification:

(0.5 CV2finish – 0.5 CV2start)

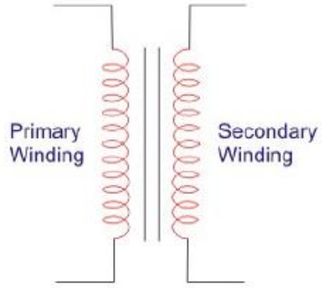
This rearranges to give

C = 2 Po th/ η (Vfinish2 – Vstart2)

For AC output inverters, hold-up may not be an issue and a minimum capacitance is just needed to be low enough impedance at the inverter switching frequency to minimize voltage ripple. In practical circuits, the ripple current that the capacitor must handle without overheating by dissipation in the ESR is often the overriding factor. The current can be so high that for a given voltage, a minimum physical size of capacitor is required to achieve low ESR, high dissipation and long lifetime. This often leads to a capacitance which is well over the minimum from line ripple or hold-up calculations. The ripple current waveform is very difficult to predict as it is a combination of line frequency and input and output stage frequencies and their harmonics. The wave shapes depend on the topologies of the stages and can vary from triangular, high-rms currents in discontinuous mode PFC stages to more square-shaped currents from following bridge converter or inverter stages. The input and output stage currents are sunk and sourced respectively from the capacitor and are not necessarily in phase or at fixed frequency,complicating matters further.

Isolation Transformer

Transformers are electromagnetic devices which transform alternating current (AC) electrical energy from primary to secondary side. The energy is transformed with equal frequency and approximately equal power by means of the transformer core magnetic field. Thus, they provide galvanic isolation in the electrical system. Isolation transformers are the type of transformers having primary and secondary windings separated from each other, so in case of fault in one side of the winding will not be transferred to the next stage. The input power and output power in an isolation transformer are electrically separated by a dielectric insulation barrier thus providing the galvanic isolation in the electrical system. They can work as step-up transformer or step-down transformers but often operate with turns ratio N1/N2 = 1. This means that the primary and secondary voltage values are equal. This is obtained with a same number of turns on the primary and secondary windings.



ISOLATION TRANSFORMER

Electrical circuit isolation which is not galvanized from the network, because the current circuit can be closed between oscilloscope common point and grounding. The main purpose of the isolation transformer is safety and protection of electronic components and the persons against electrical shock. It physically separates the power supplying from primary side and a secondary side circuit connected to electronic components and grounded metal parts which are in contact.

Basically, the transformer secondary side is isolated from the grounding. Isolation transformer provides available supplying even if the device is broken. The primary side remains under voltage which can be used to supply some alarm or warning beep circuits when the device is broken. When the isolation transformer is designed it is very important to pay attention to windings capacitance values which create capacitive coupling. This enables AC signal to pass from primary to the secondary side which significantly increased the noise level. For this purpose, the windings are surrounded by a metal strip which is grounded (creating a Faraday shield).The isolation transformers are used as instrument transformers when the high voltage should be measured. The high voltage is dangerous for the person who tries to measure high voltage, but it can also harm the measurement circuits. In this case, the step-down isolation transformer is used to reduce the high voltage to the safe level and for measurement range.

III. MATRIX CONVERTER

3.1 INTRODUCTION

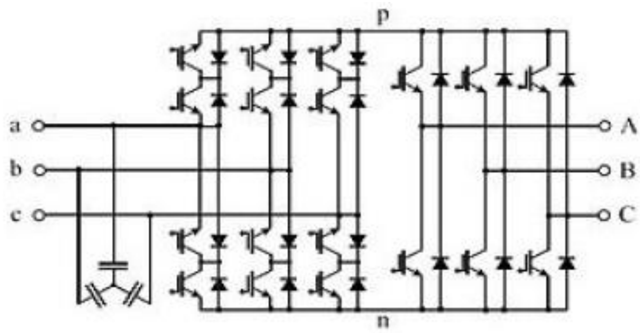
A matrix converter is a circuit which is defined as a converter capable of single stage conversion. It uses mainly bidirectional switches such as IGBT (Insulated Gate Bipolar Transistor) or MOSFET (Metal Oxide Semiconductor Field Effect Transistor) with anti-parallel diodes to achieve automatic conversion of power from AC to AC. It provides an alternate to PWM voltage rectifier (double sided). A matrix device is capable of changing an input voltage directly into a discretionary AC voltage, instead of converting that voltage into a DC voltage as inverters. This matrix device has higher potency, smaller size, longer lifespan and fewer input current harmonics than inverters and has high potential for realizing the above mentioned demands.

3.1TYPES OF MATRIX CONVERTER

There are 2 main types of matrix converter. They are

1. Direct matrix converter
2. Indirect matrix converter

<u>Indirect matrix converter</u>

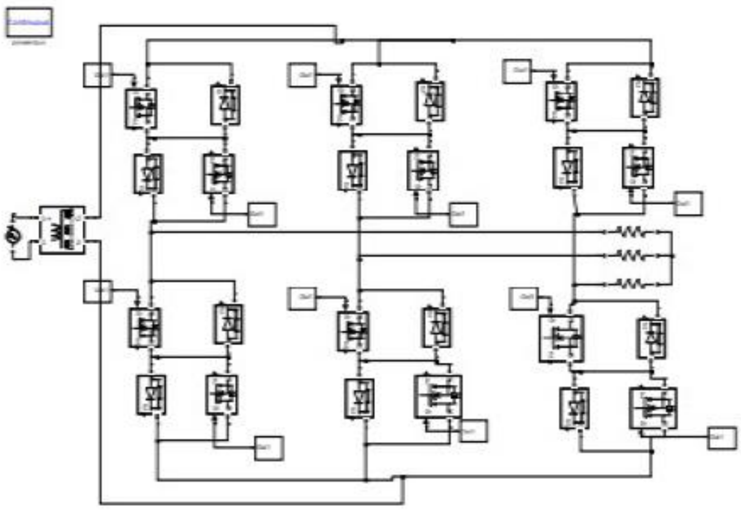


INDIRECT MATRIX CONVERTER TOPOLOGY

The direct matrix converter shown in above figure , is one which converts AC to AC voltage with a technique of AC-DC-AC. Hence it works as a rectifier in the input stage to convert AC to DC and the inverter in the output stage to get back the AC from DC.A DC link capacitor is present in between to hold the output of rectifier and to isolate the two parts of the matrix converter. There are different types of indirect matrix converter:

Simulink model of Matrix Converter

The Simulink model of Matrix converter is shown in Figure 3. The model is developed for time domain simulation and the input is assumed to be 50 Hz .From the available 230 V single phase AC, a step-up transformer is used before load to produce 440 V output voltages.

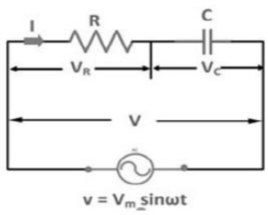


SIMULINK MODEL OF MATRIX CONVERTER

3.2FILTERS AND TANK CIRCUITS

RC Filter

The combination of a pure resistance R in ohms and pure capacitance C in Farads is called RC circuit. The capacitor store energy and the resistor connect in series with the capacitor control the charging and discharging of a capacitor. The RC circuit is used in camera flashes, pacemaker,timing circuit etc.

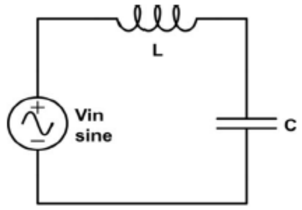


RC CIRCUIT

The formula to find the frequency cutoff point of an RC circuit is, frequency= 1/2πRC.

LC tank circuit

An LC circuit, also called a resonant circuit, tank circuit, or tuned circuit, is an electric circuit consisting of an inductor, represented by the letter L, and a capacitor, represented by the letter C, connected. The circuit can act as an electrical resonator, an electrical analogue of a tuning fork, storing energy oscillating at the circuit's resonant frequency. LC circuits are used either for generating signals at a particular frequency, or picking out a signal at a particular frequency from a more complex signal; this function is called a bandpass filter.They are key components in many electronic devices, particularly radio equipment, used in circuits such as oscillators, filters, tuners and frequency mixers.



LC CIRCUIT

An LC circuit is an idealized model since it assumes there is no dissipation of energy due to resistance. Any practical implementation of an LC circuit will always include loss resulting from small but non-zero resistance within the components and connecting wires. The purpose of an LC circuit is usually to oscillate with minimal damping, so the resistance is made as low as possible. While no practical circuit is without losses, it is nonetheless instructive to study this ideal form of the circuit to gain understanding and physical intuition.

IV. RESULT ANALYSIS

4.1 Design of the AC input

The input side is designed with different loads connected to the input

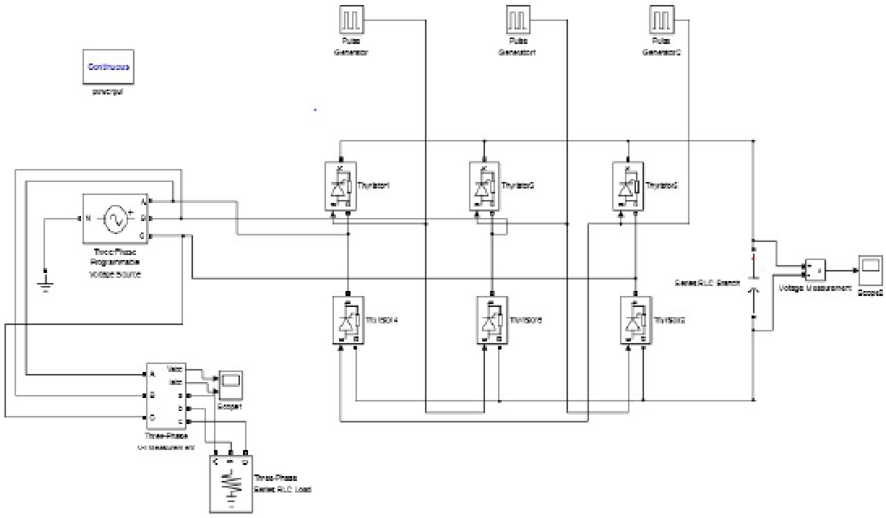
R load
Vrms = 440V
Vmax = 440*√2 = 622.25V
Frequency = 50Hz
P = 100W
P = √3*Vrms*Irms*pf
Since it is a resistive load, power factor=1
Irms = 0.1312A
Imax = 0.1312*√2=0.1855A
RL load
Vrms = 440V
Vmax = 440*√2 = 622.25V
Frequency = 50Hz
P = 100W
Q l = 50W
S = √3*Vrms*Irms*pf
pf = cos(26.53) = 0.894
Irms = √3*Vrms*Irms*pf
Imax = 0.16*√2= 0.226A

RC load
Vrms = 440V
Vmax = 440*√2= 622.25V
Frequency = 50Hz
P = 100W
Qc = 50W
S = √3*Vrms*Irms*pf
pf = cos(26.53) = 0.894
Imax = 0.16*√2= 0.226A

RLC load
Vrms = 440V
Vmax = 440*√2 = 622.25V
Frequency = 50Hz
P = 100W
Ql = 60W

Qc = 40W
S =√3*Vrms*Irms*pf
pf = cos(11.33) = 0.9805
Imax = 0.136*√2= 0.193A

4.2 RECTIFIER

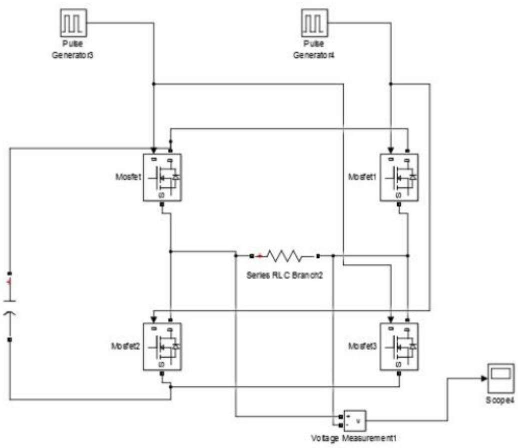


SIMULINK OF RECTIFIER

Vdc = 890V (α=30)
Simulink output = 440 *√2 = 622.25V

<u>Filter circuit</u>
For RC filter
Vc = 440V
E = 440√2 V
t => keeping the value as small as possible to get the maximum output value quickly,we take the t=2.5ms.Then,
RC =2.035 * 10-3
Therefore, obtaining values of R to be 0.02Ω.Hence, from product capacitance C is found to be C≈100μF
<u>DC link capacitor</u>
Vstart = 0V; Vfinish = 622.25V
C = 1.53μF

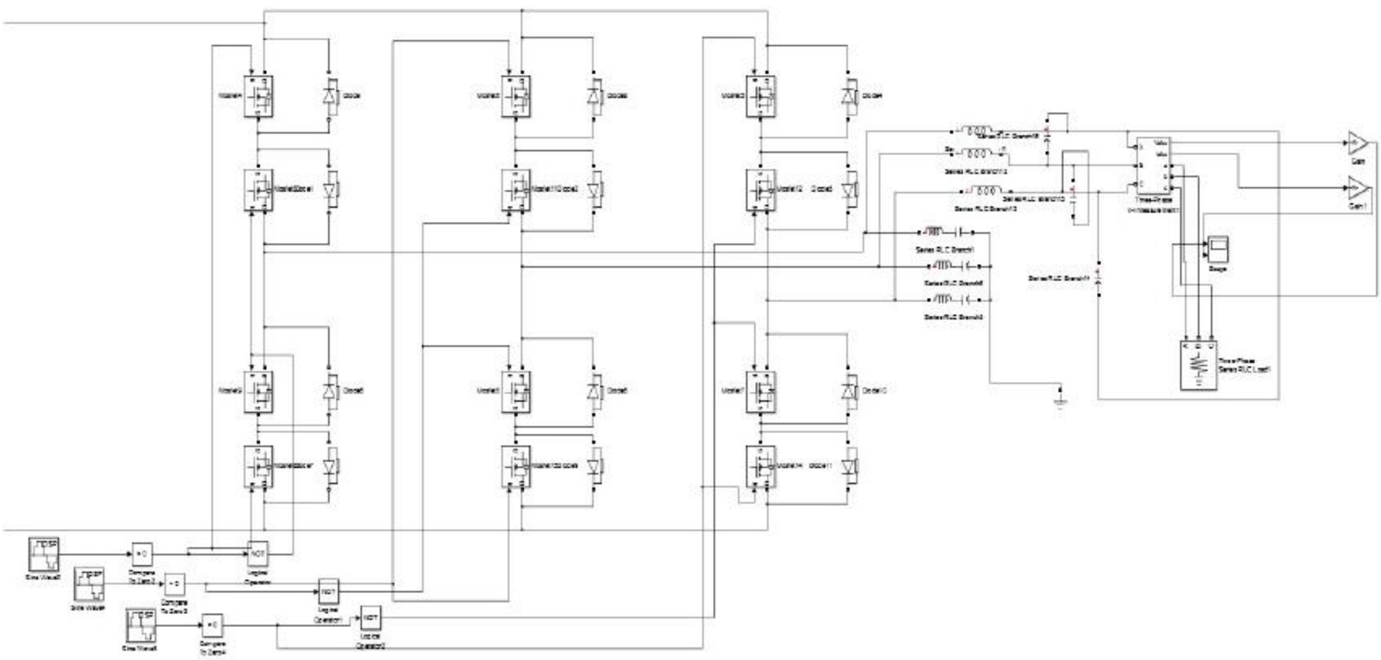
INVERTER



SIMULINK OF DC LINK CAPACITANCE AND INVERTER

Vo = duty ratio * Vin
Taking 50% as duty ratio we get,
Vo = 0.5 * 620

Vo = 310V



SIMULINK MODEL OF MATRIX CONVERTER WITH FILTER AND TANK CIRCUITS

RLC filter

In order to get a 3 phase sine wave as output from the matrix ,a 1-phase sine wave has to be given as input. Thus square wave is been converted to sine wave by using a RLC filter circuit. Inductance is used to obtain a proper square wave.

R = 1Ω

L = 1.85mH

C = 2200µF

Transformer parameters

We use an isolation transformer to isolate power device from the power source. To avoid the inductance effect in the output, R and L values were reduced to zero.

Winding 1 Parameters

Vrms = 630V

R = 0pu

L = 0pu

Winding 2 Parameters

Vrms = 230V

R = 0pu

L = 0pu

7.2.8 Filter circuit for matrix converter

LC filter circuit is used to get proper sine wave (3-phase) without ripples

L= 150mH

C = 220µF

7.2.9 Tank circuit for matrix converter

LC series circuit is used for the tank circuit. Tank circuit stores energy where L and C values are varied to give the necessary output frequency

L = 250mH

C = 550µF

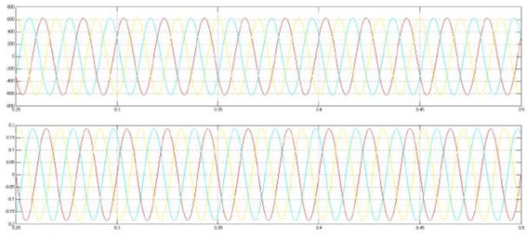
7.2.10 Gain

The output peak voltage obtained was 80V due to the losses present in the matrix converter. In order to get the standard 3 – phase 440V, a gain block is used.

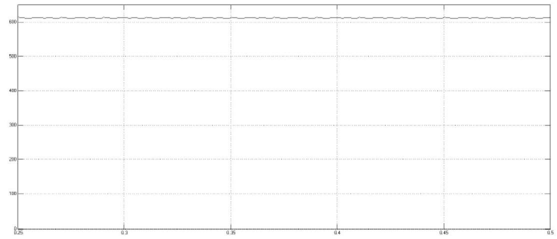
Output maximum voltage = 622.25 V

4.3 Simulation Results

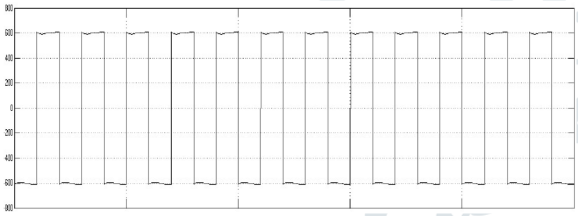
To evaluate the expected performance of the PET, the design was simulated to predict steady state performance. A prototype based on the proposed topology is simulated using MATLAB/SIMULINK. Operation of proposed Fig. 7.3.1 shows input line voltage of PET. As it can be seen in figure, the DC-link voltage of input stage is 622.5V. Figures depict 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.



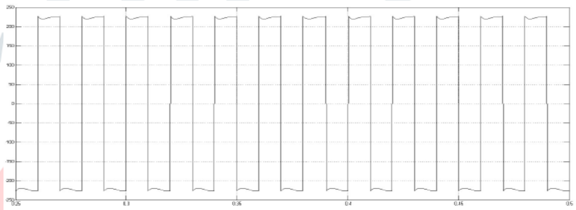
THREE PHASE AC INPUT GIVEN TO RECTIFIER



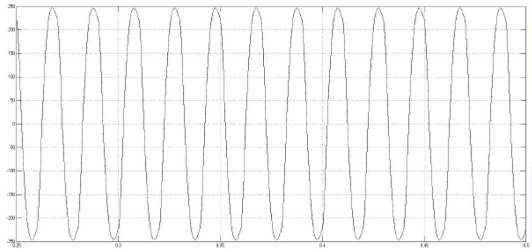
OUTPUT OF THE RECTIFIER



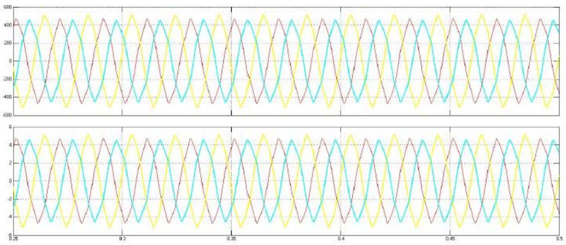
OUTPUT OF THE INVERTER



OUTPUT OF THE ISOLATION TRANSFORMER



OUTPUT OF THE FILTERING CIRCUIT



OUTPUT OF THE MATRIX CONVERTER

4.4 Comparison of 3- phase to 3- phase and 1- phase to 3- phase matrix converter

PARAMETER	PROPOSED PET	CONVENTIONAL PET
Number of Bi-directional switches	Here we use 12 Bi-directional switches.	9 Bi-directional switches are used.
Design Complexity	Easier to design when compared to conventional PET	It involves complex design
Voltage transformation	It is possible.	It is not possible.
Filter circuit	Filter circuit design is less complex due to single-phase input.	More complex due to three phase input.

V.CONCLUSION

A new configuration, which consists of power electronic transformer with DC-Link capacitor and a matrix converter, has been proposed. In order to obtain higher efficiency, the AC/DC and DC/AC converters have been integrated in one converter. This topology has many advantages such as power factor correction, voltage regulation, voltage sag, swell elimination and 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. It provides direct ac-ac conversion thus eliminating the need for reactive energy storage elements. The Matrix Converter provides an inherent four quadrant operation. It provides independent control of the output voltage magnitude, frequency and phase angle and operation at lagging, unity or leading power factor. The matrix converter has several advantages over traditional rectifier-inverter type power frequency converters. It provides sinusoidal input and output waveforms, with minimal higher order harmonics and no sub harmonics; it has inherent bi-directional energy flow capability; the input power factor can be fully controlled.

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