# MITIGATION OF POWER QUALITY ABERRATION USING SOLID STATE TRANSFORMER WITH MATRIX CONVERTER FOR GRID SYSTEM

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***ABSTRACT***

*This paper presents design of solid state transformer with a direct AC-AC matrix converter which is placed at output stage of solid state transformer. This proposed solid state transformer help to get higher efficiency for grid system. This Solid State Transformer (SST) is consist of three stage, AC-DC converter, DC-AC converter, AC-AC converter have been integrated. To obtain a higher efficiency from other SST with DC-link topologies, the two stage of conversion i.e. AC-DC and DC-AC conversion have been integrated in one matrix converter. The new proposed SST performs typical functions and has advantage of power factor correction, voltage sag, voltage swell, voltage flicker and protection under different fault conditions which are very important to maintain in grid system. This new proposed topology has light weight, reduction of dangerous dielectrics, low volume and very well protected because SST uses medium frequency transformer. The performance and operations of the SST with matrix converter have been investigated in MATLAB/Simulink and verified by simulation results.*

***KEYWORDS:*** *AC-DC converter, Solid State Transformer, Medium frequency transformer, Matrix converter.*

## I. INTRODUCTION

Transformer are extensively used in electrical power system especially in grid system to perform a primary functions like voltage transformation, power distribution and isolation. Transformer is one of most heaviest and expensive devices in electrical system because of huge number of iron core and heavy copper windings in composition [1-2]. A new type of electronic transformer based on power electronic converters has been introduced, which apprehend voltage transformation, galvanic isolation and power quality improvement in single device. The SST provide more fundamentally different and more complete approach in transfer design by using power electronic on primary side and secondary side of transformer. Several features like voltage sag, voltage swell, and voltage regulations are compensated and power factor correction combined into SST.

In era of grid, customers have advanced requirement of power supply such as various custom power quality, kinds of power supply and so on. The traditional transformer have been challenged, which could not satisfy the demand of grid system in medium low voltage distribution work, users hope that transformer could supply kinds of functions with elimination of power quality aberration and provide cascaded power quality and various type of power resources [17-18]. Solid state transformer is better solution for this type of work. Fig 1 shows the connection of SST with grid system. Different type of topologies has been presented for realizing the SST. This AC-AC buck converter has been used without isolation transformer. This method has causes the semiconductor devices to carry a high stress.

In second type, line side AC waveform is modulated in medium frequency square wave and coupled to the secondary side of Medium Frequency (MF) transformer and again is demodulated to AC form by a converter in second side of transformer. This method however does not provide any benefit such as voltage regulation and voltage sag due to lack of energy storage system [3-6]. Another three part

design has been introduced that utilized an input stage, isolation stage, output stage [7-13]. This type enhanced the flexibility and functionality of electric transformer owing the availability of DC-links.
In recent years, matrix converter has increases attention as variable voltage variable frequency AC-AC power processing system with the applications of require smaller size, high power density and easier maintenance [14-16]. This paper investigate the SST that includes three parts input stage, isolation stage, output stage including the AC-AC converter. AC-AC converter can generate the desired output from the square input voltage and its main purpose is to reduce the component and conversion stage. There are many different switching algorithm in converter has been used. In this paper, carrier based SPWM is used which is very popular. To verify the performance of SST with matrix converter, computer aided simulation are carried out by MATLAB/Simulink.

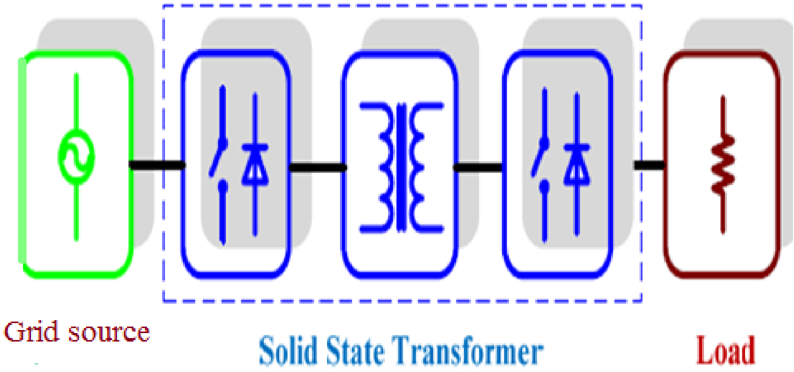



**Fig 1** Basic structure of SST with grid connected.

## II. CONVENTIONAL SST

In SST using the MF AC-link without DC-link capacitor, the line side AC waveform is modulated with a converter to a MF square-wave and passed through a MF transformer and again with a converter; again demodulated to a AC power frequency. Since the transformer sixe is proportional to frequency, the MF transformer will be much than power frequency transformer. So, the transformer size, weight and stress factor are reduced [3]. This converter does not provide any benefits in term of control or power factor improvement, and may not protect the critical loads from the instantaneous power interruptions due to lack of energy storage system and also does not provide any protection from harmonics from propagating into load side. SST with DC-link includes three stages. First stage consist is an AC-DC conversion step which is utilized to shape the input current, to correct the power factor and to regulated the voltage of primary bus. Second stage is an isolation stage which provides isolation between primary side and secondary side. In this stage, DC voltage is converted into the medium frequency square wave voltage, coupled to secondary MF transformer and converted to form the DC-link voltage. The output voltage is voltage source inverter which is converted into desired AC voltage [4-8]. In comparison with first SST, the voltage or current of SST can be flexibly controlled in either side of MF transformer. It is possible to add energy to enhance the ride-through capability of SST or to prepare integrated interface for distributed resources due to available of DC-links. It prevents the voltage or current harmonics to propagate either side of transformer even if the input voltage has low order harmonic but they need they need too many AC or DC-link, large bulky magnetic component or DC electrolytic capacitor. Thus they are resulted in a rather cumbersome solution and multiple conversion steps can losses the efficiency of transformer.

## III. PROPOSED SST

Proposed solid state transformer is consist of three stage, first stage is consist of AC-DC converter, second stage is isolation stage which provide isolation between the primary and secondary side of transformer and it is consist of DC-AC converter with medium frequency transformer, provide high insulating capability. The first and second stage is same as the conventional transformer. In this paper, a new configuration based matrix converter is shown in Fig 2, in proposed SST the output stage consist of AC-AC converter which is matrix converter.

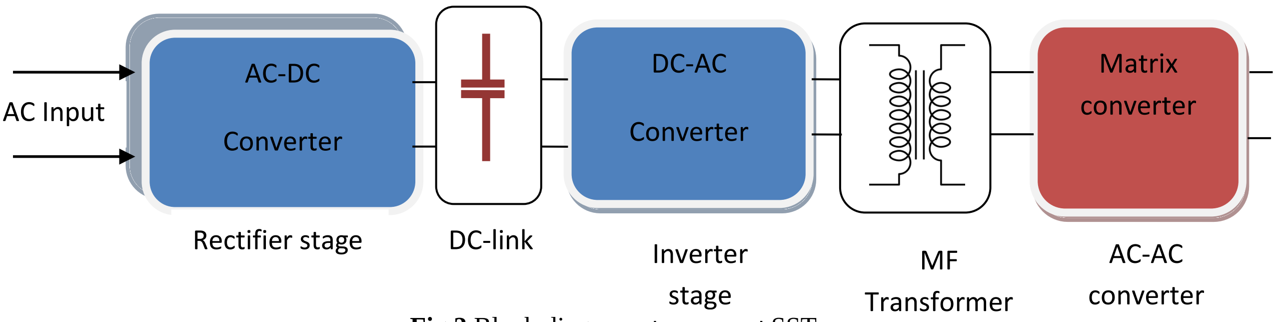



**Fig 2** Block diagram of proposed SST

It can provide desired output voltage and it performs power quality problems like voltage sag compensation, power factor correction. SST has capability of providing three phase output from single phase system. Three stage of SST can be controlled independently from other one. Capability of eliminate the power quality problem can be done by using closed loop control and correlative research is necessary. The reliability of system is proportional to the number of its components. The main purpose of proposed SST is reduced in power delivering stage in SST with DC-link.

## 3.1 Input stage

Input stage is a three phase Pulse Width Modulation (PWM) rectifier, which is used to convert primary low frequency voltage to DC voltage. The main function of rectifier is to produce a nearby sinusoidal waveform, shaping the input current, controlling the input power factor and keeping the DC voltage at desired reference value. There are many control methods that presented for control of input stage of conventional SST, which could be used for control of input stage of proposed SST. In Fig 3, shows three phase rectifier with inductances. A three phase PWM rectifier is used in this paper, which work as same as conventional SST input stage. To keep the desired DC voltage and input current sinusoidal, a DC voltage outer loop, a AC current inner loop is used are adopted [6-8]. Fig 4 shows the input stage control, the reference of active current derive from the DC voltage outer loop. The reference of reactive current should be zero to get unity power factor. The current error signals are input the current regulators and then from modulation signals. If the d-axis of reference frame is synchronous to the grid voltage then we obtain $V_{inq}=0$.

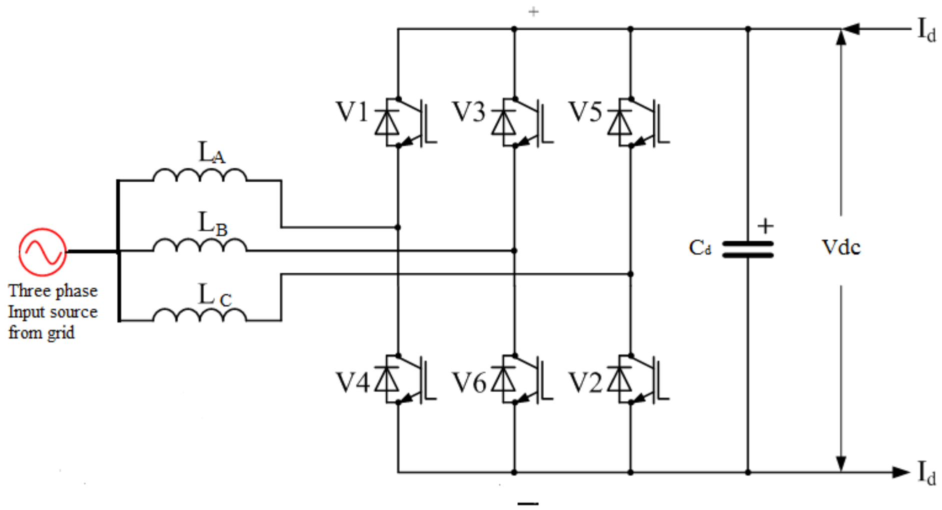



**Fig 3** Structure of proposed input stage of SST

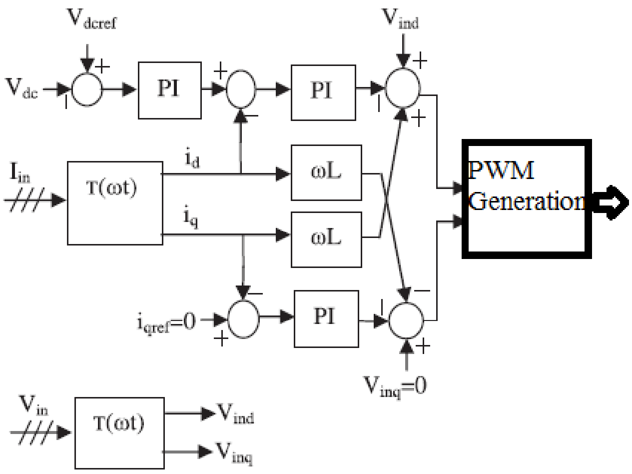



**Fig 4** Input stage control diagram

### 3.2 Isolation stage

Isolation stage is consists of a single phase medium frequency voltage source converter which convert the DC voltage to AC voltage square voltage with a medium frequency and MF transformer. The main functions of MF transformer are voltage transformation, isolation between the source and load side [8-9]. Structure of isolation stage is shown in Fig 5. The circuit diagram is same as H-bridge cell. To simplify the control of h-bridge cell, an open loop control is used. The main principle of modulation is to provide comparison between square reference waveform with a zero carrier waveform. The operation of voltage source converter is described as bellow:

Condition 1, if sine wave is greater equal to 0 then H1 and H2 are turn ON.

Condition 2, if sine wave is less than 0 then H3 andH4 turn are ON.

If sine wave have a frequency $f_r$ and an amplitude $A_r$ then output voltage of voltage source converter frequency will be $f_r$. By neglecting the losses of medium frequency, the medium frequency transformer can be treated as proportional amplifier. The simplified model of transformer is presented as:

$$V_s = \frac{N_s}{N_i} V_i \qquad (1)$$

$V_s, V_i$ are the primary and secondary voltage of transformer and $N_s, N_i$ are turn ratio of primary and secondary side of MF transformer.

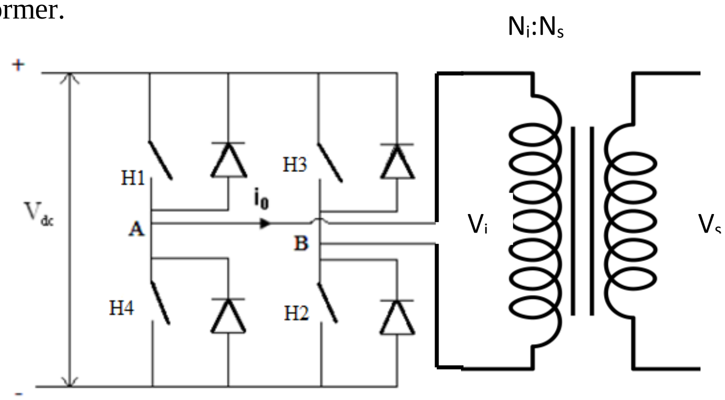



**Fig 5** Structure of proposed inverter stage

### 3.3 Output stage

The output stage of SST contained Matrix Converter (MC) which has a novel functional conversion of square wave medium frequency to power frequency voltage. Matrix converter topology employs six bidirectional switches to convert medium frequency to direct power frequency (50 or 60 Hz) three phase output. The anti-parallel IGBT with diode pair arrangement has been done in proposed SST and this bi-directional switch consist of two IGBTs and two diodes, which have capability of blocking voltage and current in both directions. This proposed matrix converter provide us desired output voltage and current with suitable frequency and perfect waveform shape. Sinusoidal Pulse Width Modulation (SPWM) has been used to provide switching to matrix converter. The operation of SPWM is based on comparison of a sinusoidal references waveform with triangular waveform and the result of comparison provide us correct switching operation corresponding to the given output voltage level. In this paper, SPWM is applied to the matrix converter is employed. For proposed SST, matrix converter is composed with SPWM and one control signal. The signal produce by the SPWM is compare with control signal (NPD). NPD is a negative polarity detective. Fig 6 shows the circuit of NPD generator and switching pattern is expressed as bellow:

Gate signals = (SPWM signals) XOR (NPD signal) (2)

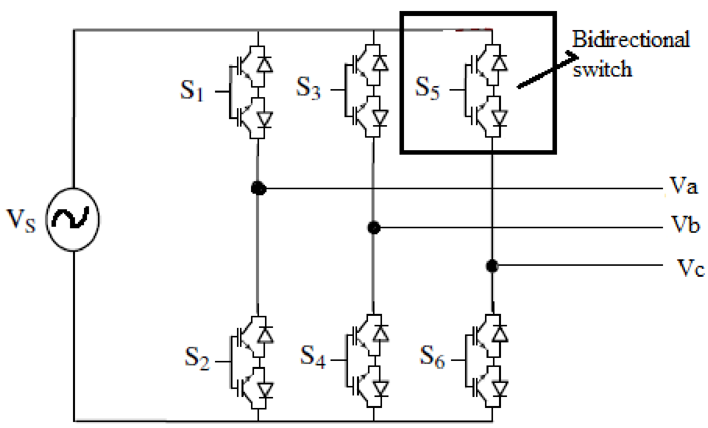



**Fig 6** Proposed matrix converter

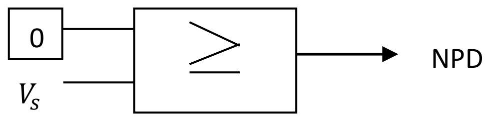



**Fig 7** NPD generator

There two important parameters to define the amplitude modulation ratio or modulation index *m*, and the frequency modulation ratio *p* in switching algorithm which define bellow:

$$m = {V_{refmax}}/{V_{carriermax}} \quad (3)$$

$$p = \frac{f_T}{f_S} \quad (4)$$

Equation 3 shows the amplitudes of references voltage $V_{refmax}$and carrier voltage $V_{carriermax}$ and Equation 4 shows modulation ratio with frequency of main supply $f_S$and frequency of triangular carrier$f_T$. The matrix converter is controlled by the PWM method, in which the direct axis, quadratic axis, zero sequence quantities for three phase sinusoidal signal are computed by Park transformation. Then d-q voltage terms are compared by $V_{dref}$ and $V_{qref}$and error signal enter to three phase sinusoidal abc voltage terms and used to generate appropriate matrix gate pulse.

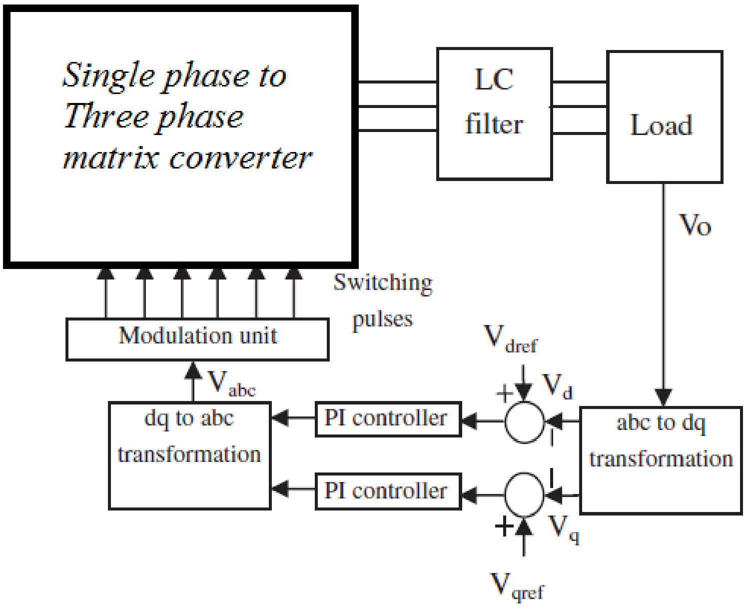



**Fig 8** Control circuit of output stage

## IV. SIMULATION RESULTS

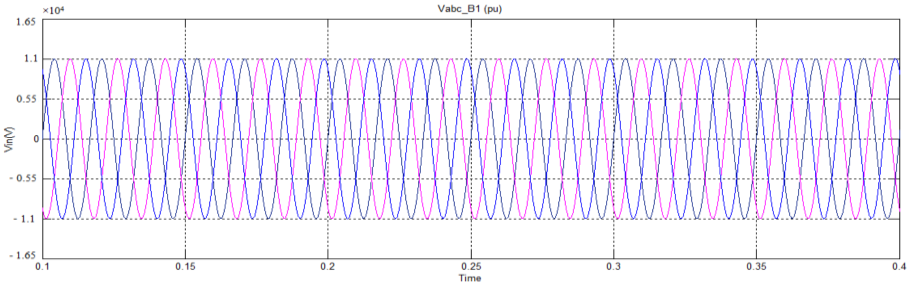
To investigate the performance of proposed SST, the design was simulated to predict as a steady state condition and results obtained on the computer software based MATLB/Simulink. In this simulation input phase to phase voltage is taken as 11kV and SST power is 30kVA and other different parameters are shown in Table 1.

**Table 1** Parameters of simulation

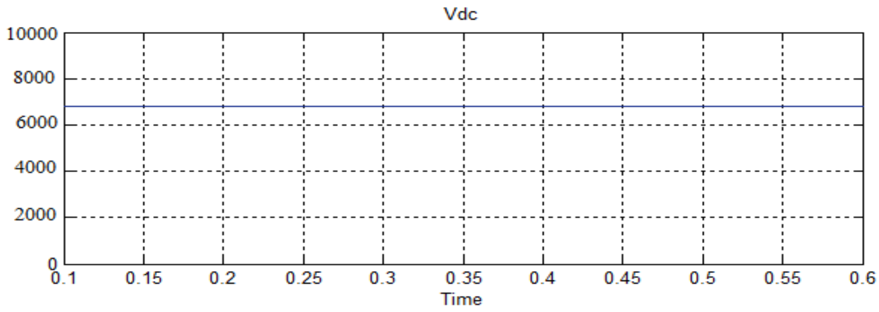
| **Parameters** | **Values** |
|---|---|
| Input phase-phase voltage | 11kV |
| DC link capacitor | 2000$\mu F$ |
| Power Frequency | 50Hz |
| M.F. Transformer | 10:1, 1000Hz, 30kV |
| Output phase voltage | 400kV |
| Matrix converter switching frequency | 2050Hz |
| LC filter | 2mH, 220$\mu F$ |
| SST Load | 20kW + j10kVAR |

### 4.1 Operation of Proposed SST

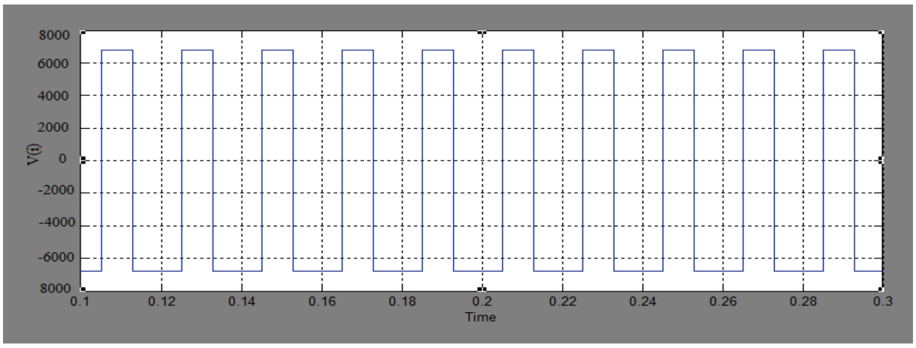
Result s of output waveforms of proposed SST are shown in figure 9. Fig 9 (a) shows the input phase to phase voltage, (b) shows the input DC link voltage is 6800 V and the voltage controller act so that DC link regulated to the reference value, (c) depicts the output voltage of VSC in isolation stage that transfer DC voltage to medium frequency AC voltage as primary voltage of MF transformer. The level of secondary side voltage is changed by MF transformer in (d) in the output stage the medium frequency voltage is revealed as a 50 Hz by matrix converter. (e) shows line voltage between phase (a) phase (b) before LC filter and Load voltage is shown in (f).


Vabc_B1 (pu)
×10⁴
1.65
1.1
0.55
0
- 0.55
- 1.1
- 1.65
Vin(V)
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Time

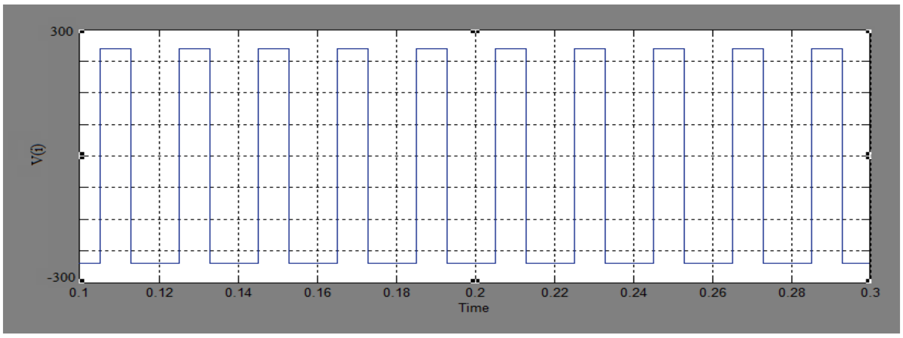
(a)


Vdc
10000
8000
6000
4000
2000
0
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
Time

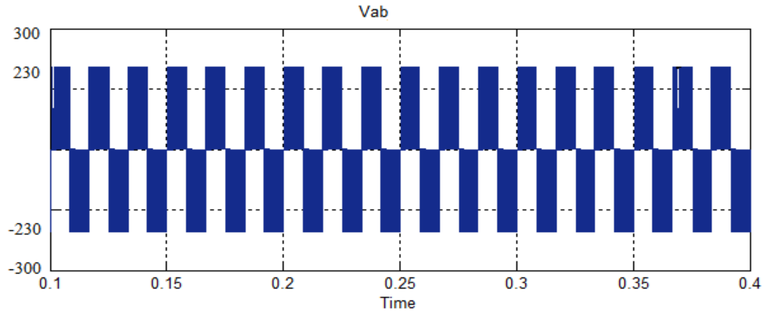
(b)


8000
6000
4000
2000
0
-2000
-4000
-6000
8000
V(t)
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
0.3
Time

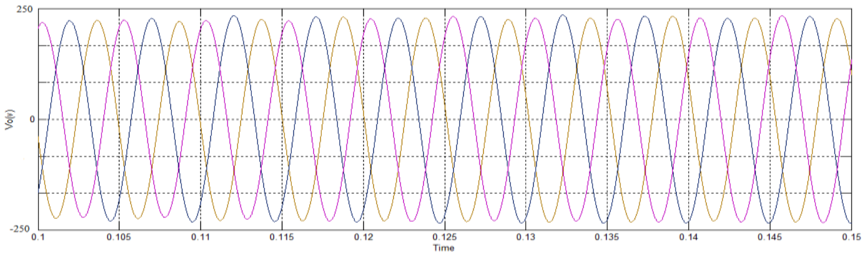
(c)


300
-300
V(t)
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
0.3
Time

(d)




(e)

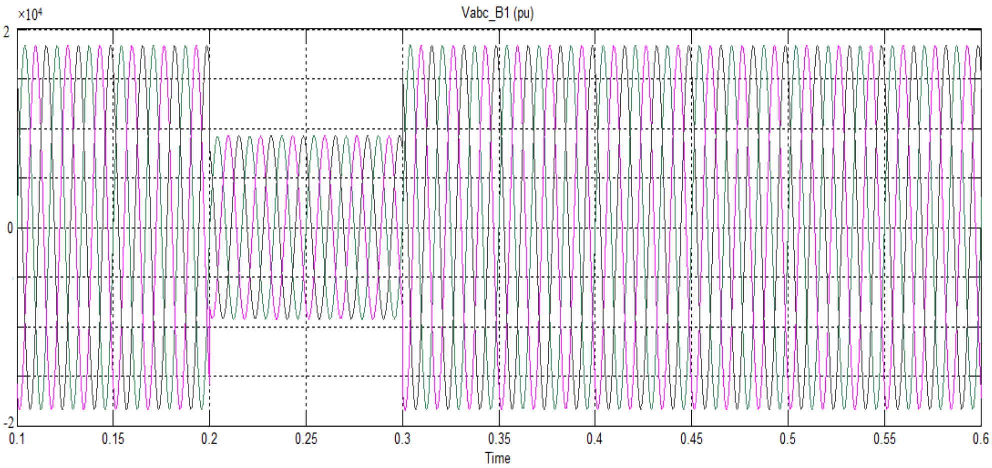


(f)

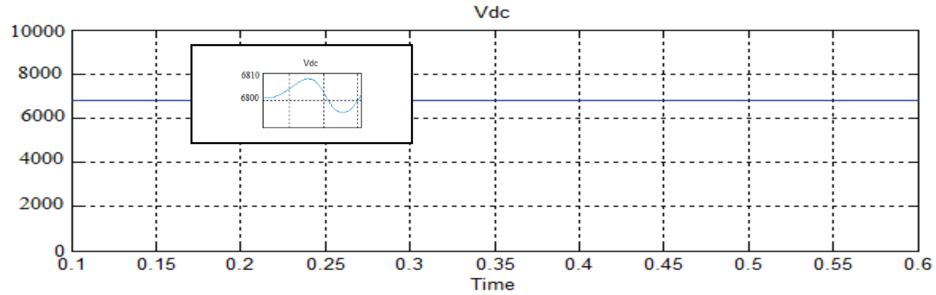
**Fig 9** (a) Input phase voltage (Vabc_B1) (b) DC-link voltage (c) MF primary side voltage (d) MF secondary side voltage (e) Output line voltage before filter (f) Output line voltage

### 4.2 Proposed SST work under voltage sag condition

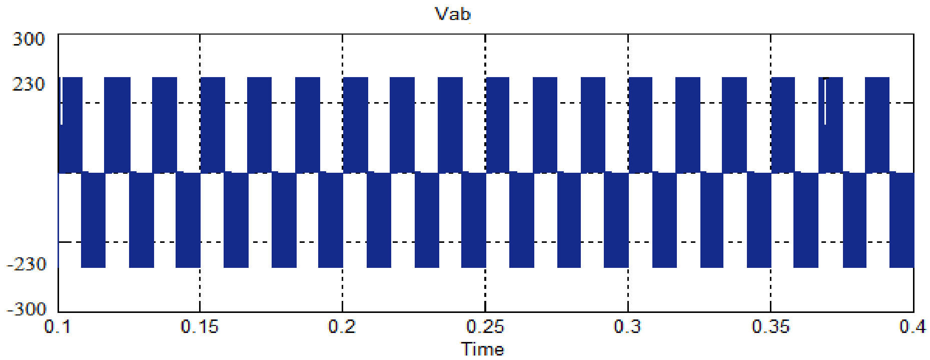
Considered a three phase balanced voltage sag with 50% depth created 0.2s by simulating a remote three phase voltage fault. Input line voltage $V_{in}$, the DC link voltage $V_{dc}$, output voltage before filter Vab, the load voltage Vo of the system with proposed SST are shown in figure 10. When the voltage occurs and clears the DC voltage deviated shown in Fig 10(b). The grid current during the sag is not instant, the current will increase to maintain the DC voltage $V_{dc}$. The allowable increased in current is depends upon the compensation percent. Also the output voltage controller makes the matrix converter to generate the voltage so that the load voltage remains as presage voltage.



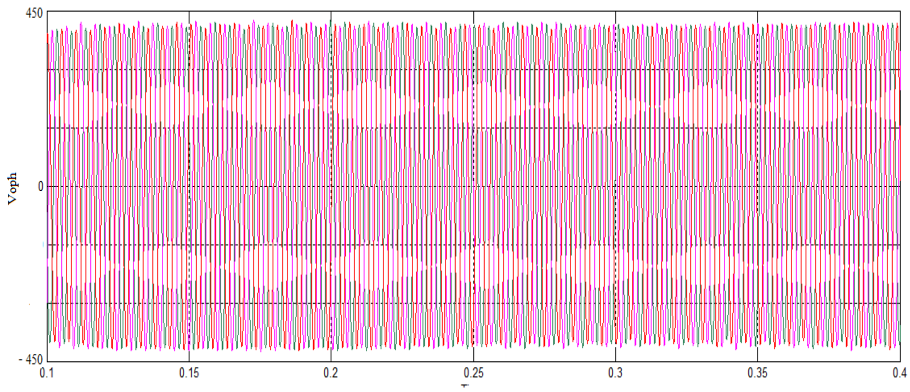

(a)




(b)




(c)

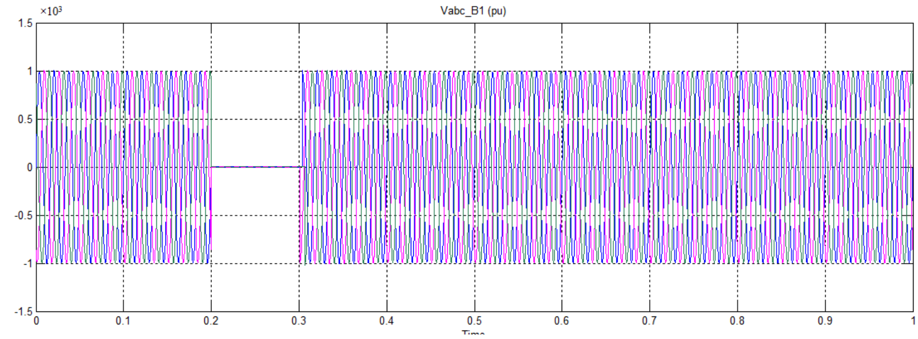



(d)

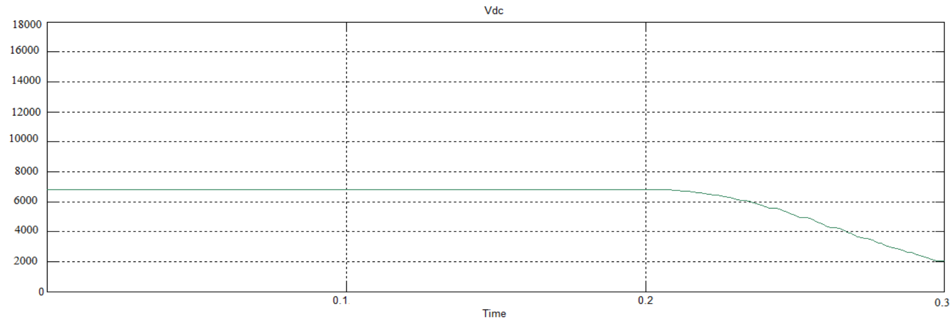
**Fig 10** (a) input voltage (b) DC link voltage (c) output line voltage before filter (d) output line voltage before filter (d) output voltage

## 4.3 When DC link value is undesirable

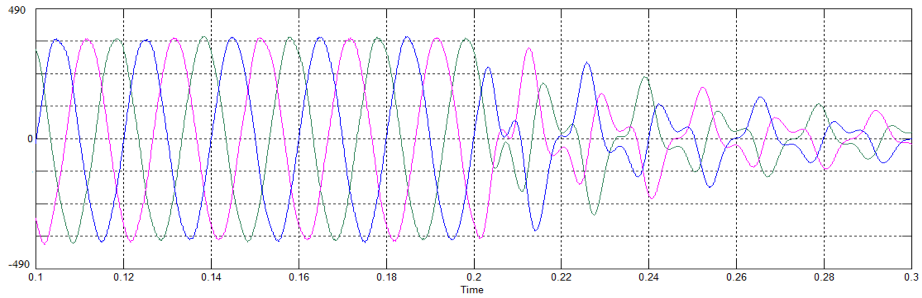
If the DC-link voltage is not adjustable in desired value then the voltage of load drop is not supplied well. Fig 11(a) input voltage with fault condition at 0.2s. (b) voltage DC-link, in 0.2s the voltage is decreased. The load output voltage is shown in (c). In this state the converter cannot regulate output voltage at desired value.




(a)




(b)




(c)

**Fig 11** (a) Output voltage (b) DC-link voltage (c) output voltage.

# V. CONCLUSION

In this paper, a new configuration of solid state transformer with DC-Link capacitor has been configured. To obtain higher efficiency AC-DC and DC-AC converters has been integrated in one converter without any DC-link at output stage of SST and only one DC-Link has been used in proposed SST. In proposed SST AC-AC converter matrix converter has replaced two converters (AC-DC and DC-AC converter) and switching of matrix converter is easy and not complex. These plans decrease the installation area and increase the dynamic velocity of transformer. In addition, in this paper has many advantages such as power factor correction, voltage regulation, voltage sag and swell elimination, voltage flicker reduction. Simulation result shows some of the advantages of proposed SST.

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