Solid state transformer using matrix converter

Submitted by

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ABSTRACT:

The integration of renewable energy sources and the increasing demand for high-efficiency power conversion have led to the development of advanced power electronic systems. The solid-state transformer (SST) emerges as a key technology to address these challenges by offering improved power quality, bidirectional power flow, and enhanced control flexibility. This paper presents a novel approach to the design of a solid-state transformer using a matrix converter topology.

The matrix converter, known for its ability to provide direct AC-AC power conversion without the need for bulky energy storage components, serves as a promising candidate for realizing the SST concept. The proposed solid-state transformer leverages the inherent benefits of the matrix converter, such as reduced size, higher efficiency, and enhanced controllability. Through careful design and optimization, the matrix converter-based SST achieves improved voltage and current quality, fault tolerance, and efficient power transfer between different voltage and frequency grids.

INTRODUCTION:

SST technology has undergone a quick development during the past two decades, and numerous different topologies, systems, and applications have been—and are being—proposed and analysed. Various projects have been or currently are dedicated to developing SST technology as a key building block of future smart distribution grids, where SSTs could facilitate the integration of renewable energy sources or energy storage systems with either direct current (dc) or alternating current (ac) interfaces, e.g., photovoltaics and wind power, into the grid or where they could enable power routing and facilitate energy management in local micro grids.

The matrix converter is a forced commutated converter which uses an array of controlled bidirectional switches as the main power elements to create a variable output voltage system with unrestricted frequency. It does not have any dc-link circuit and does not need any large energy storage elements. The key element in a matrix converter is the fully controlled four-quadrant bidirectional switch, which allows high-frequency operation. The early work dedicated to unrestricted frequency changers used thyristor's with external forced commutation circuits to implement the bidirectional controlled.

THE FIRST ELECTRONIC TRANSFORMER:

- Includes four quadrant switches.
- Transformer is called a high frequency link.
- Output voltage can be regulated by delaying the firing of the secondary side bridge.

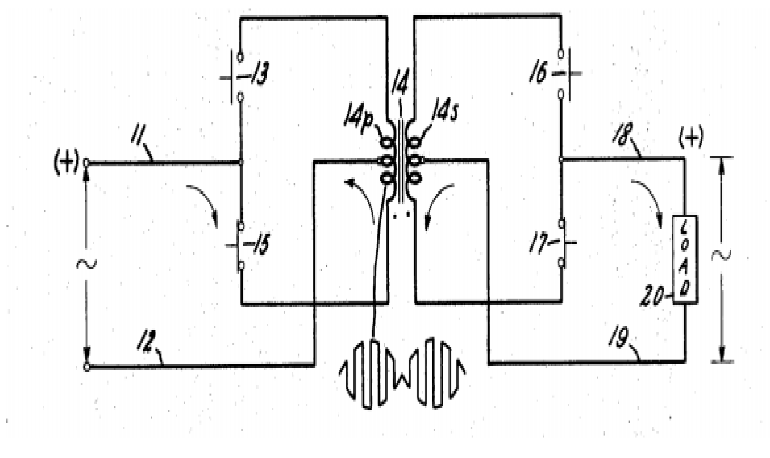


Fig.1 First electronic transformer

TOPOLOGY CLASSIFICATION

- On the basis of number of power conversion stages

1. Single stage power conversion
2. Two stage power conversion
3. Three stage power conversion

➨ On the basis of type of isolation

1. Single isolation
2. Multiport isolation
3. Modular isolation

➨ On the basis of location of the controlling stage with respect to the isolation stage [3]

1. Isolated front end
2. Isolated back end

SINGLE STAGE POWER CONVERSION:

➨ Single AC/AC power conversion stage with high frequency isolation.

➨ Example: Matrix converter based SST

➨ Advantages:

1. High efficiency
2. High power density

➨ Disadvantages

1. Limited functionalities
2. Absence of inherent DC link

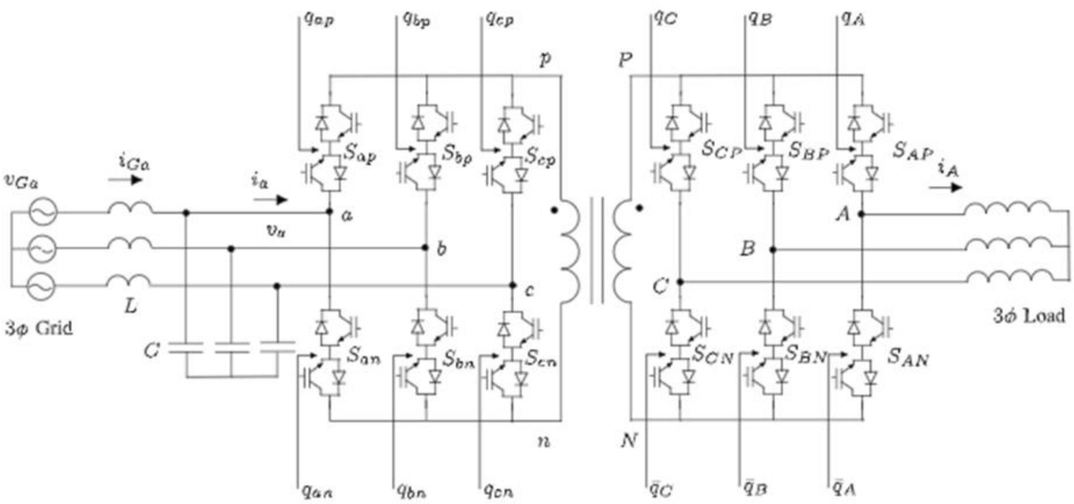
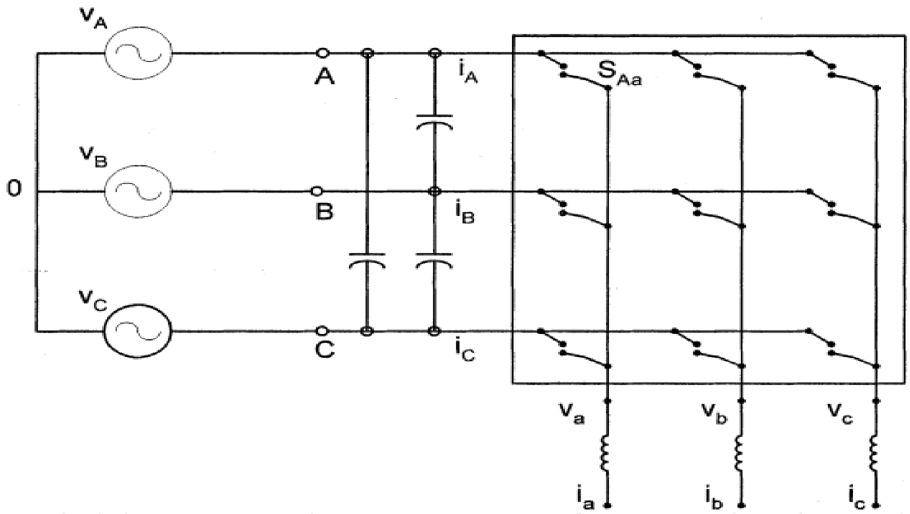


Fig.2 single stage power conversion

3X3 MATRIX CONVERTER:

- In general, a (n X p) matrix converter circuit can be constructed.
- The switch matrix resembles an original matrix with rows and columns.
- $V_{out} = Q(t)V_{in}$
- Q(t) is the switching function matrix.
- Switching function matrix is derived by evaluating the KCL and KVL constraintson the matrix.
- For eg. S11+S21+S31=1 could be one Such constraint equation.



MATRIX CONVERTER SWITCHING TOPOLOGY

PRIMARY SIDE SWITCH CONTROL TECHNOLOGY (3-phase to single phase)

This primary converter part is used to synthesize the high-frequency ac voltage V, from the balanced three-phase input voltage and then, transfer single-phase HFAC square wave pulses to the utility interactive 3ϕ/1ϕ matrix converter part through an isolated HF transformer. The PWM strategy for the 6 bidirectional switches is expanded from the PWM method. It is assumed that the input source voltages are balanced and described by

$$V_a = V_{im}\cos\theta_a = V_{im}\cos(\omega_{in}t)$$
$$V_b = V_{im}\cos\theta_b = V_{im}\cos(\omega_{in} - 2\pi/3)$$
$$V_c = V_{im}\cos\theta_c = V_{im}\cos(\omega_{in} + 2\pi/3)$$

Where w_n the input angular frequency and is changeable according to an operating point of distributed generating system. Within any 60' interval between two successive zero crossings of input phase voltages, shown in Fig. 3, only one of the three-phase input voltages has the maximum absolute value and the other phase voltages have opposite polarity voltage. For example, in the mode 1, phase "a"has the maximum positive value and phase "b" and "c" have negative values in below fig.

Here $|V_a| = |V_b| + |V_c|$

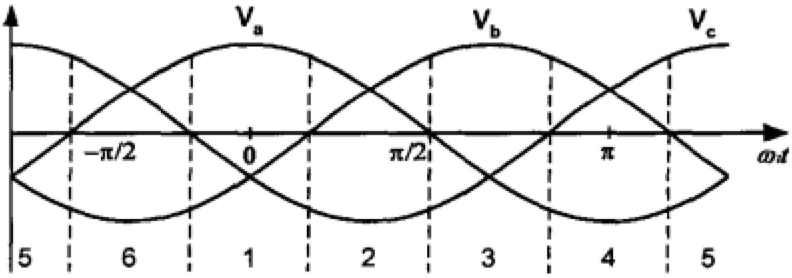


Fig. **3** six modes of input phase voltages

Under mode 1 and positive pulse mode at Vp, switch S_{ap} remains turned on and switch S_{bn}, S_{cn} are modulated within one switching period T_s while all other switches remain turned off In order to satisfy unity displacement power factored input current requirement and full utilization of input source voltage, the output dc link voltage is given by

$$V_{dc} = n(d_b(V_a - V_b) + d_c(V_a - V_c))$$

Table 1 switch states and corresponding voltage V_P and V_{dc} according to mode of input phase voltages

Mode	Duty ratio	Positive pulse		Negative pulse		V_{dc}
		Turn-on SW pair	V_P	Turn-on SW pair	V_P	
1	d_b	S_{ap} - S_{bn}	V_{ab}	S_{an} - S_{bp}	V_{ba}	nV_{ab}
	d_c	S_{ap} - S_{cn}	V_{ac}	S_{an} - S_{cp}	V_{ca}	nV_{ac}
2	d_a	S_{cn} - S_{ap}	V_{ac}	S_{cp} - S_{an}	V_{ca}	nV_{ac}
	d_b	S_{cn} - S_{bp}	V_{bc}	S_{cp} - S_{bn}	V_{cb}	nV_{bc}
3	d_c	S_{bp} - S_{cn}	V_{bc}	S_{bn} - S_{cp}	V_{cb}	nV_{bc}
	d_a	S_{bp} - S_{an}	V_{ba}	S_{bn} - S_{ap}	V_{ab}	nV_{ba}
4	d_b	S_{an} - S_{bp}	V_{ba}	S_{ap} - S_{bn}	V_{ab}	nV_{ba}
	d_c	S_{an} - S_{cp}	V_{ca}	S_{ap} - S_{cn}	V_{ac}	nV_{ca}
5	d_a	S_{cp} - S_{an}	V_{ca}	S_{cn} - S_{ap}	V_{ac}	nV_{ca}
	d_b	S_{cp} - S_{bn}	V_{cb}	S_{cn} - S_{bp}	V_{bc}	nV_{cb}
6	d_c	S_{bn} - S_{cp}	V_{cb}	S_{bp} - S_{cn}	V_{bc}	nV_{cb}
	d_a	S_{bn} - S_{ap}	V_{ab}	S_{bp} - S_{an}	V_{ba}	nV_{ab}

Where $V_{ab} = V_a - V_b$, $V_{ba} = -V_{ab}$, $V_{bc} = V_b - V_c$, $V_{cb} = -V_{cb}$, $V_{ca} = V_c - V_a$, $V_{ac} = -V_{ca}$

$$d_a = |cos\theta_a| / cos\theta_{max} \text{ , } d_b = |cos\theta_b| / cos\theta_{max} \text{ , } d_c = |cos\theta_c| / cos\theta_{max}$$

$$cos\theta_{max} = max(|cos\theta_a|, |cos\theta_b|, |cos\theta_c|)$$

MODE 1 OPERATION

Flux Balance

- Phase a clamped. Phase's b and c switch.
- V_{ab}, V_{ac} are applied to the HFT.
- To keep the flux balance, a negative voltage pulse, by turning on the alternate switches than the positive case is applied across the HFT.

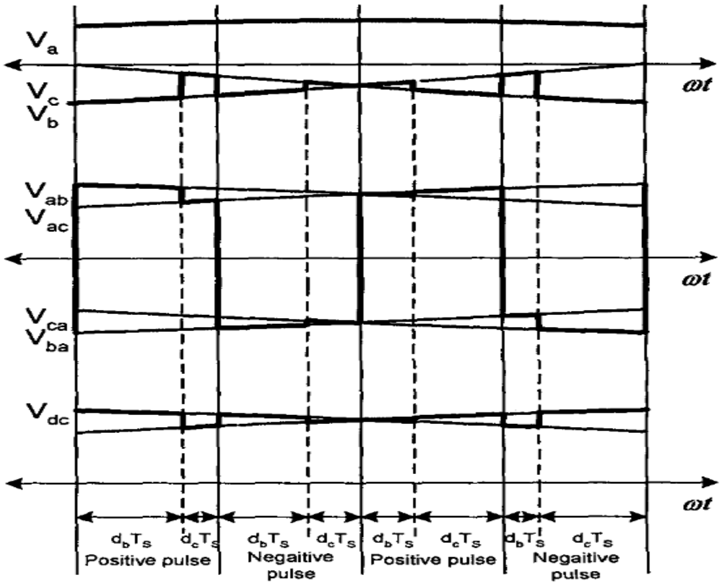


Fig. 4 Mode 1 operation

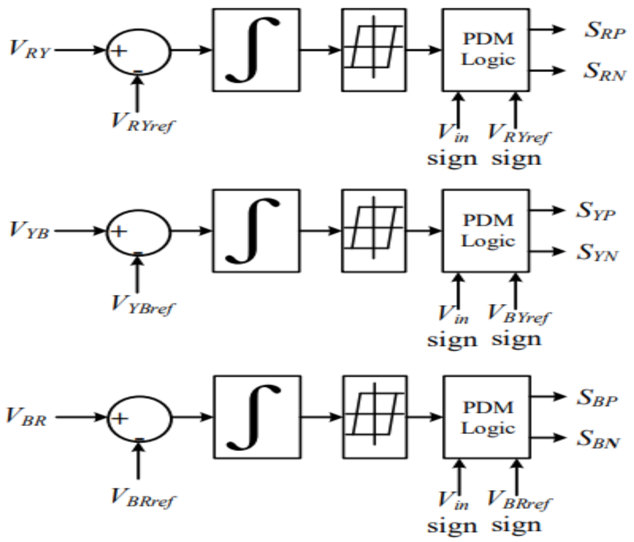
➨ LIMITATIONS

1. Commutation of leakage energy not considered.
2. Low order harmonics in input current.

SECONDARY SIDE SWITCH CONTROL TECHNOLOGY (1-phase to 3 phase)

Pulse Density Modulation-

The implementation of PDM in FPGA is shown in Fig 2.3. Table 2.2 illustrates the determination of transformer secondary voltage from the source voltages sensed for the source side converter. VRY , VY B, VBR are line voltages at the output of the load-side converter. In usual PDM implementation, these are sensed real time. However, in our implementation, they are determined without any sensing inside the FPGA. The logic for output line voltage determination using phase R as an example is explained



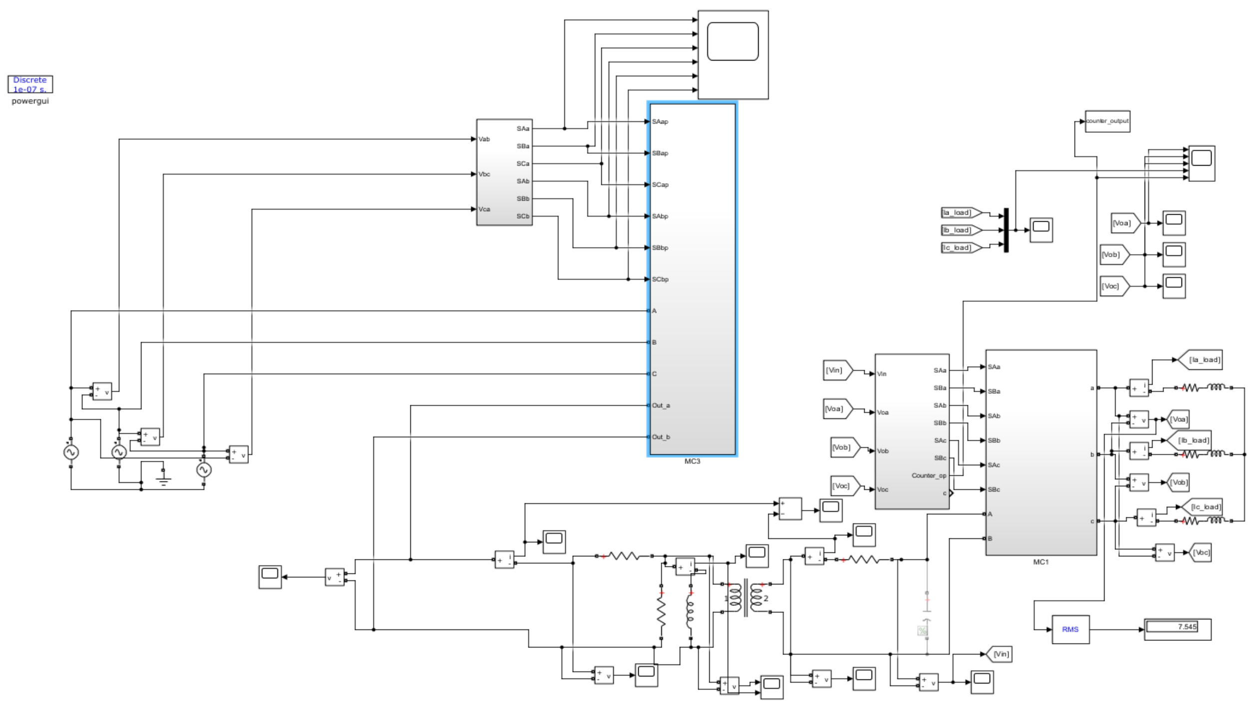
$V_{in}>0$	$V_{RYref}>0$	e>0	S_{RP}	S_{RN}
0	0	0	1	0
0	0	1	0	1
0	1	0	1	0
0	1	1	0	1
1	0	0	0	1
1	0	1	1	0
1	1	0	0	1
1	1	1	1	0

Fig.5 Pulse Density Modulation Controller technique

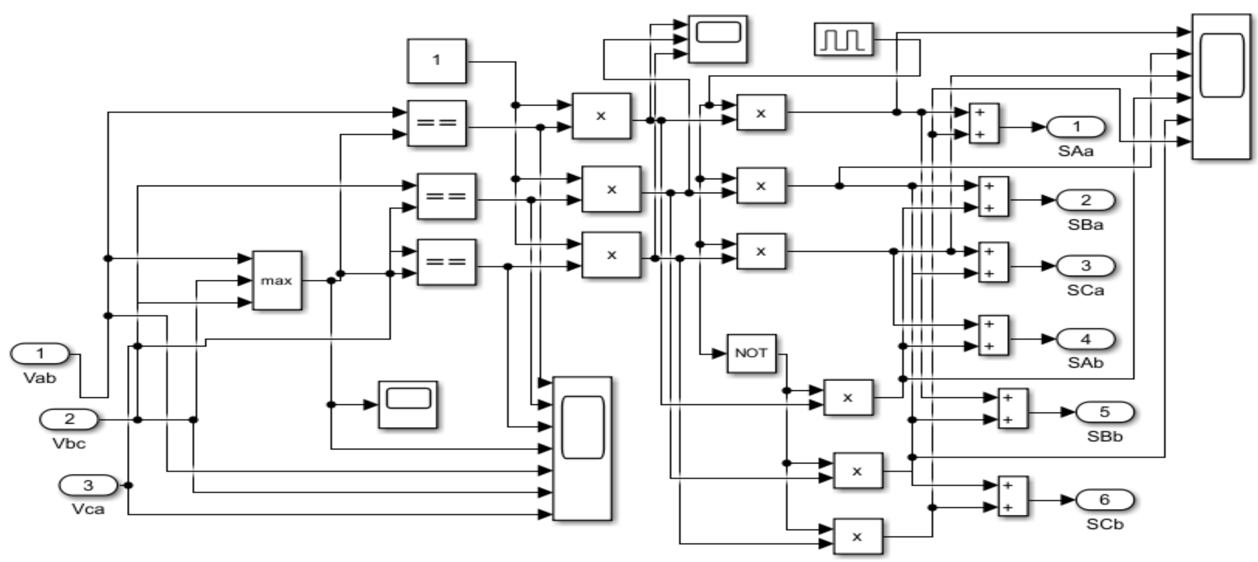
Switch combination	Transformer Secondary Voltage
S_{rp},S_{yn}	V_{ry}
S_{rn},S_{yp}	-V_{ry}
S_{yp},S_{bn}	V_{yb}
S_{yn},S_{bp}	-V_{yb}
S_{bp},S_{yn}	V_{br}
S_{bn},S_{rp}	-V_{br}

Table 2. Output secondary side Voltage

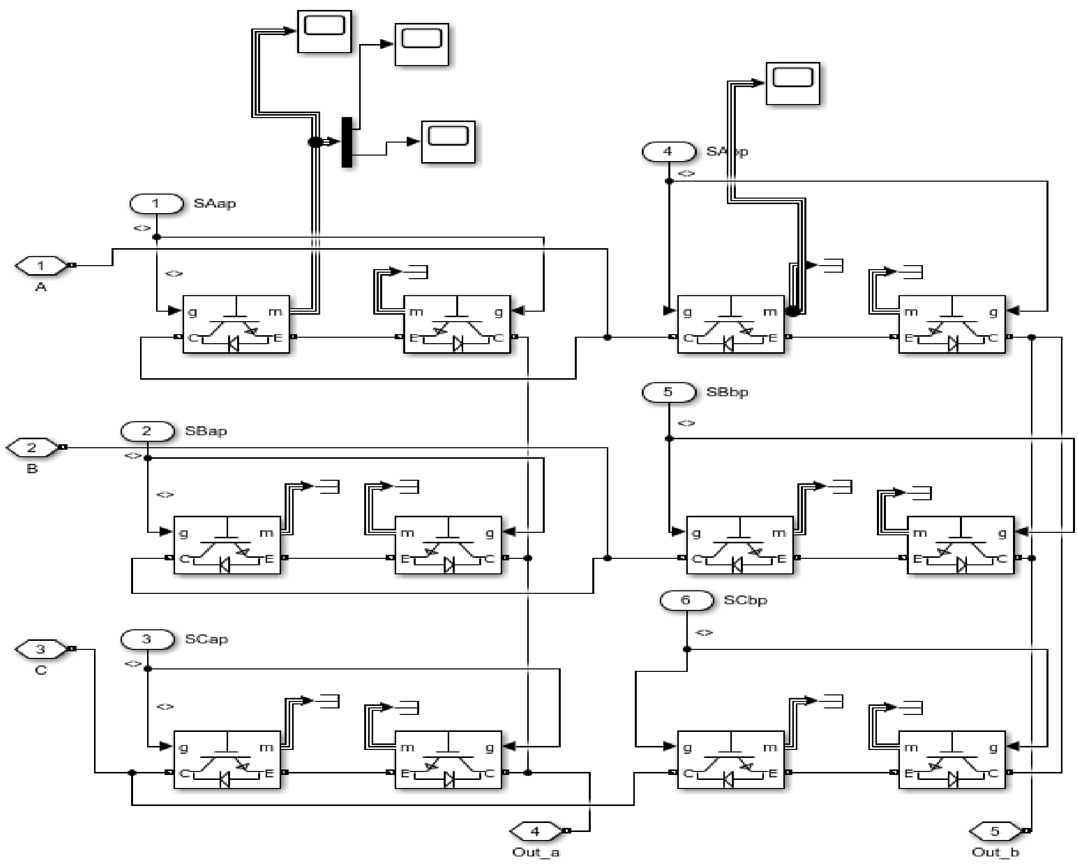
SIMULATION:



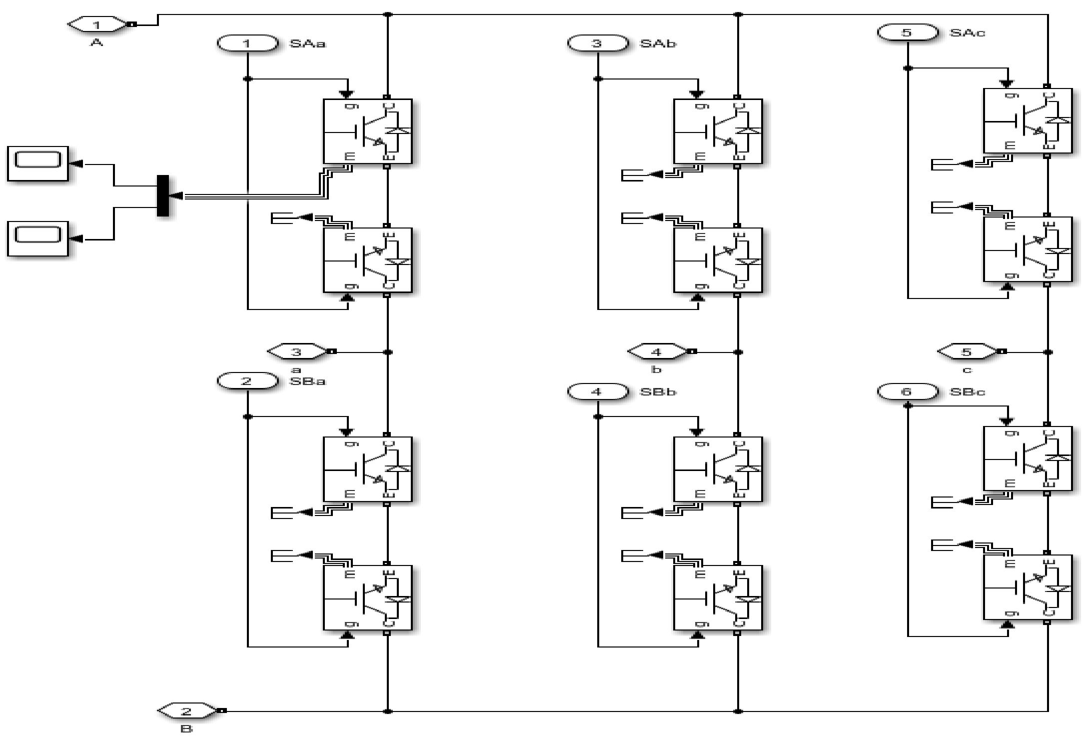
Subsystam 1



Subsystam 2

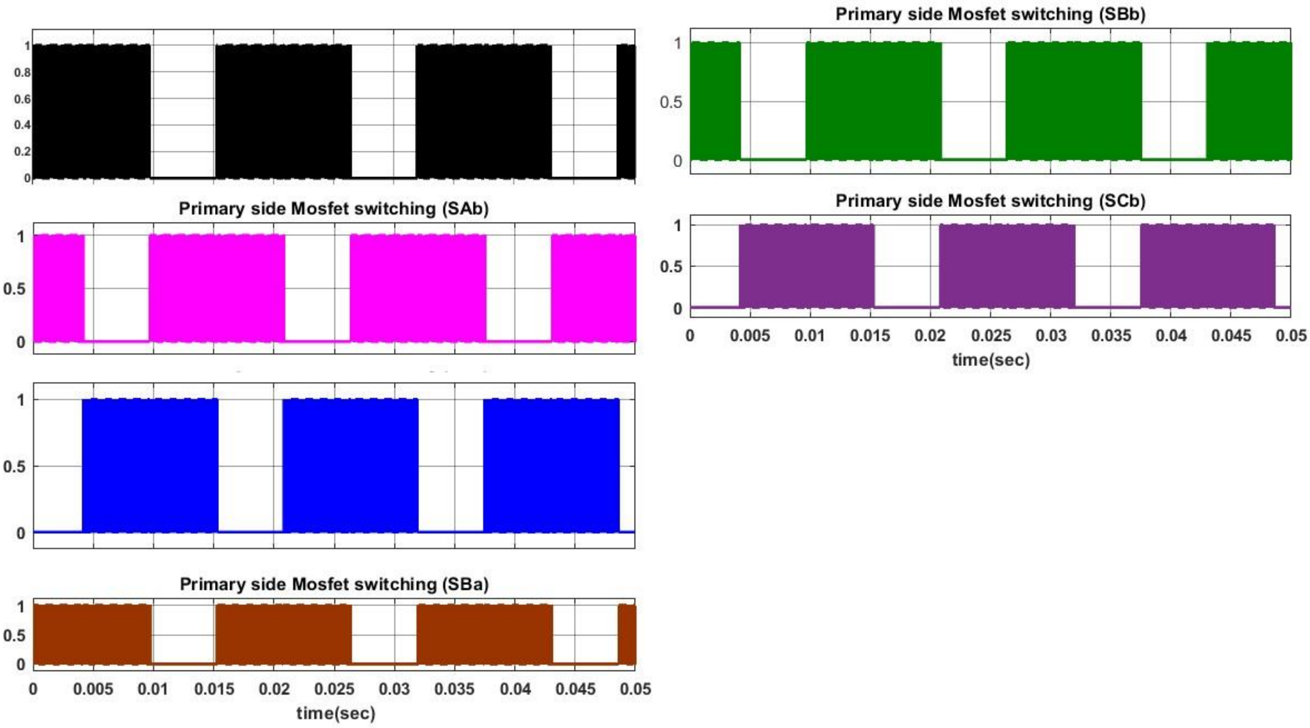


Subsystam 3

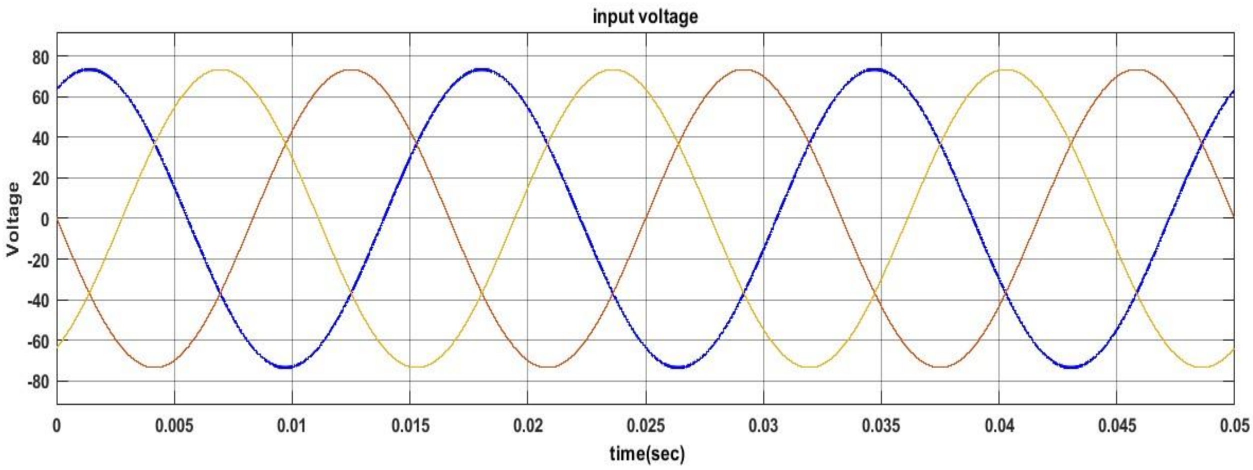


Simulation result

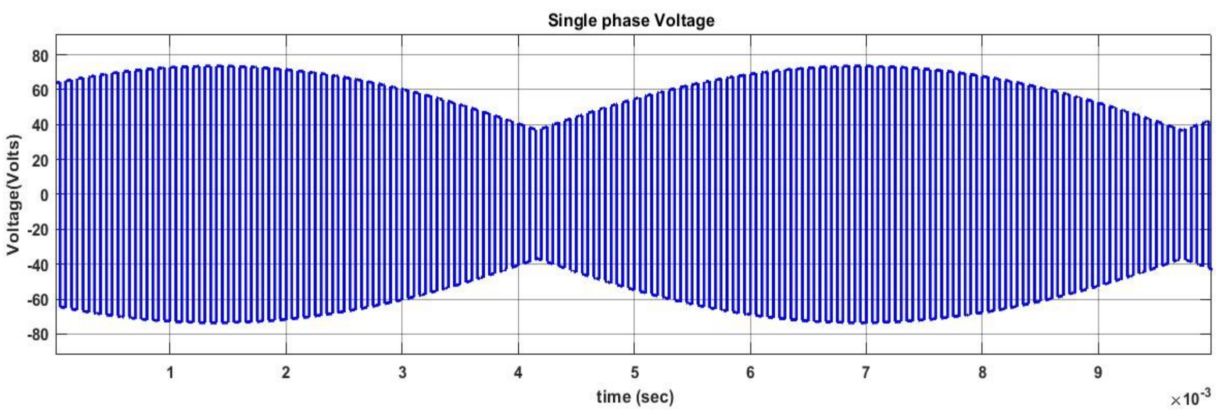
1. **Output waveform of subsystem 1(Mosfet switching)**



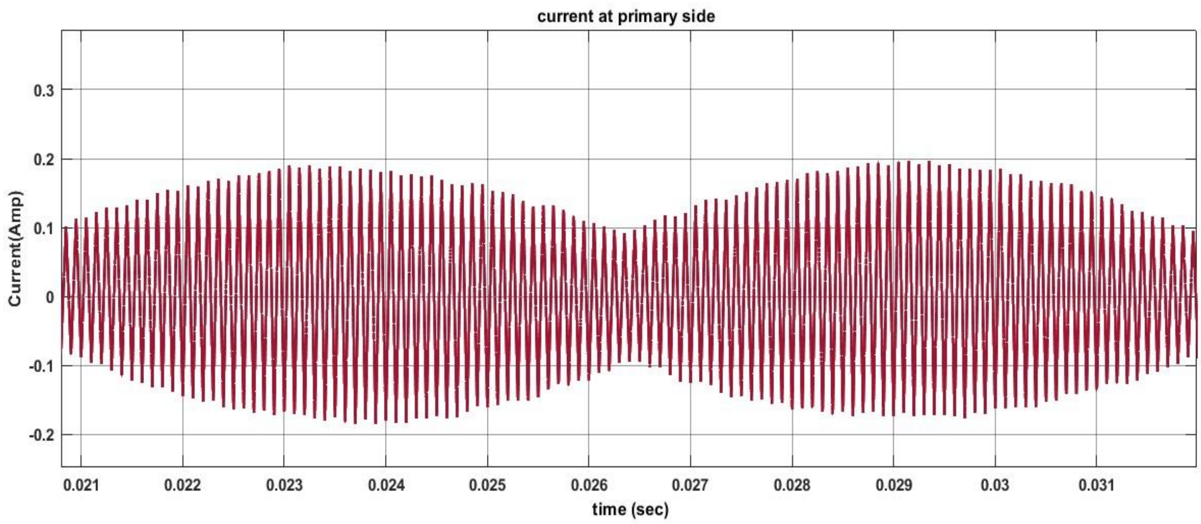
2. **Input voltage waveform (3 phase)**



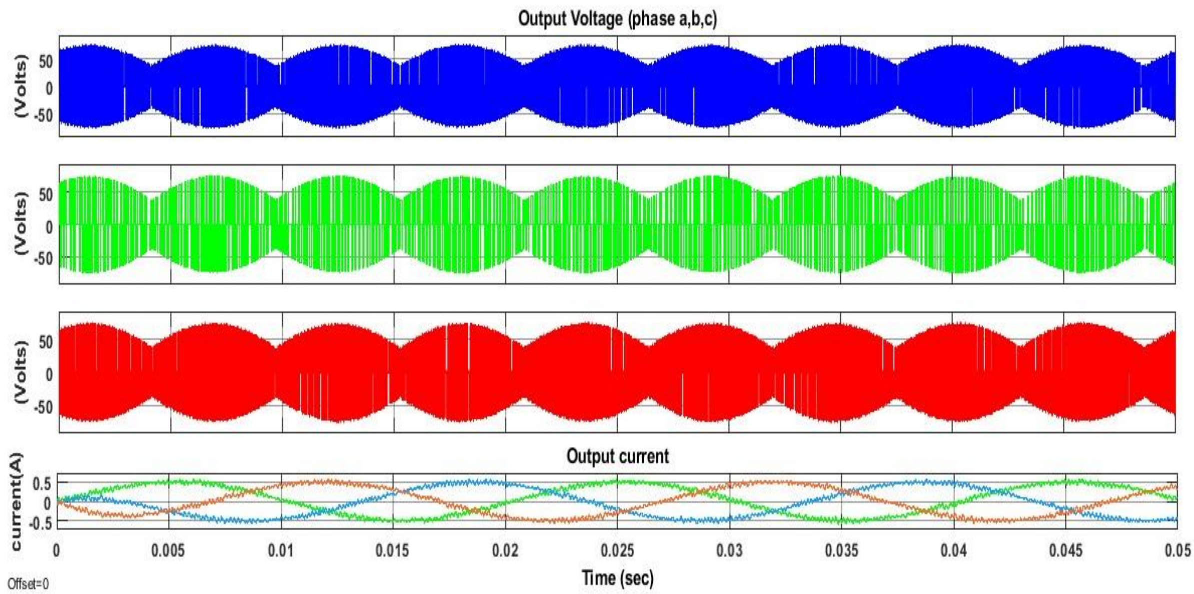
3. **Output waveform of subsystem 2 (3 phase to single phase Voltage)**



4. Output current (resistive load from sub system 2)



5. Output of subsystem 4 [output voltage and output current (3 phase)]



Conclusion:

We have completed the simulation of solid state transformer using matrix converter .we used the topology single stage power conversion. Primary side we use the PWM strategy for the 6 bidirectional switches is expanded from the PWM method to get 3 phase to single phase and secondary side we used pulse density modulation technique to get 1 -phase to 3 phase.