A THREE PHASE ANALYSIS OF SOLID STATE TRANSFORMER FOR RACTIFICATION, CONVERTING AND INVERTING STAGES, FOR NEW TREND AND APPLICATIONS

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***Abstract*: The energy demand and the constrain of fossil fuel and the demand of renewable energy resources in the utility grid, the increase of the direct current (electric vehicles, solar photovoltaics etc.), the Conventional transformers are vulnerable to DC and possess no controllability when employed. Solid state transformers (SSTs) are identified as alternative to conventional transformers due the modernization and harmonizing alternating current (AC) and (DC) electrical network and it suitable in application such as microgrid, traction electric ships and aerospace etc. with the used of power semiconductor e.g. MOSFET. In this paper it provides the concept of three stages of SST in the form of rectifier stage (AC-DC), converter stage (DC-DC) and the inverter stage (DC-AC). The models are designed using MATLAB/SIMILINK and the output voltage of 450V with frequency designed at 10KHz.**

***Keywords*: MOSFET, Transformer, semiconductor, rectifier, converter and inverter.**

1.0 INTRODUCTION

The complexity in power system networks because of enormous scope creation of renewable energy generating station has developed enormously. Solid State Transformer gives a successful means to defeat such complexity to accomplish productive framework control[1]l. Then, at that point, significance of distributed energy resources (DER) and distributed energy storages (DES) must be accentuated so much not just for energy improvement and monetary development of the nation yet in addition for the maintainability[2]. The current situation of power conveyance incorporates move of power from more significant level to bring down voltage level through medium voltage association towards the buyer side, all did in low lattice frequency of 60/50Hz[3]. A solid-state transformer (SST), or Power Electronic Transformer (PET) is really an AC-AC converter a kind of electric power converters that replaces a traditional transformer it can't be considered as a solitary gear yet a bunch of power electronic circuit comprising of a regular front-end rectifier associated with a medium voltage network and to from the low voltage side It is more mind literally than a customary transformer working at utility frequency however it tends to be more modest and more proficient than a customary or traditional transformer(bulky and high weight)[4] since it works at high frequency , as it works in a way of AC-to-DC-to-DC-to-AC converter (in which a functioning rectifier supplies power to a DC-to-DC converter, which supplies power to a power inverter). However, A DC/DC converter utilizing an exceptionally high frequency transformer[5] and DC to AC inverter at the mass end assists with changing over the DC voltage for homegrown and business supply just a solid-state transformer as a rule contains transformers, inside the AC-AC converter or DC-to-DC converter[6], which gives electrical confinement and conveys the full power. This transformer is more modest because of more modest DC reversing stages between transformer curls, which thus mean more modest transformer loops expected to move forward or venture down voltages. SST is a flowed organization of AC to DC rectifier[5] alongside disengaged DC to DC converter followed by DC to AC inverter (Figure 1). As a result of the expanded usefulness over conventional transformer-based framework[7]. There has been a need to send power through significant distances since generation and utilization isn't generally in a similar area. This transmission likewise requires voltage change for power proficiency and economy of the framework[8]. Generally, regular iron center transformers that work in low frequency have been being used. Notwithstanding the regular transformer being less expensive and solid for power transmission, a few deficiencies utilize ordinary transformer deterring. Not many of the inadequacies incorporate the accompanying[9].

- As how much power transmission builds the volume and weight of the transformer increments enormously.
- These low frequency transformers in spite of being productive doesn't dispose of the music created by them.
- Unidirectional power stream restricts the adaptability of these transformers.
- The requirement for involving fluid oil for the purpose of cooling additionally discouragers their utilization.
- Autonomous control of dynamic/receptive power is very hard to get.
- The likelihood of further developing the power variable of the framework is totally zero.
- These ordinary transformer-based frameworks have the issue of enormous voltage drop under stacking and voltage guideline also[10]

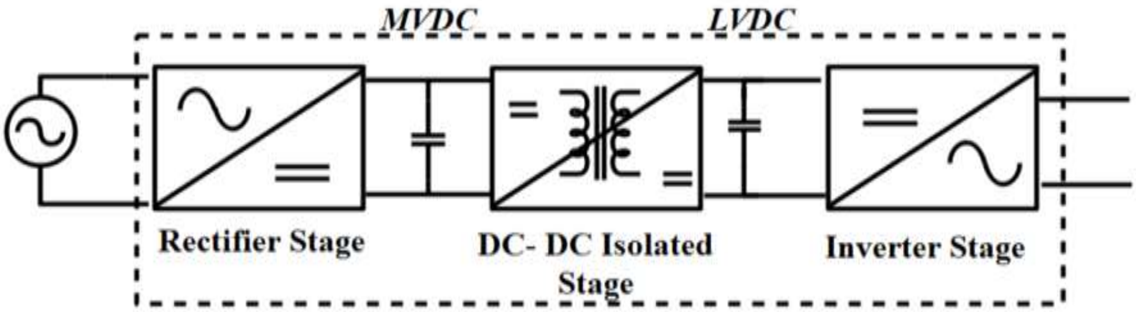

Figure 1 Simple solid state transformer

2.0 Solid State Transformer topology

Over past few decades several SST topologies have been present in numerous literature review. These topologies can be broadly classified in following configurations.

1. Single stage SST topology
2. Two stages SST topology with LVDC link
3. Two stages SST topology with HVDC link

Three stages SST topology with HVDC and LVDC link

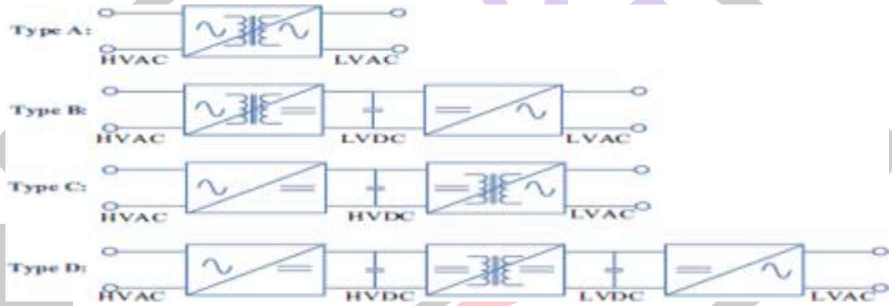

Figure 2.1 topologies of SST

Figure above shows four different SST topologies. Each differ from one another with respect to presence and absence of the DC link either in MV side or LV side. The single stage topology is basically an isolating transformer with no DC links available in either side of the transformer[11].

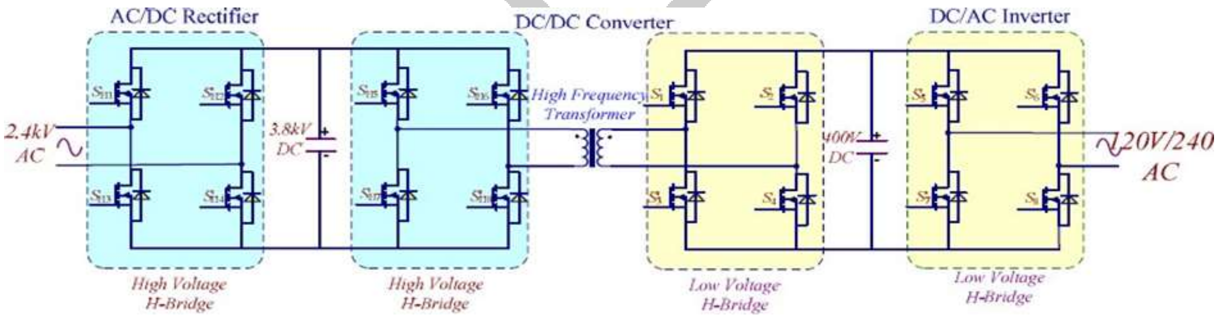

Figure 2.2 topologies of AC-DC, DC-DC and DC-AC

2.1 Rectifier stage

Rectifiers are used in numerous areas from little electronic machines to high power applications, for example, switching AC over completely to DC for high-voltage direct current power transmission[12]. Contingent upon the application, types are shifted like diode, thyristors or then again PWM rectifiers. Application areas of rectifiers which have semiconductors as switching components are growing with the progression of semiconductor technology, because of the requirement for high proficiency, solidarity power factor, bidirectional activity and result voltage with high controllability. Three Phase PWM Rectifiers with IGBT switching components are one of the most widely recognized kind of rectifiers in industry where the highlights above are expected to use[13].

2.2 Three Phase PWM Rectifier Topology

Three Phase PWM Rectifier Topology For AC-DC change there are different topologies that are broadly utilized in the business, for example, line commutated with diode and thyristors, or with power factor revision like Vienna, support or regenerative rectifiers. Albeit many enjoy benefits in various applications, regenerative three phase two level voltage source rectifier is the one with the capacities appropriate for our work. Three Phase PWM Rectifiers can be suitable for many systems at medium power levels. By using Three Phase PWM Rectifier, the unity power factor operation is accomplished and low THD input is obtained, the output DC voltage is adjustable and the power flow is unidirectional[2].

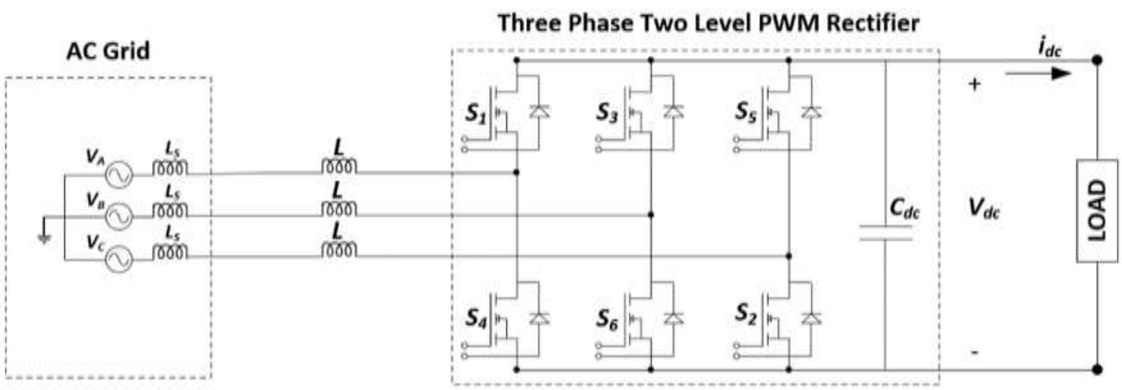

Figure 2.3 A three phase two level pwm rectifier

2.2.1 Pwm as a Battery Charger

PWM Rectifier can be utilized as quick and ultrafast battery charger in numerous configurations [17]. It furnishes variable result voltage with unidirectional power stream in off-board battery chargers of every electric vehicle. The rectifier can be associated straightforwardly to the battery on the off chance that the voltage rating of the battery is around dc yield voltage level of the PWM Rectifier. the result is between 600V-1000V. Almost symphonious free activity is achieved at solidarity power factor on the framework side.

2.2.2 Operation Modes of PWM Rectifier

at given AC supply side voltage and current waveforms, the operation instance is marked with dotted line while the PWM Rectifier is in rectification. This line corresponds to the time instant where Vb and Vc are positive and Va is negative. Therefore, Ib and Ic are conducting at positive direction and Ia current is in negative direction. A switching pattern represents the gate signals sent to the high side of the SiC MOSFETs. Therefore, the opposite signals are applied to the low side of the corresponding MOSFETs. The aim of these switching patterns is to create purely sinusoidal current waveform at the AC side of the rectifier at steady state and this is achieved by changing the width of the pulses in each step. The switching frequency for this operation is set to 10 kHz[14].

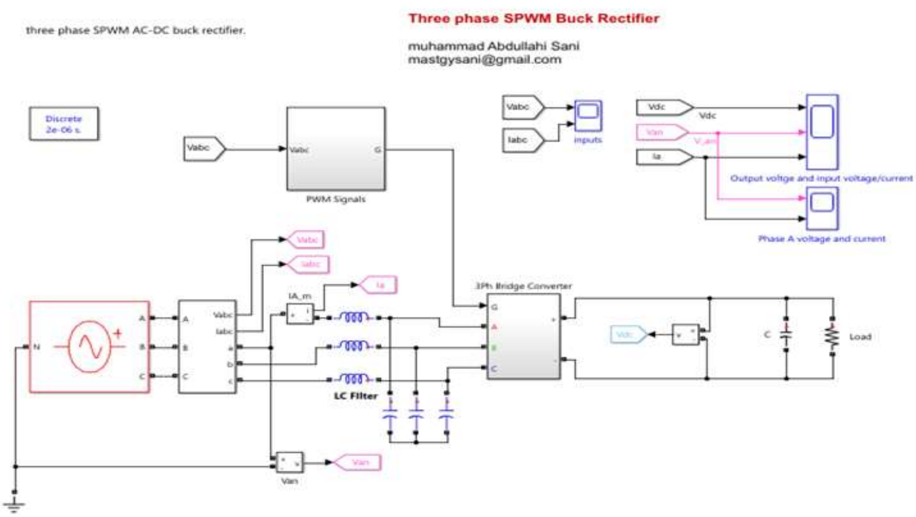

Fig 2.4 A 3phase bridge buck rectifier

2.3 Bridge converter

A buck converter (step-down converter) is a DC-to-DC power converter which steps down voltage (while drawing less typical current) from its input (supply) to its outcome (load). It is a class of switched mode power supply (SMPS) typically containing something like two semiconductors (a diode and a transistor, yet present day buck converters a large part of the time override the diode with an ensuing transistor used for synchronous revision)[6] and something like one energy storage part, a capacitor, inductor, or the two in blend. To diminish voltage ripple, filters made of capacitors (sometimes in blend in with inductors) are commonly added to such a converter's outcome (load-side channel) and input (supply-side filter). It is known as a buck converter in light of the fact that the voltage across the inductor "bucks" or conflicts with the stock voltage. Trading converters (like buck converters) give significantly more unmistakable power capability as DC-to-DC converters than direct regulators, which are simpler circuits that lower voltages by dispersing power as force, yet don't step up output current[15].

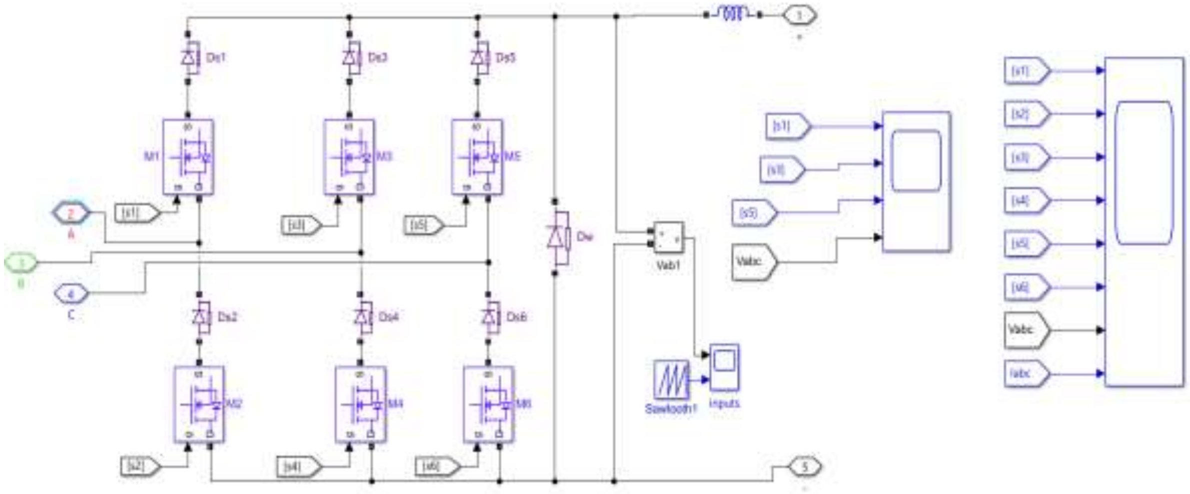

Figure 2.5 A three phase bridge converter

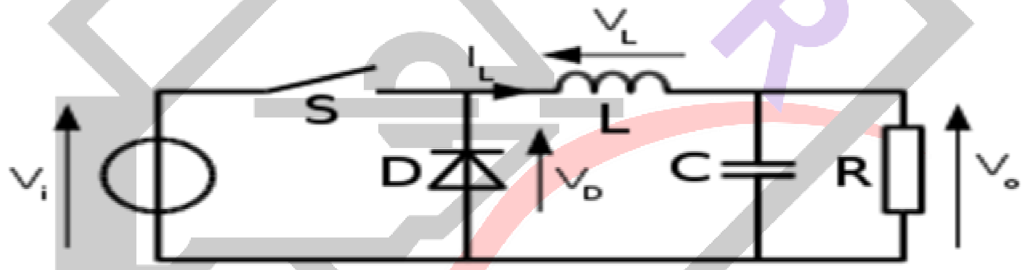

Figure 2.6 a simple circuit of a buck converter

The energy stored in the inductor

$E = \frac{1}{2} LI^2{}_L$

Where

L increases during on time as I_L increases and then decreases during the off-state L

The rate of changes of I_L

$$V_L = L\frac{dI_L}{dt}$$

$$V_L = V_{IN\ max} - V_0$$

And $-V_0$ off state

the inductor ripple current $= \frac{(V_{in\ max} - V_{out})\ D}{fs\ .\ L}$

$D =$ Duty cycle $0 - 1$

$fs =$ minimun switch frequency of the converter

$L =$ selected inductor value

For the MOSFET voltage drop approximation R_{DS} and V_{DS} and I_{DS} relationship is used from the data sheet at multiple V_{GS} values.

$Power_{leakages} = I_{leakages}$ x V

Where

$I_{leakages}$ = is the leakage current of the switch

V = is the voltage across the switch
For switching power

$$P_{sw} = \frac{VI_0(t_{rise} - t_{fall})}{6T}$$

P_{sw} = switch power drop
t_{rise} and t_{fall} = are switch rise and fall times
T = the switching periods
Many MOSFET based buck converters has a diodes so that to aid the MOSFET with conducting during non-overlapping time. So the diode is used exclusively for lower lower switch and reduction of efficiency in lead voltage overshoots.
The power loss on the diode is given as

$$P_D = V_f . I_0 . t_{no} . f_{sw}$$

Where V_f = is the diode forward voltage
t_{no} = non − overlapping time
The overall power loss at MOSFET switches losses can be deduced by energy required to charge or discharge the capacitance of the MOSFET gate between the threshold voltage and selected voltage.

$$P_{G\,drive} = Q_G . V_{GS} . f_{SW}$$

Where
Q_G = gate charge of the mosfet
V_{GS} = peak gate source voltage

2.4 Bridge inverter

Three stage bridge inverter are utilized for high power applications. Three stage bridge inverter comprises of six MOSFET switches and six diodes, here MOSFET has been picked as the switch. The principal capacity of the three stage bridge inverter is to transform the DC voltage to AC voltage; thus this is accomplished by applying the right exchanging arrangement[16]. A three stage inverter is framed by three single stage inverters which are associated in equal; the gating signs of single stage inverters ought to be postponed by 120° as for one another to get three stage adjusted voltages. Here the MOSFETS‟s is constrained by door drive; each entryway drive will control one MOSFET. Consequently, for six MOSFET‟s six door drives are required for the activity.

2.4.1 OPEARTION OF THREE PHASE INVERTER 180^0

The output voltage waveform of the inverter PWM of a MOSFET switches S1- S6 are 180^0 and the inverter output voltage line-to-line have a width of 120^0 (V_{ab},V_{bc}, and V_{ca}), since the inverter is a three phase operates properly when switches are paired. During the first interval (0, $^{\pi}/_3$) the line current $i_a>0$, $i_c>0$ and $i_b<0$ and the S1, S5 and S6 are conducting and generating output voltage of $V_{a0} = +^{Vin}/_2$ the freewheeling diode conduct and generates the same output voltage level. For each operation interval a group of three MOSFETs will conducts. In the second interval ($^{\pi}/_3$,$^{2\pi}/_3$) switches S1,S2 and S6 are conducting while the output voltage $V_{a0} = +^{Vin}/_2$. in the third interval ($^{2\pi}/_3$, π) switches S1, S2 and S3 then at fourth interval (π, $^{4\pi}/_3$) the switches are S2, S4 and S3 and the conducting and generating voltage is $V_{a0} = -^{Vin}/_2$ at the fifth interval ($^{4\pi}/_3$, $^{5\pi}/_3$) the switches are S5, S4 and S3 are conducting. In the sixth interval ($^{5\pi}/_3$, 2π) the conducting switches are S5,S4 and S6 and the output phase voltage is $V_{a0} = -^{Vin}/_2$. There are six methods of activity in each cycle and the length of every mode is 60°. The switches of any leg of the inverter ought not be switched on as it brings about hamper the voltage supply. At the point when a DC power supply is given to the MOSFET switches, the MOSFET‟s plays out its modes operation and converts the DC to AC. The changed over alternating current is gone through the channel to decrease the harmonics[17].

3.0 Simulation

To ensure the feasibility of the system simulation is carried through pulse width modulation method for three- stage a simulation is performed using MATLAB/SIMULINK and the result are obtained using the graphs below for the rectification stage, converting stage, inverting stage and the general output of the solid state transformer.

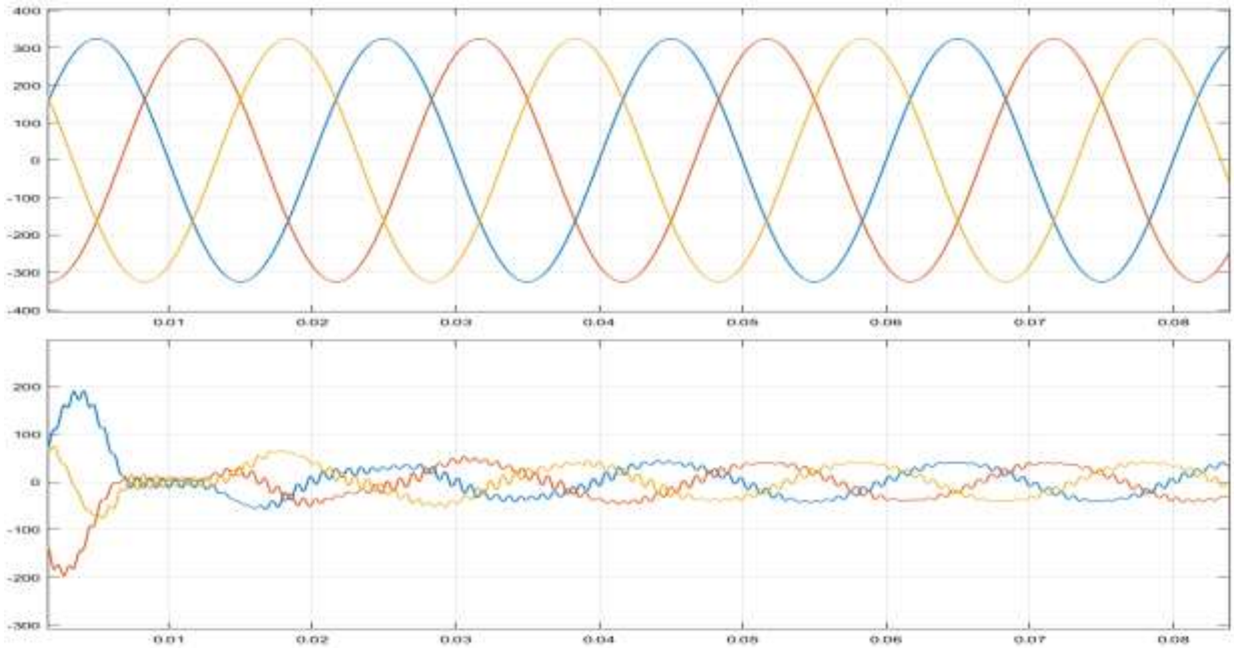

Figure 3.1 the input current and voltage at spwm

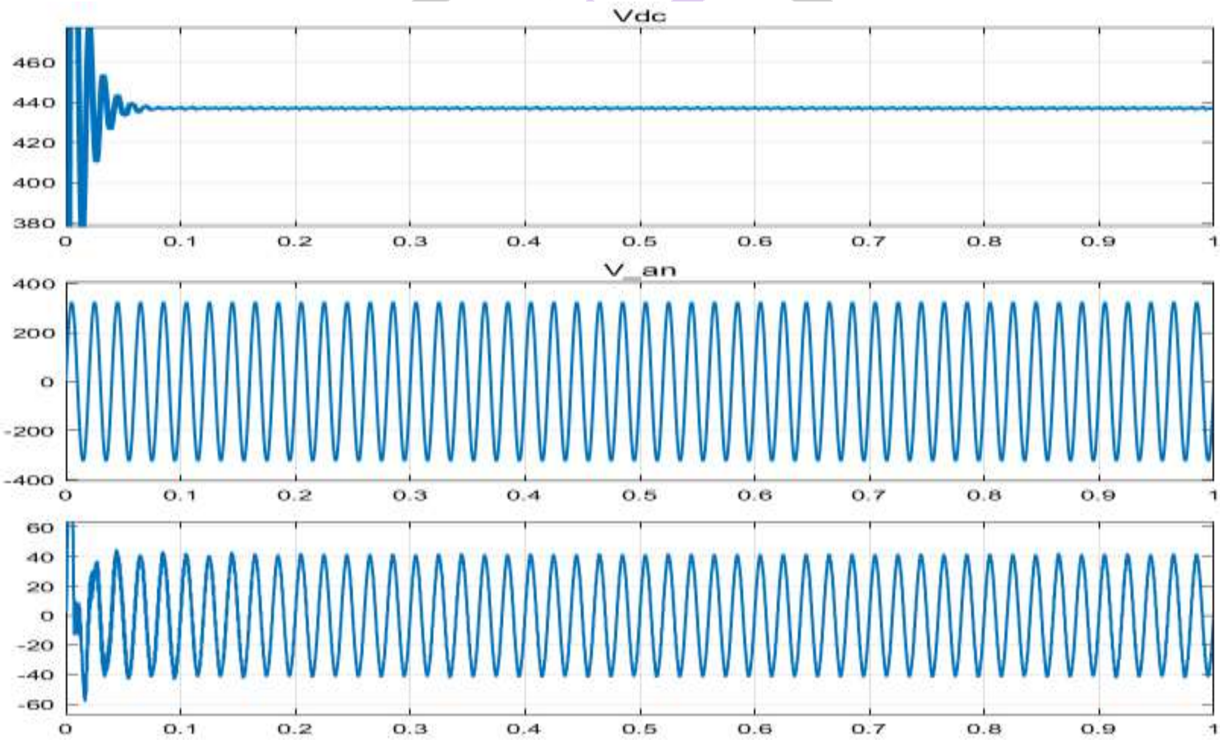

Figure 3.2 rectifying SPWM AC-DC output Vdc phase voltage and phase current.

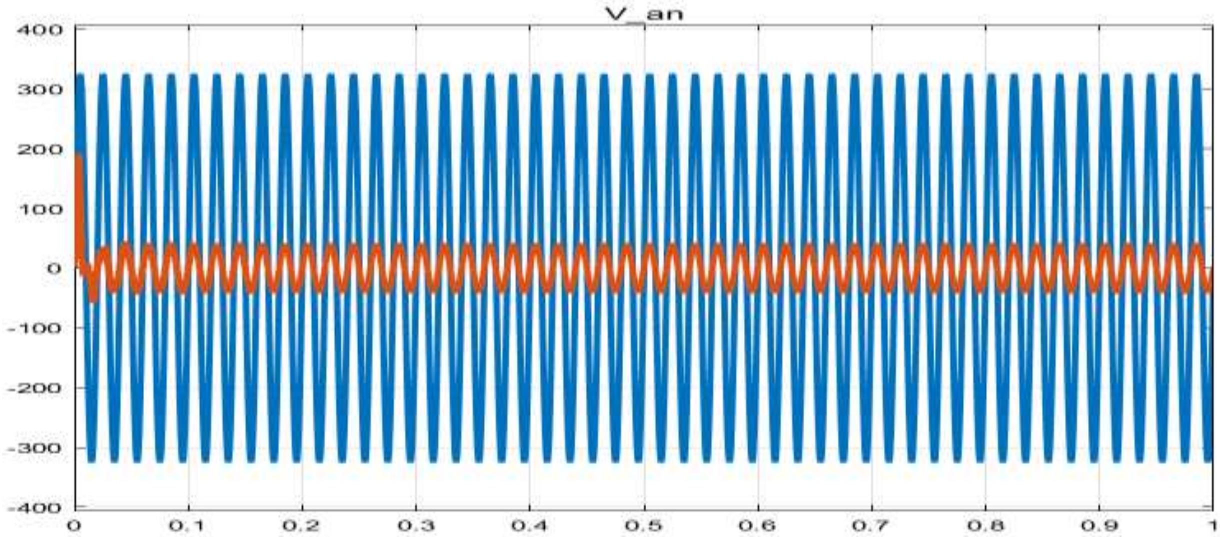

Fig 3.3 Phase A voltage and current waveform of the rectifier

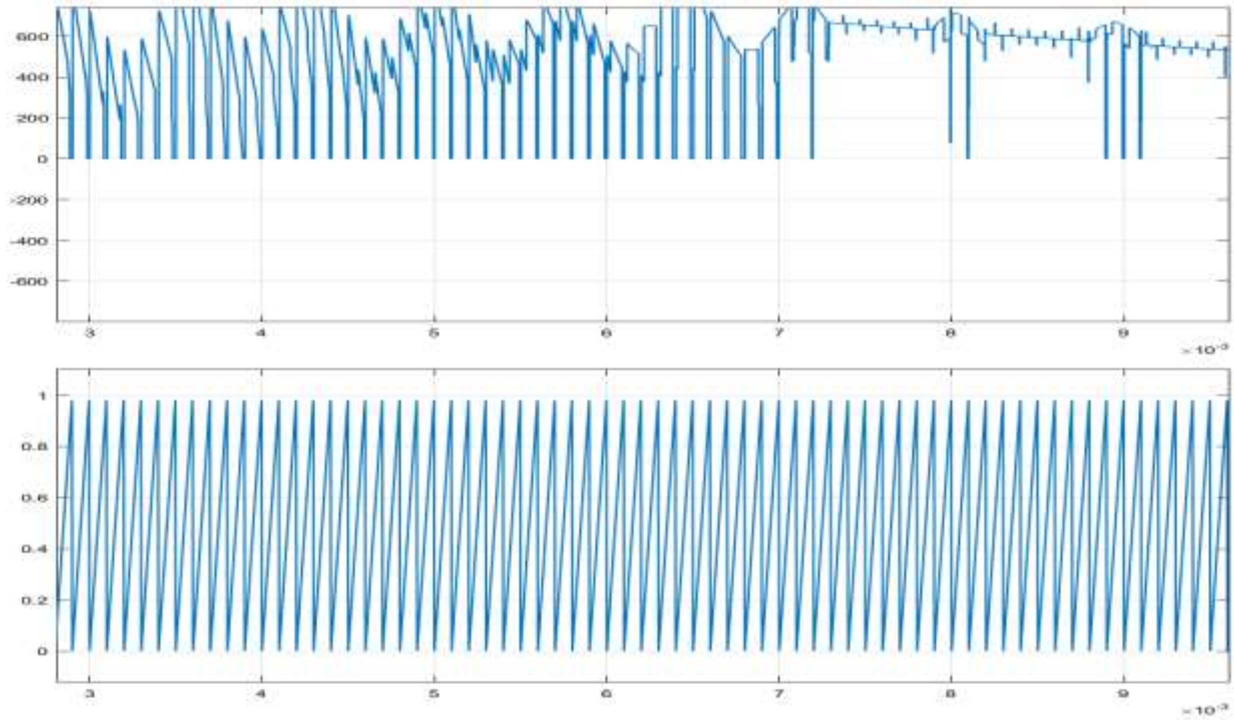

Figure 3.4 input voltage and current of the bridge converter

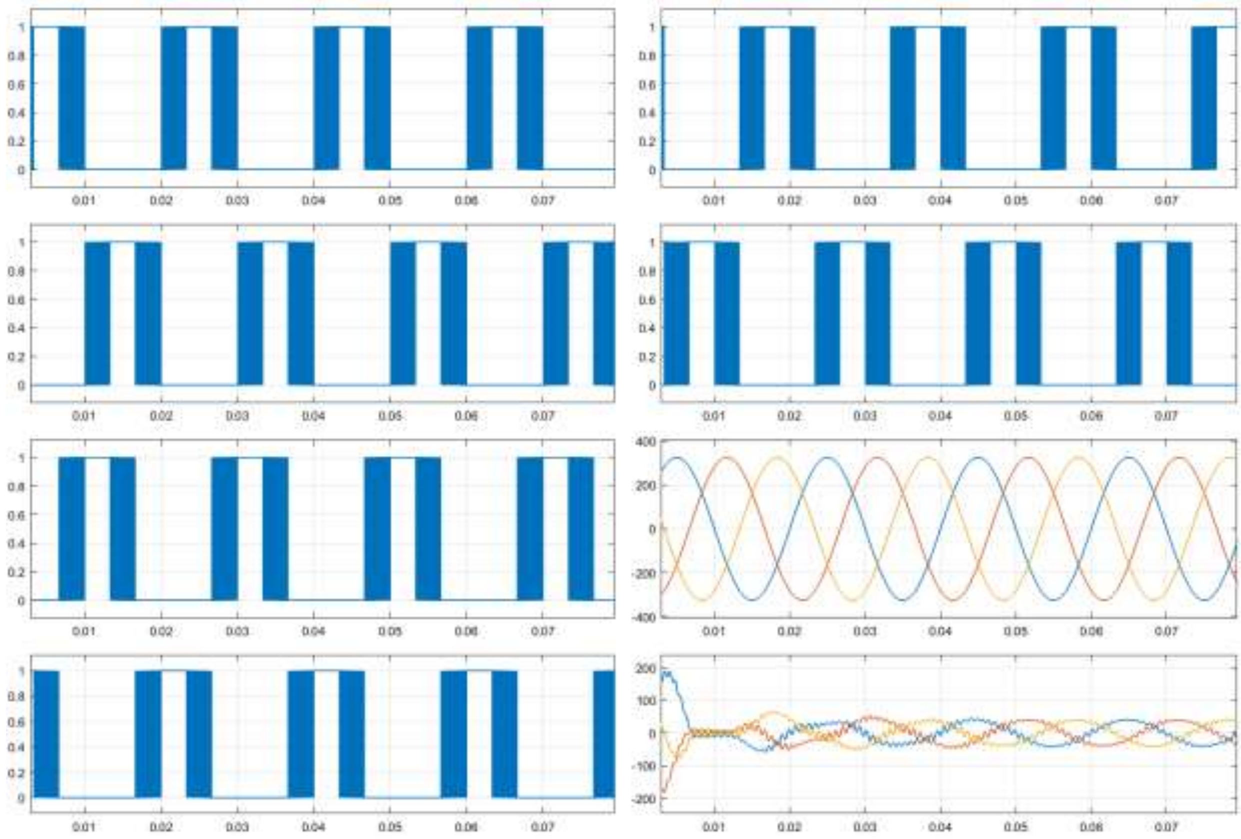

Figure 3.5 Inverter output showing gate switches with phase voltage and phase current

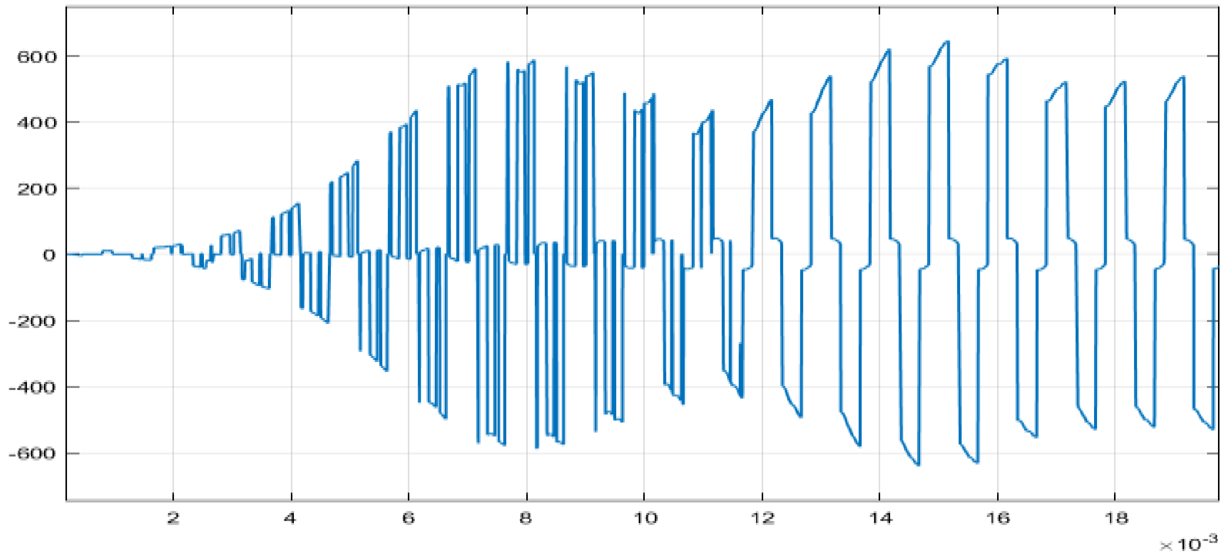

Figure 3.6 total output load voltage at one phase

4.0 Conclusion

It is concluded that the conventional transformer which was utilized generally in industrial applications so far has disadvantages like saturation of core for non-direct burden, no voltage droop and swell moderation, unfortunate voltage regulation, less efficiency, high losses, isolation shortcomings and so on.. Larger part of these issues are decreased or totally alleviated by solid-state transformer or power electronic based smart transformer. Likewise, it has the ability to function as energy switch for brilliant grid energy web. In this manner, the field of application of force electronic based solid-state transformer is not restricted up to distribution level yet in addition having ability to supplant the conventional power transformer excessively. However, as we need smaller things having high power thickness, we will utilize these transformers rather than conventional transformers. In this manner, SST has shown to be promising compensator with many benefits like high power quality, voltage control, issue isolation and many more. There is no general topology for every single commonsense application, so a different topology is to be utilized for a specific application, which makes tremendous issue to design.

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