DC–DC Converter for High Current and Voltage Step down Applications by using 3SSC

S.Ravikanth [1] *B.Rama Krishna Singh* [2] *B.Raviteja* [3]

[1] Assistant Professor, Dept of EEE, DVR & Dr.HS MIC college of Technology, Krishna, A.P., India

[2]Assistant Professor, Narayana Engineering College, Nellore, A.P, India

[3]Assistant Professor, Narayana Engineering College, Nellore, A.P, India

Abstract*—This paper presents a pulse width modulation dc–dc non isolated buck converter using the three-state switching cell, constituted by two active switches, two diodes, and two coupled inductors. Only part of the load power is processed by the active switches, reducing the peak current through the switches to half of the load current, as higher power levels can then be achieved by the proposed topology. The volume of reactive elements, i.e., inductors and capacitors, is also decreased since the ripple frequency of the output voltage is twice the switching frequency. Due to the intrinsic characteristics of the topology, total losses are distributed among all semiconductors. Another advantage of this converter is the reduced region for discontinuous conduction mode when compared to the conventional buck converter or, in other words, the operation range in continuous conduction mode is increased, as demonstrated by the static gain plot. The theoretical approach is detailed through qualitative and quantitative analyses by the application of the three-state switching cell to the buck converter operating in non overlapping mode ($D < 0.5$). Besides, the mathematical analysis and development of an experimental prototype rated at 1 kW are carried out.

Keywords: Three state switching cell, buck converter

1. INTRODUCTION

Pulse width modulation (PWM) dc–dc converters are widely employed in numerous applications, e.g., audio amplifiers, uninterruptible power supplies, fuel cell powered systems, and forklift vehicles, although many other ones can be easily found. Conventional hard switching converters with a single active switch such as buck, boost, buck–boost, Cu´ k, single-ended primary-inductance converter (SEPIC), and Zeta typically present low power density, while attempts to further minimize the size of filter elements lead to increased switching losses, compromising the efficiency of the converters. In order to overcome such limitation, several soft switching approaches have been introduced in the literature. Soft switching is supposed to reduce the overlap between voltage and current during the commutation, and can be classified in either active or passive methods, as one must choose between the aforementioned snubbers for a given application. Active methods can reduce the switching losses by using auxiliary switches. Unfortunately, an auxiliary switch increases the complexity of both power and control circuits. Synchronization problems between control signals of the switches during transient also complicate the control strategy. Circuit cost is in- creased and reliability is affected by using active snubbers.

A passive lossless snubber can effectively restrict switching losses and electromagnetic interference (EMI) noise using no active components and no power dissipative components. No additional control is needed and no circulating energy is generated. Circuit structure is as simple as *RCD* (resistor–capacitor–diode) snubbers while circuit efficiency is as high as active snubbers and resonant converters. Low cost, high Performance and high reliability are the distinct advantages of a passive loss- less snubber. However, soft switching may not be achieved for the entire load range, and besides the accurate design of the resonant tank is not a trivial task, even what is also valid when active snubbers are considered. Significant effort has then been made to improve the characteristics of the traditional non isolated dc–dc converters in the last few years. For instance, the study of a dc–dc buck converter with three-level buck clamping, zero voltage switching (ZVS), active clamping, and constant-frequency PWM is proposed in. A family of converters commutation cell, and decreased switching losses obtained from a soft switching technique. is also derived, which combines the advantages of reduced voltage across the switches using a three-level.

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), current that flows in only one direction, a process known as rectification. Rectifiers have many uses including as components of power supplies and as detectors of radio signals. Rectifiers may be made of solid state diodes, vacuum tube diodes, mercury arc valves, and other components.

A device which performs the opposite function (converting DC to AC) is known as an inverter.

When only one diode is used to rectify AC (by blocking the negative or positive portion of the waveform), the difference between the term diode and the term rectifier is merely one of usage, i.e., the term rectifier describes a diode that is being used to convert AC to DC. Almost all rectifiers comprise a number of diodes in a specific arrangement for more efficiently converting AC to DC than is possible with only one diode. Before the development of silicon semiconductor rectifiers, vacuum tube diodes and copper(I) oxide or selenium rectifier stacks were used.

For three-phase AC, six diodes are used. Typically there are three pairs of diodes, each pair, though, is not the same kind of double diode that would be used for a full wave single-phase rectifier. Instead the pairs are in series (anode to cathode). Typically, commercially available double diodes have four terminals so the user can configure them as single-phase split supply use, for half a bridge, or for three-phase u

Most devices that generate alternating current (such devices are called alternators) generate three-phase AC. For example, an automobile alternator has six diodes inside it to function as a full-wave rectifier for battery charging applications.

2. TOPOLOGY

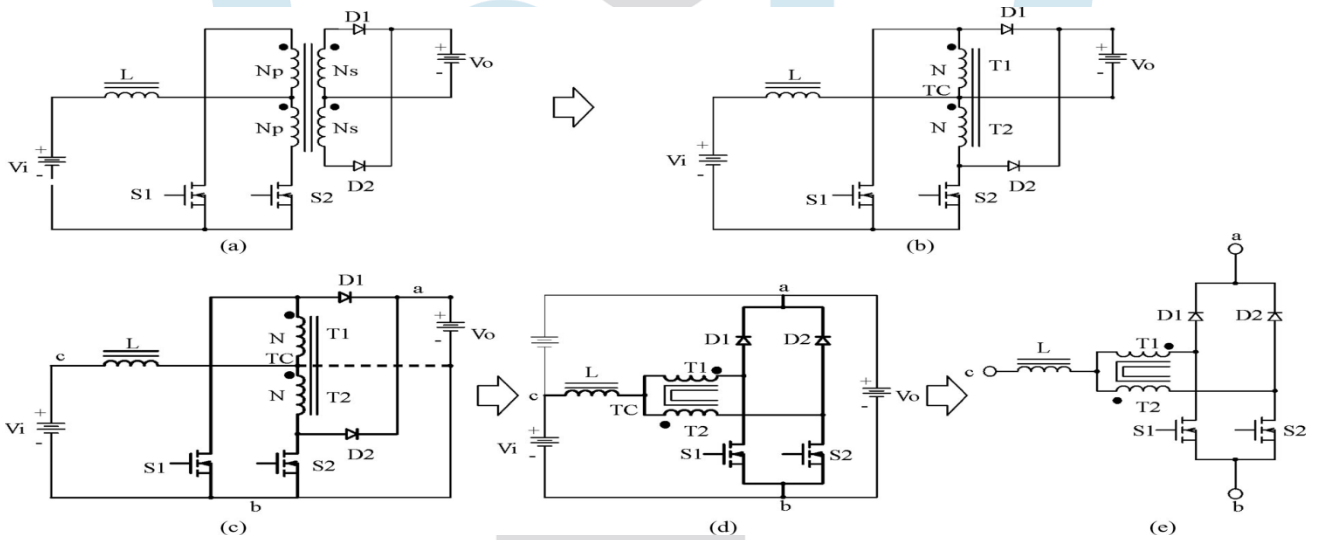

Fig. 1. 3SSC type *B*

The canonical switching cell is an approach that allows us to obtain and classify the classical dc–dc converters, from which some families of converters can be derived. Buck, boost, and buck–boost converters, which are second-order systems, as well as Cu´ k, SEPIC, and Zeta, which are fourth-other systems, have a single switching cell that is part of their respective power stages. Literature has also shown appreciable effort to improve the characteristics of the original structures, even though the novel resulting topologies are more complex approaches with higher component count.

The aforementioned switching cell is composed of three terminals, which are active, passive, and common. Its behaviour is based on the complementary operation of two switches connected by the common terminal. In other words, one switch is turned ON while the remaining one remains turned OFF, and vice versa. Therefore, this arrangement can be called 2SSC.

With the aim of achieving higher power density, switching frequency is usually increased, with consequent reduction of size and volume of reactive elements. Consequently, it leads to the increase of both switching losses and the volume of heat sinks. This practice, therefore, compromises the very reduction of physical dimensions in static power converters.

The aforementioned losses must then be reduced, and soft switching circuits using the resonance phenomenon have been widely proposed as a possible solution. By using well-known techniques such as ZVS and zero current switching, the performance of converters can be improved. However, even though switching losses are mitigated or eliminated, conduction losses are still of major concern and may even increase depending on the adopted snubber.

With the aim to further reduce voltage and/or current stress, the association of semiconductors or even converters in series or in parallel has been thoroughly investigated. Other topologies can also be obtained, such as multilevel converters.

It is also possible to increase the efficiency by the use of the 3SSC, which has been employed in recent publications and is originally derived from the dc–dc push–pull converter. In order to obtain the cell type *B*, let us consider the classical push– pull topology shown in Fig. 1, which is formed by switches S1 and S2 , two rectifier diodes *D*1 and *D*2 in the secondary side, and a high-frequency transformer. The circuit corresponds to a dc–ac–dc conversion system. If the central tap transformer is considered ideal with unity turns ratio, the primary and secondary windings can be replaced by the respective magnetizing inductances, which are coupled and constitute an autotransformer.

The negative terminal of the output stage represented by *Vo* , which was formerly connected to the central tap of the transformer, is then connected to the negative pole of the input voltage source to generate a boost topology, as seen in Fig. 1(c). Otherwise, if connected to the positive pole, a buck–boost converter is derived. The cell type *B* can then be applied to the dc–dc buck converter substituting the 2SSC, while the resulting topology is presented in.

It can be seen that the 3SSC is formed by two controlled switches S1 and S2, two diodes *D*1 and *D*2 , one autotransformer *T*1 *T*2 , and one inductor *L*. Even though the resulting cell seems more complex with higher component count than the conventional 2SSC, the advantages over its counterpart will be clearly demonstrated in this study. For instance, the use of the 3SSC may lead to the need of switches with reduced current rating, which is desirable in step-down high-current applications.

Considering that the operation of the switch and the diode of a same leg is complementary, two modes regarding the main switches can be obtained for the proposed topology. If the duty cycle *D* is higher than 0.5, overlapping mode (OM) occurs, where two switches remain turned ON at the same time. Otherwise, if $D < 0.5$, the converter operates in NOM, while only one switch remains turned ON in a given operating stage.

The proposed approach can be seen as the integration of the interleaving technique and the 3SSC. The following advantageous characteristics can be then addressed to the introduced topology:

1) Reduced size, weight, and volume of magnetics, which are designed for twice the switching frequency analogously to the interleaved buck converter.

2) The current stress through each main switch is equal to half of the total output current, allowing the use of semi-conductors with lower current ratings.

3) Losses are distributed among the semiconductors, leading to better heat distribution

And consequently more efficient use of the heat sinks.

4) Part of the input power, i.e., 50%, is directly transferred to the load through the diodes and the coupled inductors (autotransformers), and not through the main switches. As a consequence, conduction and switching losses are reduced. This is the main difference between the functionality of this approach and that of the interleaved buck topology.

5) The use of the 3SSC allows the parallel connection of switches and, therefore, inexpensive power devices and drives can be used.

6) Energy is transferred from the source to the load during most part of the switching period, which is a distinct characteristic of the proposed converter, since in other buck- type converters, it only occurs during half of the switching period. As a consequence, reduction of current peaks and also conduction losses are expected.

As mentioned earlier, it is desired that the ac output voltage, *vo* = *vaN*, follow a given waveform (e.g. sinusoidal) on a continuous basis by properly switching the power valves. The carrier-based PWM technique fulfils such a requirement as it defines the on- and off-states of the switches of one leg of a VSI by comparing a modulating signal *vc*(desired ac output voltage) and a triangular waveform *v_* (carrier signal). In practice, when *vc*>*v_* the switch *S*+ is on and the switch *S*− is off; similarly, when *vc*<*v_* the switch *S*+ is off and the switch *S*− is on.
Simulink is a tool used to visually program a dynamic system (those governed by Differential equations) and look at results. Any logic circuit, or control system for a dynamic system can be built by using standard building blocks available in Simulink Libraries.

3. SIMULINK RESULT

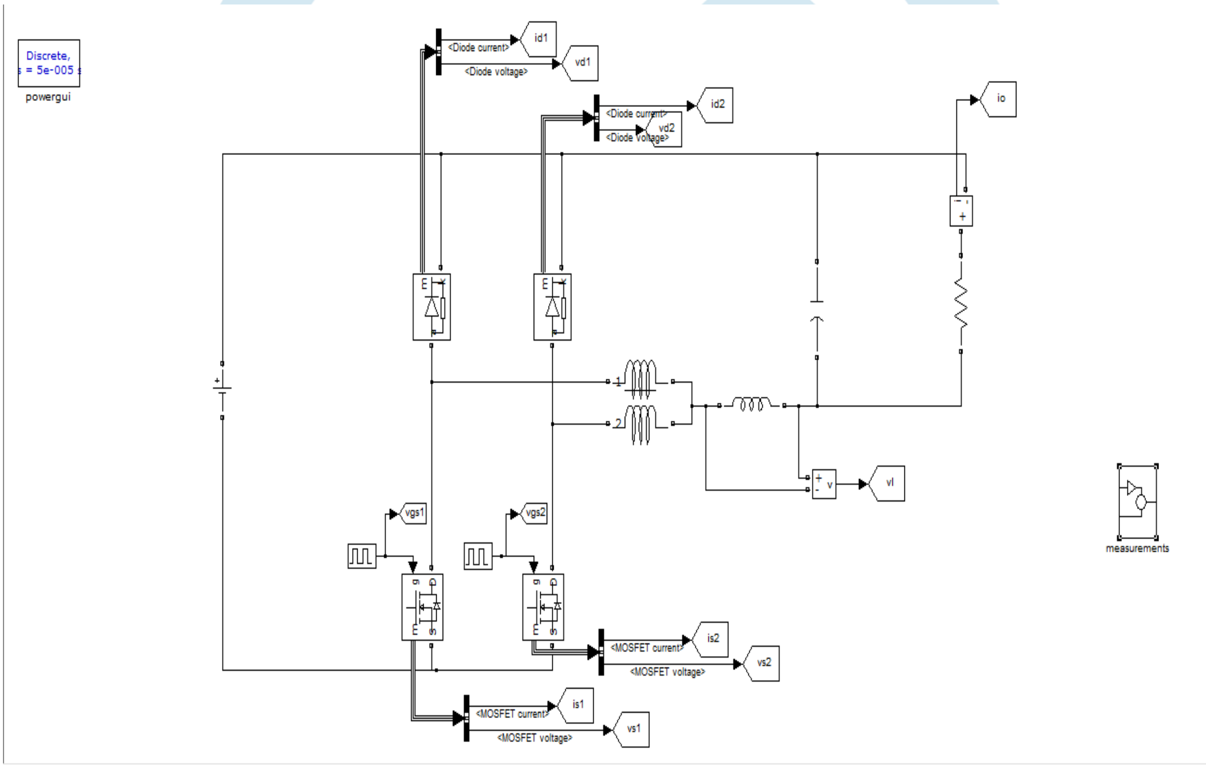

Fig. 2. Simulink representation

The problem with the operation of the circuit in Fig above(forward converter) is that only positive voltage is applied across the core, thus flux can only increase with the application of the supply. The flux will increase until the core saturates when the magnetizing current increases significantly and circuit failure occurs. The transformer can only sustain operation when there is no significant DC component to the input voltage. While the switch is ON there is positive voltage across the core and the flux increases. When the switch turns OFF we need to supply negative voltage to rset the core flux. The circuit in Fig. below shows a tertiary winding with a diode connection to permit reverse current. Note that the "dot" convention for the tertiary winding is opposite those of the other windings. When the switch turns OFF current was flowing in a "dot" terminal. The core inductance act to continue current in a dotted terminal.

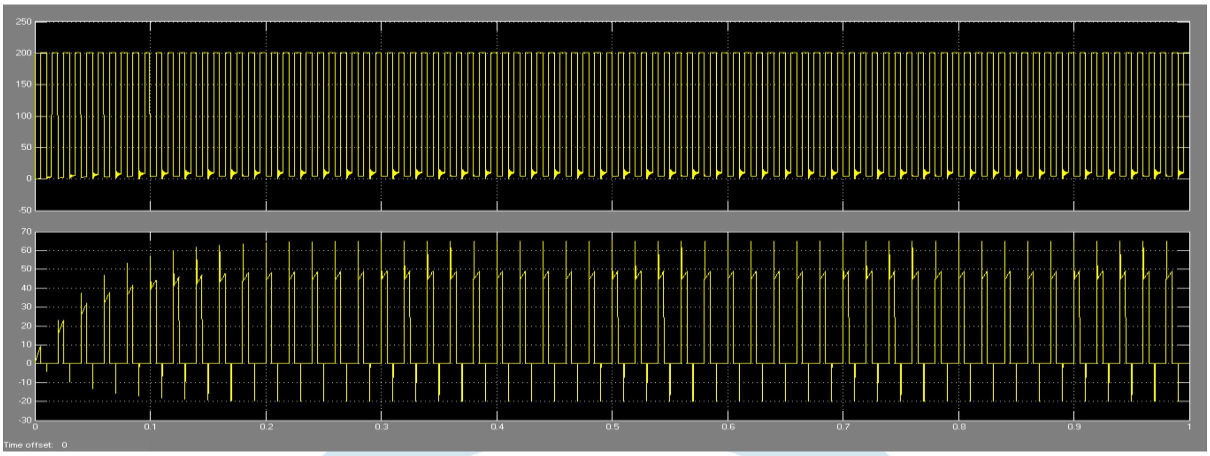

Fig. 3. Vs1, Is1 waveforms

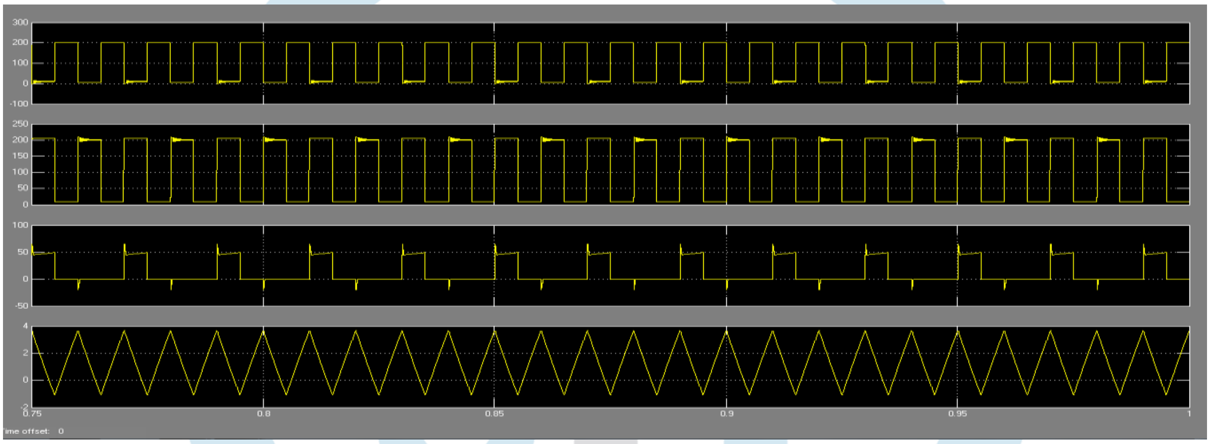

Fig. 4. Vd1, Id1, Vd2, Id2 waveforms

Progressive control adds enormous flexibility to the use of this controller. Hi Speed is that same as hard wiring the motor to a steady 12 volt DC source. The controller is providing 100% PWM, steady 12 volt DC power. Hi Speed is selected three different ways on this controller: 1) Hi Speed is automatically selected for about one second when power goes on. This gives the motor full torque at the start. If needed this time can be increased (the value of C1 would need to be increased). 2) High Speed can also be selected by applying 12 volts to the High Speed signal wire. This gives Hi Speed regardless of the Progressive signal. When the Progressive signal gets to approximately 4.5 volts, the circuit achieves 100% PWM – Hi Speed.

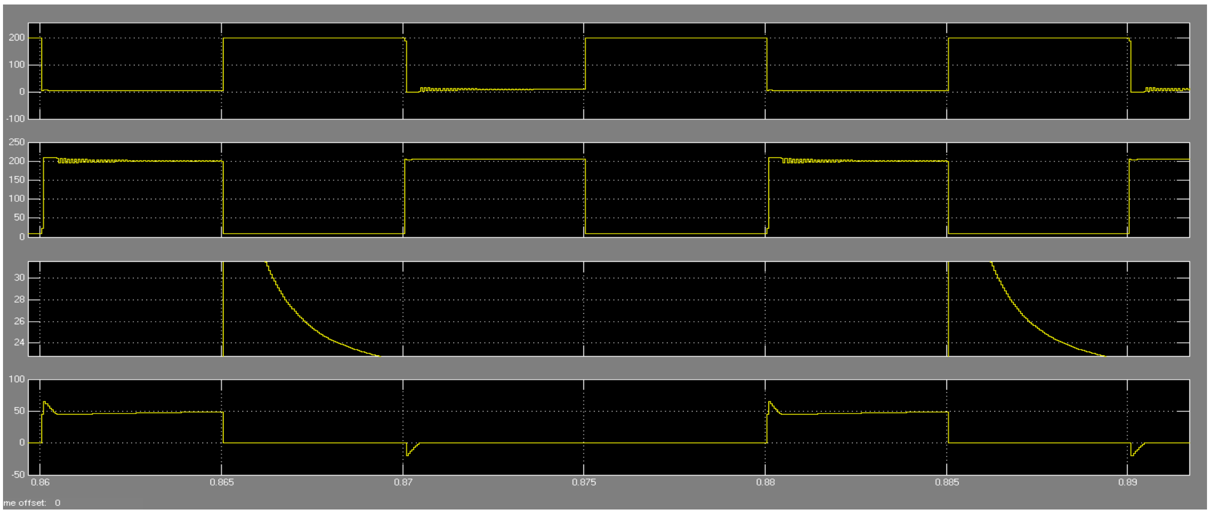

Fig.5 Vd1, Vs2, Vd2, Is1 waveforms

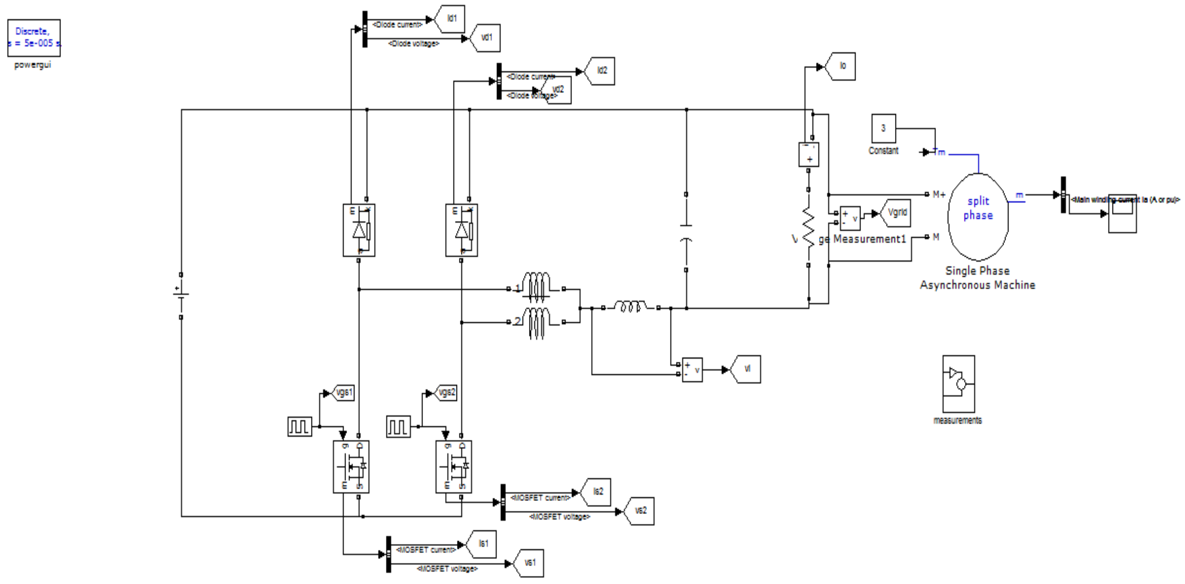

Fig. 6 Simulink representation with asynchronous machine

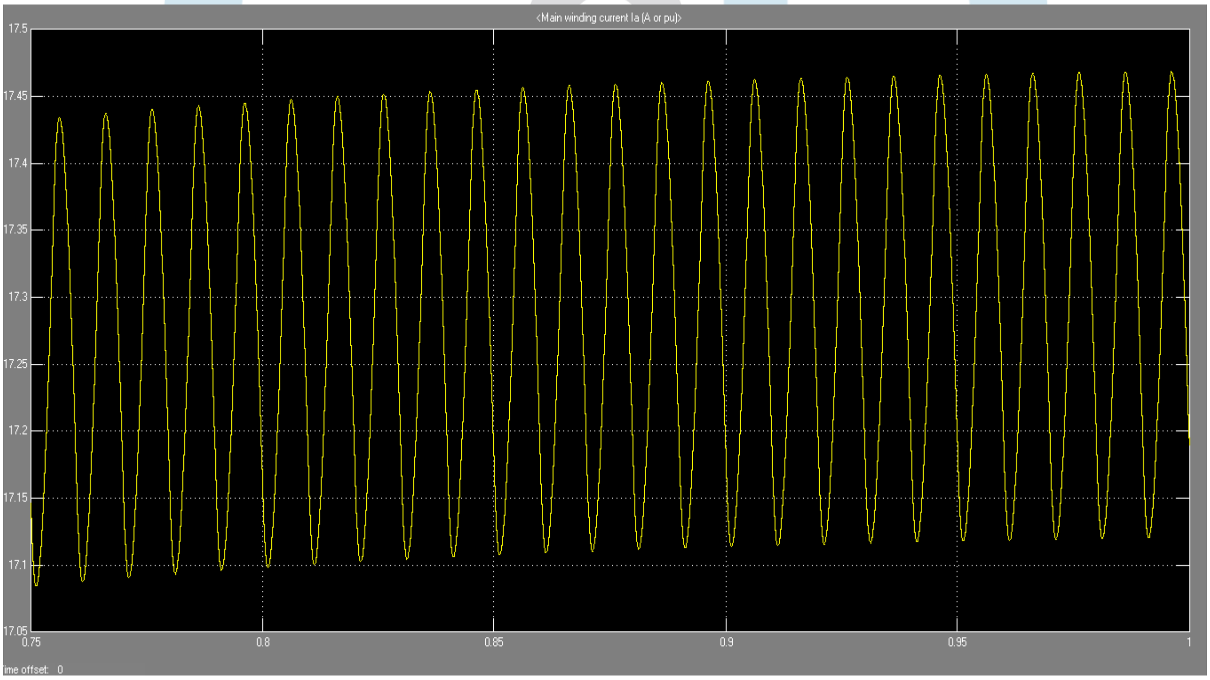

Fig.7 Stator current waveform

4. CONCLUSION

A dc–dc buck-boost converter depended on the 3SSC has been developed. When the 3SSC is applied, the current is distributed among the power electronic semiconductors. Additionally, only part of the power from the input source flow from side to side the active switches, while the residual part is directly delivered to the load exclusive of being processed by these switches, i.e., this energy is delivered to the load through passive components, such as the diodes and the transformer windings.

Despite the increase in the number of semiconductors, the current levels on these devices are reduced, enabling the use of inexpensive switches and simplified command circuits because the isolated drive is not required like in the interleaved buck converter. In front of these characteristics, its use is recommended for high-power high-current applications where the traditional approach may be inadequate, while good current sharing is achieved.

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First Author: S.Ravikanth, graduate in Electrical and Electronics Engineering (EEE) from Prasad Institute Of Technology and Sciences, Jaggayyapet and Post Graduate from Nalanda Institute of Engineering and Technology, Guntur District, A.P, India. He is working as **Assistant Professor in Department Of EEE at DVR&Dr.HS MIC College of Technology**, Kanchikacherla, Vijayawada. Affiliated to JNTUK, Kakinada, A.P, India His Research Interests are **Power Systems, Power Electronics, and drives & FACTS devices.**

Second Author: B.RamaKrishna Singh, graduate in electrical and electronics engineering (EEE) from Prasad Institute Of Technology and Sciences, Jaggayyapet,& his M.Tech from LBRCE Krishna Dist.,A.P,India,He is working as **Assistant Professor in Dep. Of EEE at**, Narayana Engineering College, Nellore, A.P, India.Affliated to JNTUA, Ananthpur, A.P, and India His Research Interests are **Power Systems, Power Electronics, and drives & FACTS devices.**