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Review of Integrated Power Factor Correction (PFC) Boost converter topologies for Telecommunication systems

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***Abstract*— This paper provides a review of various Power Factor Correction (PFC) boost converter topologies suitable for telecoms. A novel integrated PFC topology is proposed which acts as a backup power supply for telecommunication systems. The advantage of the proposed circuit is that it operates based on soft switching principle thereby reducing the switching losses in the converter. The topologies analyzed in this paper are conventional average current mode control boost PFC, bridgeless boost PFC, semi-bridgeless boost PFC, totem-pole bridgeless boost PFC and proposed integrated boost PFC. All these topology studies are investigated by carrying out the simulation of the converter circuits using PSIM software. A detailed comparison of all the topologies have been done and they are compared in terms of supply power factor, supply current THD and displacement factor. From the results, it is inferred that the proposed integrated PFC provides a reduced supply current THD and improved power factor. The results are validated.**

***Index Terms*—PFC, boost topology, Telecom power supply, power factor, THD.**

I. INTRODUCTION

Telecommunication is one of the money-spinning and growing fields and it is a critical application which requires continuous uninterrupted supply of power. The time-out of such applications not only cause financial loss in various sectors like banking, e-commerce business but also they are inadmissible in mission-critical applications that deal with human lives. Thus telecom industry demands the technically sound supporting equipment-like power supply for telephone exchanges. Also in rural and remote areas there is a huge demand for the power supply unit to withstand fluctuations from the electric supply line and it is expected to provide regulated supply to the load.Fig.1 shows the block diagram of a conventional telecommunication setup. Under normal working conditions, AC mains will power the tower through AC-DC converter followed by DC-DC conversion enclosed in power supply cabinet. Also during starting of the back-up supply, battery will provide required electric supply. There are certain industry standards that Telecommunication power system has to follow. Following the international standard IEC1000-3-2 is of prime importance. This standard is introduced in 1995 to regulate harmonics drawn from mains supply. Telecom power system is

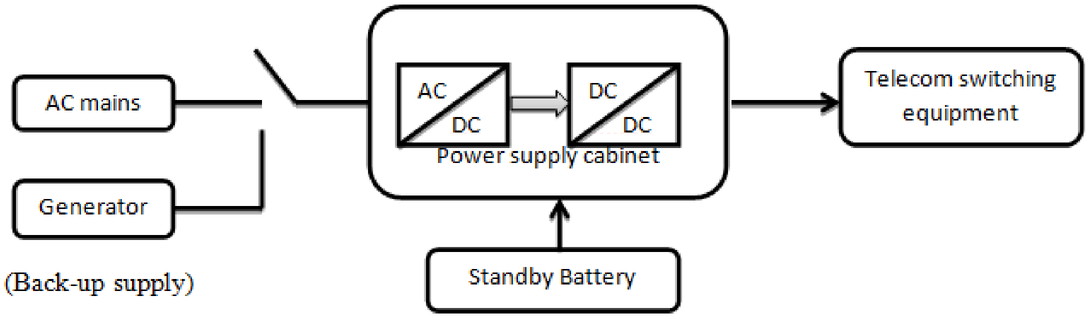

Fig.1. Block diagram of a Telecommunication setup

categorized under Class-A division which includes electrical and electronic equipment that draws input current up to 16A per phase [23]

This emphasizes the need for Power Factor Correction (PFC) [14] in telecom which is simply regulating the harmonic currents. Earlier power factor correction was done in two stages where first stage being power factor correction [5] followed by DC-DC converter. But the recent converter topologies have come up with integrated PFC which does both DC-DC function as well as power factor correction thus eliminating the need for two stage conversion. In this paper various topologies such as conventional Average Current Mode control PFC boost (ACMPFC), Back-to-back Bridgeless Boost PFC (BLBPFC), Semi-bridgeless Boost PFC (SLBPFC) and totem-pole Boost PFC are discussed. The performance of the above mentioned topologies are analyzed in terms of supply power factor, supply current THD and displacement factor. PSIM software is used to assess the basic characteristics of each topology. The proposed Integrated PFC boost converter [1] uses soft switching technique that employs Zero Current Switching (ZCS) [18] and Zero Voltage Switching (ZVS) to turn-on and turn-off the active switches being used in the circuit [16].

II. COMPARISON OF TOPOLOGIES

This emphasizes the need for Power Factor Correction (PFC) [14] in telecom which is simply regulating the harmonic currents. Earlier power factor correction was done in two stages where first stage being power factor correction [5] followed by DC-DC converter. But the recent converter topologies have come up with integrated PFC which does both DC-DC function as well as power factor correction thus eliminating the need for two stage conversion. In this paper various topologies such as conventional Average Current Mode control PFC boost (ACMPFC), Back-to-back Bridgeless Boost PFC (BLBPFC), Semi-bridgeless Boost PFC (SLBPFC) and totem-pole Boost PFC are discussed. The performance of the above mentioned topologies are analyzed in terms of supply power factor, supply current THD and displacement factor. PSIM software is used to assess the basic characteristics of each topology. The proposed Integrated PFC boost converter [1] uses soft switching technique that employs Zero Current Switching (ZCS) [18] and Zero Voltage Switching (ZVS) to turn-on and turn-off the active switches being used in the circuit [16].

A. Average Current Mode (ACM) control PFC topology

The ACM PFC topology is a commonly used PFC circuit structure [11]. The configuration of ACM PFC is as shown below in fig.2. ACM PFC boost circuit used in this study, has two FETs and two diodes controlled by a similar gate signal [2]

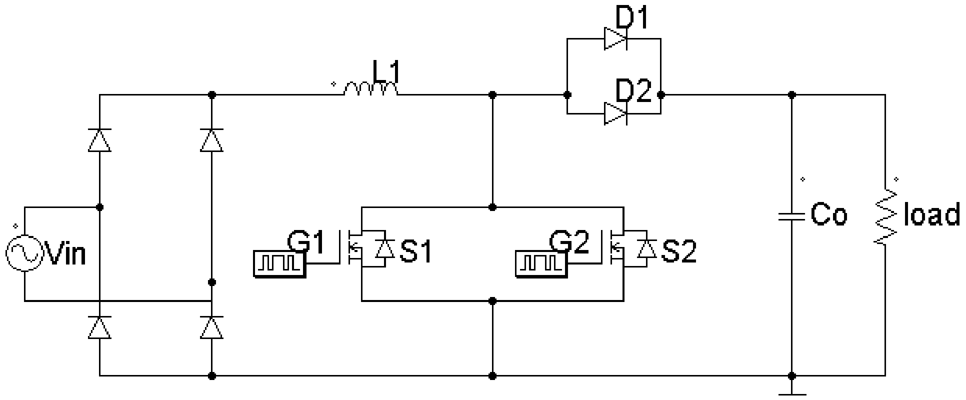

Fig.2: Circuit of ACM PFC converter

In Fig.2, fig.3, fig.4, fig.5, fig.6, fig.7 C_0 represents output filter capacitance.

Both the switches are turned on and off simultaneously. During on time of the switches, energy is stored in the inductor L_1 and during off interval of the switches energy is fed to the load through diodes D_1 and D_2 thus output voltage is boosted through boost inductor L_1. Unlike other topologies, this has a high diode bridge loss ratio. The drawback of this topology is that its output capacitor ripple current is larger than those of other topologies.

B. Back-To-Back Bridgeless PFC boost topology

In BTBBL PFC topology [3] an inductor is directly connected to each line of the input without any rectifier bridge. Fig.3 depicts the circuit of BTBBL PFC converter the switches are switched simultaneously. During On period of both the FET switches inductors store energy and during off interval of FETs the stored energy is given to the load through diode bridge thus output is stepped up. The unidirectional output voltage is obtained with the aid of full bridge diode rectifier. In this topology which is a bridgeless one [15] circulation current flow on the output side of the inductor is less than that on input side.

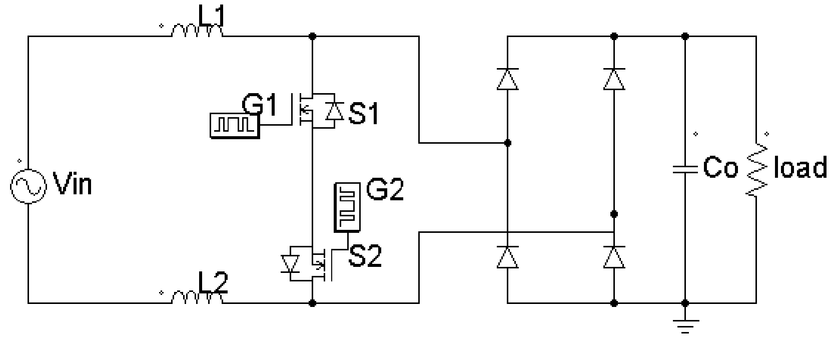

Fig.3:Back-To-Back Bridgeless PFC boost topology

However EMI increases [10] as there are no connecting components between the ground and the input line of the link voltage on the PFC output side. AC phase determines the current order that flow in the inductor and the direction of current flow in the power semiconductor switches used in the circuit since the inductor is in direct contact with the input line without any intermediate diode bridge.

It can be observed from power loss calculation [2] that value of inductance in back-to-back bridgeless PFC topology is around half of that used in ACM PFC converter.

C. Semi Bridgeless PFC boost topology

SBL PFC is a practical structure since it deploys an input diode bridge rectifier whose operation differs according to requirement of the rectifier. The configuration [6] discussed here engage a diode bridge rectifier in the input side where both the diodes in common cathode side are not used and those on common anode side is only used, hence the name Semi Bridgeless. The converter diagram is shown in fig.4.

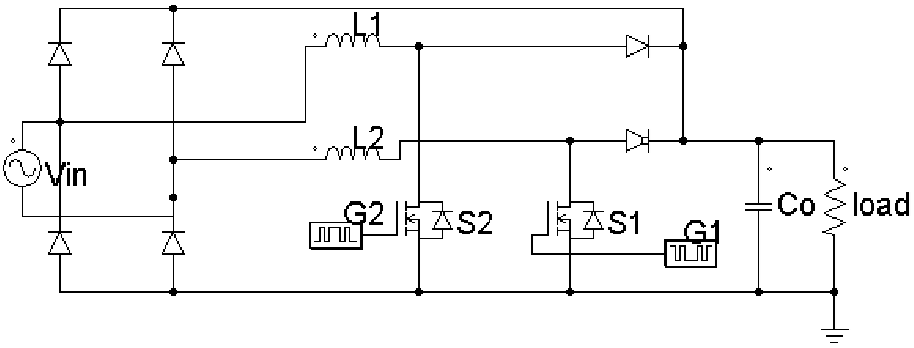

Fig.4: Circuit diagram of Semi-Bridgeless PFC boost Converter

In this topology the PWM signals for both the switches are different [19]. As in other converter structures during on period of the switches inductor accumulates energy at positive input voltage and releases it to load through diodes D1 and D2 during turn-off period. The current in the negative line is accomplished by the diode on common anode side and by the anti-parallel diode of the switch that is in off interval. Conversely, the switch on the negative line operates in a similar manner during the negative input operating interval.

With the presence of bridge diode, when one of the two MOSFETs is turned ON the negative or revere current is carried by the body diode of the other switch which is non-conducting. Moreover, the circulating current during switching cycle is shared by all ON/OFF sections and ON section. Alternatively if the diode bridge is not present, then the non-switching current is solely carried by the antiparallel body diode of the MOSFET on the negative line itself. Thus the current is divided into the antiparallel diode of the FET, diode in the bridge depending on the operation of the respective elements in the circuit with Diode Bridge and this proves for the improvement in the efficiency in the architecture with bridge diode than its counterpart.

D. Totem-pole Bridgeless PFC boost converter topology (TPBLB)

TPBLB PFC converter utilizes only two active switches and a LC resonant network thus using resonant or soft switching [8]. This topology is called totem-pole because of the position of switches and current flow from high side to low side and in reverse direction during resonance [9]. Therefore there is no requirement for any additional switches for providing resonant switching. The resonant switching [21] also helps in reducing the body diode reverse problem thus the TPBLB operate in continuous conduction mode. Fig.5 shows circuit configuration of TPBLB converter. Two IGBT switches S_1, S_2(with body diodes), two slow recovery diodes D_1, D_2, a resonant inductor L_r, resonant capacitor C_r , a fast switching diode D_3 make up the circuit of totem-pole structure.

Basically the soft switching BLB converter provides a bidirectional path between high side and low side during resonance [17]. In fig.5, point A denotes high side and point B marks the lower potential side. With the totem-pole arrangement of $S_1$and S_2, the bidirectional current flow can be realized. When both the switches S_1 and S_2 are ON then current flow from high voltage side to low voltage side and reverse is possible through D_{s1} and D_{s2} by the concept of resonance when both the switches are turned off. The resonance is generated through a network formed by L_r and C_r, which provides zero-current turn-off for $S_1$and S_2 and soft turn-on for both switches and diode D_3. It is noticeable that both diodes D_1 and D_2 are only slow recovery type as these diodes will be completely turned on for a half-cycle line period and is economical than fast recovery diode. Equivalent circuit is as seen in fig.6 below. Inductors L_1 and L_2 are sufficiently large to be considered as a constant DC current source. Similarly output capacitor C_0 is also sufficient enough to be considered as a constant DC source. It should be noted that diode D_2 is always in non- conducting state during positive half-cycle

Formula to determine L_r and C_r are given by equations (3), (4) and (5).

$$L_r \leq \frac{I_{in}}{2\pi f_r V_0} \qquad (3)$$

$$\omega_r = 2\pi f_r = \frac{1}{\sqrt{L_r C_r}} \qquad (4)$$

$$\sqrt{\frac{L_r}{C_r}} \leq \frac{V_0}{I_{in}} \qquad (5)$$

f_r= resonant frequency (Hz)
V_0= output voltage (volts)
I_{in} = Input current (A)
ω_r= resonant angular frequency (rad/sec)

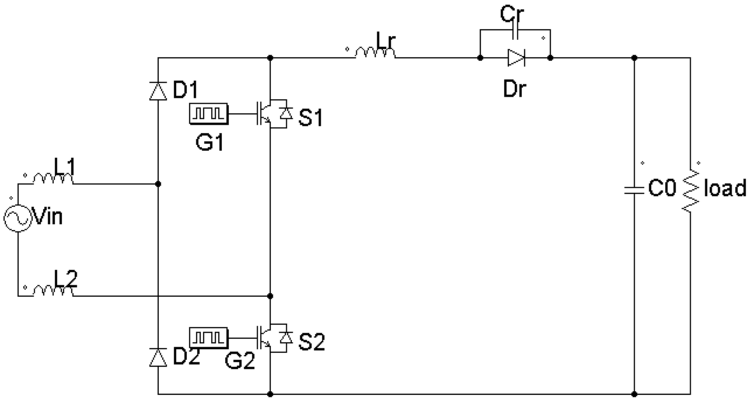

Fig.5: Circuit of Totem-pole PFC boost topology

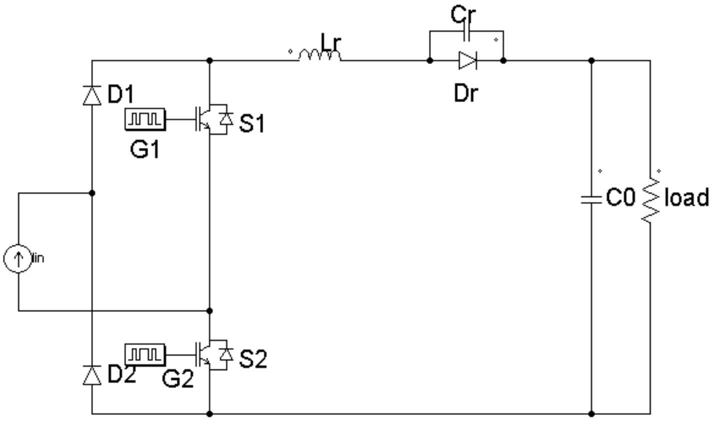

Fig.6: Equivalent circuit of TPBLB converter

E. Proposed Integrated PFC Boost Converter

The proposed integrated PFC boost converter uses passive resonant soft-commutation switching [7] which reduces EMI and improves efficiency. The circuit configuration of the proposed converter is exhibited in fig.7. The proposed converter is used as pre-regulator [20]. It consists of two main switches S1 and S2, boost inductor LB, resonant inductor Lr and resonant capacitor Cr. The non-dissipative switching cell ensures ZVS turn-on and turn- off of the main switch S1 and ZCS turn-on and ZVS-ZCS turn-off of the auxiliary switch S2. The switch S3 is used to connect the auxiliary source to the load through boost converter in case of AC mains failure. The power diode D1 ensures natural transfer of energy flow from AC source to auxiliary source. The converter is designed to work in such a way

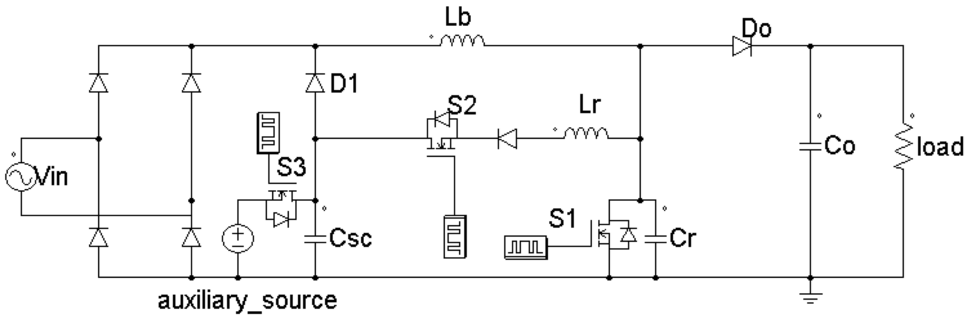

Fig.7: Circuit configuration of Proposed Integrated PFC boost converter

-that whenever AC supply is available it is utilized and during AC supply failure then Auxiliary source is used to supply the load.

III. SIMULATION RESULTS

Table-I shows the simulation parameters.

TABLE I: SIMULATION PARAMETERS

Parameters	Value
Input Voltage(V_{in})	21.5 V
Output Voltage(V0)	48 V
Output Power(P_0)	20 W
Switching frequency(f_s)	100 kHz
Output filter capacitance (C_0)	1800 µF

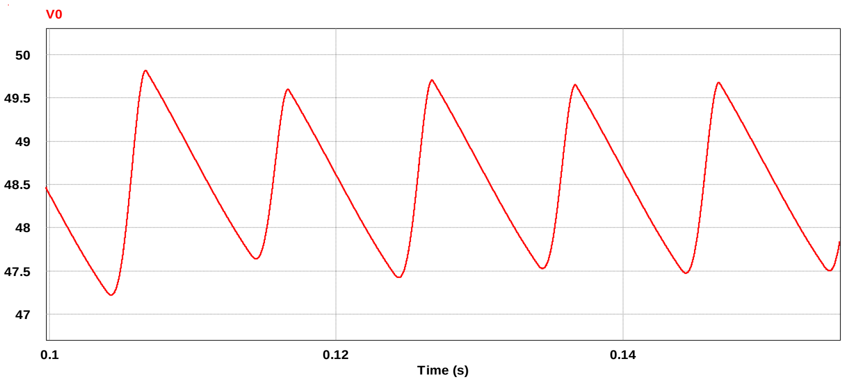

Fig.8: Output voltage waveform of ACM PFC boost topology

Fig.8 shows the output voltage waveform and Fig.9 shows the supply current and supply voltage waveforms of ACM PFC boost topology. Fig.10 is the Output Voltage waveform and Fig.11 encompass its input current and input voltage of BTBBL PFC boost converter.

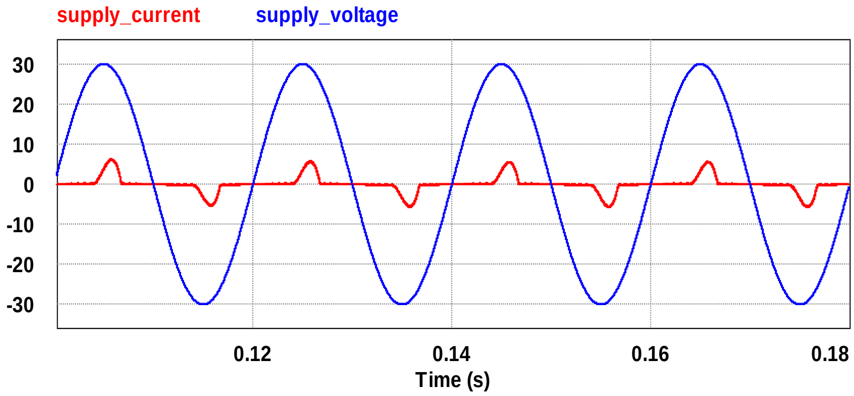

Fig.9: Supply Voltage and Supply Current waveforms of ACM PFC converter

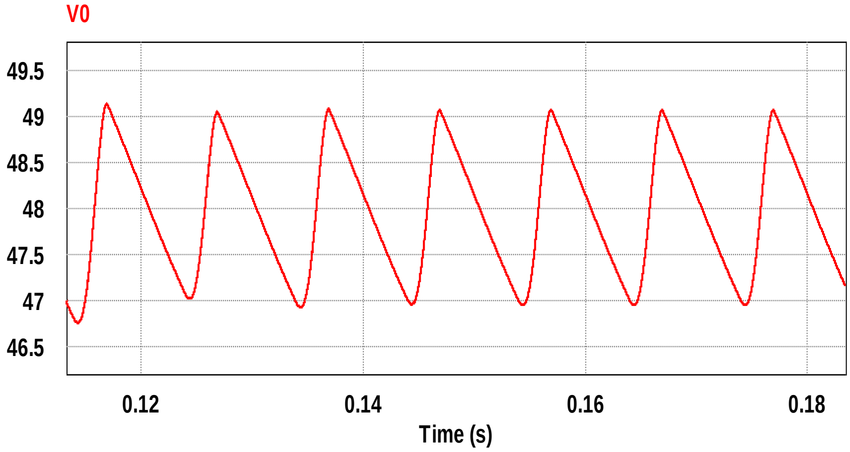

Fig.10: Output Voltage waveform of BTBBL PFC boost converter

Fig.12 depicts Output Voltage waveform and Fig.13 explains input current and input voltage Waveforms of SBL PFC boost converter and its PF is lowest around 0.606 than other converters.

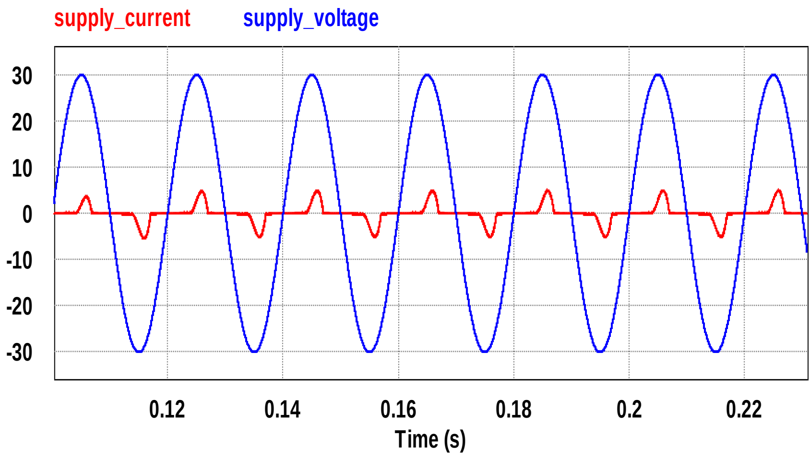

Fig.11: Supply Voltage and Supply Current Waveforms of BTBBL PFC boost converter.

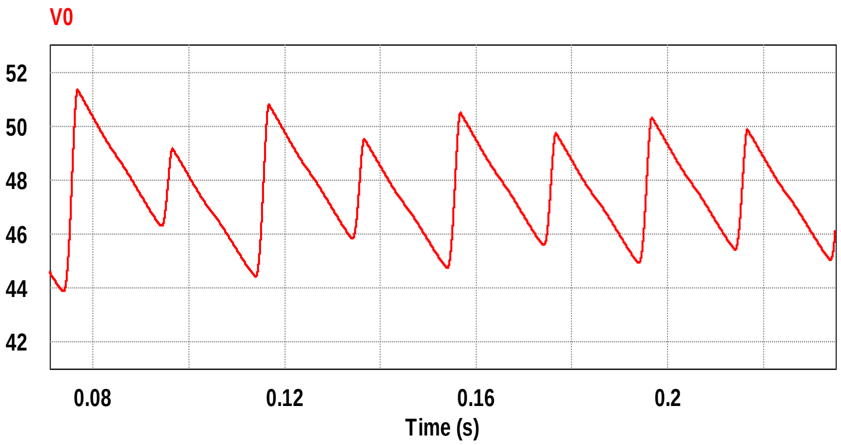

Fig.12: Output Voltage waveform of SBL PFC boost converter.

Fig.14 and Fig.15 are Output Voltage waveform and Supply Voltage and Supply Current Waveforms Totem-pole PFC boost converter respectively. Output Voltage Waveform and Supply Voltage and Supply Current Waveforms of proposed Integrated PFC boost converter is shown in fig.16 and fig.17 respectively. It can be inferred that this topology performs better than all other compared here with high PF of 0.926 and low supply current THD of 37%.

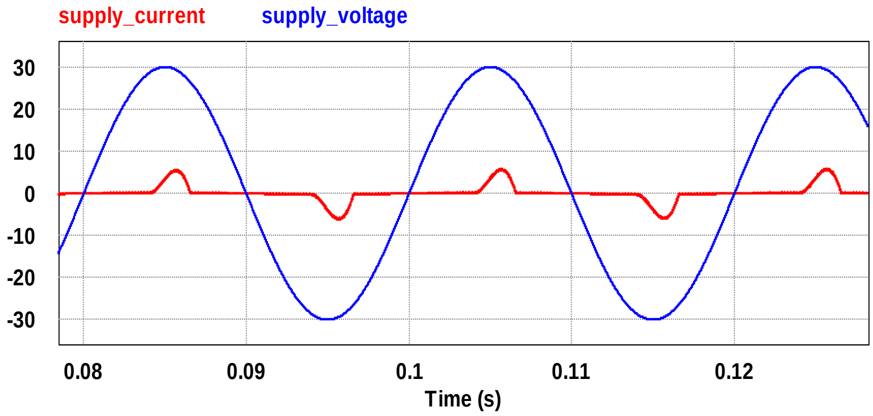

Fig.13: Supply Voltage and Supply Current Waveforms of SBL PFC boost converter.

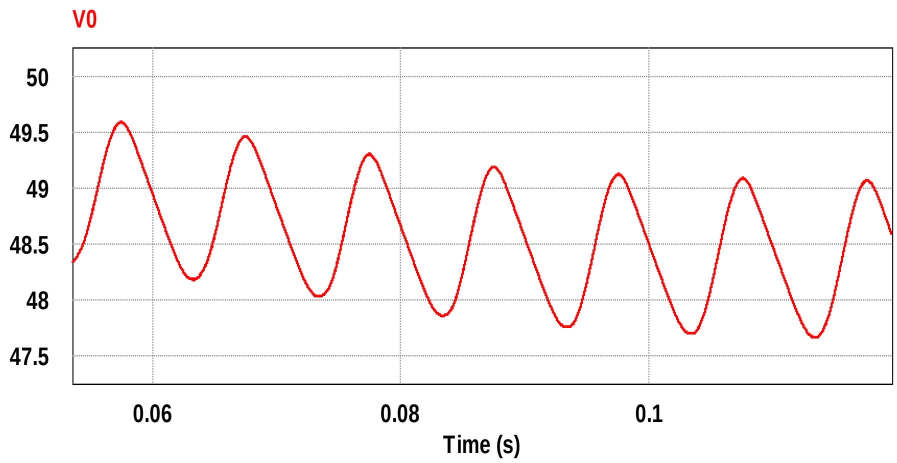

Fig.14: Output Voltage waveform of Totem-pole PFC boost converter.

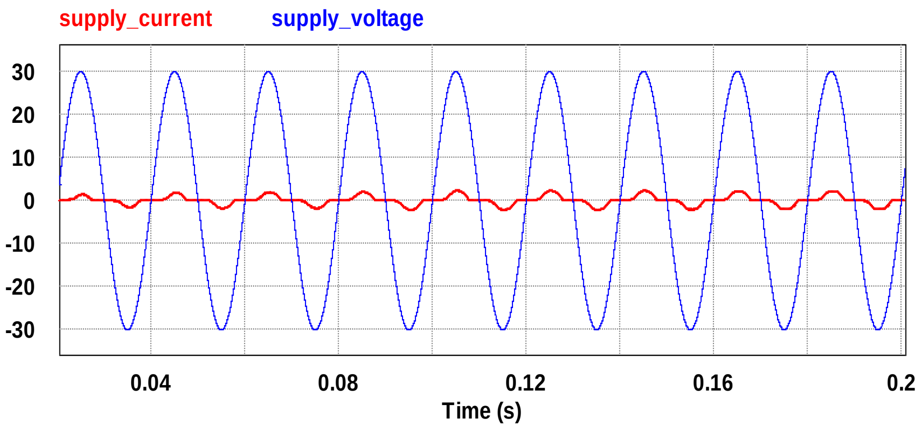

Fig.15: Supply Voltage and Supply Current Waveforms of Totem-pole PFC boost converter.

Table-II: Comparison of topologies

Configuration	**Power factor**	**% Supply current THD**	**Distortion Factor**
ACMPFC	0.66	108.9%	0.676
BTBBL PFC	0.67	107.3%	0.681
SBL PFC	0.602	131.6%	0.605
TPBLB PFC	0.87	52%	0.8872
Proposed Integrated PFC	0.926	36.9%	0.938

Table-II shows Comparison of topologies. From Table II, it can be inferred that supply current THD is highest for Semi-bridgeless topology whose value is around 131.6% and has least power factor of 0.602 and lowest distortion factor of 0.605. Totem-pole configuration has improved pf and less current THD but proposed converter achieves still higher power factor.

The proposed integrated PFC converter has least input current THD and highest Power factor and distortion factor. Thus it can be concluded that the proposed integrated PFC boost topology results in better power factor, reduced supply current THD. Thus it is wise to choose proposed converter for telecom applications.

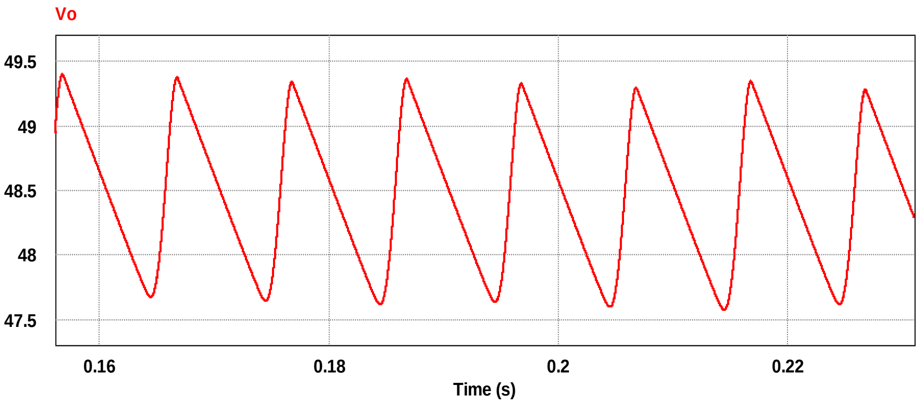

Fig.16: Output Voltage Waveform of Proposed Integrated PFC boost converter.

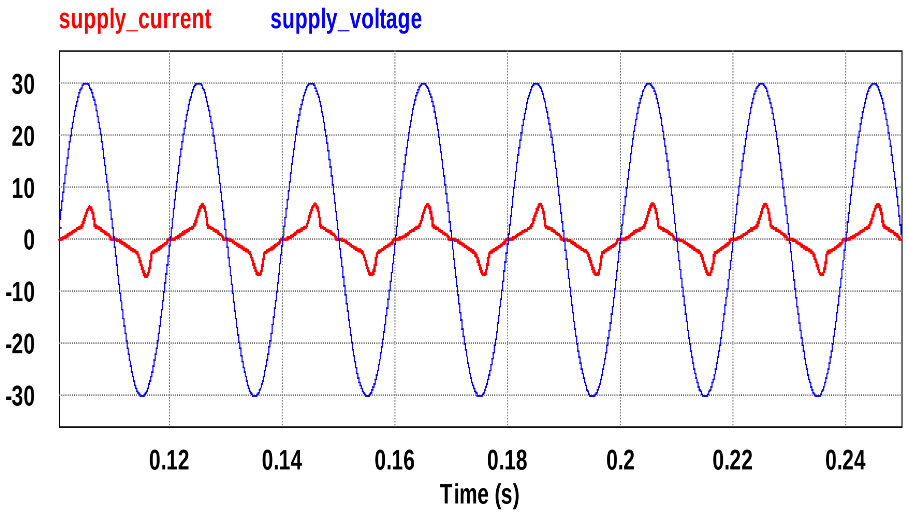

Fig.17: Supply Voltage and Supply Current Waveforms of proposed Integrated PFC boost converter.

IV. CONCLUSION

In this paper, distortion factor, pf supply current THD of five different topologies are compared. It is observed from the results that the proposed integrated boost converter has highest power factor of around 0.926, lower THD of 37% compared to the other four converter topologies. In addition to this, the proposed topology results in reduced components and provides high efficiency. Thus it can be concluded that the proposed integrated PFC converter is a suitable topology for telecommunication systems.

V. FUTURE SCOPE

The simulation work can be extended to hardware and a prototype of all the above discussed topologies can be developed for the same parameters. Performance parameters such as pf, input current THD, output voltage ripple, distortion factor of all the above topologies can be evaluated and compared in real time thus enhancing the selection of suitable converter structure for telecom power supply.

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