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Analysis of Parallel Topology for Active Power Factor Correction Using Single and Dual Mode Boost Converters

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ABSTRACT: *The ratio between real or average power and apparent power known as power factor has a high impact on power system industries. Efficient usage of the real power is very indicative in developing a power system. With the profusely development of technology in power semiconductor devices, the rate of using power electronic systems has expanded to new and wide application range that include residential, commercial, aerospace and other systems. In the nonlinear system, loads are the main source of harmonics. So that nonlinear behavior puts a question mark on their high efficiency. The current drawn by power electronic interfaces from the line is distorted resulting in a high total Harmonic Distortion and low p.f. this creates adverse effects on the power system include increased magnitudes of neutral currents in three phase systems, overheating in transformers and induction motors. This paper aims to develop a circuit for PFC by using active filtering approach by implementing two (single & dual) boost converters arranged in parallel, for improving circuit quality and switching loss. This work actually involves simulation of basic power electronic circuit and it starts with simple circuit with a gradual increase in complexity by inclusion of new components and their subsequent effect on current and voltage wave forms. We focused to improve the condition of input current waveforms for making it sinusoidal by tuning the circuits.*

KEYWORDS: *Boost converter, Power factor, Dual Boost converter, Harmonics, Active PFC, Passive PFC, Average current mode control.*

I. INTRODUCTION

Converters are very essential elements in power electronics industries. AC to DC converter has a diode bridge rectifier with a high value of capacitor for filtering purpose. This capacitor cut downs the cost of the converter and makes it robust. However due to the presence of harmonic ac line current, the power factor is poor [1]. The most common power quality disturbance is instantaneous power interruption. Various power factor correction (PFC) techniques are employed to overcome these power quality problems out of which the boost converter topology has been extensively used in various ac/dc and dc/dc applications. In fact, the frontend oftoday's ac/dc power supplies with power-factor correction (PFC) is almost exclusively implemented with boost topology [2][3]. The basic boost topology does not provide a high boost factor. This has needed many proposed topologies as cascaded boot tapped inductor boost etc. This paper introduces another variation dual Boost PFC convertor addition in parallel with rectifier circuit to provide a higher boost factor and also provides proper controlling. This paper involves with PSPICE simulation of different types of electronic conventional rectifier circuit and voltage waveforms. It starts with simple rectifier circuit and different MOSFETs and switches to improve by implementing advanced techniques such as active PFC, where we mainly focusing on the objective of improving the input current waveform. All the simulation work is carried out/done in PSICE simulation manager.

II. POWER FACTOR WITH DIFFERENT LOADS

Power factor is defined as the cosine of the angle between voltage and current in an ac circuit. If the circuit is inductive, the current lags behind the voltage and power factor is referred to as lagging. However, in a capacitive circuit, current leads the voltage and the power factor is said to be leading.

Linear System: It is AC electrical loads where the voltage and current waveforms are sinusoidal. The current at any time is proportional to voltage. Power factor is determined only by the phase difference between voltage and current.

Non Linear System: Applies to those ac loads where the current is not proportional to voltage. The nature of the nonlinear current is to generate harmonics in the current waveform. This distortion of the current waveform leads to distortion of voltage waveform. Under this condition, the voltage waveform is no longer proportional to current. For sinusoidal voltage and non-sinusoidal current P.F can be expressed.

$PF = \frac{V_{RMS} I_{1RMS}}{V_{RMS} I_{RMS}} \cos\theta$ or $PF = \frac{I_{1RMS}}{I_{RMS}} \cos\theta$ or $PF = K_p \cos\theta$; Here, $K_p = \frac{I_{1RMS}}{I_{RMS}}$, $K_p \approx [0-1]$

cosθ is the displacement factor of the voltage and current. *Kp* is the purity factor or the distortion factor. Another important parameter that measures the percentage of distortion is known as the current total harmonic distortion (THDi) which is defined as follows:

III. EFFECTS OF HARMONICS ON POWER QUALITY

The contaminative harmonics can decline power quality and affect system performance in several ways [4]. As presence of harmonics declaims the transmission efficiency and also creates thermal problems, both conductor and iron loss are increased. In 3-0 system, neutral conductor becomes unprotected due to odd harmonics. Triggering are misconducted as the peak harmonics create currents which interrupts the protection system of an automatic relay. Huge current flows through the ground conductor of system with four wire 3-0 when odd number of n- current is present in harmonics. Finally, harmonics could cause other problems such as electromagnetic interference to interrupt communication, degrading reliability of electrical equipment, increasing product defective ratio, insulation failure, audible noise etc [5]-[8].

IV. RECTIFIERS

A rectifying circuit is one which links an ac supply to dc load, that is, it converts an alternating voltage supply to a direct voltage. The direct voltage so obtained is nor normally level, as from a battery, but contains an alternating ripple component superimposed on the mean (dc) level.

Uncontrolled Rectifiers: The simplest uncontrolled rectifier use can be found in single-phase circuits. There are two types of uncontrolled rectification. They are (1) half-wave rectification and (2) full-wave rectification. Half-wave and full-wave rectification techniques have been used in single-phase as well as in three-phase circuits. As mentioned earlier, uncontrolled rectifiers make use of diodes. Diodes are two-terminal semiconductor devices that allow flow of current in only one direction. The two terminals of a diode are known as the anode and the cathode.

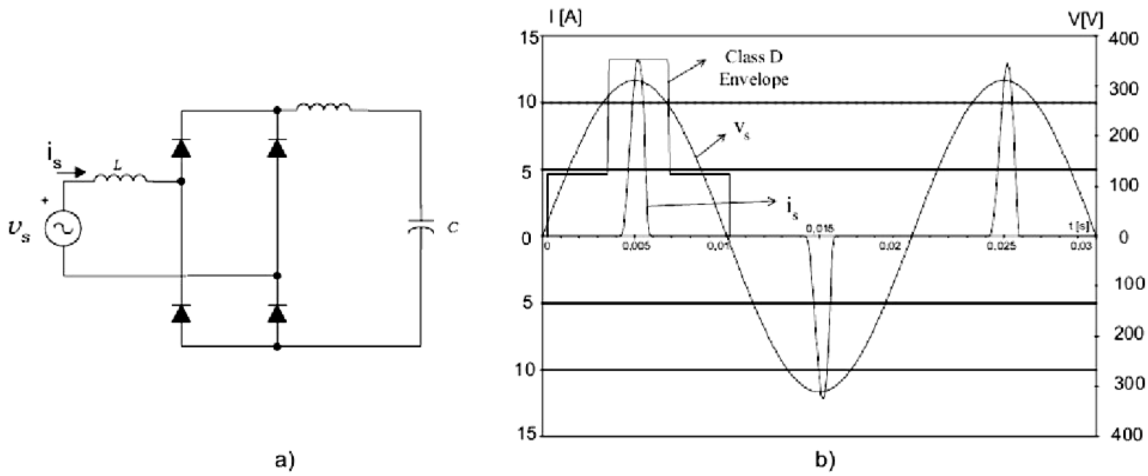

Figure 1: Single phase rectifier (a) circuit (b) waveforms of input voltage and current [9].

Controlled Rectifiers: Controlled rectifier circuits make use of devices known as “thyristors.” A thyristor is a four-layer (*pnpn*), three-junction device that conducts current only in one direction similar to a diode. The last (third) junction is utilized as the control junction and consequently the rectification process can be initiated at will provided the device is favorably biased and the load is of favorable magnitude.
The presence of harmonics in the waveform of the network voltage can be attributed to various causes such as rectifiers, variable speed drives, thyristors, saturated transformer, arc furnaces etc[9]-[14].Problems like interferences in telecommunications systems and equipment, distortion of the electricity supply voltage, erratic operation of control and protection relays, failures in transformers and motors due to overheating caused by core losses are caused by harmonies in system. Amplification of both voltage and current at the same time will occur if the resonant frequency is close or equal to one of the harmonic frequencies present in the distribution system. The power feeder (overhead line or underground cable) have an inductive impedance. By putting a capacitor in parallel with the load (for Power factor correction) it is possible for the combined system to have a resonance condition. As the power factor of a three phase system decreases, the current rises. The heat dissipation in the system rises proportionately by a factor equivalent to the square of the current rise. Power factor correction is necessary for overcome above mention problem.

TYPES OF POWER FACTOR CORRECTION

Passive PFC : The simplest form of PFC is passive (Passive PFC). A passive PFC uses a filter at the AC input to correct poor power factor. The passive PFC circuitry uses only passive components: an inductor and some capacitors (Figure. 1).

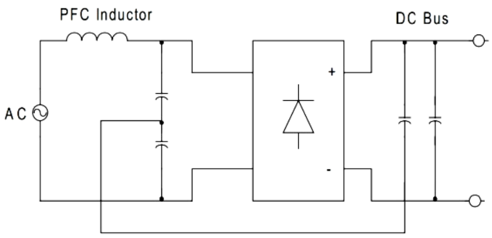

Figure 2: A passive PFC circuit requires only a few components to increase efficiency, but they are large due to operating at the line power frequency [5], [9].

Although pleasantly simple and robust, a passive PFC rarely achieves low Total Harmonic Distortion (THD). Also, because the circuit operates at the low line power frequency of 50Hz or 60Hz, the passive elements are normally bulky and heavy.

Active PFC : Active PFC offers better THD and is significantly smaller and lighter than a passive PFC circuit. To reduce the size and cost of passive filter elements, an active PFC operates at a higher switching frequency than the 50Hz/60Hz line frequency.

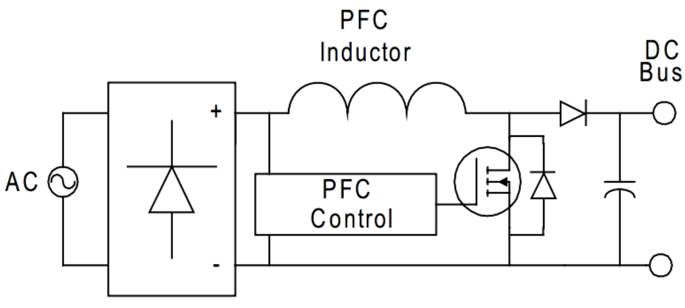

Figure 3: An active PFC circuit produces low THD and uses relatively small passive component [5].

BASIC PRINCIPLE OF BOOST CONVERTER: Stepping up the power stage without isolating topology, the boost converter works perfectly. In practical field of power designing, required output should be always higher that input voltage. This topology is fulfilled perfectly with boost power stage. The basic working principle of boost converter is to generate non-pulsating input current to output diode as diode conducts only during a portion of the switching cycle. The output capacitor supplies the entire load current for the rest of the switching cycle. Figure 4 shows a simplified schematic of the boost power stage. Inductor L and capacitor C make up the effective output filter.

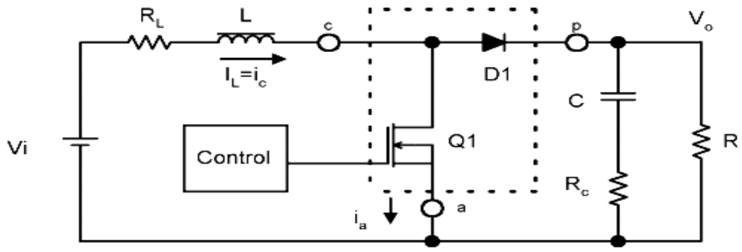

Figure 4: Boost Power Stage Schematic diagram

Boost power stage can work out both in modes considering continuity of current in the inductor. This current inductor mode current flows either continuously in the inductor during the entire switching cycle in steady-state operation or inductor current is zero for a portion of the switching cycle. A periodicity is maintained as it approaches towards peak value from zero and returns back to it during each switching cycle. It is desirable for a power stage to stay in only one mode over its expected operating conditions because the power stage frequency response changes significantly between the two modes of operation.

V. BASIC PRINCIPLE OF DUAL BOOST CONVERTER

Conventionally, boost converters are used as active Power factor correctors. However, a recent novel approach for PFC is to use dual boost converter i.e. two boost converters connected in parallel. Circuit diagrams for both types of PFCs are as given below:

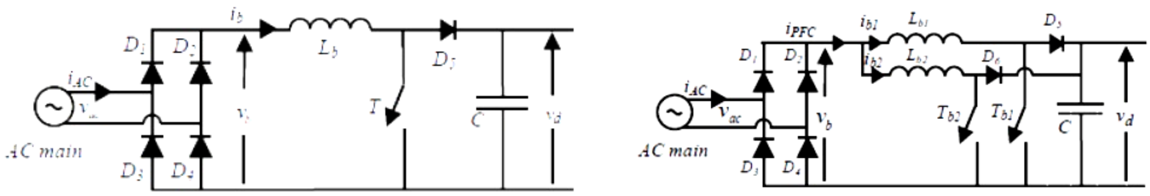

Figure 5: (a) Classical PFC circuit (b) Dual Boost PFC circuit [9]

Here, we use a parallel scheme, where choke L_{b1} and switch T_{b1} are for main PFC while L_{b2} and T_{b2} are for active filtering. The filtering circuit serves two purposes i.e. improves the quality of line current and reduces the PFC total switching loss. The reduction in switching losses occurs due to different values of switching frequency and current amplitude for the two switches. The parallel connection involves phase shifting of two or more boost converters connected in parallel and operating at the same switching frequency.

VI. CONTROL PRINCIPLE OF DC-DC CONVERTERS

Control strategy for an electrical system is intended to develop a set of actions that can detect the time evolution of electrical quantities and to impose them to follow a desired time evolution. In general, a control algorithm can be split into three functional sub-blocks:

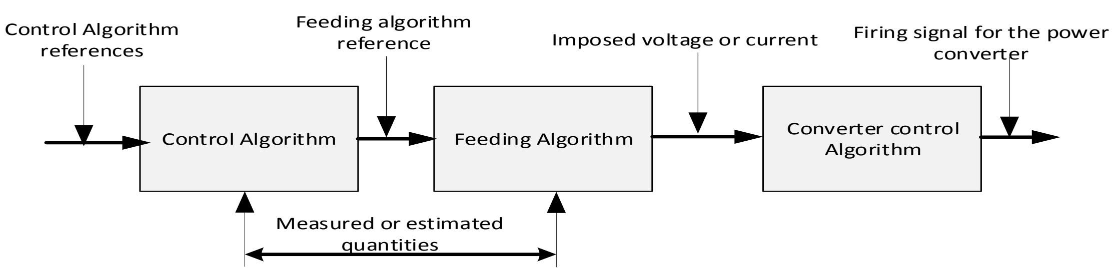

Figure 7: Basic description and splitting of the Control algorithm [6]

Control Algorithm operates to generate reference values to the feeding algorithm on the basis of reference values imposed to the controller. On the other hand, feeding algorithm gives the voltage or current values to impose at the considered system in order to follow the time evolution of the reference values coming

from the control algorithm. And finally, converter control algorithm provides the right sequence of firing pulses for management of the power modules based on the information derived from control and feeding algorithm.
A dc-dc converter provides a regulated dc output voltage under varying load and input voltage conditions. The converter component values are also changing with time, temperature and pressure. Hence, the control of the output voltage should be performed in a closed-loop manner using principles of negative feedback.

VII. SIMULATION AND RESULT

This paper deals with the current control common closed loop mode approach for PWM dc-dc converters, Signals in current form have a natural advantage over voltage signals. Voltage being an accumulation of electron flux, is slow in time as far as control mechanism is concerned. This led to the development of a new area in switch mode power supply design, i.e. the current mode control. Here, the averaged or peak current of magnetic origin is employed in the feedback loop of the switch mode power converters. It has given new avenues of analysis and at same time introduced complexities in terms of multiple loops[9].

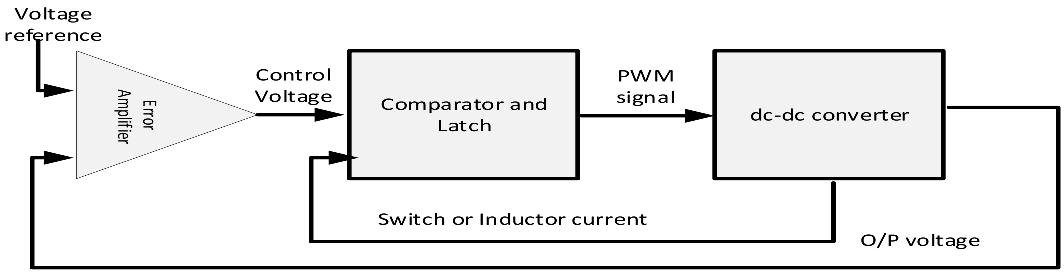

Figure 8: A current control mode

A schematic diagram of current mode control is shown in Fig 8. It comprises of an additional inner control loop. The inductor current signal, converted to its voltage analog fed back by this loop is compared to the control voltage. The dynamic behavior of the converter is significantly altered by this modification of replacing the saw tooth waveform by the converter current signal. The key difference between voltage and current mode control is the way the reference map is generated. In the case of voltage mode control, the ramp is external from the viewpoint of the power plant, whereas for current mode control, it is internal.

The main approach of the paper to adopt a circuitry approach of a PFC circuit with parallel boost converter with feedback loop. Furthermore, the circuit is simulated through PSPICE and parameters are observed.

Circuitry and simulation diagrams of a PFC circuit without any feedback: The classical boost regulated PFC circuit is implemented here .IRF 540 power MOSFET used as switch .No feedback part is attached with. That is why full control over circuit is absent here.

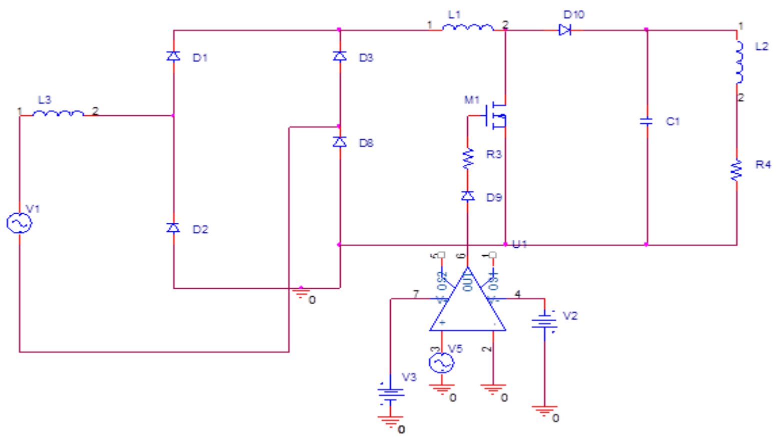

Figure 9: PFC circuit without feedback

Here in fig (9) we found the PFC circuit without feedback. The difference in this circuit is the absence of variable pulse width generation supply in feedback loop. Here the RMS wave contributes to calculate the power factor.

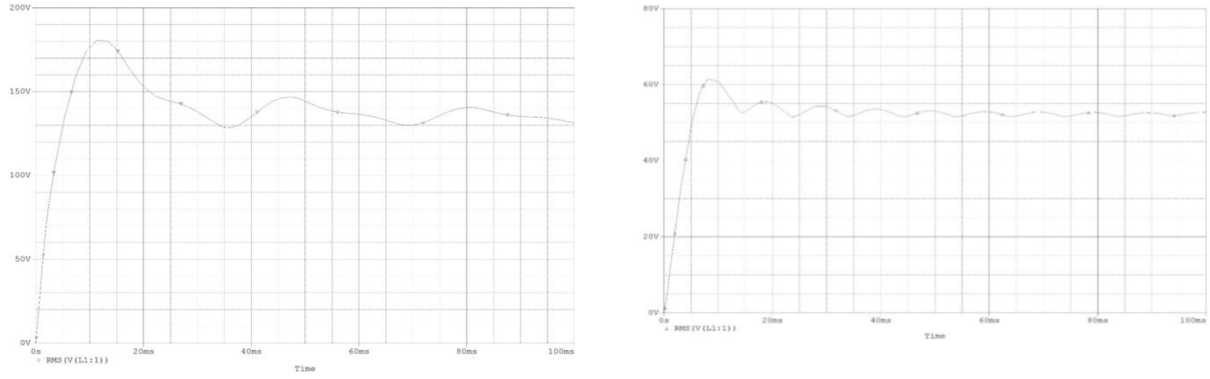

Figure 10: RMS wave of input and output voltage

Here in fig (20) we found the ultimate input & output voltage of the RMS wave. RMS wave contributes to calculate the power factor.

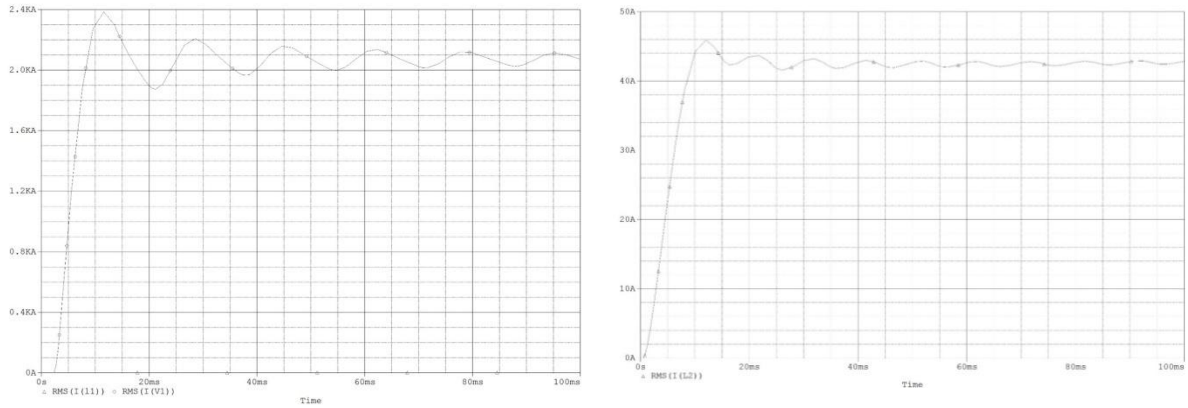

Figure 11: RMS wave of input and output current

Here in fig (11) we found the ultimate input and output current of the RMS wave. RMS wave contributes to calculate the power factor.

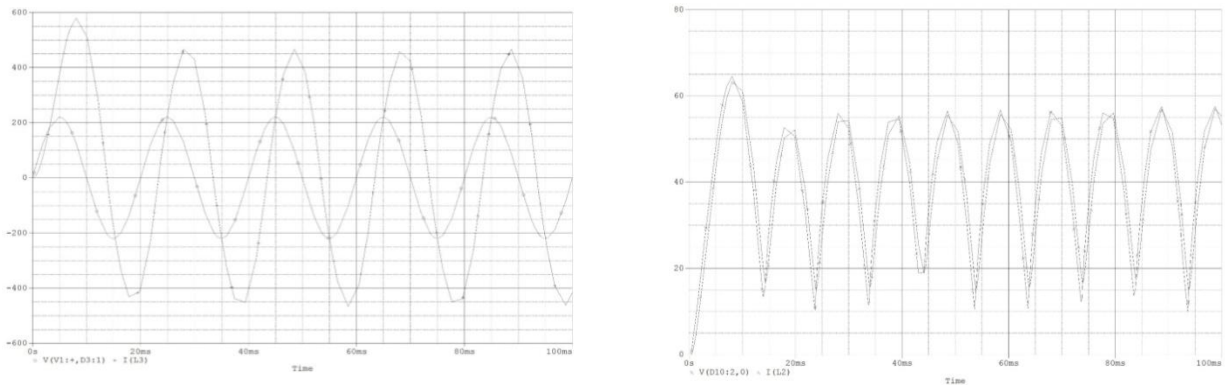

Figure 12: Input and output curves PFC circuit using boost converter without feedback.

Here, in fig (12) we found the ultimate input & output curves of the PFC circuit using boost converter without feedback as inductive load is connected current lags. Because of comparative better power factor, harmonics reduces. This least situation is also improved within next PFC design.

Circuitry and simulation diagram of a PFC circuit having Parallel Boost Converter with Feedback

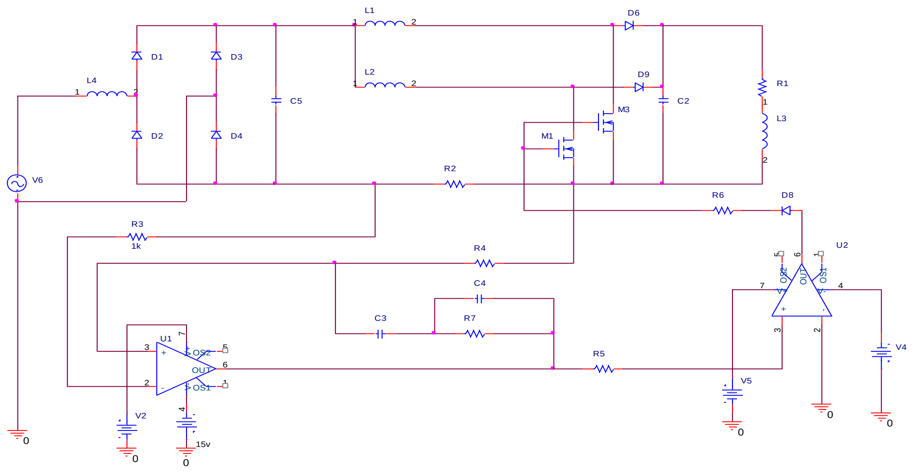

Figure 13:PFC circuit with parallel boost converter feedback

Here fig (13) shows our final effort-boost controlled PFC circuitry with feedback system. The key which makes the difference, is the usage of two different type of power MOSFET, P-type and N-type. Which specify the specified boost regulator loop at separate time. The PWM creates a square wave by comparing the saw-tooth with the sinusoidal wave which came from CEA. The output of CEA varies with the variation of load. A gate drive IC should have to be implemented which was given at ACM control mode design but is absent here. Cause the accurate gate drive IC model IR2771C was not available in out library and the IR26771 model is obsolete. We used a resistance and diode instead. Sometimes in practical, the MOSFET supplies back some of the current that which is harmful for the system. To avoid this, a diode is used as reverse for that backing current. MOSFET needs 1-2 A current flow to its gate to work as a switch.

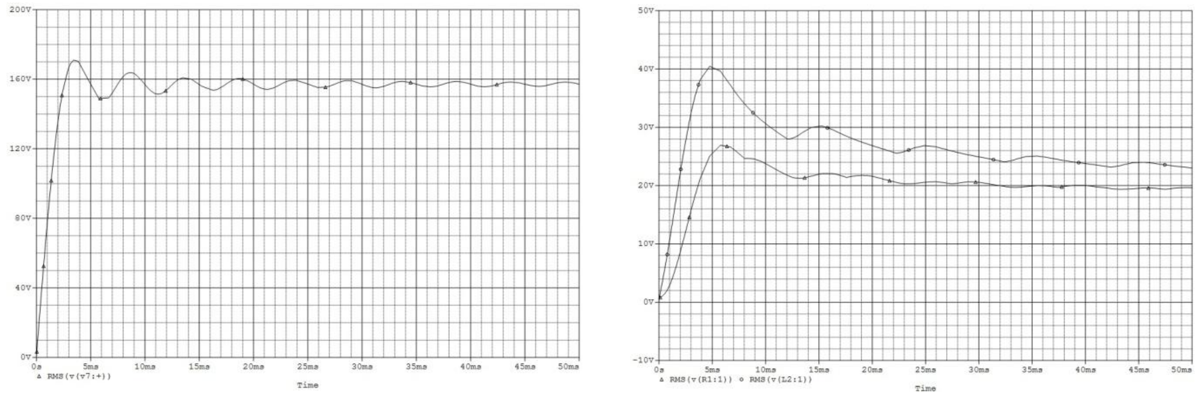

Figure 14: RMS wave of Input and Output Voltage.

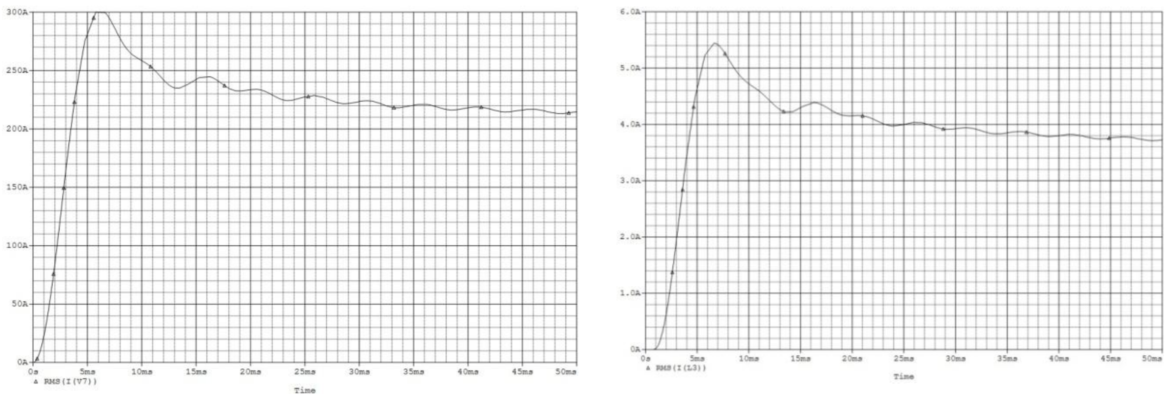

Figure15: RMS wave of input and output current

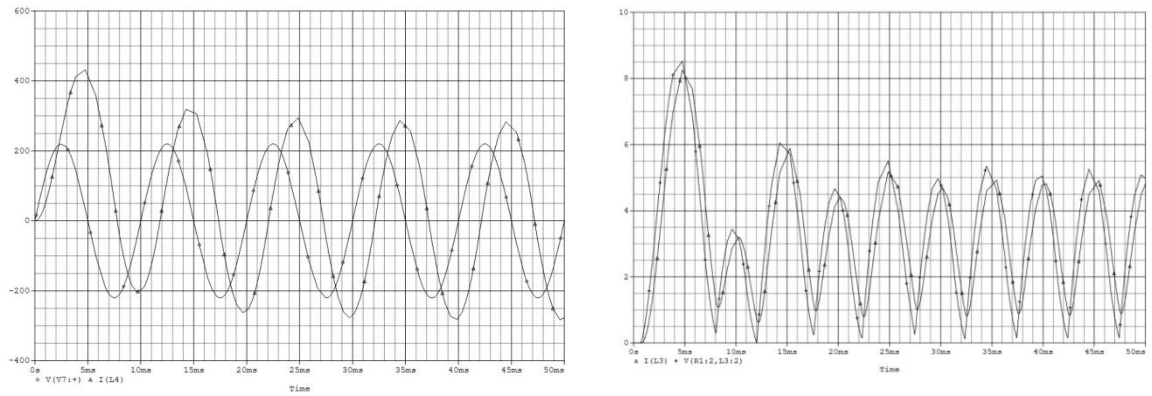

Figure 16: Input Voltage and current wave shape as a function of time

Here fig (16) shows Input V-I wave shape and Output V-I wave shape. Here we have found our longed curve which represents a very successful power factor as practical. On the previous circuit, the power factor could be recommended as better and this could be the best.

VIII. COMPARISON BETWEEN THE OUTPUT WAVE SHAPES OF LAST TWO CIRCUITRY-

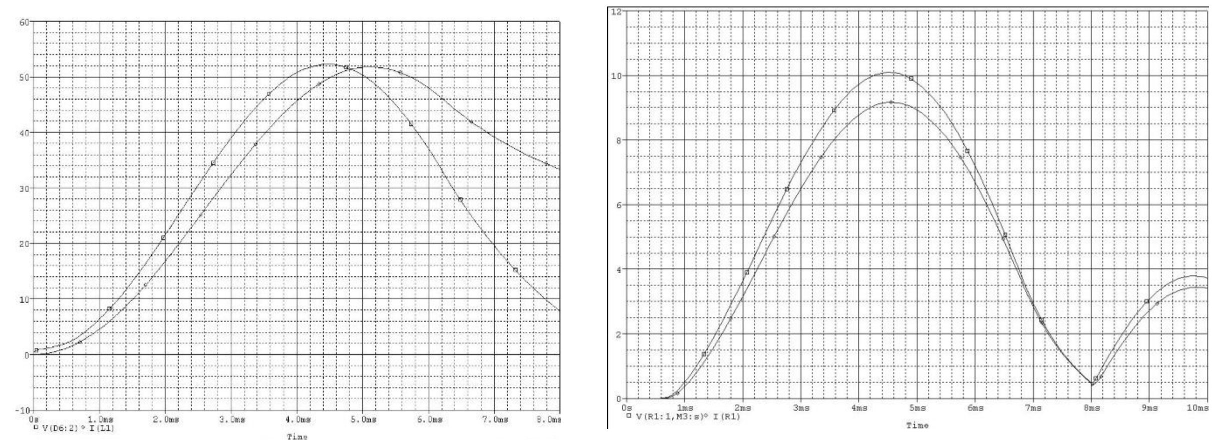

Figure 17: PFC circuit using boost converter (a) without feedback (b) with feedback

This figure shows that with feedback and using parallel boost converter which the PFC circuit works. Here ,in the 1st figure ,we see that without using feedback circuit the V-I curve starts at approximately in millisecond ,which represents that p.f is not that improved .But if we add a feedback circuit thisphenomenon is been improved.

Table I.: Analysis of different PFC circuits[9]

SI.No	Circuit	Power Factor
1	Conventional Rectifier (without boost converter)	0.9706[9]
2	Boost Converter without feedback	0.989[9]
3	Boost Converter with feedback	0.99

IX. CONCLUSION

The power factor corrections with boost converters are simulated by PSPICE simulator link. In this paper conventional converter, we used the parallel topology of boost converter to correct the power factor and brought it near unity by elimination of harmonics effects step by steps, when first one improves and second one filtering the power factor. Here we use one n-type and one p-type MOSFET instead of using two a kind and a smaller fractional value of PF range capacitor across the R-L load, this paper will be most innovative and important handbook to improve the power factor for non-linear loads.

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