Study of Power Factor Correction in Single Phase AC-DC Converter

Avneet Kaur, Prof. S.K Tripathi, Prof. P. Tiwari

Abstract: This paper is regarding power factor correction in AC-DC converters with Simulink model and results in MATLAB. When nonlinear elements are present in circuit they produce harmonic distortions in input current waveform which results in lower power factor and increase the losses in power quality.

Keywords: Boost converter, DC motor Drive, forward converter, Power factor, Total harmonic distortion

I. INTRODUCTION

Power Factor, the ratio between the real or average power and the apparent power forms a very essential parameter in power system. It is indicative of how effectively the real power of the system has been utilized.

With rapid development in power semiconductor devices, the usage of power electronic systems has expanded to new and wide application range that include residential, commercial, aerospace and many others. Power electronic interfaces e.g. switch mode power supplies (SMPS) have proved to be superior over traditional linear power supplies. However, their non-linear behavior puts a question mark on their high efficiency. The current drawn by the SMPSs from the line is distorted resulting in a high Total Harmonic Distortion (THD) and low Power Factor (PF). Individually, a device with harmonic current does not pose much serious problem however when used on a massive scale the utility power supply condition could be detoriated. Other adverse effects on the power system include increased magnitudes of neutral currents in three-phase systems, overheating in transformers and induction motors etc. Hence, there is a continuous need for power factor improvement and reduction of line current harmonics. It helps in development of new circuit topologies and control strategies for Power Factor Correction (PFC) and harmonic reduction. This project aims to develop a circuit for PFC using active filtering approach by implementing boost converters; it shall be based on an optimized power sharing strategy to improve the current quality and at the same time reduce the switching losses.

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The work initially involves simulation of basic power electronic circuits and the analysis of the current and voltage waveforms. It starts with simple circuits with a gradual increase in complexity by inclusion of new components and their subsequent effect on the current and voltage waveforms. We focus on the objective of improving the input current waveform i.e. making it sinusoidal by tuning the circuits. All the simulation work is done in MATLAB Simulink environment and the results are attached here with.

II. POWER FACTOR

Power factor is the cosine angle between voltage and current in ac circuit. Generally there is a phase angle Ø difference voltage and current in ac circuit, '*cos* Ø' [1] *is* called as Power factor of the ac circuit. If the circuit is capacitive the current will lead by the voltage and power factor is known as leading, however if the circuit is inductive the current will lag by the voltage and power factor is called as lagging.

$$POWER\ FACTOR = \frac{REAL\ POWER}{APPARENT\ POWER} \tag{1}$$

A. Power factor Correction

Power factor correction is the method of improving the power factor of a system by using suitable devices. The objective of PFC circuit is to make the input to a power supply behave like purely resistive or a resistor. When ratio between voltage and current is constant, then the input will be resistive hence the power factor will be 1.0. When the ratio between voltage and current is other than 1 due to the presence of nonlinear loads, the input will contain phase displacement, harmonic distortion and thus the power factor gets degraded.

B. Source of poor power factor

- Poor PF caused by reactive linear circuit elements results as the current either leads or lags the voltage, depending on whether the load looks capacitive or inductive.
- Less than acceptable power factor typically associated with electronic power conversion equipment is caused by nonlinear circuit elements. In most off-line power supplies, the AC-DC front end consists of a bridge rectifier followed by a large filter capacitor.

C. Need of Power Factor Correction

The rise in the industrial, commercial and residential applications of electronic equipment's has resulted in huge variety of electronic devices requiring main supply. These devices have rectification circuits, which is the prominent reason for harmonic distortion. These devices convert AC to DC power supply which causes the current pulses to be drawn from the AC network during each half cycle of the supply waveform [3]. Even if the single device for e.g. A television may not draw a lot of reactive power nor it can generate enough harmonics to affect the supply system significantly, but within a particular face connection, there may exist several such devices connected to the same supply phase resulting in the production of a large amount of reactive power flow and harmonics in the line current.

Pulsating current contains harmonics which results in additional losses in cables, increasing current in binding of rotating machines and transformers and noise emission in many types of equipment. The rectifier used in AC input side is the prime source of this problem. Thus in order to decrease the effect of this distortion, power factor correction circuit are added to supply input side of equipment used in industries and domestic applications to increase the efficiency of power usage.

III. AC-DC CONVERTER

Typically rectification, which produces a non-sinusoidal line current due to the non-linear input characteristic, Line-frequency diode rectifiers convert AC input voltage into DC output voltage in an uncontrolled manner. Single-phase diode rectifiers are needed in relatively low power instrument that needs some kind of power conditioning. Harmonics in rectifier is approx. 153.2% which is very high and power factor will degrade.

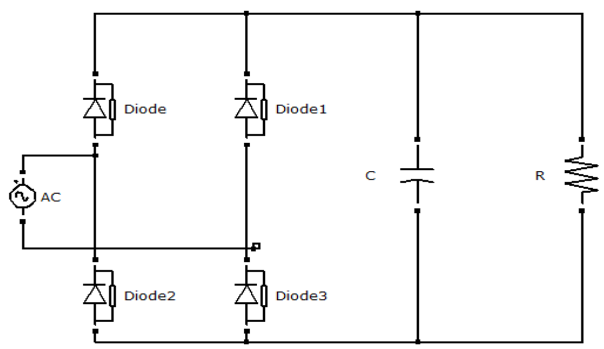

Fig.1. AC-DC Converter (Rectifier)

IV. TYPES OF POWER FACTOR CORRECTION

Power Factor Correction can be classified as two types:

- Passive PFC
- Active PFC

A. Passive Power Factor Correction

In Passive PFC, in addition to the diode bridge rectifier, passive elements are introduced to improve the nature of line current. By using this, power factor can be increased to a value of 0.7 to 0.8 approx. as the voltage level of power supply increases the size of PFC components also increase. The idea of passive PFC is to filter out the harmonic current by use of low pass filter and only allow 50Hz power frequency wave to increase the power factor. Passive PFC is not reliable method for power factor Correction

Table.1: Examples of power factor correction using passive elements

Passive PFC	**THD%**
AC side Inductor in Rectifier	17.23%
DC side Inductor in Rectifier	51.73%
Series LC on AC side of Rectifier	7.43%
Parallel LC on AC side of Rectifier	70.65%
Capacitor on AC side of Rectifier	43.25%

B. Active Power Factor Correction

An active PFC is a power electronic device designed to control the amount of power drawn by a load and obtains a power factor close to unity. Commonly any active PFC design functions by controlling the input current in order to make the current waveform follow the supply voltage waveform closely (sine wave). A combination of reactive elements and some active switches increase the effectiveness of the line current shaping and to obtain controllable output voltage. Boost Converter can use for power Factor Correction

Table.2: Examples of power factor correction using Active elements.

Active PFC	THD%
Buck Converter	69.77%
Boost Converter	27.00%
Buck-Boost Converter	89.64%

V. BOOST CONVERTER

A boost chopper circuit constructs the PFC converter with a switching device in the DC side of the diode bridge rectifier circuit. Good characteristics such as a sinusoidal current waveform in phase with the AC line voltage and the constant DC voltage can be obtained from the PFC converter[4].

This explanation is describing that boost converter when connected to AC-DC converter (rectifier) THD becomes considerably less and Boost up the output DC voltage and improves the input power factor of circuit. As the output is improved but still THD=27% are there so to have regulated output DC-output we need to connect another circuit in cascade. Further forward converter is used in the paper.

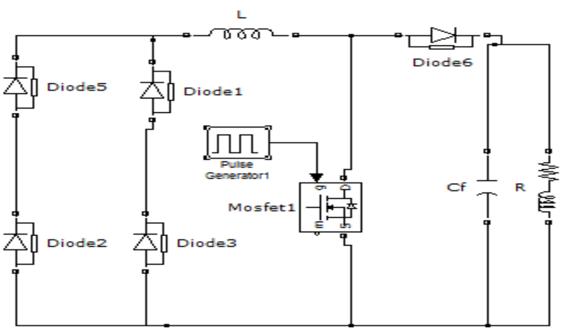

Fig.1: Boost Converter.

VI. FORWARD CONVERTER

Forward converter is another popular switched mode power supply (SMPS) circuit that is used for producing isolated and controlled dc voltage from the unregulated dc input supply [1].

Fig.2. shows the basic topology of the forward converter. It consists of a fast switching device 'S' along with its control circuitry, a transformer with its primary winding connected in series with switch 'S' to the input supply and a rectification and filtering circuit for the transformer secondary winding. The load is connected across the rectified output of the transformer-secondary [4].

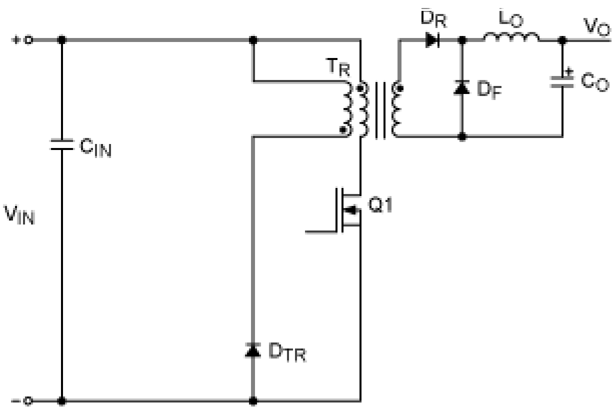

Fig.2. Forward Converter

VII. SIMULINK MODEL

Here the power factor correction Simulink model using MATLAB is introduced for AC –DC Converter of single phase supply. AC-DC converter (rectifier)[2] is cascaded with boost converter and further with forward converter to make the power factor unity.

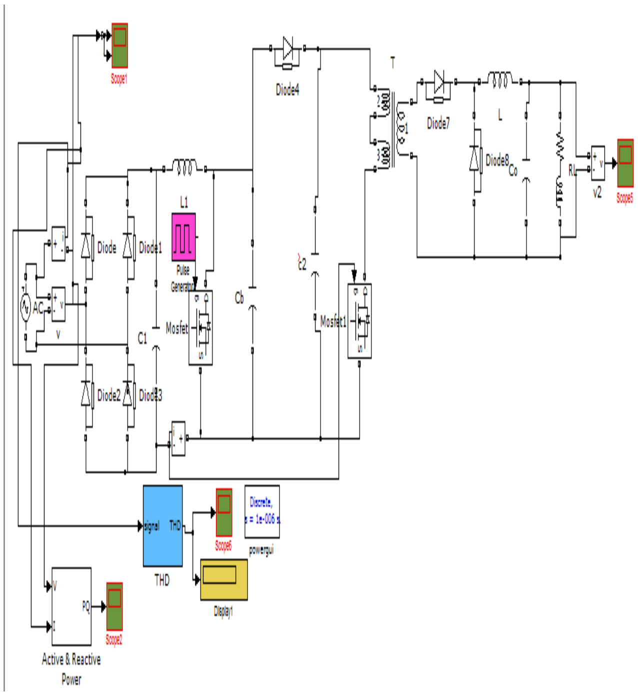

Fig.4: Simulink Model of Power factor correction with cascaded rectifier, boost converter and forward converter for RL load.

Further waveforms are showing the current is following the voltage sine wave so it is concluded that power factor is improved i.e. unity.

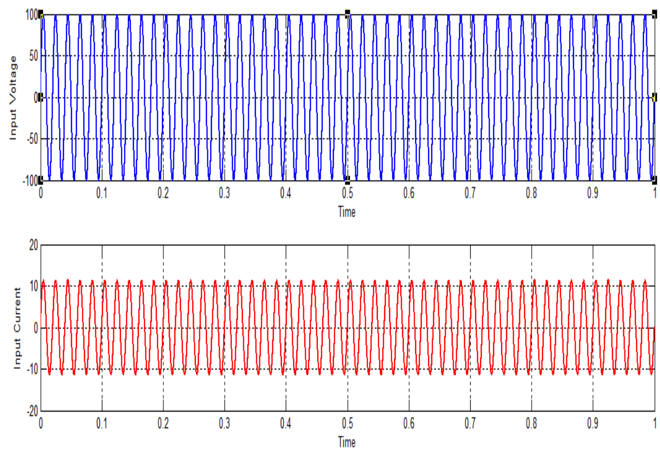

Fig 5 Waveforms of Input Voltage & current.

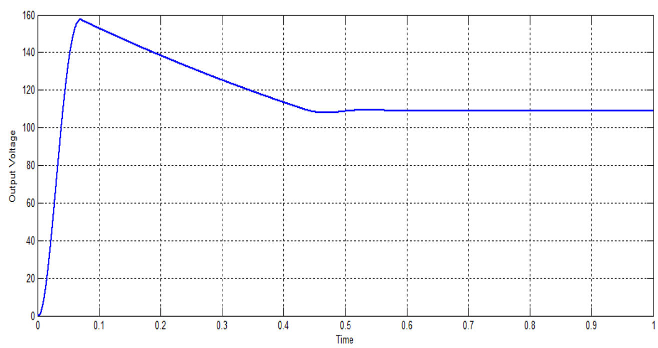

Fig.6: Waveform of output Voltage

Power factor basically depends on harmonics in circuit and harmonics produced because of non- linear loads and elements present in circuit. Here the AC-DC converter is working with three loads first RL load and two DC motor Drives [5].

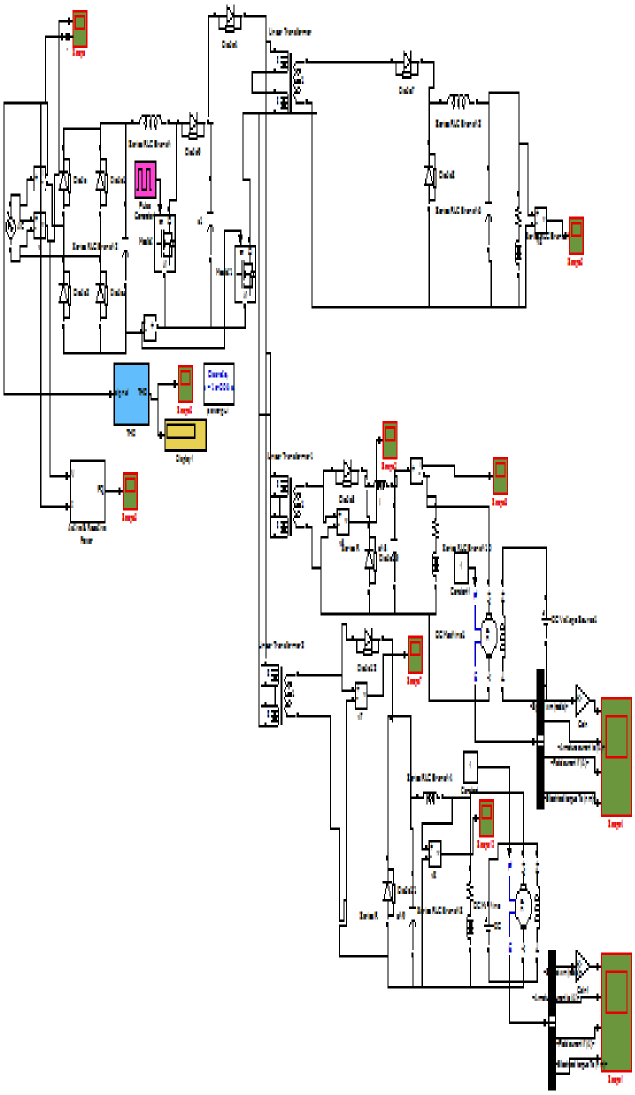

Fig.7: Simulink model of PFC AC-DC Converter with multiple loads.

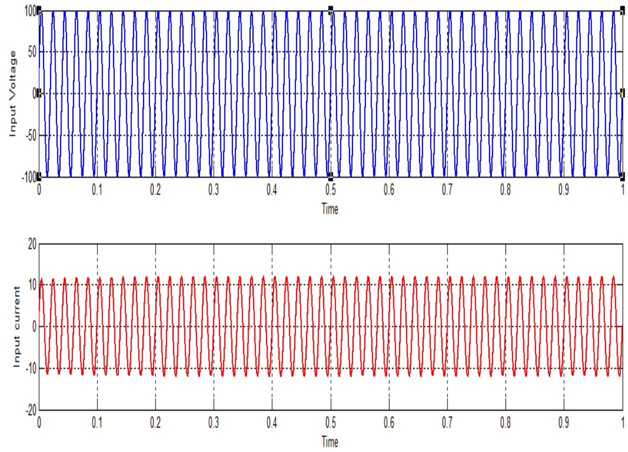

Fig.8: Waveform of Input Voltage and Current in circuit.

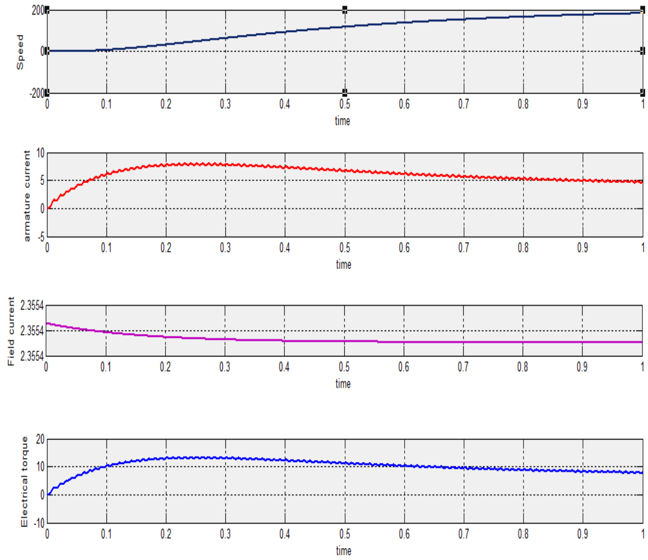

Fig. 9. Waveforms of speed, armature Current, Field Current and Torque of Dc motor 1.

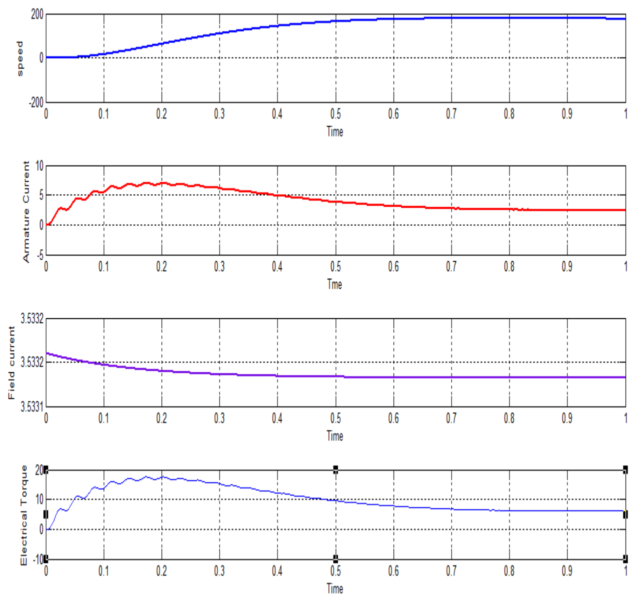

Fig.10: Waveform of speed, Armature Current, field Current, Torque of DC Motor 2.

As Boost forward Converter is used with AC supply with rectifier power factor can be corrected. As the PQ (Active & Reactive Power) is calculated with the formula:

$$S = \sqrt{P^2} + \sqrt{Q^2} \qquad (2)$$

Where, S is apparent power;
P is Active or real power;
Q is Reactive power.
Here P = 260 kW and Q = 10 kVAR
Putting these values in (2) resulting Apparent power 260.19 VA.
Now as per equation (1) Power factor can be calculated which is equals to .99[6].

VIII. CONCLUSION

Power factor is depending on load connected to supply, with non-linear loads the power factor degrading and harmonics exceeds and when the THD is higher the power factor is low. So to make the power factor unity some reactive elements and switches are used thus unity power factor is achieved.

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