DESIGN AND SIMULATION OF HIGH POWER EV CHARGER

A PROJECT REPORT

Submitted in partial fulfilment for mid-semester evaluation submitted by

BACHELOR OF TECHNOLOGY
IN
ELECTRICAL ENGINEERING

Submitted by:
Bellamkonda Jai Abhiram
Vankudoth Prashanth

Guided by:
Prof. Amod C Umarikar

INDIAN INSTITUTE OF TECHNOLOGY, INDORE

SEPTEMBER, 2023

What is a charger?

An EV charger recharges high-voltage batteries in electric vehicles (EVs) and plug-in hybrids. They come in levels: Level 1 (household), Level 2 (faster), and Level 3 (DC fast charging), differing in speed and compatibility.

Types of chargers:

- **On-board chargers (AC-charging mechanisms)**
  They play a vital role in PHEVs and EVs, converting AC electricity from outlets into DC for battery charging. They offer convenience but have slower charging speeds than DC fast chargers.
- **Off-board chargers (DC-Charging mechanisms)**
  Off-board charging infrastructure provides DC electricity externally to recharge EVs and PHEVs, which is essential for long-distance travel. They excel at quickly replenishing batteries but have higher installation and operating costs than AC chargers.

Basic Structure of Charger:

An EV charger consists of many components, which include Rectifier, DC-to-DC converter, Communication interface, Heat management unit, and so on

The two key components are:

- AC to DC converter
- DC to DC converter

AC to DC converter (Rectification) takes the AC Power from the Grid, and it converts into DC.DC-DC converter is used to step up or down the DC voltage level to match the Battery voltage level.

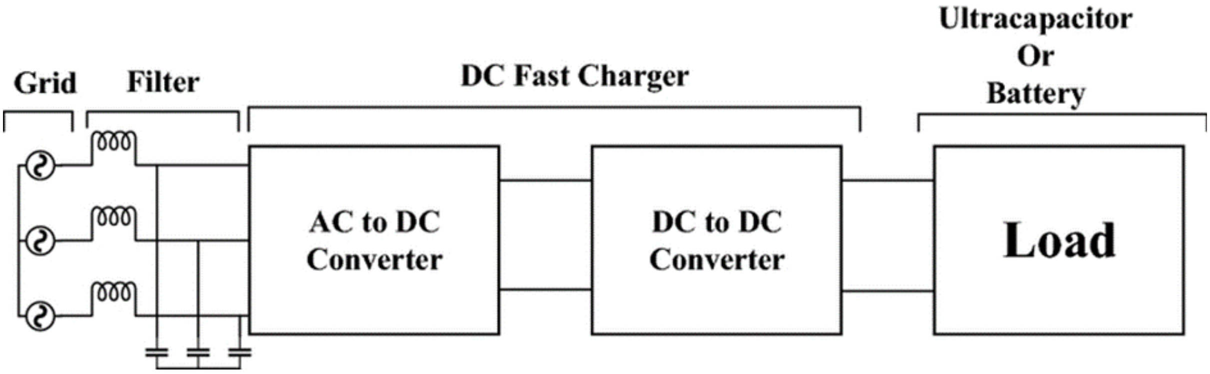

Fig 1: Basic structure of EV Charger

This Report describes the AC to DC conversion part.

PWM-Based AC to DC Converter:

There are various AC to DC topologies available. Out of which, our interest is in PWM rectifiers.

The main Advantages of using a PWM Rectifier are:

- Improved Power factor
- Low Total Harmonic Distortion
- Dynamic Response
- Efficiency across Wide Load Range

The basic structure of PWM Based AC to DC Converter:

PWM rectifier consists of Input Power supply, Filter, IGBT Switching circuit, Control block, PWM Generator, Phase-locked loop, Smoothing Capacitor

In simple terms,

The input current and output voltage derived from a Phase-Locked Loop (PLL) are provided as inputs to a control block. These input signals are processed inside the control block to generate an error signal. The control mechanism within the block determines how this error signal is created. This is sent to a Pulse-Width Modulation (PWM) generator. This generator compares the error signal with a reference signal to determine how long specific switches should be turned ON and OFF. These switches will control the flow of electrical current in the system. By precisely controlling the switching of these IGBT switches, the system can regulate the output voltage according to the desired specifications.

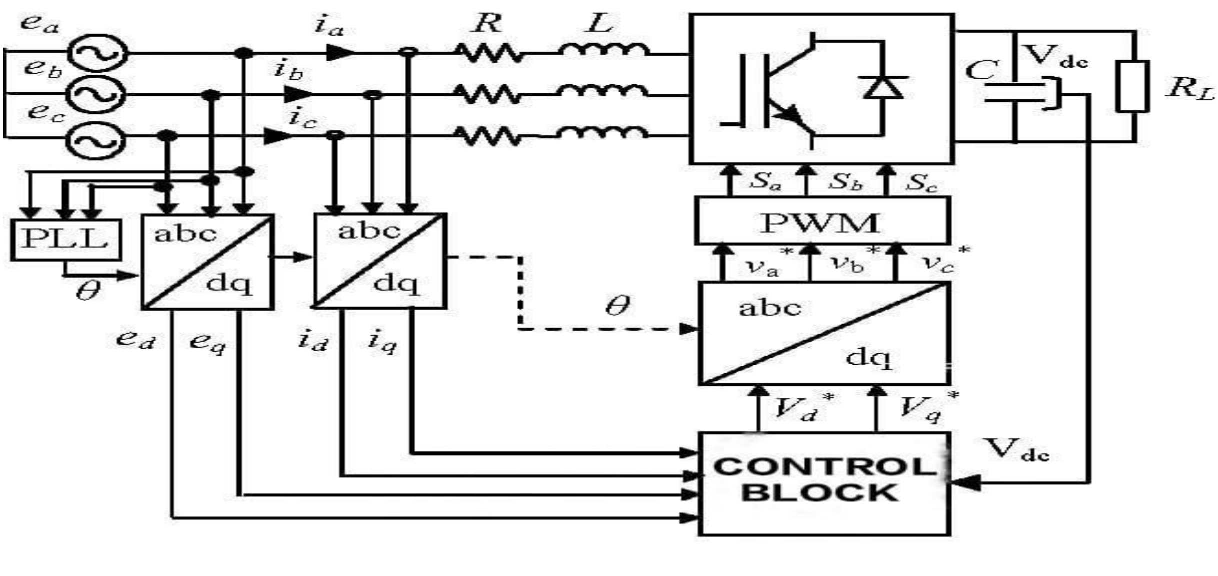

Fig 2: Basic structure of 3 phase PWM Rectifier

Key objectives required in Rectifier:

- **Desired output voltage**
- **Unity input power factor**
- Unity power factor is a critical factor in efficient electrical utilization. It ensures that electrical energy drawn from the source is used effectively for practical work, reducing power diversion into reactive power generation, which consumes energy without contributing to practical work. Beyond energy efficiency, the unity power factor is also pivotal in ensuring grid stability. It safeguards the smooth operation of sensitive electronic equipment by preventing voltage fluctuations averting issues like overheating and potential damage.

The Primary objective is to develop a Pulse-Width Modulation (PWM) Based Rectifier system capable of maintaining the output voltage at a specified level while achieving a unity input power factor.

- The structure of 3 phase IGBT Rectifier is given below:

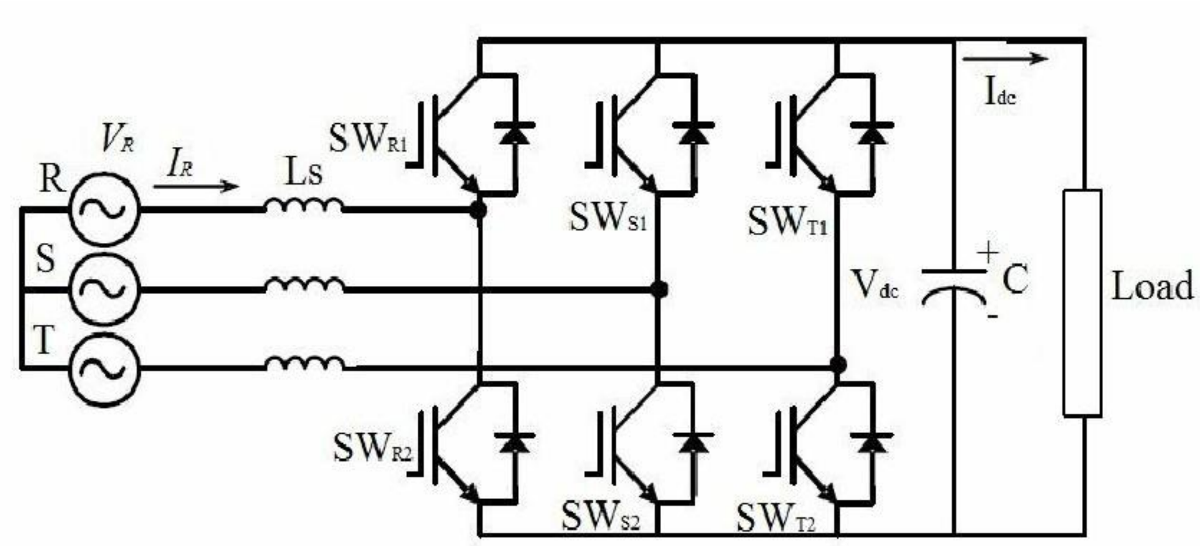

Fig 3: Three-Phase Boost Converter

Working:

As mentioned earlier, the operation of the Rectifier closely resembles that of a single-phase IGBT-based rectifier. When the SWR2 switch is ON, the inductor Ls accumulates energy as the voltage is applied. Conversely, when the SWR2 switch is OFF, the energy stored in the inductor is transferred to the capacitor through the SWR1 diode. The functioning of the remaining phases is analogous to this.

Precise control IGBT switching is required to get the desired output voltage and unity power factor.

Control Technique:

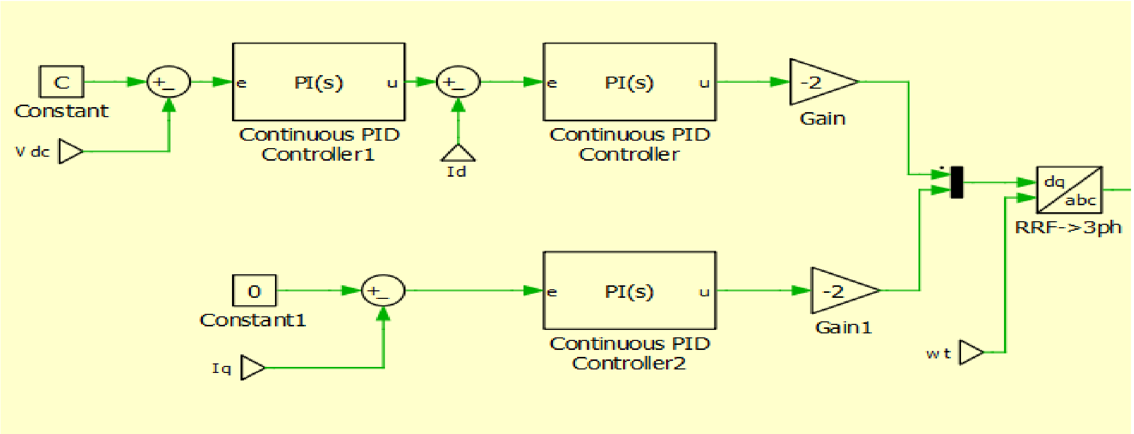

Fig 4: Control Block

The above-employed control technique ensures the desired output DC Voltage and unity power factor between the input current and voltage supplied by the Grid.

PLL Block:

The internal working of PLL can be thought of as below.

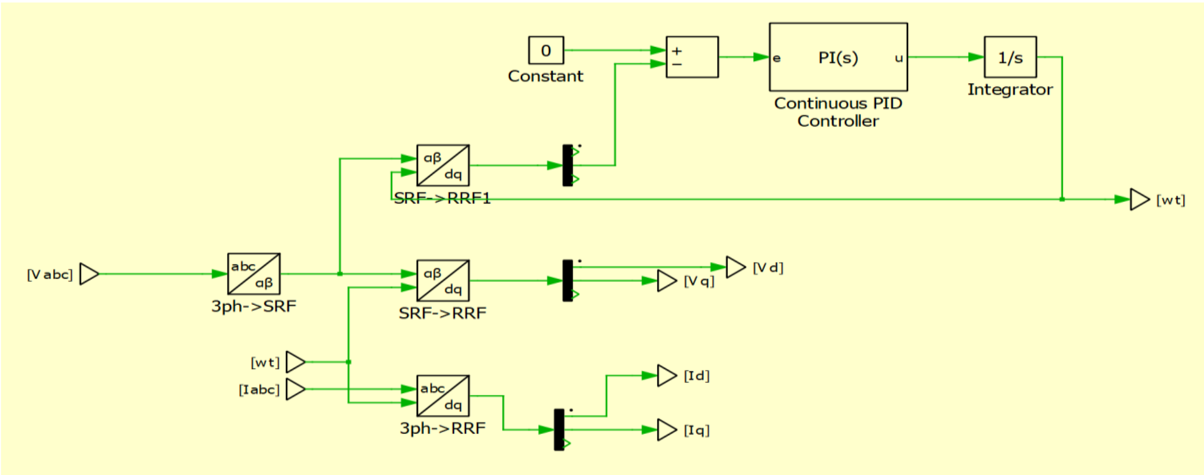

Fig 5: Phase Locked Loop Internal working

It consists of a PI controller and an abc to dq transformation block. It takes the grid voltage in abc form as input and converts it into dq form. The quadrature voltage component is made to zero via the PI controller to generate the output angle and is fed to the dq block. Moreover, the same angle is used in converting current in abc coordinates (Iabc) to dq coordinates (Idq). Hence, we achieve a synchronous voltage and current mode in our converter.

Voltage control block:

This block controls the Output voltage of the Rectifier, Vdc, which is regulated to reach the desired voltage level, denoted as Vdc*. This error signal is processed through a Proportional-Integral (PI) controller block. In turn, the output of this controller block serves as the reference current required for the subsequent current control section.

Current control block:

This block controls input current components Id and Iq obtained from the PLL block. The output from the voltage controller block is taken as the current reference for the Id component of the input vector, and Iq is set to zero. This simplifies the analysis further. We can see that the input current can be treated as a 1D vector rotating synchronously with the input voltage.

The error signals of Id and Iq are sent to the PI controller to control the respective components. This output is sent to dq to abc Block along with the input angle calculated in PLL Block (inverse of what we had done before). The output will be a rotating 3-phase vector in phase with input supply passed to the PWM Block.

PWM Block:

The dq to abc transformation output is input into the PWM block, where it's compared with an automatically generated symmetrical triangular waveform acting as a reference. When the input exceeds the triangular reference, the PWM block outputs a high signal (indicating switch ON). Conversely it produces a low signal when the input falls below the triangular reference (indicating switch OFF). The figure below depicts the VABC input waveform, the triangular reference waveform, and the PWM block's comparison process for determining the switch state (ON/OFF) based on their values.

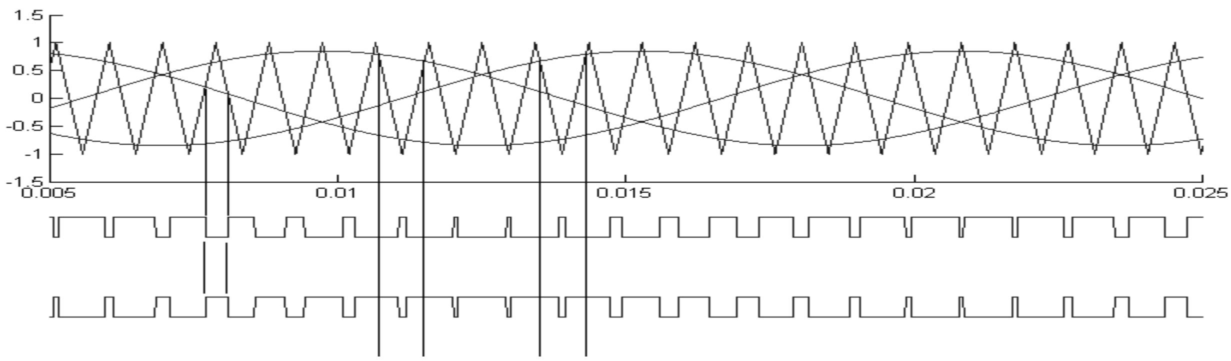

Fig 6: PWM Signal generation Technique

Simulation and results

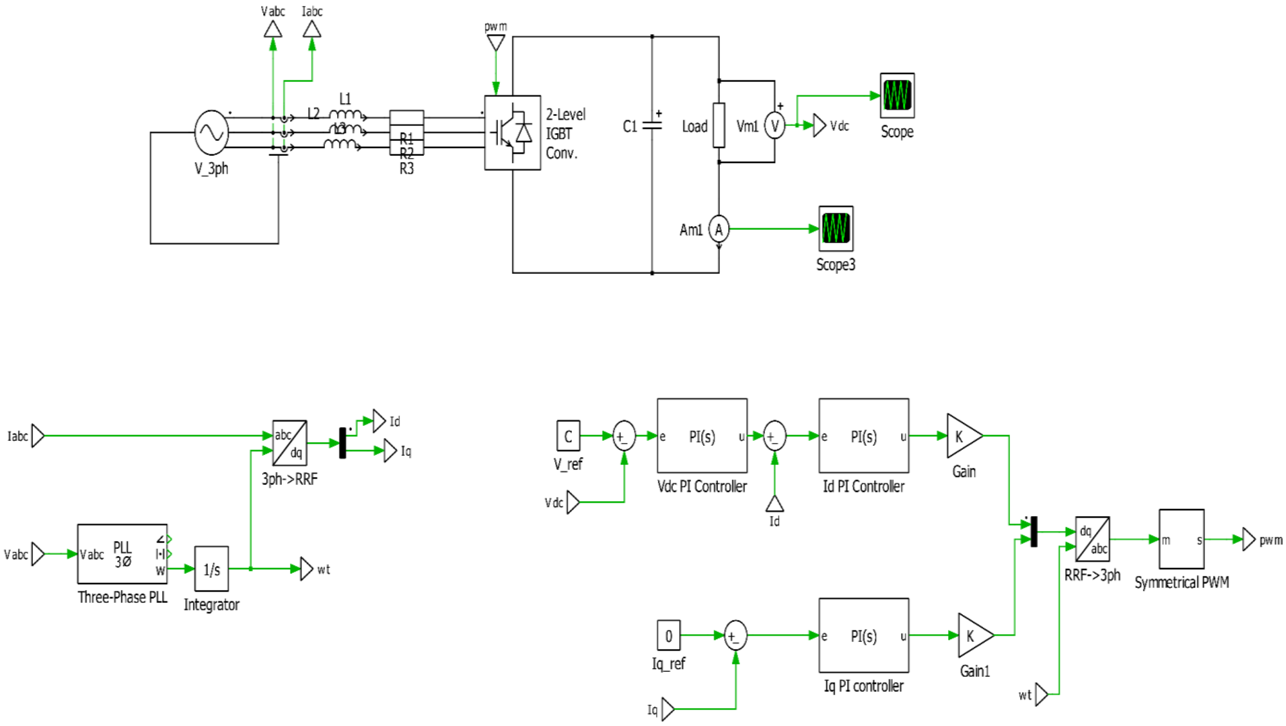

Fig7: Simulation Schematic

Parameters	**Value (in Units)**
Grid Voltage	325 V
Frequency	50 Hz
Input Series Inductance L	2 mH
Input Series Resistance	0.5 ohm
DC-Link Capacitor C	2000 µF
DC output Voltage Vdc	800V
Load Resistance	100 ohms
Kp(Voltage Control loop)	0.1
Ki(Voltage Control loop)	10
Kp(Current Control loop)	0.02
Ki(Current Control loop)	20

Table 1 AC/DC Converter Simulation Parameters

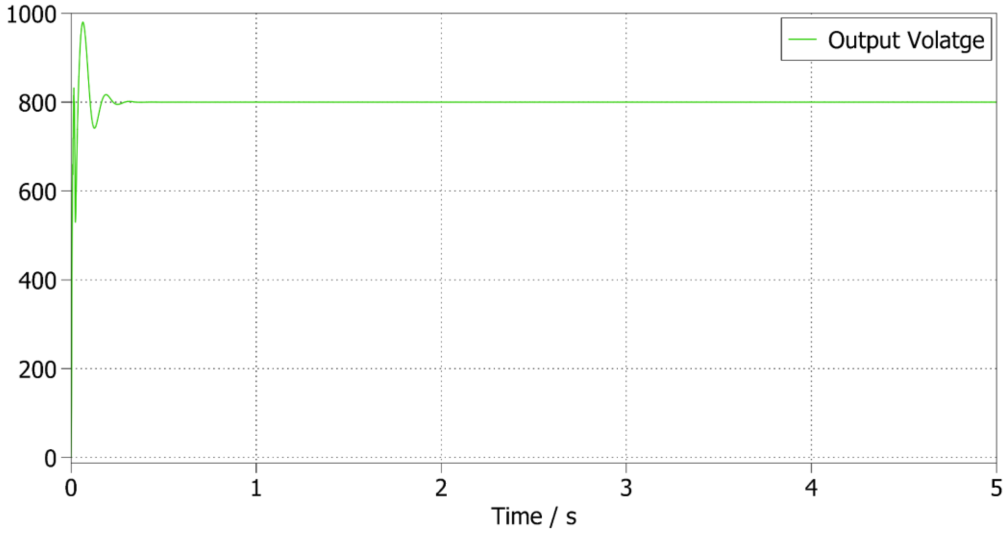

Fig8: Output Voltage Measured Across Load

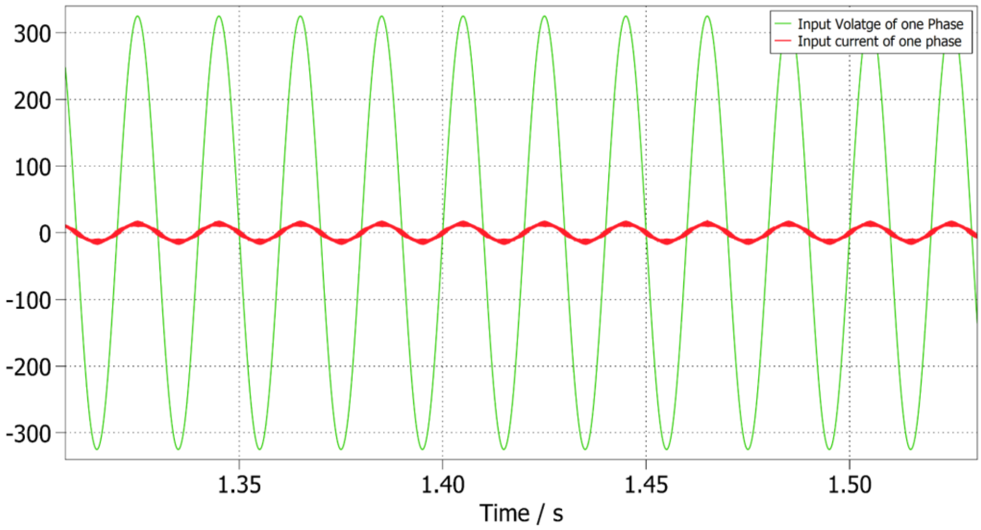

Fig 9: Input Voltage and Current of One phase

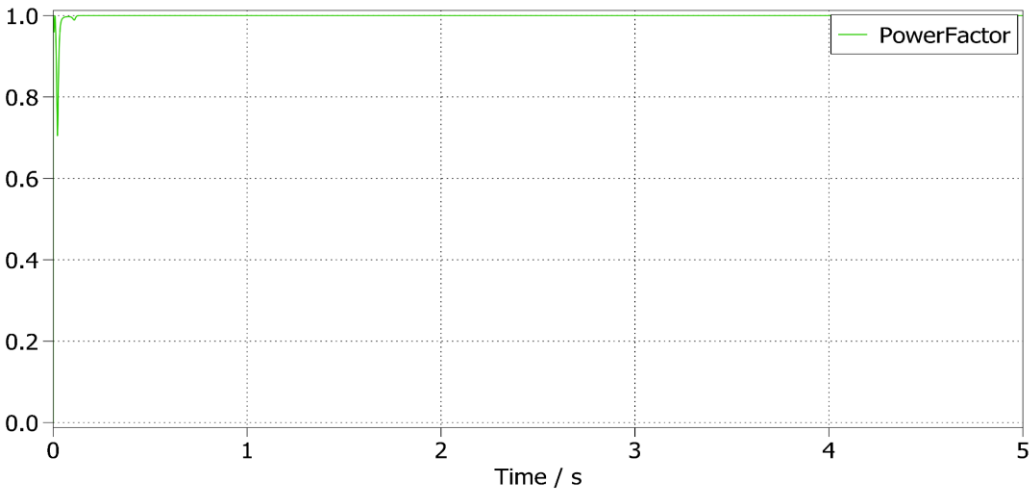

Fig10: Input power factor

References

1. M. Khan, M. Naveed, Dil. Hussain, “Three phase six-switch PWM buck rectifier with power factor improvement”. J. Physics Conf. Series. vol. 439, Jul. 2013. 10.1088/1742-6596/439/1/012028.

2. X. Wang, K. Huang, S. Yan, B. Xu, Bin , “Simulation of Three-Phase Voltage Source PWM Rectifier Based on Direct Current Control”. 2008 Congress on Image and Signal Processing. vol. 5, 194-198. 2008.

3. Wen. Qiang, Liu. Yong-bao, He. Xing, Liang. Qian-chao, “Simulation Study of Three - phase PWM Rectifier with Square of the Voltage Double Closed Loop Control”. IOP Conf. Series: Materials Science and Engineering. vol. 199, May. 2017.

4. https://youtu.be/IfPh5KHg_88?si=KS61QfEgT_MB4BVS (as on dated 24/09/2023)

5. https://www.youtube.com/watch?v=Lh4shWrxlqI&ab_channel=TechSimulator (as on dated 24/09/2023)