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Control Analysis of Active Front End Converter

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Abstract— nonlinear load on the power system where at any time its current is not proportional in magnitude and phase to the voltage. It caused the poor power factor and generating the Harmonics at the load site. To mitigate this problem, we use an Active front end converter (AFE). By using Pulse Width Modulated (PWM) technique. This paper represents the main objective of AFE to regulate the DC output voltage and improve the load side power factor.

Keywords: Active front end converter (AFE), Pulse Width Modulated (PWM) technique

I. Introduction

Power electronics and energy quality became one of the major problems of electrical engineering. Power electronics technology played an important role in power quality issues. Power electronics devices are widely used for applications in different fields like medical science, drives control, HVDC transmission, etc. These devices generally use the switching circuits consisting of semiconductor switches like thyristors, GTOs, MOSFETs, or IGBTs which are mostly used. These circuits also involve passive elements such as inductors, capacitors, and resistors and they all are being used for different purposes [1].

An AC to DC power converter is an important part of many power electronic systems such as uninterruptible power supplies (UPS), battery chargers, dc motor drives, front end converter in adjustable ac motor drive [2]. The front end of dc-link power converters as an interface with the ac line power (grid). The rectifiers act as non-linear loads on the power system and draw input currents, which are rich in harmonics and have poor supply power factor. Low input power factor and a large amount of harmonic in supply current causes various undesirable effects such as failure on capacitor banks or blown fuses, de-rated operation of transmission lines & transformers, reduced life of equipments, reduced reliability of nearby metering or communication circuits [3]. To solve the Power Quality problems caused by the Harmonics Current, AFE takes place for high power quality giving very good performance in term of Power Factor (PF) and Total Harmonic Distortion (THD) of the supply currents and supply voltages on ac side [4] [5] [6] [7].

Active Front End (AFE) converters use semiconductor switches (such as IGBTs) as rectifiers instead of the diode bridges which are generally used. When diodes are used for converting the AC power into the DC Power, they produce harmonics that are transferred back into the power system, resulting in additional heat and losses, and even causing erratic behavior of connected equipment. Multiple rectifiers (i.e. 12-pulse, 18-pulse, or 24-pulse) can reduce harmonics, but as rectifier sections are added, footprint and cost go up. Another solution to reduce harmonics is to add passive filters, which introduce a low impedance to absorb harmonic frequencies. But passive filters are useful only in limited conditions, and they have a large footprint and generally use more energy than other alternatives. Hence, we are used active front end converter.

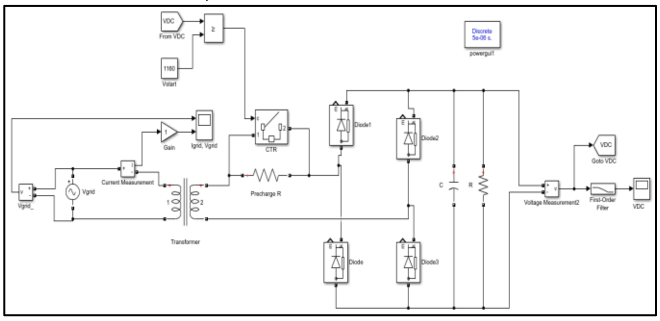

Fig. 1.1: Power Circuit of Diode Uncontrolled Rectifier

II. Active front end converter

An Active Front End (AFE) converter – single or three-phase system - is a bidirectional power flow converter with high quality, sinusoidal line current waveform. A front-end power electronic converter is a term used when a converter is connected to an ac mains/source either using a transformer or without using a transformer. Today, the AFE systems can be used as an interesting solution to realize AC drives. The AFE's main advantages are the four quadrants operation mode and the full control in regenerative braking [4] [5] [8]. Active front end inverter which refers to a power converter which consists of line side converter which is controlled by active switches like IGBTs. It also consists of a DC link voltage capacitor banks and the load side inverter. It works in two modes one being the normal mode and other being the regenerative mode in which the bidirectional power flow action takes place i.e. feeding the power back to the line [1]. The line side converter is the PWM converter with IGBTs. The intermediate dc-link voltage should be higher than the peak of the supply voltage [9] [10]. This is required to avoid saturation of the PWM controller due to insufficient dc-link voltage, resulting in line side harmonics. The main objective of AFE to regulate the DC output voltage and the compensation for undesired harmonics on the line current [4] [7].

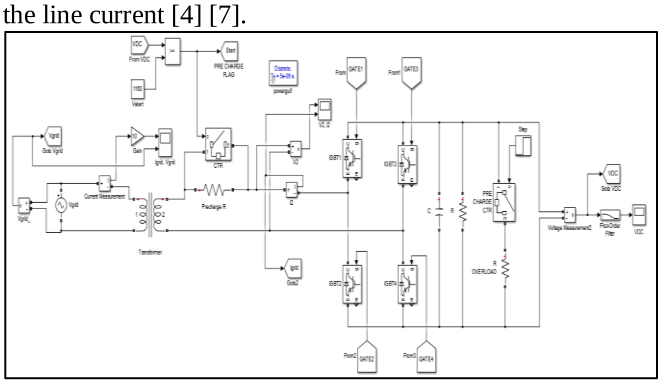

Fig. 2.1: Power Circuit of Active Front End Converter

The Power circuit is mainly divided into the following parts:

1) Single-Phase Step-Down Transformer
2) Pre-charge resistor and contactor

3) IGBT PWM Rectifier
4) DC Link or DC Bus

A. Single-Phase Step-Down Transformer

It is used to step down the grid voltage with the transformation ratio, V1/V2= 26.69. It is also used as a booster to step up the DC Voltage. Hence no other boosting inductor is required.

B. Pre-charge Resistor and Contactor

The capacitor acts as a short circuit at the moment instant when applying DC voltage, hence it draws a very large amount of current from the grid which may result in the damage of the power semiconductor device and the capacitor itself. Hence pre-charge resistor is used to limit the starting current drawn from the DC link capacitors and to smoothly charge the DC bus. It is then bypassed by the contactor when the sufficient DC link voltage is achieved.

C. IGBT Based PWM Rectifier

PWM Based IGBT rectifier is used to boost up the DC link Voltage to the 1800V. It also provides a unity power factor and reduces the THD in the input current.

D. DC Link or DC Bus

DC link capacitor is placed in parallel with the load to minimize the effects of voltage variations as the load changes. The DC-link capacitor also provides a low-impedance path for ripple currents generated by power switching circuits.

The Control Method is mainly divided into the following parts:

1) Start-up logic
2) Phase Lock Loop
3) SPWM Control Loop

1) Start-up logic

The pre-charge resistor is used to limit the starting current drawn from the DC link capacitors and to smoothly charge the DC bus. In the start-up control circuit, DC link voltage is compared with 1160 VDC. When the soft-start finishes and DC link voltage crosses the 1160V, then START=1 and pre-charge resistor is then bypassed by the contactor.

PWM Start Logic: It takes around 0.2 seconds to smoothly charge the DC bus through pre-charge resistor and PWM are started with a delay of 0.4 seconds. Hence by that time, DC link is built up through IGBT body diodes.

Hence when START=1 and the delay of 0.4 seconds are achieved, then the PWM flag is setup and the PWM control loop is started.

2) Phase Lock Loop

To maintain the input power factor to unity, the input grid voltage phase and frequency must be known. Hence Phase Lock Loop is used to generate a Theta (in radians) in such a way that this theta is the same as the theta of the input grid voltage.

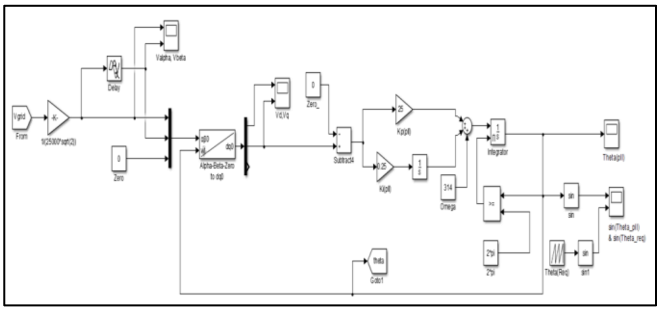

Fig. 2.2: Control Circuit of PLL

First, The Vgrid is scaled down by the gain of 25000*1.412. Then it is applied as an alpha component to the Alpha-beta stationary reference frame. Since we have only one phasor as an input, this alpha component is delayed by 90° to generated the beta component of the Alpha-beta stationary reference frame. These vectors are then converted into the DC quantity by transforming this vector into the dq-rotating reference frame.

Since we know that when the frequency and phase of the d-rotating reference frame is aligned with the alpha component, then the Vd = Peak amplitude of the alpha component and Vq = 0. Hence, this condition is used to control the speed of the dq-rotating reference frame in such a way that Vq becomes zero. The actual Vq is compared with the Vq(reference) i.e. 0. The difference between the actual Vq and Vq(reference) is called the error which is then applied to the PI controller. The aim of the PI controller is to reduce this error and generate the omega in such a way that this error becomes zero.

This omega is then integrated to generate the theta which is then fed back to the dq the rotating reference frame for the closed loop control of the theta.

3) SPWM Control

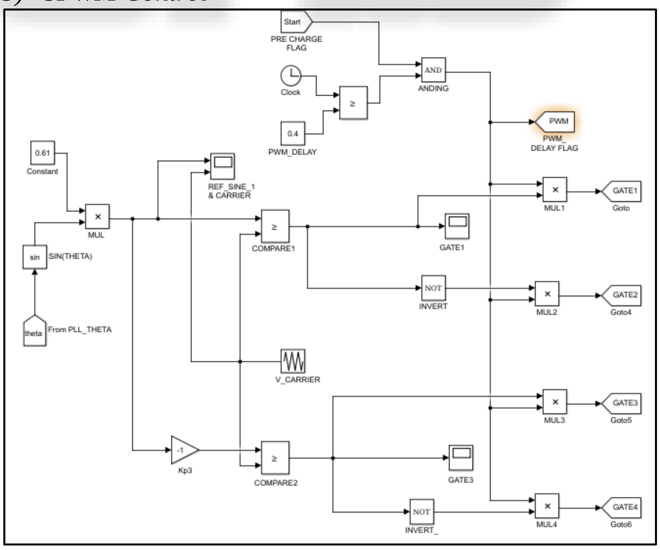

Fig. 2.3: SPWM Control Circuit

For now, the control circuit is implemented with a fixed modulation index of 0.61 which means open loop control of dc-link voltage. This control loop generates the gating signals for the power semiconducting devices. Theta obtained from PLL is used to generate the unity sine wave which is then multiplied with the fixed modulation index of 0.61 to generate the reference sine wave for Phase lag 1. This sine wave is then inverted which becomes the reference sine wave for phase lag 2. This both sine waves are then compared with the high frequency carrier wave for the generation of gating signals. When the amplitude of the reference sine wave 1 is greater than the carrier wave, the IGBT1 is turn on and invert logic is applied for the IGBT2. Similarly, when the amplitude of the reference sine wave 2 is greater than the carrier wave, the IGBT3 is turn on and invert logic is applied for the IGBT4.

III. SIMULATION RESULTS

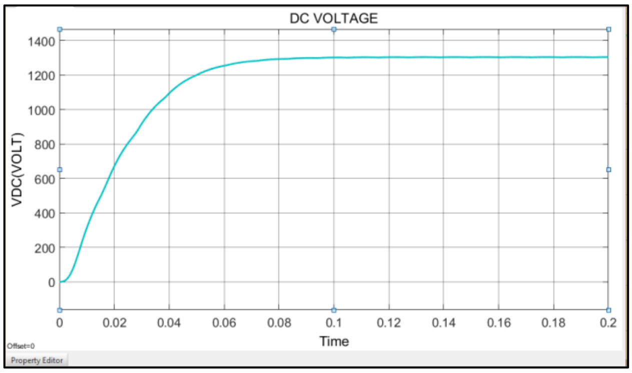

Fig. 3.1: Voltage Waveform of Diode Uncontrolled Rectifier

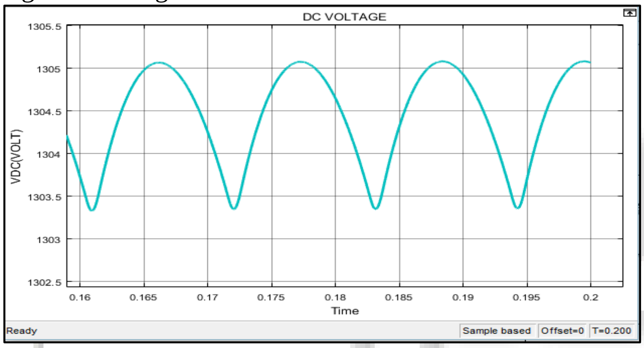

Fig. 3.2: Ripple Voltage of Diode Uncontrolled Rectifier

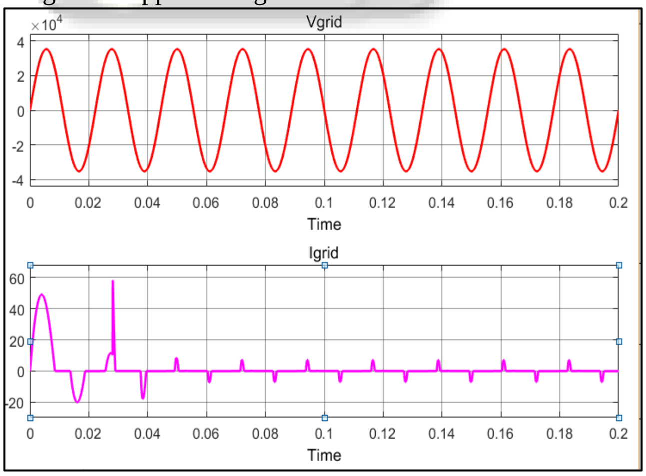

Fig. 3.3: Input Side Grid Voltage and Current Waveform of Diode Uncontrolled Rectifier

From the input current waveform, it is clear that the input current drawn from the grid contains harmonics in case of diode bridge uncontrolled rectifier and also, we cannot control the dc-link voltage in case of diode bridge uncontrolled rectifier.

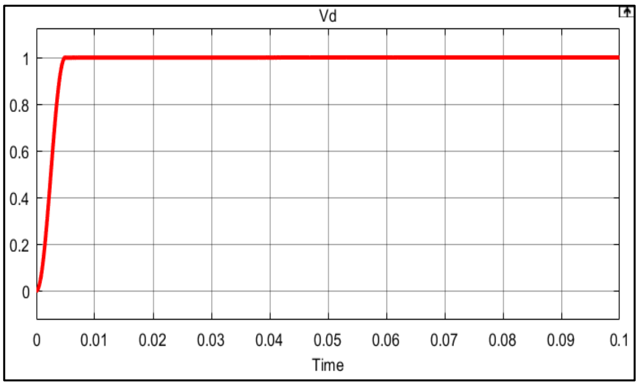

Fig. 3.4: Controlled Vd Generated from PLL

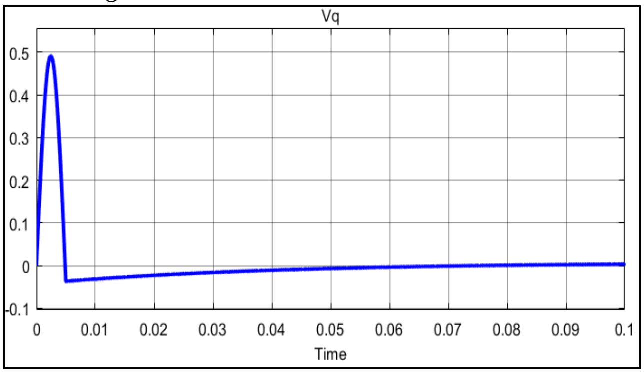

Fig. 3.5: Controlled Vq Generated from PLL

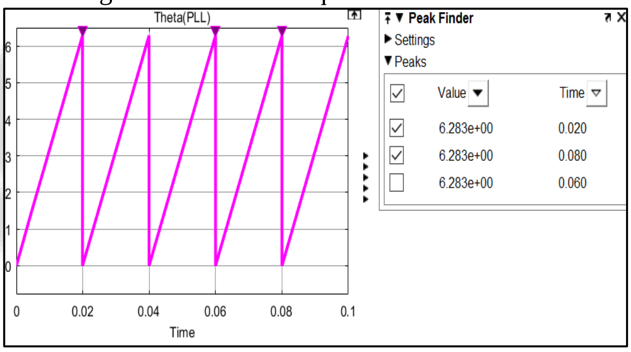

Fig. 3.6: Controlled Theta Generated from PLL

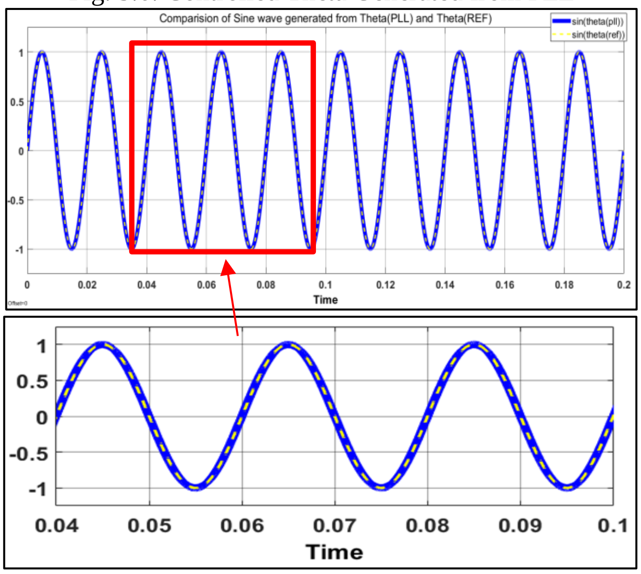

Fig. 3.7: Comparison of Sine Wave Generated from Theta(PLL) and Theta(REF)

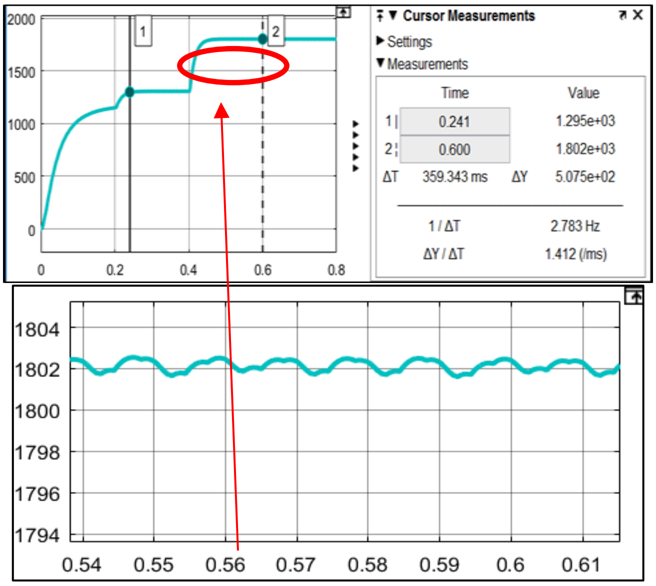

Fig. 3.8: Output DC Voltage Waveforms with SPWM Control

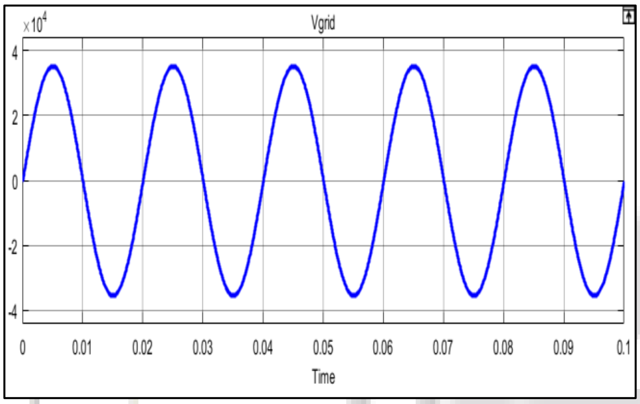

Fig. 3.9: Input Grid Voltage Waveform

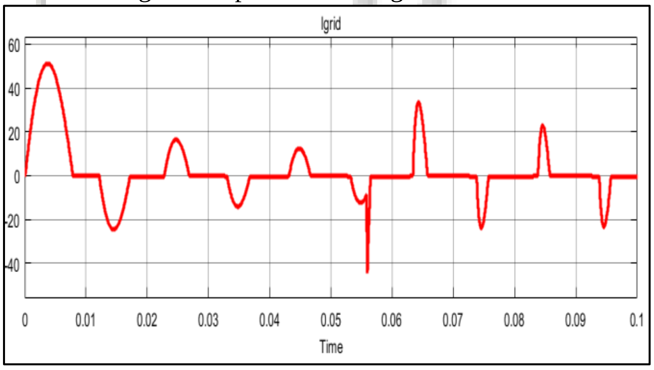

Fig. 3.10: Input Grid Current Waveform during Pre-charge Time

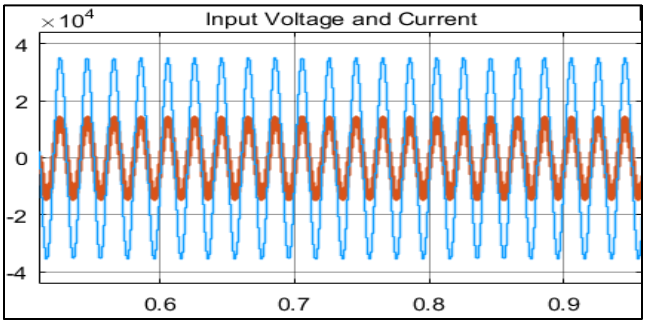

Fig. 3.11: Input Grid Voltage & Current Waveform at Steady State

IV. Conclusion

From the results, the following points are worth noting:
In the Uncontrolled Rectifier with Booster, the Unity power factor is not achieved. This is because the input current contains the harmonics and there is a displacement in the angle between the input voltage and current. This is because the input current is indirectly controlled by controlling the current through the inductor. There is no direct control of input current as input power semiconductor devices are uncontrolled. While in the AFE, we can eliminate the harmonics by suitable control strategy and achieve current THD within the standard limits and we can also achieve power factor near unity.

In the Uncontrolled Rectifier with Booster, Regenerative power cannot be fed back to the grid as input power semiconductor devices are uncontrolled. While in the AFE, this is the added advantage to fed back the Regenerative power cannot be fed back to the grid.

In the Uncontrolled Rectifier with Booster, boosting the inductor is required to boost up the DC bus at the required level. While in the AFE, the input power transformer itself acts as the booster.

In the AFE, the size of the magnetic component and capacitor can be reduced by selecting high switching frequency. Because we know that the size of the L and C is inversely proportional to switching frequency. Hence this also results in the saving of the cost.

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