

Control Strategies for Design of Programmable AC Active Electric Load

Jain Jimmy¹, Shabbir S. Bohra²M.E. Student, Department of Electrical Engineering, Sarvajanic College of Engineering & Technology, Gujarat, India²Associate Professor, Department of Electrical Engineering, Sarvajanic College of Engineering & Technology, Gujarat, India²

ABSTRACT:The AC active electronic loads is a new type of power electronics instrument which can simulate a variety of load characteristics, and test energy can be feedback to the utility power system with little loss and high power factor. It is widely used in testing of UPS (Uninterruptible Power Supply), wind turbines, micro-turbines, hybrid energy conversion systems, solar arrays and energy storage systems such as batteries, ultra-capacitors, flywheels, inverters etc. The AC active electronic loads (AELs) based on pulse width modulation (PWM) converters are capable of emulating nonlinear load requires effective current control techniques and power stages. These two aspects of an AEL are interdependent mainly due to the presence of electromagnetic compatibility filters to reduce electromagnetic emissions.

This paper presents the design and construction of a programmable electric load for high power tests with different control strategies is explained. The key technology of AC electronic load is current characteristics simulation for the simulation accuracy. Simulation based on theoretical analysis is doing using the MATLAB / Simulink model.

KEYWORDS: Alternating current (ac) active load, current control techniques, state feedback, state observers, converters.

I. INTRODUCTION

In recent years, there has been a considerable increase in the use of uninterruptible power supply (UPS) to provide a low output voltage distortion, fast dynamic response, high reliability and continuous power supply system especially for sensitive and critical loads such as computer systems, hospitals etc. need UPS. Low total harmonic distortion (THD) and high efficiency are commonly required in high power applications, such as three-phase inverter systems. Nonlinear loads draws non-sinusoidal current which cause more voltage drop on the supply network impedance resulting in unbalanced conditions. They also cause electromagnetic interference (EMI) and resonance conditions.

The burn-in routines is a vital step during manufacturing process and maintenance procedure. To perform the burn-in tests, the traditional methods includes the association of resistors, capacitors, inductors, transistor and static converters that tries to reproduce the desired load profile defined by the end user or standards for the given applications. But this solution results in heavy and large equipment with excess of energy consumption during the tests. Above 10 kW, the losses are unacceptable due to the difficulty to dissipative the generated heat. Also, the size of product becomes bulky and unattractive. To solve this problem, the active electronic load can be used. Active Electronic loads are used to sink regulated current from the power supply. The plenty of designs and usages of electronic loads are reported in the literature.

The e-loads are also used to test switch-mode power supply performance under steady-state and dynamic-loading conditions. Due to the frequency mismatch with the grid voltage, nonlinear loads connected to distribution networks generate harmonic currents that do not add to their active power. But, their circulation through feeders creating produces joule losses and electromagnetic (EM) emissions the harmful effects. Equipment which is subjected to distort currents is required to withstand the additional requirements produced by such currents. Therefore, test setups including the injection of high amplitude harmonic currents into energy supply equipment are able to provide close to real application conditions. There are the several advantages of AEL over traditional methods are highly energy-

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efficient system as the energy can be returned back to the utility grid, so a large amount of energy can be saved during test procedures for, mainly in case of high-power equipment's.

This paper proposes the two of the control strategies suitable for a switch mode ac AEL. In first strategy the design of AC AEL based on modern power electronics three-level converter and the proposed control strategy endures the added challenges of an LCL filter with high grid interfacing inductance values. For this system, aiming to mitigate the influence of the LCL filter on the controlled plant prefers the use of state-space description, in which the basis of a state feedback strategy is used. Basically the current on the EUT side is needed to be controlled i.e. the grid interface transformer current, but it cannot be measured directly. The option would be to observe the both currents however this increase the cost and degrades the filter performance related to EM emissions. The current which cannot be measured directly can be estimated and controlled using Luenberger Observer. To minimize the influence of external disturbance errors in the system the observer gains are chosen based on H_∞ formulation. The design of AC AELs shown in fig-1 can be implemented through various configurations. The basic blocks of an AC AEL are power source, an electronic converter that draws the power from the EUT and an effective current control technique to achieve the objective.

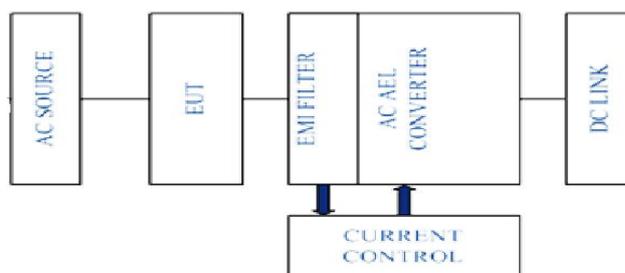


Fig 1 Block Diagram of Active Electronic Load

In the other novel strategy to design the same AEL load of fig 1 includes the synchronous reference frame theory to achieve the reference current and the hysteresis current controller technique is used to reduce the error signal for tracking the reference the current of any harmonic order.

II. LITERATURE REVIEW

- R.Klein, A.de.Paiva and M.Mezaroba, "Emulation of Nonlinear Loads with Energy Regeneration" [1] in Proc.COBEF, Sep.2011, pp.884-890 presented a nonlinear load emulator with energy regeneration capability for testing AC power supplies. The proposed structure based on back to back three-phase PWM voltage source inverter (VSI) with independent control strategy for both PWM VSI to achieve power balance. The proposed strategy uses the current loop and voltage balanced and unbalanced loop. It allows the compensation of unbalanced load current with the harmonic compensation. The proposed emulator can be used for any type of load.

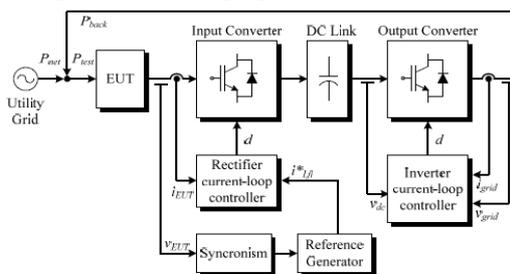


Fig 2 Regenerative AC Electronic Load Emulator [1]

According to the desired load profile, the input converter connected to EUT draws the current. The output converter is connected to the utility grid which sends the drained energy feedback to the grid with unity power factor.

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- Ju- Won Baek, Myung- Hyo Ryoo, Jong Hyun Kim, Jih- Sheng Lai, “50 kVA Regenerative Active Load for power test system”[2] in European Conference on Power Electronics and Applications in 2007 pp. 1-8 presented the 50kVA active load with little losses that regenerates the power to the utility. Using DSP320C33 three phase back to back inverter was been made and tested. It can be used as a nonlinear load, resistive load and reactive load for 1-phase and 3-phase AC. It can also be used for load step change and unbalanced load conditions. The conceptual control block diagram for 3-phase regenerative load is shown in fig 2.2.

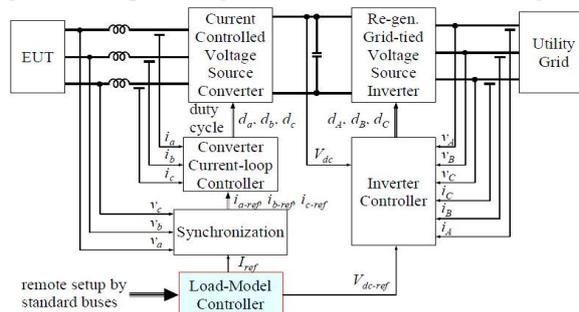


Fig 2 Conceptual Control block diagram for a 3-phase Regenerative-type Electronic Load [2]

III. CONTROL STRATEGIES

3.1 Control Strategy-I

The simplified schematic diagram of Fig 3 for designing the AEL Load is simulated using MATLAB/Simulink.

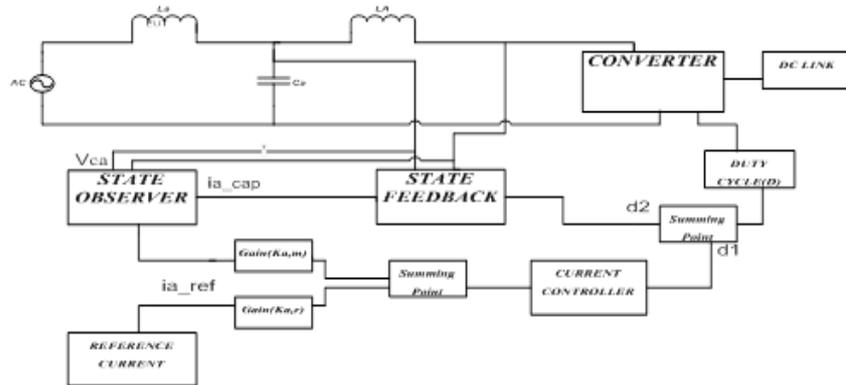


Fig 3 Schematic diagram of designing the Active Electronic Load [1]

3.1.1 Modeling of AEL Load

It's a pole placement technique that reallocates the original poles of the controlled system in such a way that the closed loop system presents a dynamic behavior. The mathematical model of AC AEL is shown in figure in 4.

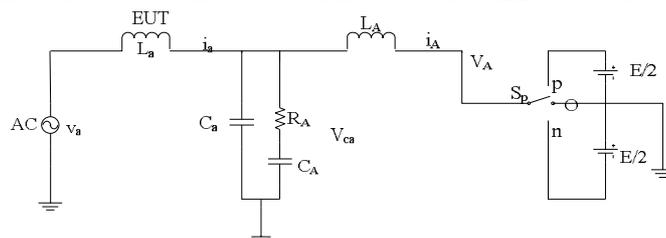


Fig 4 Equivalent Circuit used for control oriented modeling of single-phase AC AEL [3]

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State Equation: $\dot{\vec{x}}_s = A_s \vec{x}_s + B_s \vec{u}$

Output Equation: $\vec{y} = C_s \vec{x}_s$

The converter current i_a and the filter capacitor voltage V_{ca} are the measured variables. A state observer based on the converter duty cycle d_a and the two measured variables estimates the EUT-side current \hat{i}_a .

The state observer is used in order to not add extra current sensors to the power circuit. EUT-side current sensors might deteriorate EMI filter performance due to noise coupling from the control electronics and add cost to the system.

The filter damping branch $R_A - C_A$ is neglected since it helps to reduce the dynamic requirements at the resonant peak and only adds complexity for the system analysis. The LCL filter resonance is actively damped through the use of a state feedback. The simplified model by neglecting R_A and C_A can be written as

$$\frac{di_a}{dt} = \frac{V_a}{L_a} - \frac{V_{ca}}{L_a}$$

$$\frac{di_A}{dt} = \frac{V_{ca}}{L_A} - \frac{d_a}{L_A} \left(\frac{E}{2} \right)$$

$$\frac{dV_{ca}}{dt} = \frac{i_a}{C} - \frac{i_A}{C}$$

Where $A_s = \begin{bmatrix} 0 & 0 & -\frac{1}{L_a} \\ 0 & 0 & \frac{1}{L_A} \\ \frac{1}{C_a} & -\frac{1}{C_a} & 0 \end{bmatrix}$ & $B_s = \begin{bmatrix} \frac{1}{L_a} & 0 & 0 \\ 0 & -\frac{E}{2L_A} & 0 \\ 0 & 0 & 0 \end{bmatrix}$ & $u_s = \begin{bmatrix} V_a \\ d_a \end{bmatrix}$

The state feedback implementation is done by considering k as state feedback gain where $k = \begin{bmatrix} k_1 \\ k_2 \\ k_3 \end{bmatrix}$

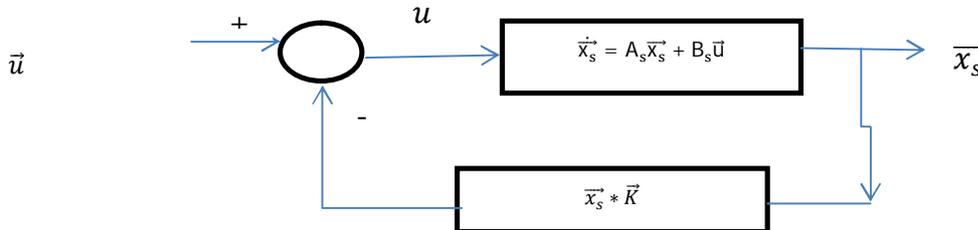


Fig 5 AC AEL State Feedback Control block diagram [3]

From fig 5 it follows that $\dot{\vec{x}}_s = [A_s - B_s \vec{K}] \vec{x}_s + B_s \vec{u}$;

Hence, the closed loop characteristic equation will be $\det[sI - (A_s - B_s \vec{K})] = 0$

3.1.2 State Observer

The EUT-side current i_a is estimated by means of a Luenberger state observer. In terms of the uncertainty of the value of L_a , the system dynamics in terms of a disturbance vector \vec{w} comprising exogenous signal and modeling errors is defined as [4]

$\dot{\vec{x}}_s = \bar{A}_s \vec{x}_s + B_{s1} d_a + B_{s2} \vec{w}$ & $\vec{y} = C_s \vec{x}_s$

Where $\bar{A}_s = A_s$ and $B_{s1} = \begin{bmatrix} 0 \\ -\frac{E}{2L_A} \\ 0 \end{bmatrix}$ and $B_{s2} = \begin{bmatrix} \frac{1}{L_a} & \delta L_a \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$, $\vec{w} = \begin{bmatrix} V_a \\ V_{ca} \end{bmatrix}$

$\begin{bmatrix} M_{31} & M_{32} \\ M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix}$ where $M = 10^6 \begin{bmatrix} 1.9525 & -0.2007 \\ -0.3356 & 0.1028 \\ 1.9665 & -0.2049 \end{bmatrix}$

$$\begin{bmatrix} \hat{i}_a \\ \hat{I}_A \\ \hat{V}_{ca} \end{bmatrix} = \begin{bmatrix} 0 & 0 & -\frac{1}{L_a} \\ 0 & 0 & \frac{1}{L_a} \\ \frac{1}{C_a} & -\frac{1}{C_a} & 0 \end{bmatrix} \begin{bmatrix} \hat{i}_a \\ \hat{I}_A \\ \hat{V}_{ca} \end{bmatrix} + \begin{bmatrix} 0 \\ E \\ 0 \end{bmatrix} d_a + \begin{bmatrix} M_{31} & M_{32} \\ M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} \left\{ \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_a \\ I_A \\ V_{ca} \end{bmatrix} - \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \hat{i}_a \\ \hat{I}_A \\ \hat{V}_{ca} \end{bmatrix} \right\}$$

3.1.3 Switched Converter

In order to effectively impose high quality currents at the ac-side most of the applications requires three-phase bi-directional PWM rectifier due to the stringent effect of power quality, EMC standards and have the better performance than two level. The voltage across the semiconductors can be halved and semiconductors with lower voltage ratings are employed. Thus, overall losses can be reduced along with cooling systems and passive components. The available conventional topologies for three level voltage source bidirectional converter like NPC(Neutral Point Clamped) and flying capacitor are applicable for high kW range. For reducing the size of AC side filter, at the high switching frequency and at the lower values of the voltage steps the AC AEL presents an application.

➤ Three level Rectifier Topology

This section shows the operation principles of the multilevel PWM rectifier topology. The topology used for the converter is TCC (Transistor Clamped Converter)[4] presented in fig 6.

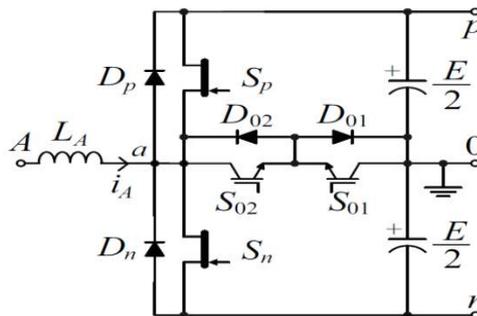


Fig 6NPCm(Modified Neutral Point Clamped) Regenerative Rectifier topologies[6]

The main difference compared to conventional is regarding the rating of semiconductors Dp, Dn, Sp and Sn are subject to the full dc-link voltage, while all other devices block half of it. The NPCm converter switches blocks the full dc-link voltage connecting point a to both p and n terminals. In order to generate the positive mean voltage values the gate pulses sequence is shown for the TCC (Transistor Clamped Converter). The negative voltages are simply symmetrical to these. For the sake of clarity the function of duty cycle is as follows:

$$\begin{aligned} \delta_{s_p}(\omega t, M) &= M \sin(\omega t) \longrightarrow (0 \leq \omega t < \Pi) \\ &0 \longrightarrow (\Pi \leq \omega t < 2\Pi) \\ \delta_{s_{02}}(\omega t, M) &= 1 - \delta_{s_p}(\omega t, M) \longrightarrow (0 \leq \omega t < \Pi) \\ &1 \longrightarrow (\Pi \leq \omega t < 2\Pi) \end{aligned}$$

3.2 Control Strategy-II

In this section the control strategy used for converter is explained. The converter is used as programmable load over here. Fig 7 shows the schematic diagram of programmable load used with the control strategy-2. The required load current specifications are used to calculate the reference load current in the highlighted block in fig 8.

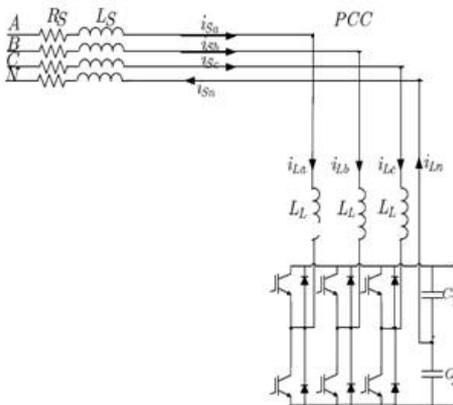


Fig 7 Schematic diagram of programmable load [7]

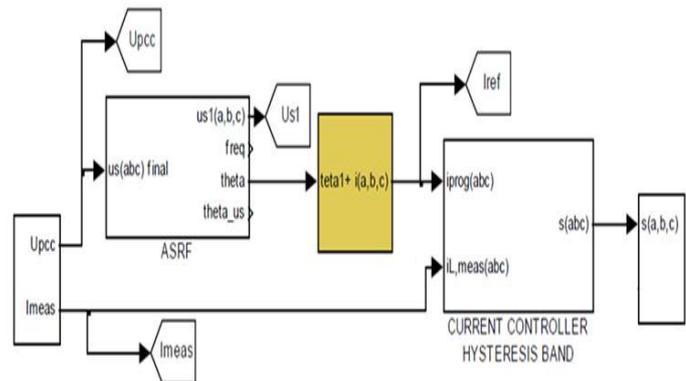
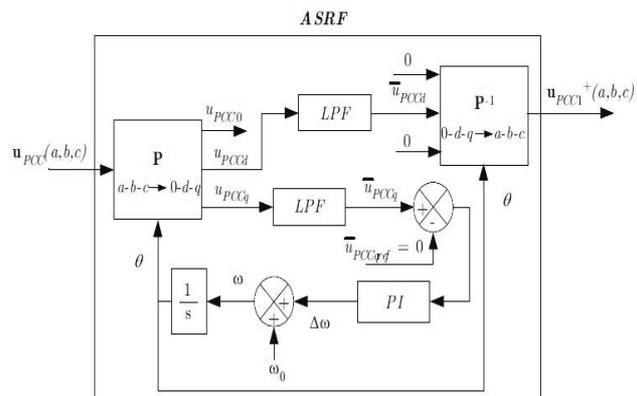
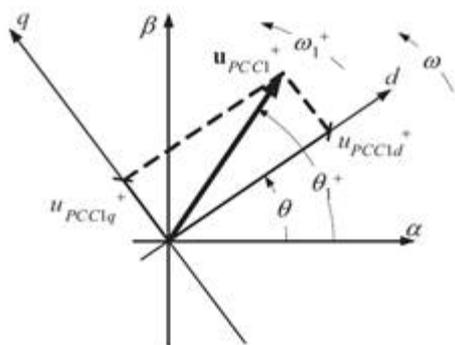


Fig 8 Control scheme for converter [7]

The highlighted block requires the angle of the positive sequence fundamental component of the voltage at the point of common coupling(PCC). The phase angle at PCC and fundamental component of the voltage can be extracted using this ASRF(Auto-adjustable Synchronous Reference Frame) block shown in fig 8[7]. The dynamic response of this method during frequency or amplitude variations is good, achieving the steady state in only two cycles of fundamental period. In ASRF method the accurate extraction is more important than the speed of response. It generates the sinusoidal signal whose amplitude and phase angle are equal to the positive sequence fundamental component of the input signal while most of the conventional synchronization methods only lock the angle as the output of the system. As the fundamental frequency is obtained, the same principle of operation can be used for extracting the harmonic components multiple of the fundamental frequency, using synchronous reference frames rotating at the corresponding multiple pulsation. It provides the immunity against distortion, imbalance, noise, phase and frequency adaptivity which can be applied to both single and three phase systems.

3.2.1 Principle & Operation of the ASRF



ASRF block uses the rotating reference frame theory whose rotation velocity is auto adjustable till receives the synchronization to the positive-sequence fundamental PCC voltages space vector, which rotates at ω_1^+ . In a rotating reference frame theory the positive-sequence fundamental space-vector will rotate at velocity ω that will be varying and forming an angle θ with the α - β -axis shown in 5. The synchronization will be performed when the velocity of the system will be ω_1^+ and also $\theta = \theta_1^+$.

The block diagram of the ASRF that permits the calculation of positive-sequence fundamental phase to neutral PCC voltages from their instantaneous values measurements is shown in Fig 10 [8].

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3.2.2 Current Controller

In this method it compares the reference load current with the measured current and according to the sign of error the switching signals to the IGBT's are given. The fig 11 shows the mechanism how the gate signals are obtained from error signals.

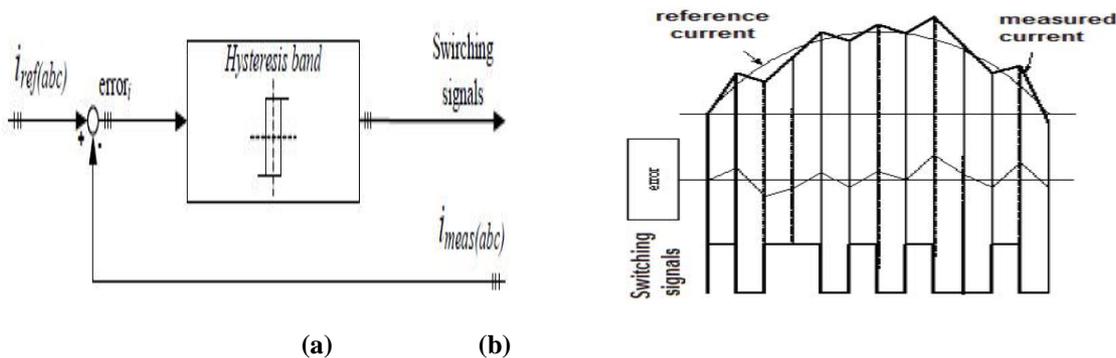


Fig 11 Hysteresis Band Controller [8]

IV. MATLAB/ SIMULATION RESULTS

Fig 12 shows the tracked EUT current as applied reference current of harmonic order h=3 with the simulation parameters of table 1 as shown for control strategy-I. The obtained results are able to track the order of harmonic.

Table 1 Simulation Parameters for control strategy-I

Simulation Parameters	La(EUT Current)	L _A (Filter Current)	C _a	M ₁₁	M ₁₂	M ₂₁	M ₂₂	M ₃₁	M ₃₂	E
Value	404e ⁻⁶	420e ⁻³	1e ⁻³	1.9525e ⁶	0.2007e ⁶	-0.3356e ⁶	0.1028e6	1.9665e ⁶	-0.2049e ⁶	400

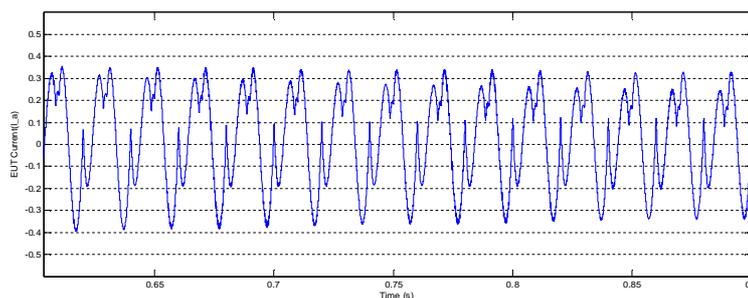


Fig 12 EUT current for h=3

Fig 13 shows the demanded load current and reference current for phase-A for various harmonic order of Control Strategy-II with simulation parameters as shown. The tracked waveforms deviates less from the given reference current.

Table 2 Simulation Parameters for control strategy-II

Simulation Parameters	F _o	V	R _s	L _s	L _{inj}	R _{inj}	C	R _{Load}	L _{Load}
Value	50 Hz	415V	0.0005	1e ⁻⁶	7e ⁻³	0.25	10000 e ⁻⁶	0.25	1e ⁻⁶



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- [7] Carlos Roncero, Maria I. Milanes, Miguel A. Guerrero, Enrique Romero “Controllable electronic load with energy recycling capability” in Power Electronics & Electric Systems(PE&ES), ISSN 0033-2097, 2011.
- [8] M. I. Milanes-Montero: E. Romero-Cadaval: A. R. e Marcos: V. M. Minambres-Macros: F. Barrero-Gonzalez “Novel Method for synchronization to distributed three-phase and single –phase systems” in Industrial Electronics, IEEE, ISEI , pp. 860-865, 2007.