Distributed Control for the Parallel DC Linked Modular Shunt Active Power Filters under Distorted Utility Voltage Condition

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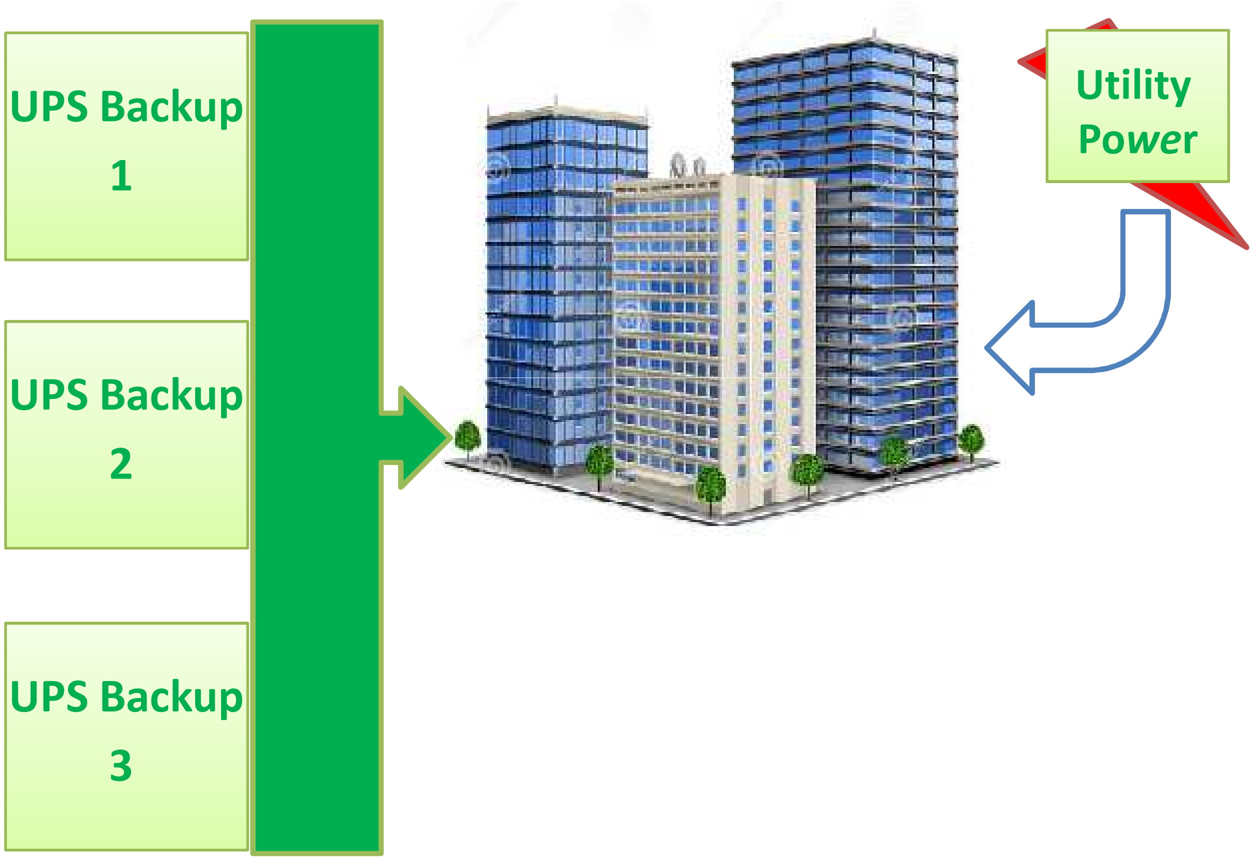
Basic Analogy (Concept)

Utility Power

1 bui

UPS Backu

Basic Analogy (Concept)



UPS Backup 1

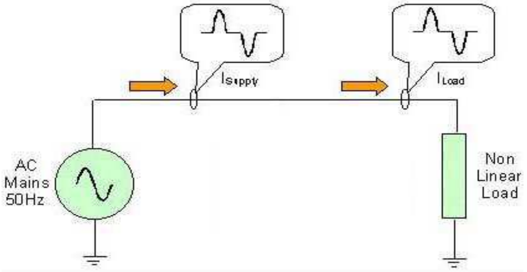
UPS Backup 2

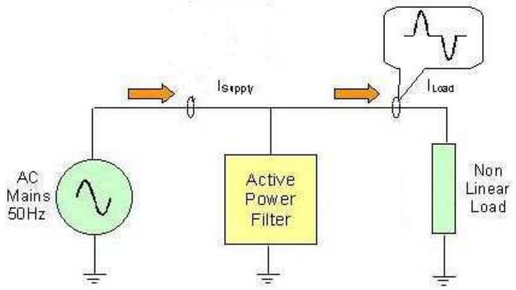
UPS Backup 3

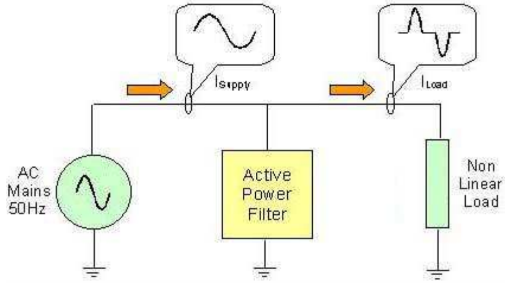
Utility Power

Active Power Filter

The main aim of the APF is to compensate for the harmonics and reactive power dynamically.







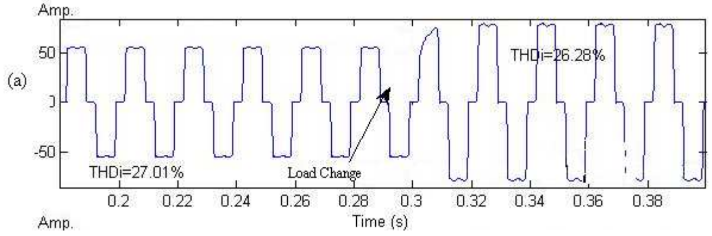


Figure 1: Non ideal-load current

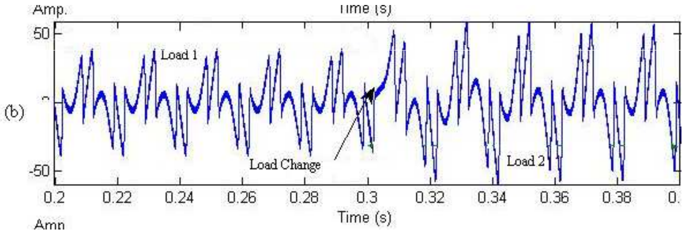


Figure 2: Injected converter compensation current

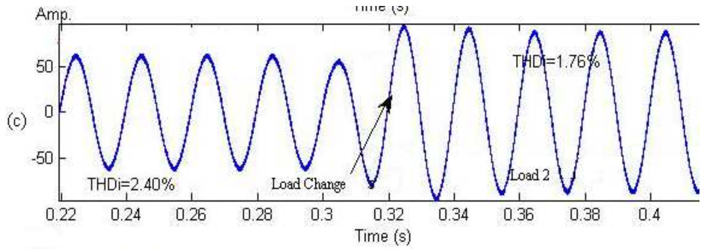


Figure 3: Grid current after active power filtering

Introduction

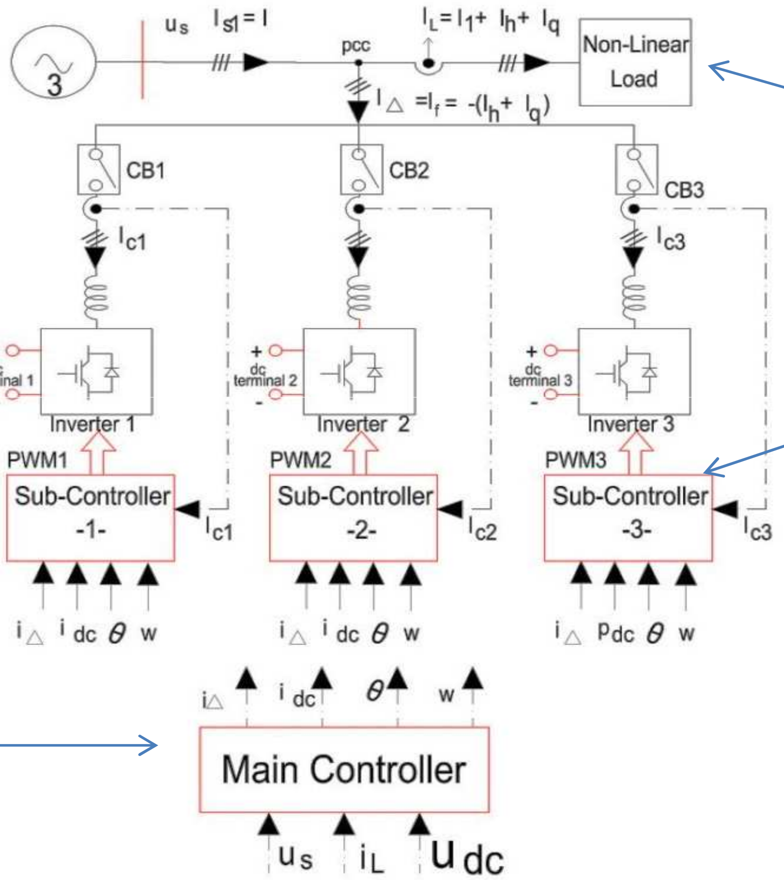
- Parallel-APF configuration is used, instead of high capacity single units, to add flexibility and reliability during operation

- Individual sub-controllers are used for each APF unit to determine distributed harmonic currents and reactive components with the PWM circuit While all the Sub-Controllers are governed by one Main Controller. The control complexity is significantly reduced with use of the proposed controller.

- The proposed system has been verified under distorted and unbalanced grid voltages.

3. Topology of Proposed Parallel Modular APF's

1. **Individual Sub-Control Units**
2. **Main Control Unit**



$$i_L(t)=i_1(t)+i_h(t)+i_q(t)$$

$$i_\Delta(t)=\frac{i_L(t)}{n}=\frac{i_1(t)+i_h(t)+i_q(t)}{n}$$

$$i_c(t)=i_\Delta(t)*n$$

Fig. The power circuit of the common dc-linked modular APF and associated control units

3. Proposed Control Strategy A-) Main Controller

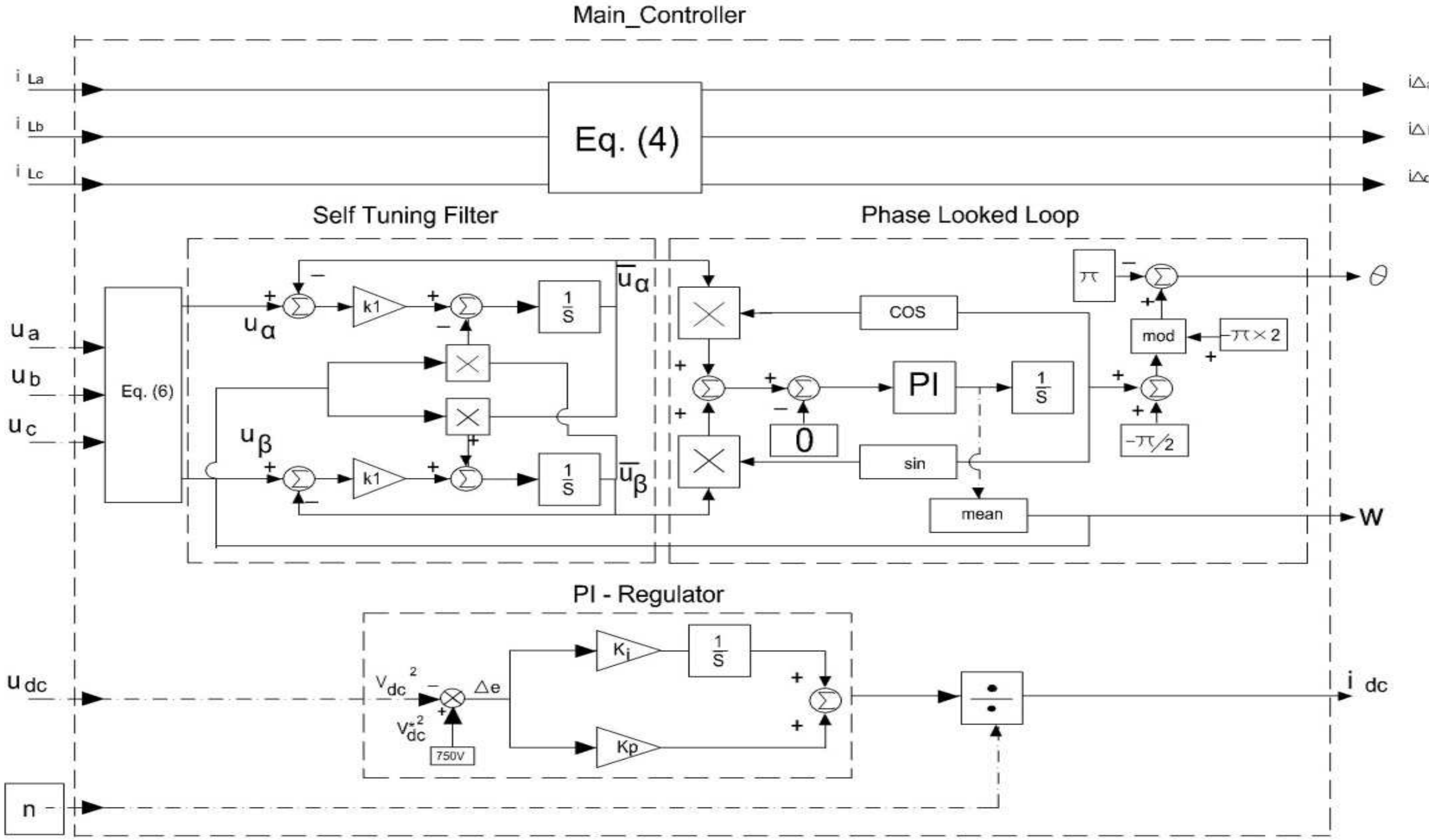


Fig. Main Controller

3. Proposed Control Strategy A-) Main Controller

Therefore, the performance of the control method is dependent on the type of PLL algorithm used. In order to improve the efficiency of the PLL, the three-phase supply voltages (u_a, u_b, u_c) are transformed using the Clarke (or α-β) transformation into a different coordinate system by using:

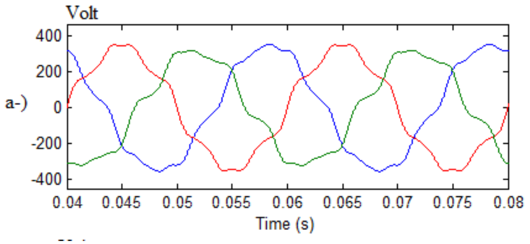
$$\begin{bmatrix} u_\alpha \\ u_\beta \\ u_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix}$$

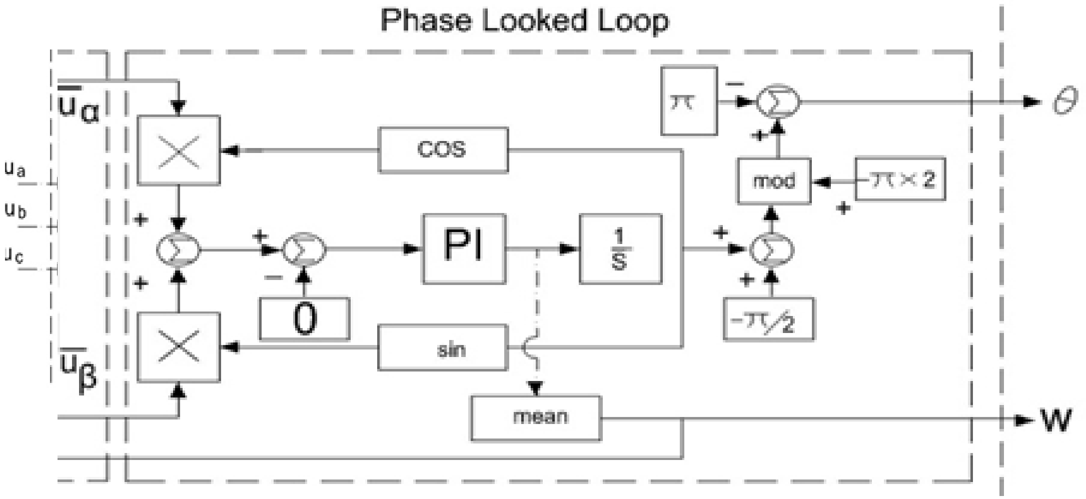
3. Proposed Control Strategy   A-) Main Controller

$$\bar{u}_\alpha(s) = \frac{K_1}{s}\left[u_a(s) - \bar{u}_\alpha(s)\right] - \frac{\omega}{s}\bar{u}_\beta(s)$$

$$\bar{u}_\beta(s) = \frac{K_1}{s}\left[u_\beta(s) - \bar{u}_\beta(s)\right] + \frac{\omega}{s}\bar{u}_\alpha(s)$$

$$\begin{bmatrix} u_\alpha \\ u_\beta \\ u_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix}$$





3. Proposed Control Strategy A-) Main Controller

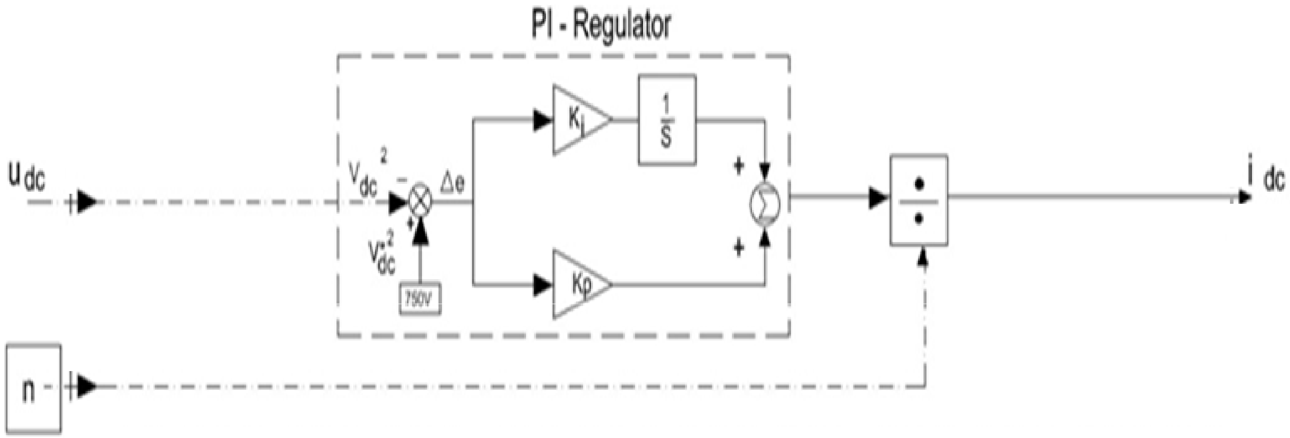


Fig. PI Regulator for Inverter Losses Measurement

3.) Proposed Control Strategy B) Sub Controller

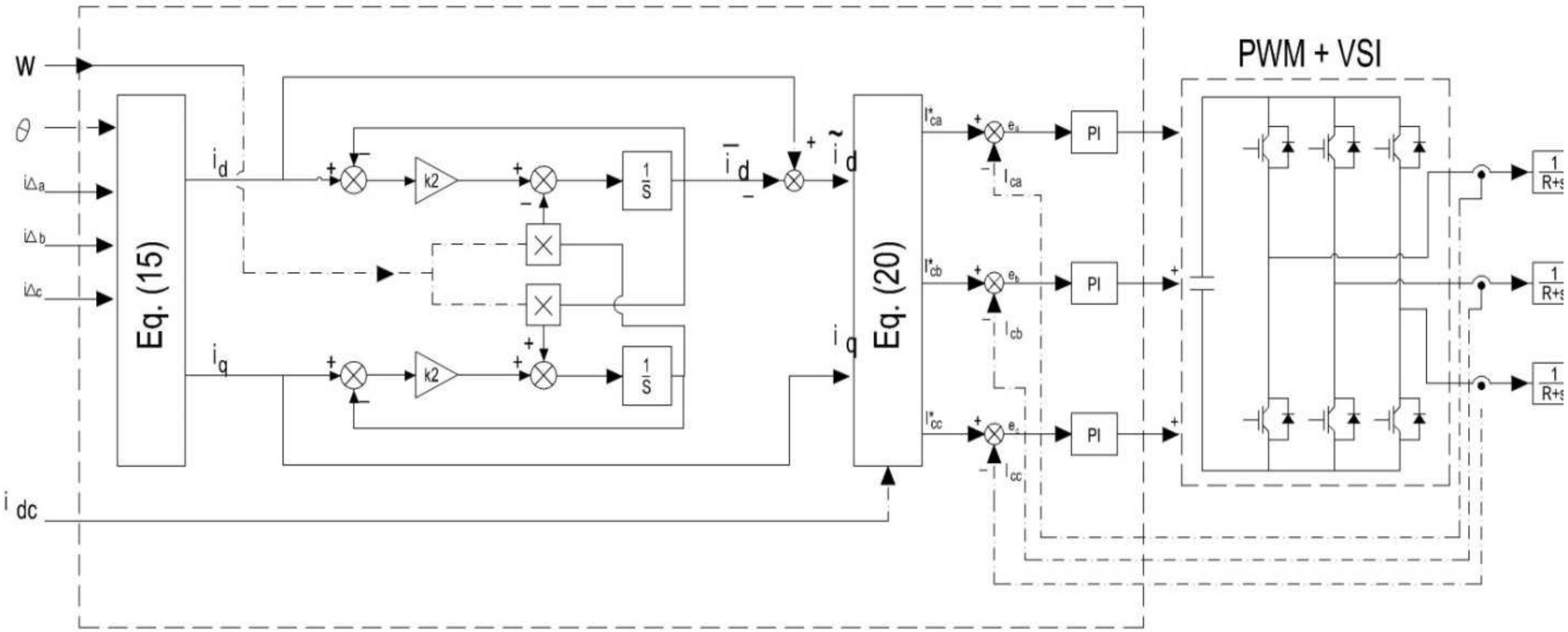


Figure 9: The proposed sub-control system unit for each Inverter

3.) Proposed Control Strategy B) Sub Controller

Beside this, the un-balanced load currents are also important power quality issue that may reduce the performance of the APF.

For this reason, the obtained i_d and i_q components of the load current are also processed with STF in order to calculate balanced current components.

$$\begin{bmatrix} i_d \\ i_q \\ i_o \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

$$\bar{i}_d(s) = \frac{K_2}{s}\left[i_d(s) - \bar{i}_d(s)\right] - \frac{\omega}{s}\bar{i}_q(s)$$

$$\bar{i}_q(s) = \frac{K_2}{s}\left[i_q(s) - \bar{i}_q(s)\right] + \frac{\omega}{s}\bar{i}_d(s)$$

3.) Proposed Control Strategy B) Sub Controller

After obtaining the balanced and undistorted current components, the fundamental and harmonics components of instantaneous currents can be obtained by using equations,

$$\tilde{i}_d = i_d - \bar{i}_d$$

$$\tilde{i}_q = i_q - \bar{i}_q$$

In the most of the control method, a low-pass or high-pass filter is used to separate the fundamental and harmonic currents. However, there is no need for an additional filter in the proposed control method

3.) Proposed Control Strategy B) Sub Controller

Finally, the obtained current harmonic components are then transformed to the three phase converter reference currents using the inverse synchronous transform as given by,

$$\begin{bmatrix} i_{ca}^{*} \\ i_{cb}^{*} \\ i_{cc}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & -\sin\theta \\ \cos(\theta - \frac{2\pi}{3}) & -\sin(\theta - \frac{2\pi}{3}) \\ \cos(\theta + \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} \tilde{i}_d \\ \tilde{i}_q \end{bmatrix}$$

3.Simulation Results

The proposed control method is simulated using MATLAB/Simulink and power system block set environment to verify the performance of the system. Three variable RL type non-linear load is used to see dynamic performances of the modular APF. Additionally, a load is used to create adadditional unbalance currents condition in the studied system. The used parameters in these work are given in Table I.

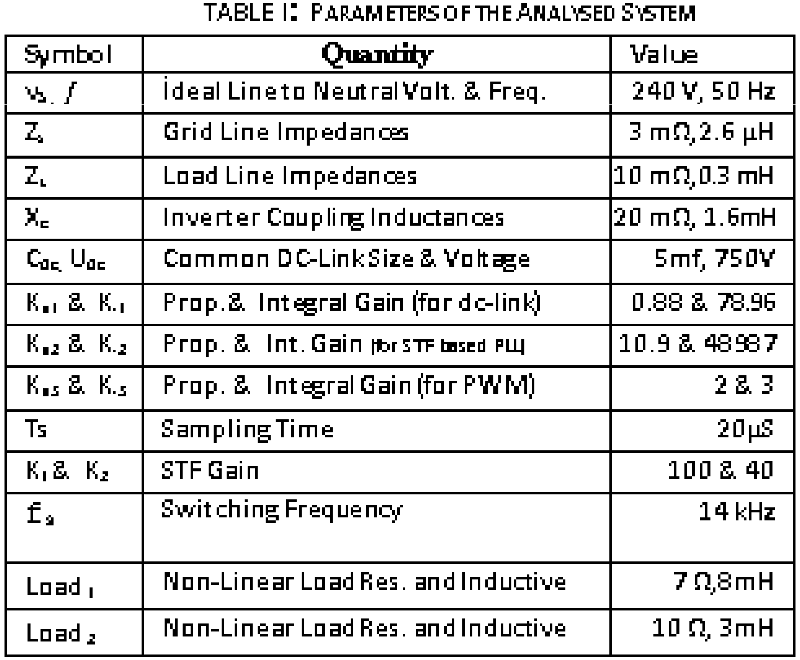


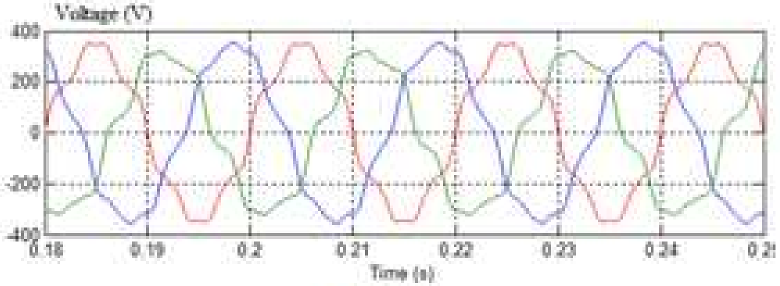
TABLE I: PARAMETERS OF THE ANALYSED SYSTEM

Symbol	Quantity	Value
v_s, f	Ideal Line to Neutral Volt. & Freq.	240 V, 50 Hz
Z_s	Grid Line Impedances	3 mΩ,2.6 µH
Z_L	Load Line Impedances	10 mΩ,0.3 mH
X_c	Inverter Coupling Inductances	20 mΩ, 1.6mH
C_{DC}, U_{DC}	Common DC-Link Size & Voltage	5mf, 750V
K_{p1} & K_{i1}	Prop.& Integral Gain (for dc-link)	0.88 & 78.96
K_{p2} & K_{i2}	Prop. & Int. Gain (for STF based PLL)	10.9 & 48987
K_{p3} & K_{i3}	Prop. & Integral Gain (for PWM)	2 & 3
Ts	Sampling Time	20µS
K_1 & K_2	STF Gain	100 & 40
f_s	Switching Frequency	14 kHz
Load$_1$	Non-Linear Load Res. and Inductive	7 Ω,8mH
Load$_2$	Non-Linear Load Res. and Inductive	10 Ω, 3mH

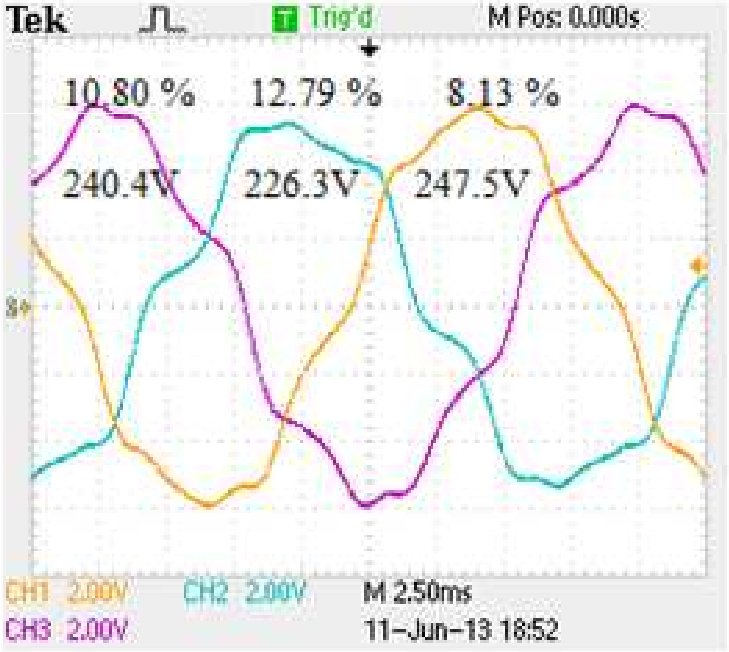
TABLE I
Parameters of the Analysed System

3.Simulation Results

a-)

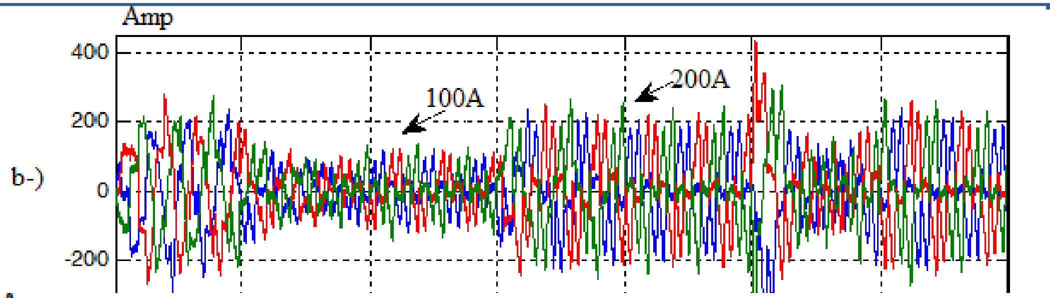


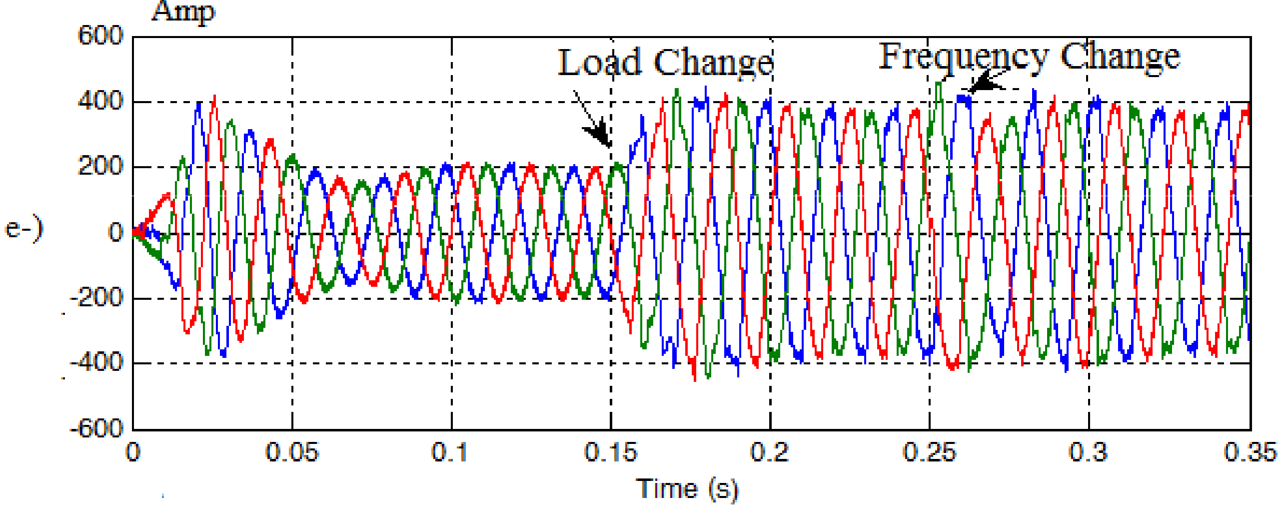
b-)

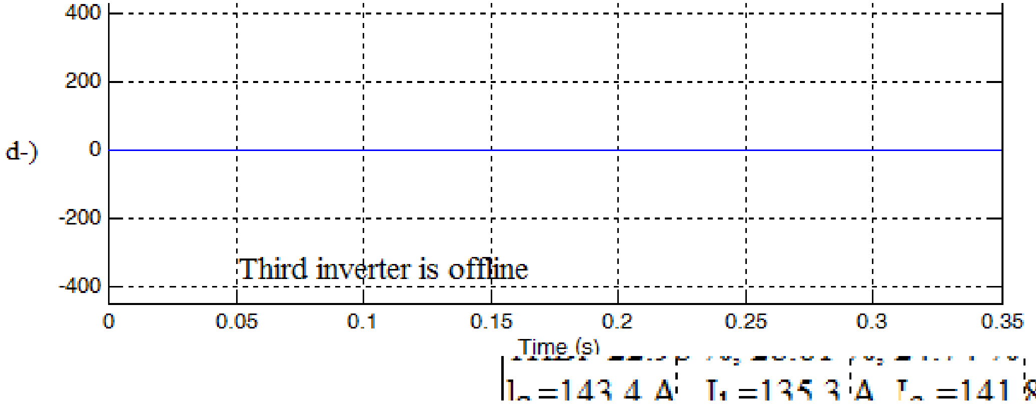


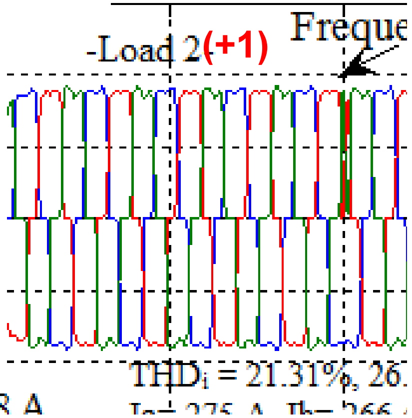
Simulation Results

3.Operation with Sing



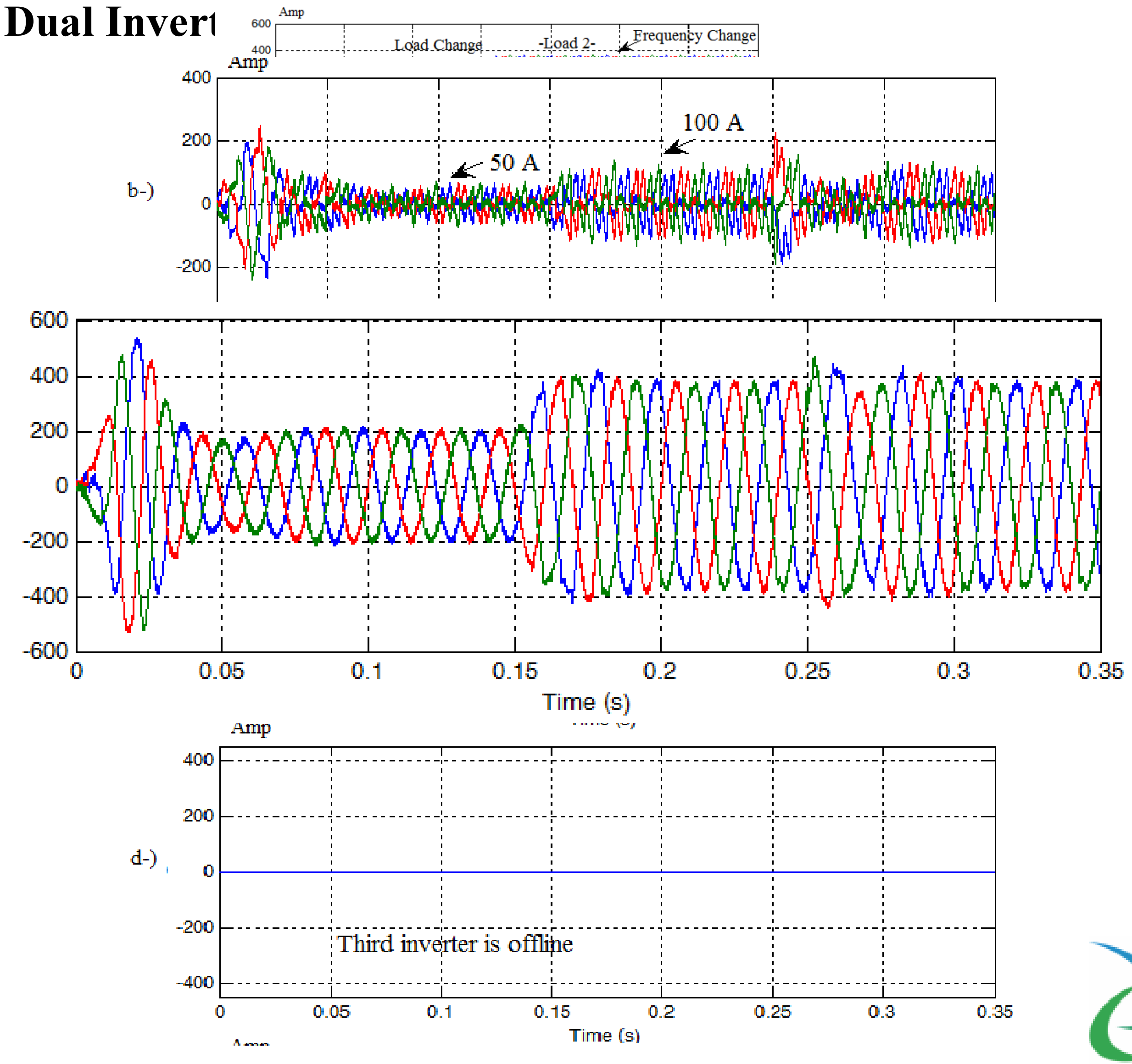






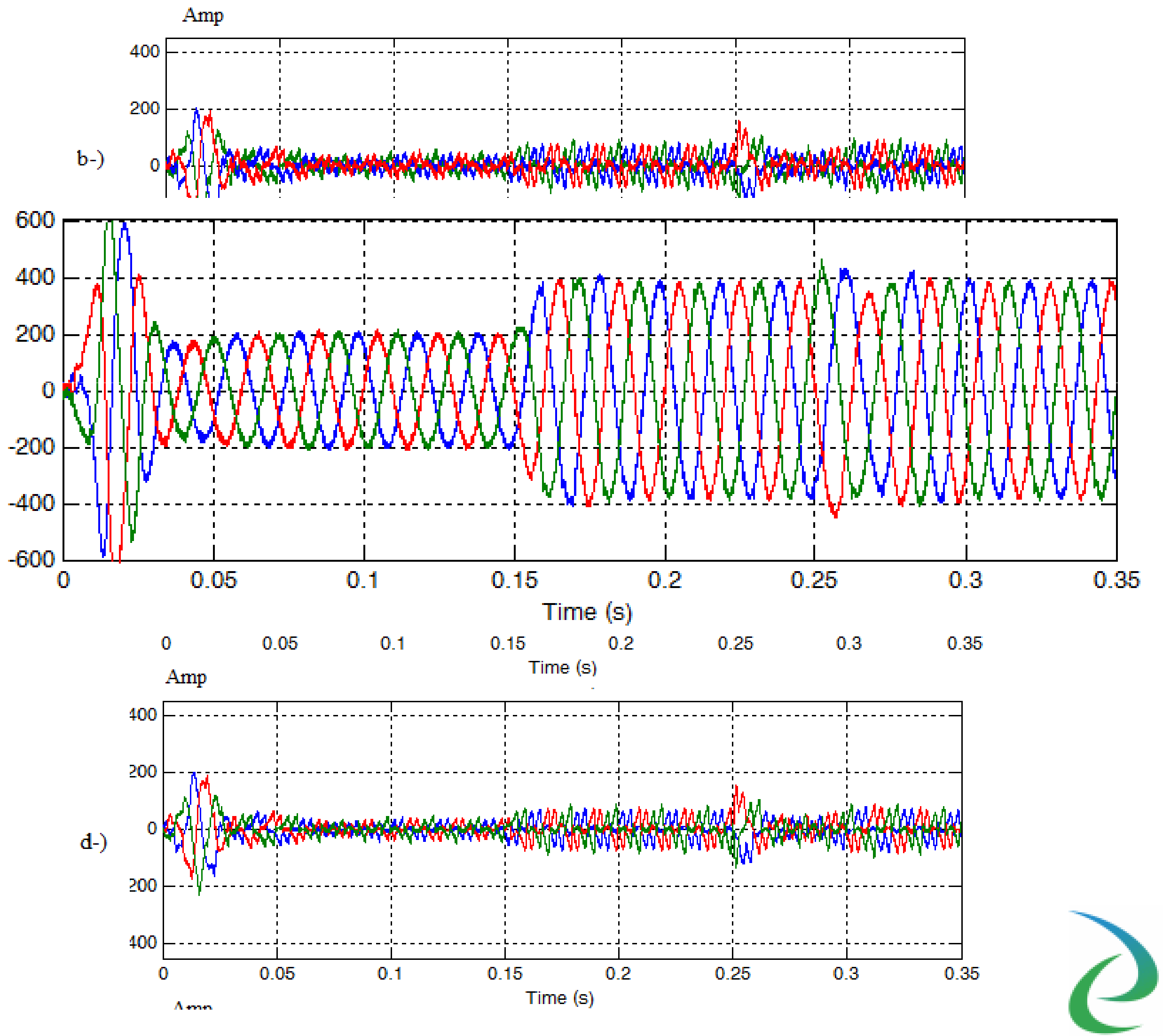
Simulation Results

3.Operation with Dual Invert



Simulation Results

3.Operation with Triple Inverter



Conclusion

In this paper, we have considered the design of a modular active power filter (APF) in order to distribute the total compensation current for unbalanced nonlinear loads.

This is achieved with a flexible and un-bulky solution that maintains low power loss for the required level of harmonic suppression and reactive power compensation.

The controller complexity of the modular APFs is significantly reduced with the use of the proposed control strategy.

The proposed system comprises a main controller and a number of sub-controllers.

The former is used to determine the required common signals for each sub-controller, whereas the sub-controllers themselves use the common signals to generate the required compensation for each branch.

Conclusion

A benefit of having a modular APF system comes from the fact that a faulty sub-unit can be isolated from the system for repair whilst the system is still in operation.

Another benefit offered by a modular system is the ability to modify the number of parallel branches depending on the power demand of the plant.

A major advantage of having the type of distributed controller scheme proposed in this paper is the elimination of the need for repeated signal processing required for each inverter.

The system under study was implemented on RT-LAB real-time experimental platform to evaluate the real-time performance of the system. The THD of the grid currents with use of proposed method are reduced to ~3 % under both grid voltage and frequency fluctuations conditions, which meets the IEEE 519-1992 recommended standard.

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Dublin, Ireland

&

Dr. Malabika Basu

Dublin Institute of Technology (DIT), Dublin, Ireland

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Thank you