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# Control Strategy for Improvement of PQ in Dc Systems Incorporating PR Controller

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***Abstract***— ***Proportional-resonant (PR) controllers for current control are described in this paper. They are suitable for converters connected in a grid. In single phase converters, steady state error problems with PI controller are reduced with this controller. Also, with PR controllers, the selective compensation of harmonics is possible. The critical power quality issue that is degrading the performance on load side and source side is the voltage and current ripples. This causes reliability concerns. These can be overcome by using PR controller. In this paper, designing of PR current controller as a selective harmonic compensator has been presented.***

***Index Terms***— ***Harmonic compensation, Proportional resonant controller***

## I. INTRODUCTION

Expression of the face is a crucial aspect in human Harmonics produced by Power Generation Systems especially due to interconnected systems is the severe power quality issue. So, it is very essential that the harmonics produced by these converters are to be controlled to reduce their harmful effects on the power quality. There can be a significant impact on current quality supplied to the load because of the current controller. So, in order to avoid harmonics, it is essential that controller gives sinusoidal output of high quality and minimal distortion. PR controller stretches infinite gain at resonant frequency and removes constant errors. Harmonic filtering or compensation is accomplished by using PR controller.

## II. RIPPLE ENERGY & VOLTAGE

A 1-Ø PWM-regulated (H-bridge rectifier), as portrayed in Fig 1 is chosen to analyze the objectives of this paper. All the components are treated as ideal to simplify the analysis.

The rectifier source current controlled to be sine wave as $i_s = \sqrt{2}I_s \sin(\omega t)$ and in Ø with source voltage $v_s = \sqrt{2}V_s \sin(\omega t)$, then the source power is

$$p_s = v_s i_s = V_s I_s - V_s I_s \cos(2\omega t) \qquad (1)$$

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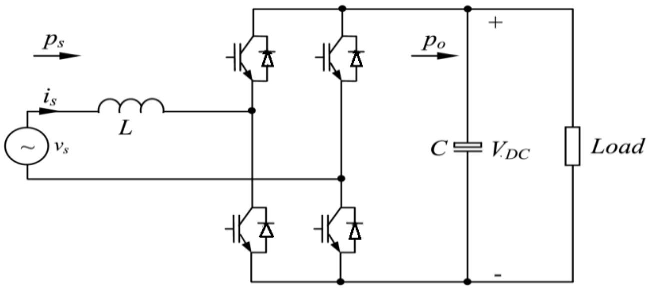


**Fig 1. 1-Ø (H-bridge) PWM-regulated rectifier.**

$V_s$ *and* $I_s$ are source rms voltage & input rms current correspondingly. $\omega$ is angular frequency. The AC power source embraces of two terms; one is continual $V_s I_s$ and a II-order ripple module $-V_s I_s \cos(2\omega t)$.

During a charging period, the energy change that is accumulated in DC bus capacitor is defined as ripple energy. It can be calculates as [5],

$$E_r = \frac{V_s I_s}{\omega} \qquad (2)$$

The capacitor ripple voltage (peak-to-peak) [4] is formulated as,

$$\Delta V_{DC} \approx \frac{E_r}{C V_{DC0}} \qquad (3)$$

$V_{DC0}$ is the average value of $V_{DC}$. This implies that the rise in capacitor value decreases the voltage ripple of DC-bus. Due to this, the weight, volume and system cost increases, the reliability of the system is decreased. If possible, this should be avoided.

## III. THE RIPPLE ELIMINATOR

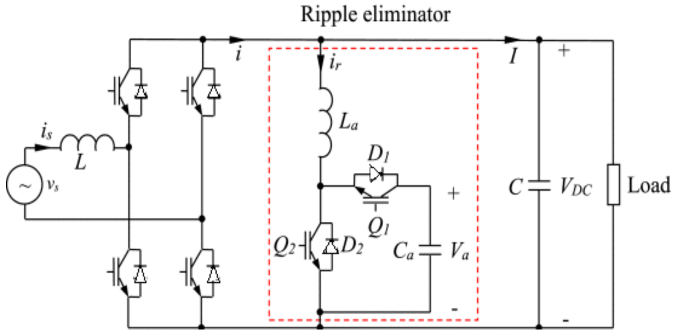


**Fig 2. Ripple eliminator**

### *A. RIPPLE ELIMINATOR (RE) OPERATION*

It It performs as two-way converter with boost-buck operation. It looks like inverter one phase is connected with DC bus and auxiliary capacitor $C_a$ to divert bi-directional current $i_r$ from the DC bus.



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To trace current with ripples, switches Q1 & Q2 are to be controlled in separate switching operations.

In the positive half cycle i.e. charging mode, only Q2 is operated with Q1 OFF. In this mode, Q2 operated by PWM signal. This gives the ripple current $i_r$ in the positive half cycle. So, the RE behaves a boost converter. In the negative half cycle, Q1 operated by a PWM signal with Q2 OFF. This gives the ripple current $i_r$ in negative half cycle. So, the circuit behaves a buck converter. Hence, in an auxiliary inductor, during a switching period, the direction of current flow can be positive or negative.

Second switching technique is operating the switches alternatively. So, Q1 & Q2 be operated by two reverse PWM signals to trace the current with ripples. The voltage against auxiliary inductor is $V_{DC}$ and $V_{DC} - V_a$ with respect to switches operating modes. In a single PWM period, Q1 will be ON and Q2 will be kept OFF with an inverse signal and the reverse will be repeated in the other period. In this case, in a single switching mode, current through the inductor be either positive/ negative. It can be considered as a better feature as tracing current is easy at zero-crossing points/huge ripple current situations. As main aim is to decrease voltage ripples in DC-bus capacitor, high values of auxiliary current ripple need not be considered which are due to high switching frequency. If the ripple is large then small inductor is required. This will diminish the magnitude of ripple eliminator. Here, RE is operated with different working conditions. Switches *Q*1 & *Q*2 be operated alternatively to trace the ripple current.

## IV. PROPORTIONAL RESONANT CONTROLLER

PR current controller could be formulated as:

$$G_{PR}(s) = K_p + K_i \frac{s}{s^2 + \omega^2} \qquad (4)$$

$K_p$, the proportional term, $K_i$, the integral term, ω, the frequency resonance term. In this controller, at the ac frequency $\omega_0$, the ideal resonant term produces infinite gain and at other frequencies, there is no gain and phase shift.

The term $K_p$ calculates the bandwidth, system dynamics, gain and phase margin. The ideal PR controller may arise problems with stability because of infinite gain. So, PR controller is changed to non-ideal by adding damping term,

$$G_{PR}(s) = K_p + K_i \frac{2\omega s}{s^2 + 2\omega s + \omega^2} \qquad (5)$$

the gain (at ac frequency) of PR controller and ω is not infinite. This is even big enough to give only a minimal steady state error. Due to its finite precision, this makes the controller suitable in the digital systems.

## V.CONTROL OF RE USING PR CONTROLLER

In this paper, Continuous Conduction Mode is opted due to its high performance in tracing the current. The tracing of ripple current can be performed as: a) to produce a reference current with ripple and b) to trace the reference current with ripple. The auxiliary capacitor voltage must also be controlled properly to achieve the proper current tracking. The control strategy of RE is as follows.

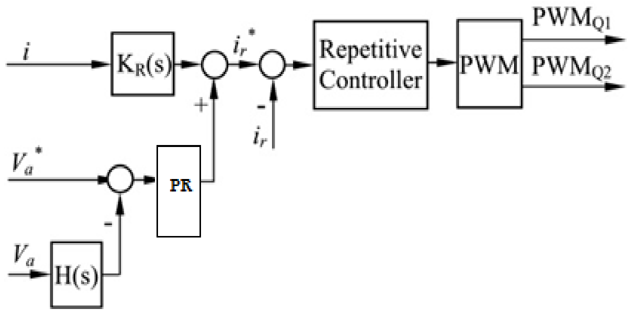


**Fig 3. Ripple eliminator control strategy**

A low pass filter is chosen for ripple elimination and to maintain the DC (average) component at some point. It is written as,

$$H(s) = \frac{1 - e^{-\tau s/2}}{\tau s/2} \qquad (6)$$

Here $\tau$ is the fundamental period which filters out other components so as to extract the average voltage for control.

The II-order harmonic component of the current *i* to be traced can be drawn using the resonant filter as,

$$K_R(s) = \frac{K_h 2\xi h\omega s}{s^2 + 2h\xi\omega s + (h\omega)^2} \qquad (7)$$

Adjusted at the II harmonic component with ξ value of 0.01, h as 2 and $\boldsymbol{\omega} = 2\Pi f$. $K_R$ (s) can be designed for harmonic components at other frequencies. For example, $K_R$ (s) includes a term h=3 for third harmonic component. Voltage across auxiliary capacitor can be manipulated by giving the extracted current to PR controller output which forms the reference ripple current $i_r^*$.

The regulation issue is necessarily to track the current. The control strategy in repetitive way can be chosen as the reference ripple current is periodic.

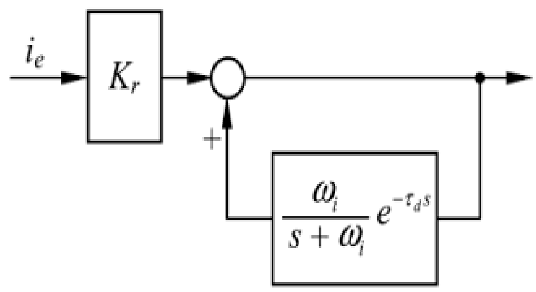


**Fig 4. Repetitive controller**

The internal model of repetitive controller involves low pass filter with a delay term. High gains are introduced at the system and other harmonic frequencies. This reduces periodic errors.


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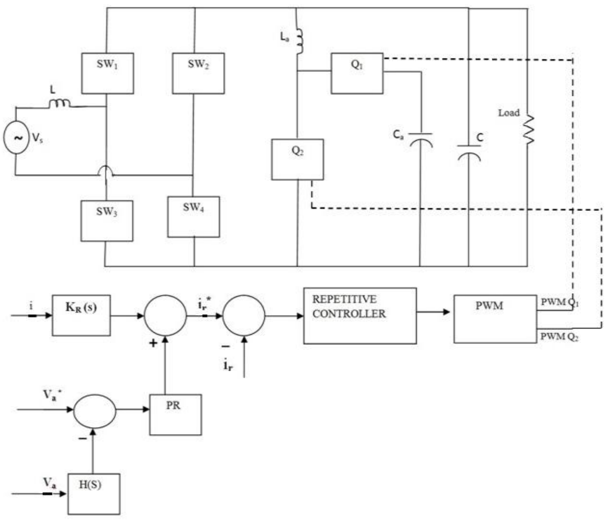
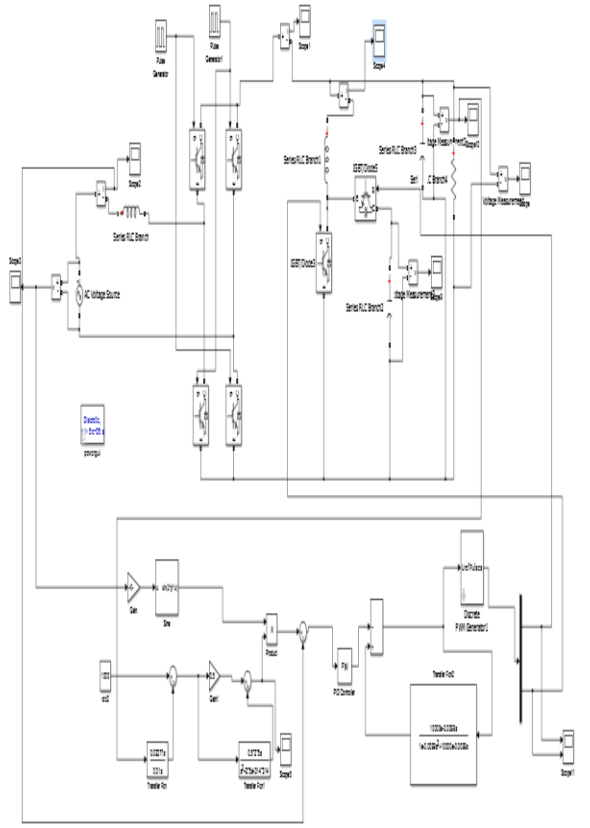



**Fig 5: Block diagram of ripple eliminator with PR controller**

In the above block diagram, $SW_1$, $SW_2$, $SW_3$ and $SW_4$ represents the four IGBTS. $Q_1$ and $Q_2$ are the controlling switches in the ripple eliminator. $L_a$, the auxiliary inductor. C represents DC bus capacitor and $C_a$ the auxiliary capacitor. PWM $Q_1$ and PWM $Q_2$ are the pwm signals given to control the switches $Q_1$ and $Q_2$.

## VI. SIMULINK MODEL OF RIPPLE ELIMINATOR WITH PR CONTROLLER



## VII. EXPERIMENTAL RESULTS

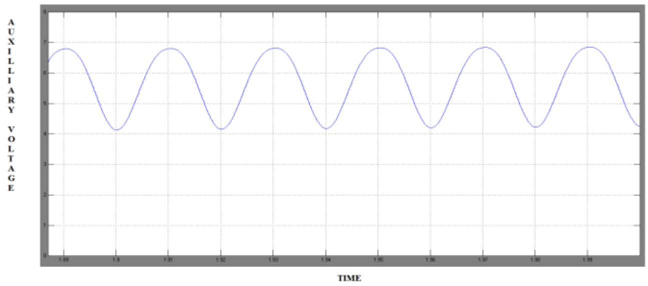



**Fig 6(a) Auxiliary capacitance voltage Vs Time**

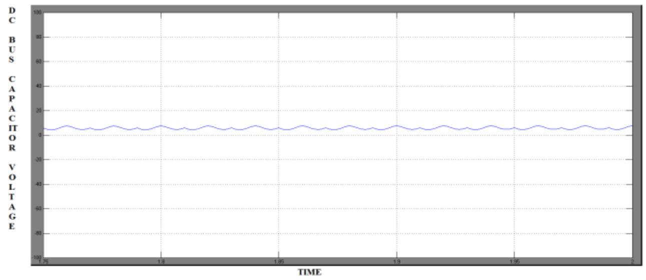



**Fig 6(b) DC bus capacitor voltage Vs Time**

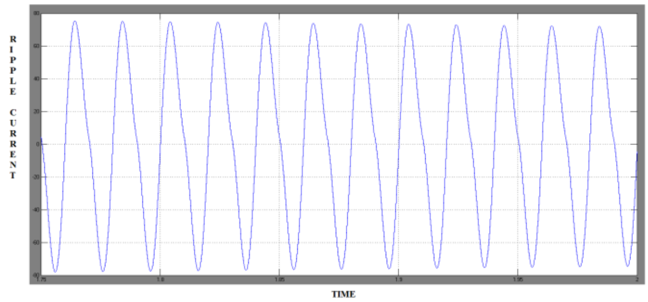



**Fig 6(c) Ripple current Vs Time**

Figure 6 shows the results of ripple eliminator controlled using PR controller. It is observed that the ripple across dc capacitor is minimized. As the voltage against capacitor is maximized, ripple voltage across $C_a$ is decreased. Whenever the voltage across $C_a$ is increased, large frequency ripples of current across auxiliary inductor also increases.

## VIII. TOTAL HARMONIC DISTORTION (THD) RESULTS

The THD of ripple eliminator with & without PR controller are tabulated as below:

**Table 1. THD results**

| System | THD value |
|---|---|
| Without PR controller | 13.77 |
| With PR controller | 8.6 |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## IX. CONCLUSION

The ripple eliminator concept has been proposed to enhance the power quality, voltage ripple reduction in DC systems & limit usage of electrolytic capacitors. Compared to [6], this paper consists of following works: 1) the capability to draw away the current with ripples from the DC bus to improve its performance 2) repetitive controller has been developed to regulate one ripple eliminator. It reduces the ripple current to reduce voltage ripples.

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