

Micro-controller operated pre-regulator for active power factor correction

TECHNICAL FIELD

5 The present invention relates to a pre-regulator for use in electronic ballast and electronic power supply systems and more particularly to a method and apparatus for control of input current to such systems.

BACKGROUND ART

10 Pre-regulators typically provide current to regulated or unregulated loads, such as electronic ballast and electronic power supply systems. The pre-regulator controls the power factor of the load. In particular, the power factor is the ratio of the actual power of an alternating or pulsating current to the apparent power drawn. For optimal efficiency, the power factor is 1.0, and the
15 pre-regulators attempt to provide this desired value or a value as close as possible to 1.0.

 When the input current relative to the input voltage contains phase displacement, harmonic distortion or both, the power factor will be less than 1.0. The amount of displacement between the voltage and current indicates the
20 degree to which the load is reactive. Harmonic distortion, that is, the production of harmonic frequencies, arises from the non-linear operation of the load in drawing power from a mains sinusoidal supply voltage.

 Known pre-regulator devices or systems generate the current by analysing the input voltage and deriving an in-phase sinusoidal current through one of the
25 following:

1. Analog programming which includes the use of electrical components such as capacitors, and resistors, that are susceptible to aging. Conventional power factor controllers often assume the input voltage to the ballast will be substantially sinusoidal. Non-linear loads drawing power from the power mains
5 can temporarily distort the mains voltage resulting in a substantially non-sinusoidal input voltage. Input current control dependent on the non-sinusoidal input voltage is difficult and may lead to a power factor correction much less than 1.0.
2. Digital programming by means of complex algorithms from a reference
10 sinusoidal lookup table. The converter is controlled by two or more feedback loops requiring the sampling of the input voltage/current as well as computing intensive algorithms.

The input voltage to the pre-regulator is usually the operating voltage of the power supply systems, which may be different among the systems, and may be
15 constant or varying.

Accordingly, it is desirable in electrical and electronic systems to provide a pre-regulator which allows an in-phase sinusoidal current to be drawn into a electrical and electronic load, such as a electronic ballast, connected to the output of the pre-regulator such that the current has a power factor at or near to
20 unity and has low harmonic distortion.

DISCLOSURE OF THE INVENTION

The present invention seeks to overcome one or more of the disadvantages of the prior art.

The invention provides a method of generating an input current to an electronic load at a power factor at or approximately unity including providing an input voltage to said load; sampling said input voltage to said load in a processing device at predetermined intervals to determine the amplitude A required for producing at the output of said processing device a discrete time switching signal sequence related to determined value A and switching points k by the relationship :

$$P(k) = PWM_{max} \left\{ 1 - A \left(\sin \frac{k\pi}{K} \right)^{\frac{1}{N}} \right\} \quad k = 0, 1, 2, 3, \dots, K$$

where PWM_{max} is the maximum duty cycle of the switching sequence and K is the number of samples, switching the input voltage to said load using the switching signal sequence to generate the input current, and selecting the value of N when producing the switching sequence such that the waveform of the generated input current is in or approximates a sinusoidal form.

The invention also provides a controller for controlling an input current to a load including a processing device having an input for receiving an input voltage to the load. The processing device samples the input voltage to determine amplitude A at discrete sampling points k to produce a discrete time switching signal sequence related to A and k by the relationship $P(k) = PWM_{max} \left\{ 1 - A \left(\sin \frac{k\pi}{K} \right)^{\frac{1}{N}} \right\} \quad k = 0, 1, 2, 3, \dots, K$. A switching device is controlled by the switching signal to switch the input voltage to the load to produce the controlled input

current. The value N is selected to produce an amplitude of the input current in the form of or approximating a sinusoidal form.

Preferably, the processing device is a programmed micro-controller.

The invention also provides a pre-regulator for an electronic ballast
5 including the above micro-controller.

Use of high speed switching of a discrete time sequence modulated signal controlled by value N ensures a smooth sinusoidal input current waveform close to the voltage, while factor A ensures that waveform is sinusoidal, closely matching the waveform of the voltage. Thus, the combined usage of both factors
10 achieves a power factor close to 1.0 for the pre-regulator. Switching at the precise duty cycle at every point on the sinusoidal input voltage ensures a smooth sinusoidal input current.

BRIEF DESCRIPTION OF THE DRAWING

15 A preferred embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 shows a schematic circuit diagram of one embodiment of the invention;

Figure 2 shows a graph of the switching sequence over time; and

20 Figure 3 shows a graph of input current against value N .

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to Figure 1 of the drawings, an a.c. voltage source 5 applies an a.c. voltage V_{ac} via an EMI filter 6 to a bridge rectifier comprising diodes 7, 8, 9
25 and 10. The rectified voltage comprises the input voltage V_{in} to the pre-regulator

4. Pre-regulator 4 includes an intrinsic boost converter comprising inductor 11, MOSFET device 13, diode 16 and capacitor 15. The output current is then applied to resistive load 17. The gate drive 14 is controlled by pulse width modulator 19. A micro-controller 20 may be included to accommodate to a marginally or continuously varying load. The modulator 19 produces a discrete time sequence of pulse width modulated signals for controlling switch 14.

Where the load is fixed, a single predetermined sequence of pulse width modulated signals is used. Where the load is marginally varying, a number of predetermined sequences are stored and the output voltage V_o is sensed and input to the controller 20 which selects an appropriate stored sequence dependent on the output voltage value V_o sensed. This feedback arrangement can be expanded to provide derived sequences on a continuous basis for a continuously varying load. A simple control function is provided by the controller 20 to continuously vary the PWM sequences based on the feedback output voltage V_o .

The pulse width modulation control factor is related to the derived values by the relationship:

$$P(k) = PWM_{max} \left\{ 1 - A \left(\sin \frac{k\pi}{K} \right)^{\frac{1}{N}} \right\} \quad k = 0, 1, 2, 3, \dots, K$$

Referring to Figure 2, a graph of the value $P(k)$, for a family of values of N over time is shown where:

1. $\frac{1}{T}$ is the base frequency of the PWM generator.
2. $\frac{1}{2(kT)}$ is the frequency of the a.c voltage (typically 50Hz or 60Hz)
3. PWM_{max} is the maximum duty cycle of the PWM sequence.

4. $1 > A \geq 0$ determines the minimum duty cycle required for proper discontinuous-mode operation of the power inductor 11 near and at peak values of the AC input sinusoid V_{ac} . A may be marginally varied to accommodate marginal changes in resistive load 17.
- 5 5. The value N shapes the resultant A.C. input current according to Figure 3. As N increases the input current approaches a sinusoidal form, as N decreases the input current approaches a bell-shaped form. N is selected for a particular load such that the input current is near to sinusoidal as possible.

The modulation switching is synchronized with the a.c. input voltage by
10 means of a zero-crossing detector 22.

It will be appreciated that further embodiments and exemplifications of the invention are possible without departing from the spirit or scope of the invention described.

CLAIMS:

1. A method of generating an input current to a load at a power factor at or approximating unity including the steps of:

- a) providing an input voltage value to said load;
- 5 b) sampling said input voltage to said load in a processing device at predetermined intervals to determine amplitude A of a switching sequence;
- c) producing a discrete time switching signal sequence related to determined value A, for a predetermined load, and sampling points k by the relationship:

$$P(k) = PWM_{max} \left\{ 1 - A \left(\sin \frac{k\pi}{K} \right)^{\frac{1}{N}} \right\} \quad k = 0, 1, 2, 3, \dots, K$$

where PWM_{max} is the maximum duty cycle of the switching sequence and K is the number of samples;

- d) switching the input voltage to said load using the switching signal sequence to generate the input current; and
- 15 e) selecting the value of N when producing the switching sequence such that the waveform of the input current is in or approximates a sinusoidal form.

2. A method according to claim 1 wherein the processing device is a
20 programmed micro-controller.

3. A method according to claim 1 or 2 wherein the method includes synchronizing the switching with zero crossings of the input voltage.

4. A controller for controlling an input current to a load including:

a) a processing device having an input for receiving an input voltage to said load ; said processing device responsive to :

- i. sample said input voltage to the load at predetermined intervals to determine the amplitude A of the input voltage at sampling points k;
- ii. produce a discrete time switching signal sequence related to determined value A and sampling points k by the relationship:

$$P(k) = PWM_{max} \{ 1 - A \left(\sin \frac{k\pi}{K} \right)^{\frac{1}{N}} \} \quad k = 0, 1, 2, 3, \dots, K$$

where PWM_{max} is the maximum duty cycle of the switching sequence and K is the number of samples;

b) a switching device controlled by said switching signal sequence to switch said input voltage to said load and produce said controlled input current; and wherein the processing means is responsive to the amplitude A of said input voltage to select a value of N in producing the switching sequence such that the waveform of said controlled input current is in the form of or approximates a sinusoidal form.

5. A controller according to claim 4 wherein the processing device is a programmed micro-controller.

6. A controller according to claim 4 or 5 including a zero-crossing detector responsive to the input signal for synchronizing the switching device with zero crossings of the input voltage.

7. A pre-regulator for an electronic ballast including a controller according to claim 4, 5 or 6.