LCC resonant converter control for high power factor rectification

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Indexing terms: Resonant power convertors, Power factor correction, Power electronics

A resonant current feedback loop is shown to provide a simple and effective method of control for the series-parallel-loaded LCC resonant converter in high power factor rectification systems.

Introduction: A well-established solution for high power factor rectification from a single-phase supply is a diode bridge followed by an appropriately controlled high-frequency DC-DC converter [1]. The boost topology operating at ~100kHz is commonly used, typically with a form of current mode control to ensure that the converter input current closely follows the full-wave rectified mains voltage.

Recent research has examined the feasibility of employing a resonant converter instead of the boost circuit in high power factor rectifiers [2, 3]; the series-parallel-loaded or LCC topology has been identified as particularly suitable. The application of resonant techniques offers the opportunity to easily incorporate a high frequency transformer (isolation is essential in many specialised systems, for example in the aerospace environment); furthermore switching frequencies may be increased to 1MHz and beyond without the penalty of switching losses, thereby allowing the miniaturisation of the transformer and filter components.

The main topic of published work has been the operation and optimisation of the power circuit [2]. Comparatively few papers have described closed-loop control strategies for achieving high quality sinusoidal input currents, with the exception of [3]. However the system described in [3] is quite complicated, requiring a voltage controlled oscillator. This Letter shows how a simple resonant current control loop may be used to achieve high power factor operation of a mains-fed AC-DC converter employing a 1MHz LCC converter.

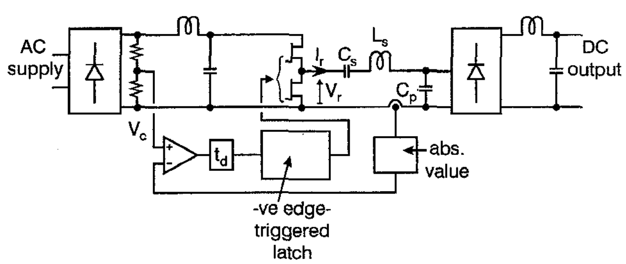

Fig. 1 *High power factor rectifier and control scheme*

System configuration: The central part of the rectifier system, Fig. 1, is a series-parallel-loaded LCC resonant converter consisting of a half-bridge transistor network and resonant components, C_s, L_s and C_p. The output voltage is derived by rectifying and smoothing the voltage across C_p. Although not shown, an isolation transformer could be included between C_p and the rectifier. The converter input voltage is formed from the AC supply by a full-wave rectifier and high-frequency filter.

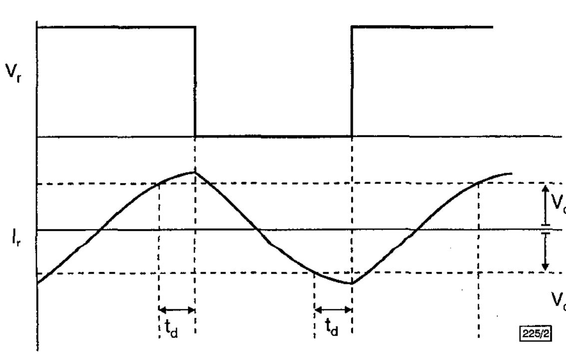

Fig. 2 *Waveforms showing operation of resonant current control loop*

The transistors operate in anti-phase with equal duty-ratios, the switching instants being determined by the resonant current control loop. The absolute value of the resonant current is compared with a reference signal V_c, which is a scaled version of the rectified mains voltage. As the magnitude of the resonant current rises, crossing the reference, the comparator output goes low signalling the latch to change state and switch the transistors. t_d is a small delay time. Sketched waveforms of the half-bridge output voltage V_r, resonant current I_r, and reference signal level V_c are shown in Fig. 2.

The operation of the resonant current control loop for DC-DC converter applications was described in [4]; an output voltage feedback loop and control amplifier was used to form the reference signal V_c. In addition to eliminating the voltage controlled oscillator which is normally used to generate the transistor switching signals, the resonant current control loop was shown to reduce the order of the converter transfer functions and desensitise the transfer functions to changes in operating conditions. The delay time t_d, typically provided by propagation and switching delays in megahertz converters, was shown to play an important role in damping the system poles.

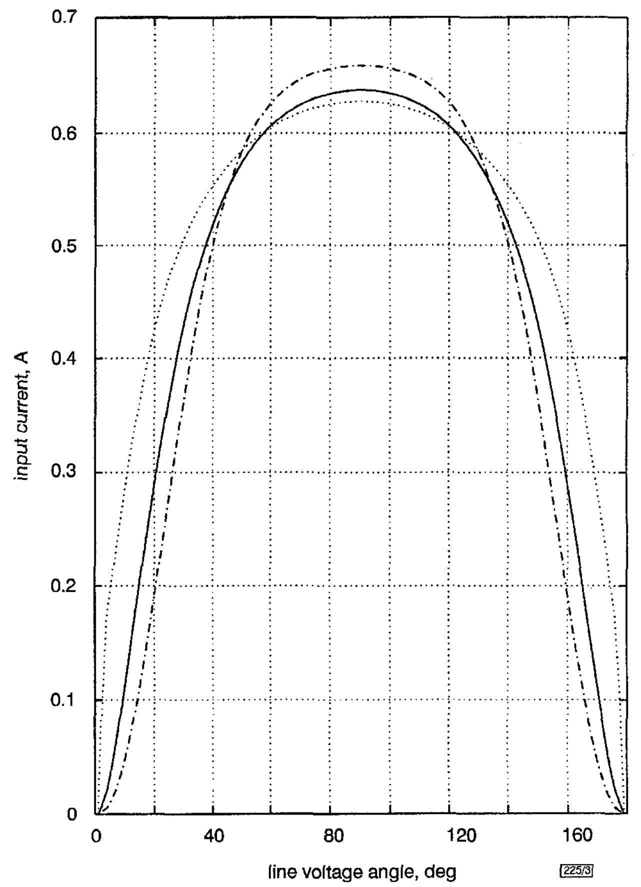

Fig. 3 *Predicted input current for 100W converter with different values of normalised delay time t_{dn}*

–·–·–·– t_{dn} = 0.07
——— t_{dn} = 0.14
·········· t_{dn} = 0.19

Effect of t_d on rectifier input current: The quasi-steady-state equivalent circuit model for the converter [2] was used to determine the input current waveform for the system in Fig. 1 with three different normalised values of t_d (Fig. 3), the power throughput being 100W from the 230V mains. The values of t_d are normalised to the series resonant period which is $2\pi\sqrt{[L_sC_s]}$. Delay times outside the range used in Fig. 3 are not permissible since the current loop would then operate incorrectly at some point over the mains waveform, degrading the input current. The maximum and minimum values of delay time arise since the intercept of the resonant current feedback with the reference must always occur as the current rises between the zero crossing and peak of the waveform.

All three values of normalised delay result in predicted input current waveforms which closely resemble a half sinewave (Fig. 3). The total harmonic distortion of the complete waveform increases from 0.88 to 2.18% as the normalised delay t_{dn} increases from 0.07 to 0.19, indicating that smaller values of t_{dn} are slightly more desirable. The precise value of t_{dn} is not particularly critical, providing that it lies within the permissible range.

Practical verification: To demonstrate the operation of the rectifier system in Fig. 1, a 100W mains-fed prototype was constructed with a switching frequency of 1–1.5MHz. The DC output voltage was 60V. The prototype was designed using the procedure in [2] resulting in resonant component values of: C_s = 3.0nF, L_s = 16μH, C_p = 3.0nF. The high frequency input filter was designed to have a corner frequency of ~50kHz, one twentieth of the switching frequency, while the output filter capacitor was sized to absorb the low frequency energy pulsation of the AC supply. The delay time t_d in the resonant current control loop was selected using the analysis described in the preceding Section; a value of t_d = 200ns was used, equivalent to a normalised value of t_{dn} = 0.15. The delay time was entirely due to propagation and switching delays.

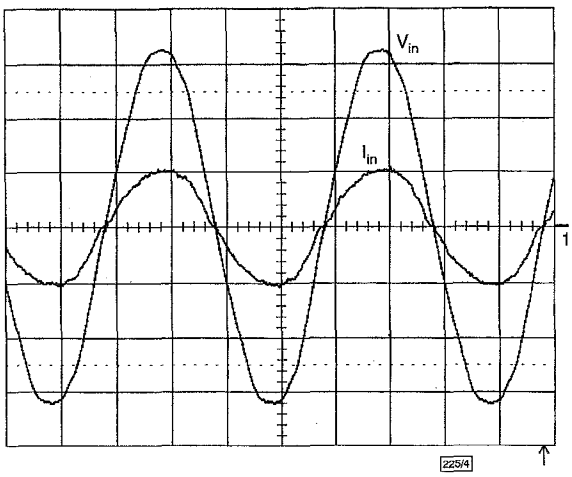

Fig. 4 *Measured input voltage and current for 100 W prototype system*

Fig. 4 shows the measured waveforms of input voltage and current for the prototype converter operating at 100W from the 230V RMS mains supply. The power factor was 0.998, the total harmonic distortion THD of the current waveform being 6.7%. The THD of the supply voltage waveform was 2.5%. The quality of the input current waveform degraded only slightly at reduced load, the power factor being 0.996 with a THD of 8.5% at 25% of full load. Also, the input waveform quality was maintained at reduced input voltage, with 170V RMS supply and 100W power throughput the power factor was 0.996 with a THD of 7.6%. The overall system efficiency was around 80% at full load.

Although not demonstrated in this work, the usual output voltage control loop could be added, the reference signal to the comparator being formed by the product of the voltage control amplifier output and the scaled full-wave rectified input voltage [1].

Conclusion: A simple resonant current loop with appropriately chosen delay time has been demonstrated to be an effective method of control for the series-parallel-loaded LCC resonant converter in a high power factor rectification system, the THD of the input current being well below 10% over a wide range of line and load conditions. Furthermore, the results demonstrate the viability of employing megahertz-switching resonant converter techniques in 230V high power factor rectification systems.

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Analysis of harmonic radiation from an integrated active antenna

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Indexing term: Active antennas

A microstrip patch oscillator is modelled using a dual LCR Van der Pol oscillator. Closed form expressions are obtained for the fundamental and first harmonic voltage amplitudes and results show reasonably good agreement with a commercial circuit simulator. These type of expressions will be useful for computer aided design of active antennas and give circuit designers greater physical insight into their operation.

Introduction: Future systems employing active antennas will require very low levels of harmonic and spurious radiation in order to meet electromagnetic compatibility specifications. Active antennas introduce nonlinear devices directly into the antenna and thus they can exhibit high levels of harmonic radiation; moreover, due to size constraints, filters cannot easily be added as in conventional systems. Planar antennas are particularly susceptible since they tend to have harmonically spaced resonances. In the case of active receiving antennas, it seems that by suppressing the harmonic resonances of the antenna the harmonic reception problem can be reduced [1, 2]. However, with patch oscillators, due to the interdependence of the active device and the patch, the solution to the problem of harmonic radiation is more complex. This Letter will present a method for obtaining closed form expressions for the level of the fundamental and harmonic amplitudes in terms of circuit parameters.

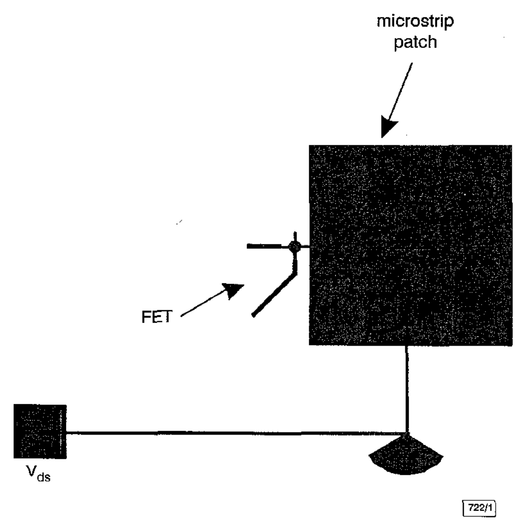

Fig. 1 *Microstrip patch oscillator*

Analysis: An example of an active antenna is shown in Fig. 1; here the drain of a field effect transistor (FET) is connected to the edge of a microstrip patch which acts as both the resonant load for the oscillator and a radiating element. The source and gate are loaded with short circuit transmission lines in order to obtain a negative resistance at the drain port.

A Van der Pol analysis of the patch oscillator was performed using a dual LCR circuit to model the patch and a nonlinear