Wave Factors for Rectifiers with Capacitor Input Filters, and Other High Crest-Factor Loads

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***Abstract*—Conventional, capacitor-input-filtered, full-wave rectifier power supplies draw much higher peak and rms line currents than the supply power drains would imply if the loads were resistive. Effective multiplication factors—termed wave factors—range from 5 to 15 for peak, and from 2 to 3 for rms, while remaining between 0.7 and 1 for average. Experimental data verify theoretical calculations for the wave factors involved.**

Ordinary clip-on and other conventional ammeters, measuring average but calibrated to read in rms for an equivalent sine wave, are thus unable to account for the difficulties sometimes encountered in the field. These include apparently undersized fuses, breakers and lines, plus severe clipping of the line voltage wave at the load.

Solutions include use of auxiliary line inductors, plus wider recognition of the need for true rms metering with adequate crest factor capability in making all line current measurements. Implications for UPS (Uninterruptible Power Supply) manufacturers and users are also discussed.

Wave factor WF is defined as the ratio of actual current drawn, to that which would be drawn by a resistive load with the same power consumption. Wave factors are derived for peak, rms and average input currents to full-wave rectifiers with capacitor input filters.

INTRODUCTION

POWER-LINE currents drawn by capacitor-input filtered, rectifier power supplies are far from sinusoidal. Their inherently spik-y nature is caused by the fact that the filter capacitor charges only during the topmost portion of the sinusoidal voltage wave of both polarities in the full-wave situation. The resulting high crest factor (ratio of peak to rms) for the current that flows, must be taken into account in sizing wires, fuses, breakers and Uninterruptible-Power-Supply (UPS) capabilities. In some cases, auxiliary filtering, usually involving line inductors, may be required to reduce peak and rms currents from the excessive values that might otherwise occur.

In many supplies, a small line inductor is supplied implicitly via the leakage reactance of the transformer often used to provide line-isolation and the correct ac voltage for the particular application. It is the usual presence of this leakage reactance that has to a large degree masked the existence of the problem to date.

The relationships among peak, rms and average values of input current in capacitor-input filtered rectifiers have been studied previously in respect to stresses on diodes and on the capacitors themselves. [1, 2, 3] As electronic power supplies and other power systems proliferate, however, it becomes of interest to study and define the effects of high crest-factor power demand on a broader basis.

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Two changes in design and application of rectified power supplies are making the high crest factor current situation more critical. One is the growing tendency to rectify the line directly, without isolation or step-down transformer. In many applications the rectified line is then used via a dc/dc converter, to obtain higher or lower dc voltages, sometimes regulated via an overall loop around the converter. Benefits of this approach include decrease in size and weight due to elimination of the 60 Hz transformer, and reduction in size due to use of the higher-voltage filter capacitor.

A second change is in application of power supplies to systems in which power must be uninterruptible, so that it is supplied via electronic power drivers operating from batteries that are trickle-charged on a continuous basis. In such systems the amount of power reserve that must be supplied is expensive, hence power budgets must be examined more critically than heretofore. Equally if not more important, electronic systems can typically supply certain peak currents, independent of the rms involved. Spik-y current requirements can conceivably limit drive capabilities of such uninterruptible supplies to figures well below nominal ratings. One of the reasons that this problem hasn't yet surfaced is that most UPS are being procured with large amounts of expansion in mind. When the systems they are associated with are indeed expanded, some will have to be modified, or appropriate chokes or filters added, to obtain power outputs that approach ratings.

With ordinary capacitor-input filtered full-wave supplies and no line inductors, values of peak line current can actually be 5 to 15 times·peaks computed on the basis of a resistive load assumption at the power level involved. Rms line currents can be 2 to 3 times the values computed on the basis of similar, unrealistic assumptions. Even with typical inductances supplied by transformer leakage reactances, peak current can be 2 to 3 times, and rms current 1.25 to 1.5 times, values computed on the basis of a resistive load assumption.

Current readings taken with conventional, clip-on or other ammeters typically measure the absolute average value of the line current, as most such meters are average-converting devices calibrated to read in terms of the rms value of a hypothetical, input sine wave. Not surprisingly, however, the average line currents are somewhat lower than would be expected with sine waves, when the load is a capacitor-input-filtered rectified supply. Typical factors range from 0.7 to 1.0 times the readings that would be obtained for sine waves. Thus conventional meter