POWER QUALITY INTERNATIONAL

e-News

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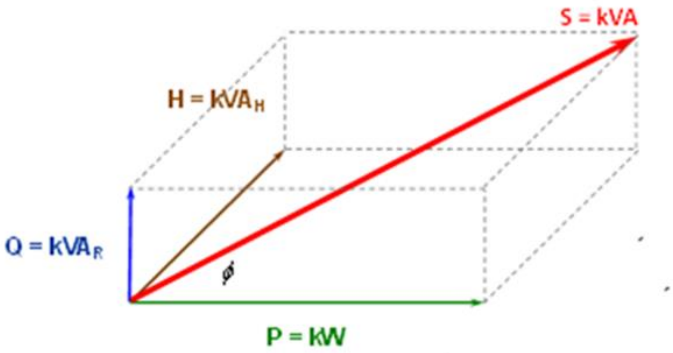
The Calculation of Circuit and Load 'Penalty Losses' [1]

In 2003, PQI developed IEEE Std C57.110 compliant software that allowed our engineers to calculate any transformer's nonlinear losses and efficiency. The PQI Calculator™ software could also compare the performance of any two transformers, including HMTs with complex zero-sequence flux cancellation windings. Based on first costs and utility rates, the software could calculate payback, return-on-investment and EPA environmental benefits.

However, based on many low voltage transformer replacement measurement and validation outcomes, PQI has consistently achieved energy savings that are more than twice those attributed to transformer efficiency improvements alone. Although we've suspected the likely sources of these additional savings, until recently, we've been unable to confirm their sources, estimate their values or include them in retrofit or power system optimization proposals. To maximize utility subsidies, estimated circuit and load 'penalty loss' reductions are essential.



P, Q, H & S Relationships [2]

Figure 1

While the relationship between $PF_{DISPLACEMENT}$, $PF_{DISTORTION}$, PF_{TRUE} and 'penalty losses' is complex and difficult to generalize, the well-established concept of Power Factor does provide some measure of the relationship and is useful when comparing the relative impacts of nonlinear loads, if harmonics are incorporated into the Power Factor definition, as shown in *Figure 1.*

The PQI Solution™ – To further demonstrate the relationship between PF_{DISP}, PF_{DIST}, PF_{TRUE} and 'penalty losses', the lower Linear Load Multiplier Curve, shown in *Figure 2,* represents the relationship between PF_{DISP} and displacement 'penalty losses' in PU of Unavoidable 60Hz Losses. Similarly, the upper Nonlinear Load Multiplier Curve represents the relationship between PF_{DIST} and distortion 'penalty losses' in PU of Unavoidable 60Hz Losses. To demonstrate this procedure, we have used a PF_{DISP} of 0.80 and PF_{DIST} of 0.8125.

To determine the combined displacement and distortion 'penalty losses' in PU of Unavoidable 60Hz Losses, the upper Nonlinear Load Multiplier curve has been raised from a multiplier of 1.00 at unity PF, which would be its position in the absence of inductive (displacement) loading, to a 1.50 multiplier at unity PF. This point is derived from the 0.80 PF_{DISP} intersection with the lower Linear Load Multiplier curve, which is 1.50.

The intersection of 0.8125 PF_{DIST} and the Nonlinear Load Multiplier curve gives us a second multiplier of 2.60. To determine the combined displacement and distortion 'penalty losses' in PU of Unavoidable 60Hz Losses, multiply the 1.50 displacement multiplier by the 2.60 distortion multiplier, which produces a combined multiplier of 3.90 (1.50 x 2.60). The combined 'penalty losses' are therefore 3.9 times the Unavoidable 60Hz Losses. Under this loading condition, PF_{TRUE} is 0.65 lagging (PF_{TRUE} = PF_{DISP} x PF_{DIST} = 0.80 x 0.8125). To confirm the accuracy of the procedure, 0.65 (PF_{TRUE}) and the combined 'penalty losses multiplier (3.90) must align vertically.

Based on four simple measurements (kW, kVA, PF_{TRUE} and PF_{DISP}), taken at the secondary terminals of a distribution transformer, PQI can now calculate PF_{DIST}, kVA_H and the combined displacement and distortion 'penalty losses'.

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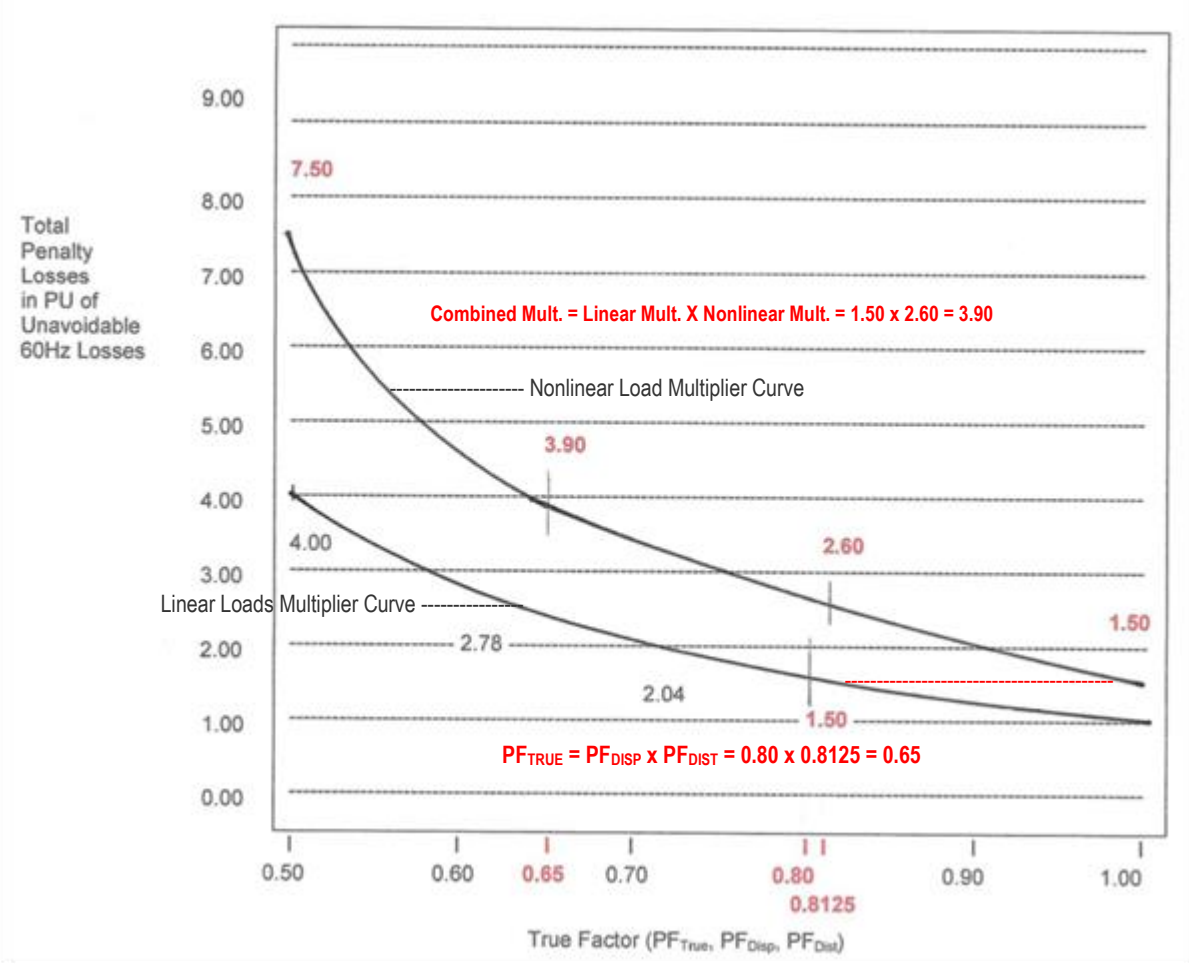
Given that most 208/120V distribution systems supply nonlinear loads that include 120V switch-mode power supplies, almost exclusively, we expect kVA_R to be insignificant. As a result, 'penalty losses' in the circuits will be due to harmonic currents while 'penalty losses' in the loads will be due to harmonic voltage distortion. Combined circuit and load 'penalty losses' are often in a range between 8% to 20% of the total load kW.

Reducing circuit and load 'penalty losses' will improve PF_{DISP}, PF_{DIST} and PF_{TRUE}, improve overall system efficiency, save energy and reduce utility costs. **The PQI Solution™** engineering services are provided on a 'no charge' basis in support of the application of our solutions.



Individual and Total Penalty Losses in Per Unit of Unavoidable 60Hz (50Hz) Multipliers [2]

Figure 2

[1] ***Penalty Losses***

'Penalty losses' are defined as consumed power that does not contribute directly to the intended work. Unavoidable transformer, circuit and load losses at 60Hz [50Hz] are excluded.

Distribution System 'penalty losses' include losses due to reactive load currents, unbalanced load currents and nonlinear load-generated harmonic currents. 'Penalty losses' also include excessive losses in pre-NEMA TP 1 distribution transformers and elevated impedance losses due to nonlinear load-generated harmonic currents.

Load 'penalty losses' include losses due to distortion of the supply voltages' sinusoidal waveforms. Load 'penalty losses' also include losses due to low voltage, when the loads are electronic.

[2] ***References:***

W. Mack Grady, Robert J. Gilleskie 'Harmonics and how they relate to Power Factor', Proc. of the EPRI Power Quality Issues & Opportunities Conference (PQA 93), San Diego, CA, November 1993