

## Utilization of Canceling Reactive Currents to Improve Power Factor

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In Industrial Circuits, the heavy use of induction motors, with their associated magnetizing currents, increases the amperage demanded from the Utility. These circuits are inductive with a Power Factor (PF) less than unity. It is customary to balance the inductive reactance of these circuits and to restore the PF toward unity by adding capacitors (CAPS) in parallel with the inductive loads or in parallel with the main plant feeds at the service entrance. When the inductive and capacitive reactances are matched, then the circuit is in parallel resonance and the amperage demanded is minimized. Typically 3000 to 4000 micro farads are added per phase to match the inductive reactance of a 100 HP inductive 480 volt motor. To maintain the balanced reactance, the capacitors must be switched on/off with the motors. If the CAPS are on while the motors are off, the plant goes capacitive, which increases the amperage demand. This complex switching task is often simplified by installing a variable capacitor bank at the service entrance with a feed-back control maximizing the Plant Power Factor. Such variable capacitor banks raise the plant PF, eliminating the PF Penalty from the bill, but they do not correct the PF within the plant nor do they reduce the I squared R power loss within the plant.

In AC circuits, as frequency increases, capacitive reactance decreases and inductive reactance increases. RCL (Resistance/Capacitive/Inductive) Resonance occurs at the frequency where the Inductive Reactance of the circuit equals the Capacitive Reactance of the PF CAP Bank. In modern circuits there are substantial harmonics caused by VFD (variable frequency driven) Motors and other solid state loads. If any existing harmonic frequency coincides with this resonant frequency, the magnitude of that harmonic increases significantly. If that harmonic is of a low order, 3<sup>rd</sup>, 5<sup>th</sup>, 7<sup>th</sup>, or 9<sup>th</sup>, then the effect of that harmonic can distort the system voltage or current wave form. This distortion causes problems such as motor overheating, breaker tripping, transformer overheating or damage to capacitors and motors. Also, in the ac circuit, a serious voltage condition occurs as a result of this Harmonic RCL Resonance. The circuit total impedance (including the CAP) is very high at the resonant frequency. If the VFDs generate harmonic current at the resonant frequency, large harmonic voltages will be developed at the CAP and at the transformer bus. These harmonic resonances are very dynamic conditions which create voltage transients that travel throughout the plant often burning out motor field coils and overheating transformers.

PF Cap banks are particularly vulnerable to the detrimental effects of power system harmonics. Most CAPS are designed to operate up to 110% of the rated voltage and 135% of the rated kVAR. Large magnitudes of current and voltage harmonics can exceed these limits and cause serious CAP bank damage. Since Capacitive Reactance is inversely proportional to the frequency, CAP banks act as sinks for the current harmonics in the system. This often causes CAP fuses to blow or CAP damage when fuses are not present. Incidentally, because of this damaging RCL Resonance effect set off by harmonics, CAPS or CAP Banks are not used for PF Correction in Navy Ships.

Utilization of modular USES Units is an improved method of PF Correction, that does not use massive capacitors or CAP Banks. The modular USES Unit can be readily retrofitted into inductive circuits without paying particular careful attention to impedance matching or without setting up the conditions for RCL Resonance. The USES Unit co-generates the capacitive reactive current instead of using large CAPS. The resonant circuit within the USES Unit consists of three-phase CAPS typically 1/50<sup>th</sup> the size of traditional PF CAPS while obtaining the same PF effect. These resonant USES Circuits are linked with wrap-around magnetic chokes that connect the electrical phases magnetically. The 3-phase, 480 volt USES Unit inserts 27 amps of canceling capacitive reactive current through each USES phase lead into the plant distribution system. This leading current migrates throughout a plant vectorially canceling any lagging inductive current, and thereby locally correcting the PF. USES Units have the benefit that they don't need to be switched on/off with the motors because if the canceling leading current saturates a plant to unity PF, then that current migrates out into the grid. This maintenance-free PF control system is less critical and the total system impedance is reduced.

Trigonometric calculations of the application of Kirchhoff's Law to the vectorial combination of amperages of different magnitudes and phase relations are given by Langsdorf (1937), in chapters 1 - 3. It is exceedingly cumbersome to apply these calculation methods to circuits as complex as the USES Unit and industrial power systems in harmonic RCL Resonance. Statements herein concerning the relationships between the of various components, such as CAPS, USES Units, motors, VFDs, conductors, etc. relate to the system metrics of power factor, harmonics, voltage, amperage, KVAR and kW taken from the Utility Bill. USES Units appear to provide reactive current that corrects the PF and lowers the amperage and kW demand of the circuit. This USES PF control system is less critical to operate and the harmonic problems are greatly reduced.

**USES Unit have the following additional benefits, which are:**

- a) In 3-phase circuits, USES Units bring the magnitudes of both the phase voltages and amperages closer to their means, because the phases are energetically linked through the magnetic chokes. Phases linked and balanced in this way are optimal for the operation of polyphase induction motors which were designed for phase-balanced power.
- b) these phase-balanced motors produce less amperage harmonics and demand less kW;
- c) the phase-balancing mechanism attenuates both amperage and voltage transient signals which protects sensitive loads;
- d) energy stored in the USES Units support the system voltage through most short-term voltage sags and surges thus providing ride-through capacity for most short-term PQ disturbances ; and
- e) the ruggedly constructed USES Units with no moving parts, are maintenance-free, generate no heat and have a useful life expectancy of 20-40 years.

USES Units can be retrofitted throughout a plant where they correct the PF locally while providing transient attenuation to protect local sensitive loads. When the distributed, articulated USES Units replace the massive PF CAP BANKS, they restore the power quality, protect the system operation and the maintenance man gets a full night's rest with his newly robust system.

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**References:**

1. A.S.Langsdorf, "Theory of Alternative Current Machinery", Chapters 1-3, McGraw-Hill Book Co. New York and London, 1937.
2. Other USES References in earlier posted papers by Emmet and Ray.