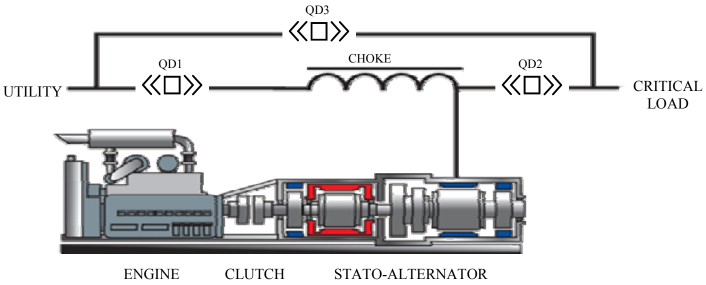
NO-BREAK E1 **Power Factor Correction and Voltage Control**

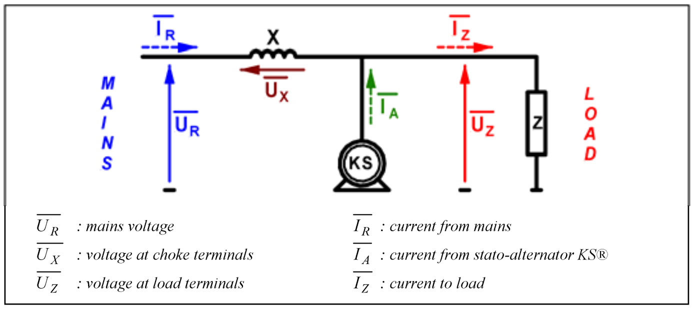
Introduction

ALL Mission Critical Loads have different Power Factor characteristics. Nearly every given load requires both active power and reactive power. The ratio of these determines the power factor (cos φ) at the load itself. Without any filter or compensation along in the power path from utility to the load, the Utility must supply both the Active and Reactive Power for the load. With the inherent capability of the No-Break E1, the requirement for Utility to provide reactive power is greatly reduced.



In Conditioning Mode, circuit breakers QD1 and QD2 are closed whereas switch QD3 is open. Therefore the Stato-Alternator is coupled in parallel on the Utility through a choke (reactance X). The Stato-Alternator excitation is continuously controlled to maintain the rated voltage at the Critical Load connected to the Output of the No-Break E1.

The following diagram represents the situation:



During Conditioning Mode the electromagnetic clutch is open and the diesel engine is stopped. The synchronous machine cannot deliver any active power: in fact, it actually absorbs a small amount of energy to compensate the different losses. Therefore the active power required by the load is only provided by the Utility.

In Conditioning Mode the No Break E1 output is regulated by control of the excitation voltage of the Automatic Voltage Regulator (AVR) and with the Reactance X of the Stato-Alternator. The Combination allows the No Break E1 to provide nearly all the Reactive Power required by the load, irrespective of how much is required. Consequently the power factor (cos φ) measured at the Input of the Choke is significantly improved and nearly reaches Unity.

Vector diagram and power flow

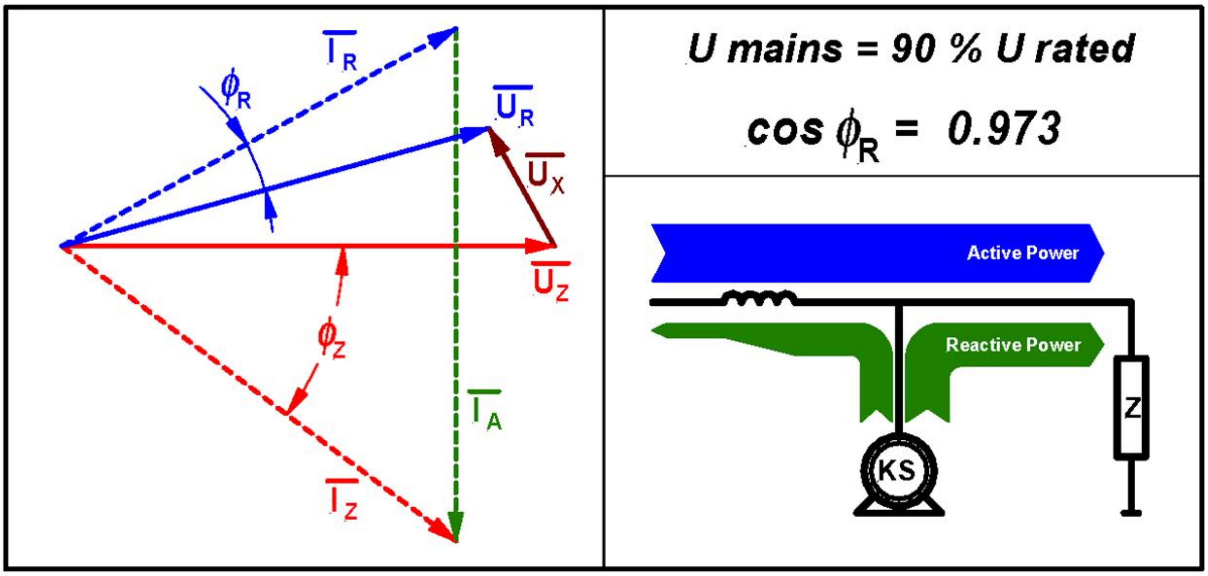
Electrical quantities are evaluated by drawing a vector diagram meeting the following conditions:

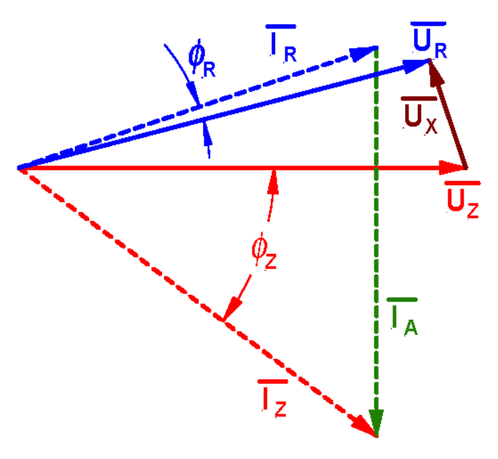
$\overline{U_R} = \overline{U_X} + \overline{U_Z}$	Utility voltage is equal to the sum of voltages at the load and choke terminals.
$\overline{I_R} = \overline{I_Z} - \overline{I_A}$	Current from Utility is equal to current to the load minus current from the Stato-Alternator
$\overline{U_X} \perp \overline{I_R}$	A 90° phase shift exists between voltage at the choke terminals and the Utility current through the choke
$\left\lvert \overline{U_X} \right\rvert = X \cdot \left\lvert \overline{I_R} \right\rvert$	Magnitude of voltage at the choke terminal is equal to the magnitude of the current through the choke multiplied by the reactance of the choke
$\left\lvert \overline{U_Z} \right\rvert = U_{nom}$	Magnitude of voltage at load terminals is equal to the rated voltage

The following diagrams show situations where Utility voltage corresponds to 90%, 95%, 100% and 105% of the rated voltage, respectively. The load is rated with a power factor (cos φ) = 0.8.

Voltage and current vectors are drawn using rated value as unit length. Voltages are represented by solid lines while currents are represented by dotted lines.

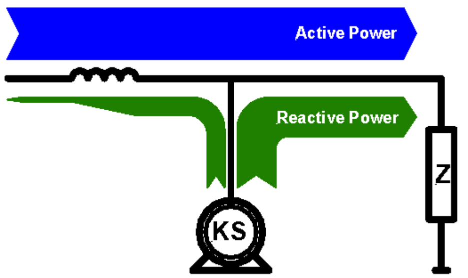
Beside each vector diagram, the single line diagram is plotted with active power flow (in blue) and reactive power flow (in green). Arrows width is proportional to the amount of (active or reactive) power flow.

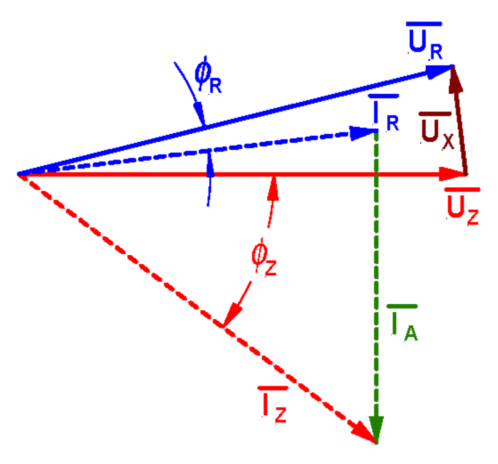




U mains = 95 % U rated

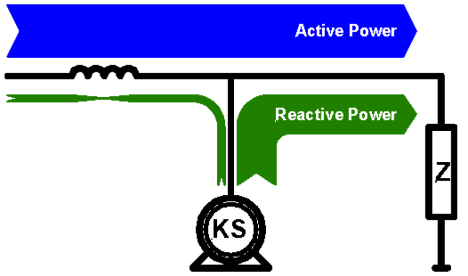
cos ϕ_R = 0.998

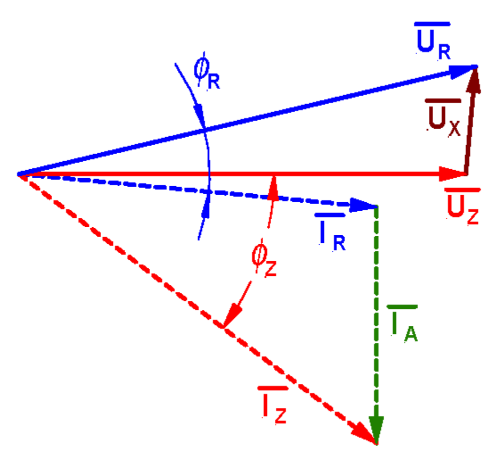




U mains = 100 % U rated

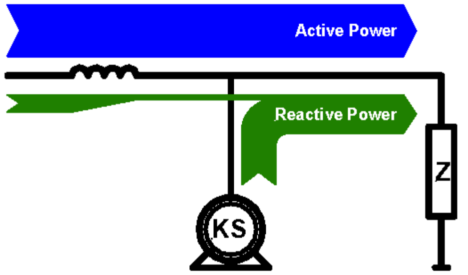
cos ϕ_R = 0.993





U mains = 105 % U rated

cos ϕ_R = 0.948



SUMMARY OF VECTOR DIAGRAMS

These illustrations clearly show that the Stato-Alternator delivers all, or at least the majority of the reactive power required by the load. Therefore the power factor (cos φ) measured at the Input is virtually UNITY.

Nominal Voltage Level

When at a Nominal voltage level, utility supplies only half of the reactive power for the choke, and i.e less than one sixth of the reactive power required by the 0.8 PF load. The Stato-Alternator delivers all the reactive power requested by the load as well as half of the reactive power for the choke.

Below Nominal Voltage (Slight Brownout)

When Utility drops below nominal, the synchronous machine delivers more reactive power. It supplies all the reactive power requested by the load. Moreover it also delivers all the reactive power for the choke, and even supplies reactive power to the Utility. The power factor (cos φ) measured at the Input approaches Unity, and current from Utility slightly leads voltage. It should be noted that, when Utility drops to 90% of Nominal, the Stato-Alternator delivers an amount of reactive power corresponding to 175% of that required by the 0.8PF load. Thanks to the resilient design of the No-Break E1, meeting this requirement is very effective.

Higher than Nominal Voltage

When Utility Voltage increases above Nominal, the Utility delivers progressively more reactive power. It eventually supplies all the reactive power for the choke, and even contributes to the reactive power requested by the load. Even so, the power factor (cos φ) measured at mains terminals is improved significantly. Resulting in a current from Utility equal to only about 80% of the current actually flowing to the load.

The following table summarizes the different situations (*load with power factor (cos φ) = to 0.8*).

Mains voltage (% U rated)	90%	95%	100%	105%
Current to load (% I rated)	100%	100%	100%	100%
Load power factor	0.8	0.8	0.8	0.8
Current from mains (% I rated)	91%	84%	81%	80%
Mains power factor	0.973	0.998	0.993	0.948

Analytic Relations

With the No Break E1, the voltage at the load is always maintained at +/- 1% of Nominal, it can be demonstrated that the power factor (cos φ) measured at the Input follows this expression:

$$\cos\varphi_K = \frac{\sin\delta}{\sqrt{1-2\gamma\cos\delta+\gamma^2}} \quad \text{with} \quad \delta = \arcsin\left(\frac{X P_2}{\gamma U_{nom}^2}\right)$$

P_2 represents the active power requested by the load

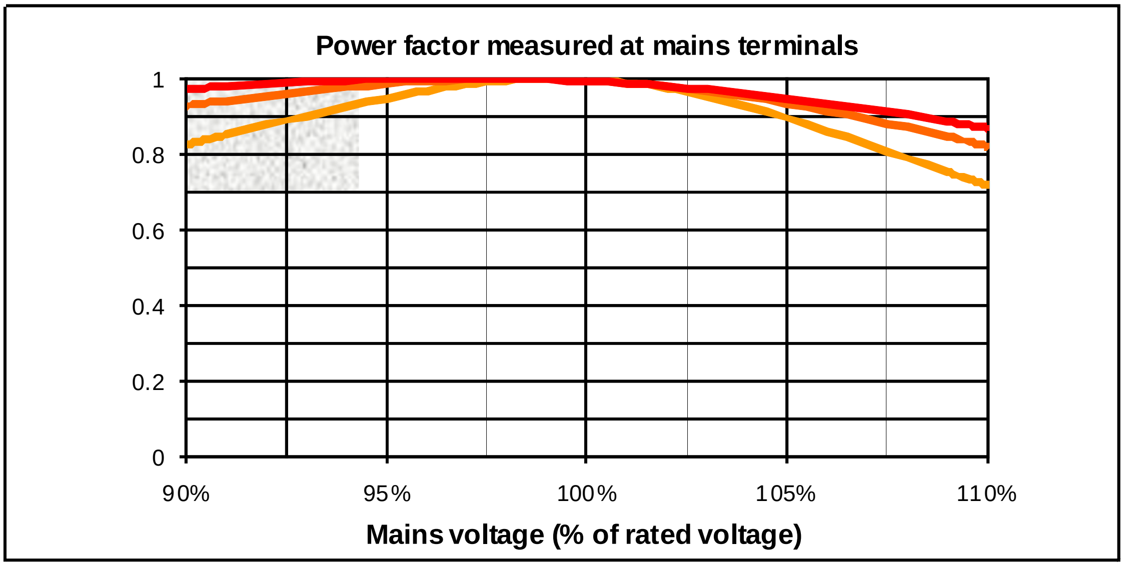
X represents the choke reactance

δ represents phase angle between voltage at load terminals and mains voltage

γ represents the ratio between mains voltage and rated voltage (U_{nom})

This expression illustrates that the power factor (cos φ) measured at Utility Input does not depend on the amount of reactive power required by the load.

The following diagram represents the power factor (cos φ) measured at Utility Input of a No Break E1 as a function of the magnitude of Utility Voltage for different load levels. It clearly shows that, except under extreme voltage deviations, the power factor (cos φ) at the Input of the No Break E1 is almost always near UNITY.



LEADING POWER FACTOR LOADS

The No-Break E1 systems are synchronous machines using Class H Alternators which are typically oversized by a factor 1.5 to 2. The synchronous reactance of the system is approximately 300% (based on the alternator's rated apparent power). In terms of thermal stress, those machines can operate at power factor 0.8 lagging (inductive load) without issue.

For capacitive loads (leading power factor), the limiting factor comes from the fact that the armature reaction tends to magnetize the machine: above a certain level of "leading" reactive power, voltage control is no longer possible and the system could enter an unstable region. To prevent this from occurring, a theoretical limit is achieved by taking the rated apparent power divided by the synchronous reactance. That theoretical limit in terms of kVAr depends on the size of the No-Break E1 system. We call this theoretical because a certain margin is necessary to keep tight control on the output voltage (+/-1%), so in practice we design using 25% of the alternator's apparent power.

Based on the Standard Design and the Resilience of the No Break E1 – Operating our system with a load with leading power factor down to 0.93 is acceptable.

In case of a High Leading Power factor Load demand, a solution can be developed using compensation chokes should be considered. With this type of solution, the leading reactive power can be balanced by the lagging reactive power characteristic of the compensation chokes.

When designing for Excessive Leading Power Factor loads consideration should be given to the overall site and system level load to be placed on the No Break E1. Our design engineering resources will work with you for the most effective solution for your particular loads.

Conclusion

Aside from its function as a Uninterruptible Power System, the **No-Break E1** plays an important role Conditioning Utility Power, Regulating Output Voltage and Corrects the Power Factor seen by Utility.

With this document it is demonstrated that with the Resilient Design of the No Break E1 System, the improvement of the power factor (cos φ) at the Utility Input, eliminates the need for any sort of capacitor banks and the phenomena associated to their switching on and off.

ADDITIONAL BENEFITS OF THE NO BREAK E1:

Regulation of Output Voltage +/-1% w/ input voltages of ±10% - See E1 Voltage Control

Protection against Harmonics - See E1 Harmonics Filtering.

The Ability to Provide Short Circuit Current Clearing - See E1 Short Circuits

The High Reliability of the System and Redundancy - See E1 Reliability

Simplicity of Preventive Maintenance – See E1 Preventive Maintenance