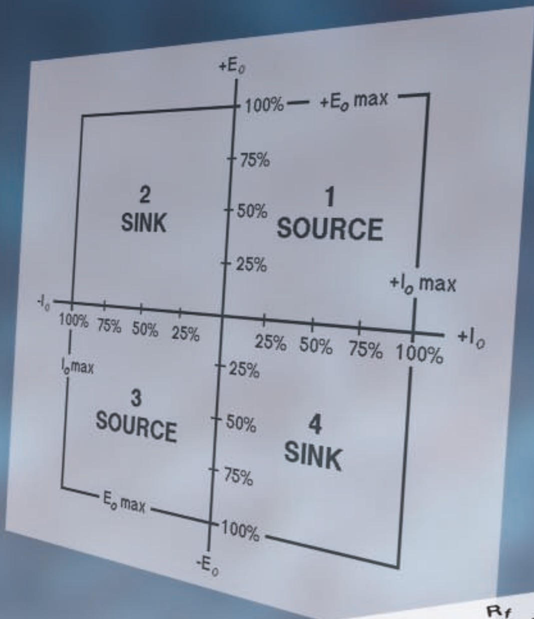
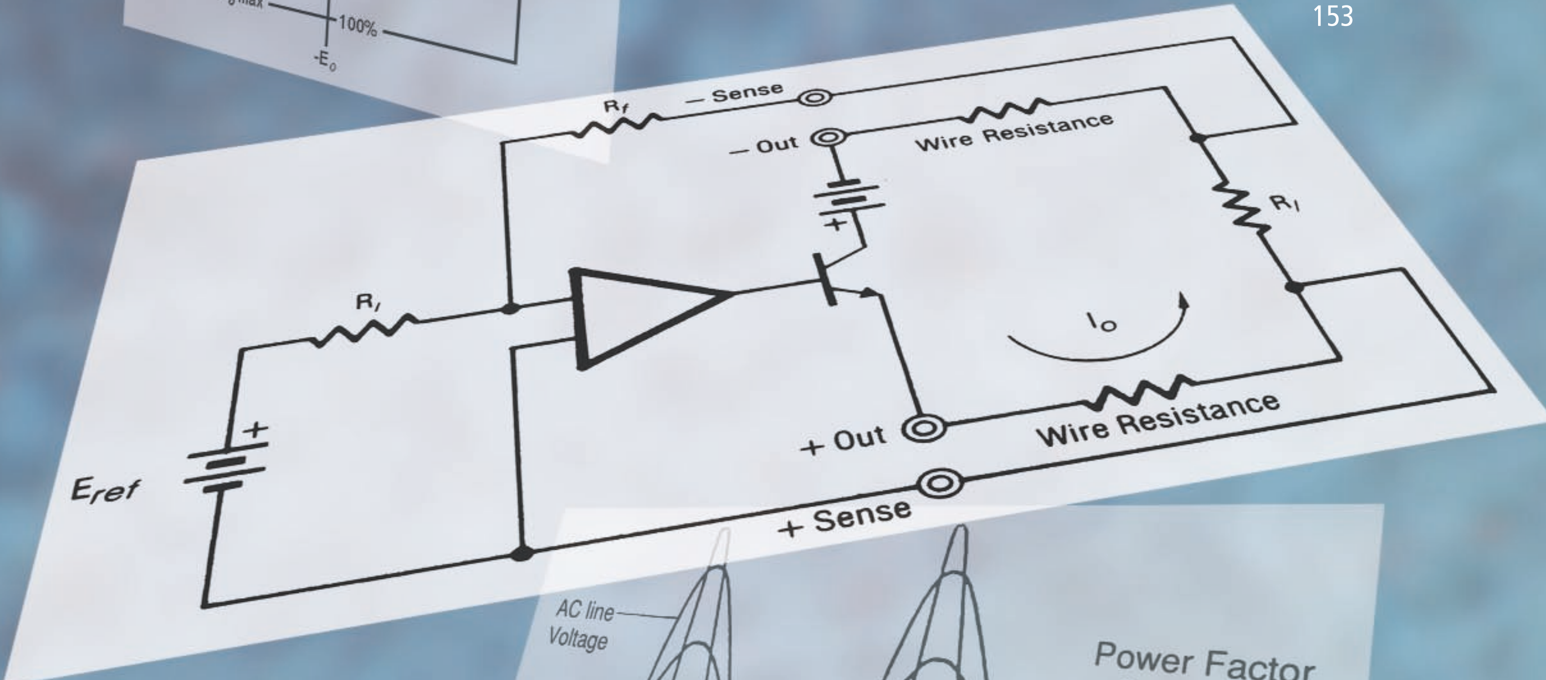
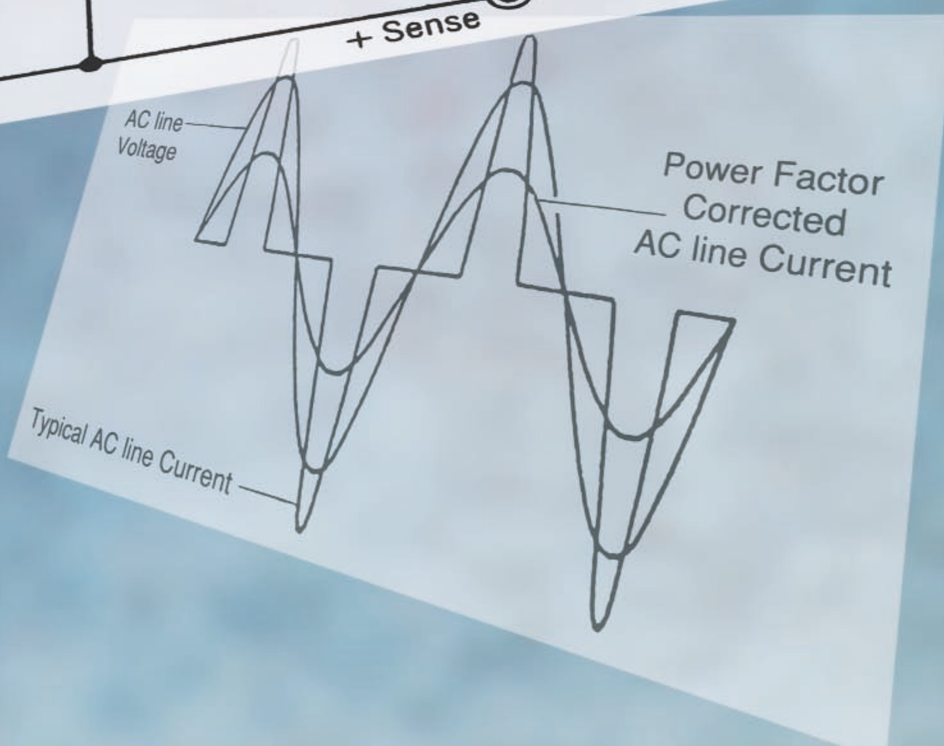
APPLICATIONS HANDBOOK







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WHAT POWER SUPPLIES DO

Power supplies exist to provide five separate and distinct functions:

1. **Change the output to a different voltage level than the input (step up or step down)**
2. **Rectify a-c into d-c**
3. **Isolate the output from the input**
4. **Stabilize the output against the influence of:**
   Source changes (source effect)
   Load changes (load effect)
   Temperature changes (temperature effect)
   The passage of time (time effect or drift)
5. **Provide the user with a means to vary the output**

Not all power supplies provide all of these functions. Instrumentation power supplies are distinct from the power supplies used to provide fixed voltages to power devices in that they are optimized to provide the user with precise means for exercising control over the output. There are two fundamental control methods: ANALOG control and DIGITAL control.

Kepco makes both analog-controlled instrumentation power supplies and models that are fully digital. Kepco also makes digital interfaces for the analog-controlled models.

ANALOG CONTROL

By analog control, we refer to a means for controlling a power supply's output by smoothly varying a signal. Common signals include variable resistances, variable voltage and variable current. When a variable resistance is chosen, the ratio of resistance to output voltage (ohms/volt) corresponds to a current. With few exceptions, Kepco has standardized on a control current of 1.0 mA which corresponds to a control ratio of 1000 ohms per volt. For control by a voltage signal, most Kepco analog power supplies may be characterized as three-terminal amplifiers in which the power supply's (+) error sensing terminal serves as the common between the input and the output. The control voltage must be positive 0 to +10V with respect to the (+) sense terminal. The output is negative as the power supply will function as an inverting amplifier.

Because it is likely that an available signal will not match the polarity and amplitude requirements, Kepco builds one or more "preamplifiers" or "uncommitted amplifiers" into many of its analog-programmable power supplies. These can serve to invert and scale the available control signal into the necessary 0 to +10V. Additionally, the uncommitted amplifiers can be used to do operational functions such as integration or summing. To characterize these extra operational amplifiers which are incorporated into Kepco's analog-programmable power supplies, the specifications contain information about the influence of source voltage changes, temperature and drift on the input offset voltage and offset current. The fixed part of the offsets are zeroable. The tabulated specifications are for the changes induced by the principal influence quantities.

The basic series-pass linear technique for stabilization offers the possibility of amplifier-like control techniques. Kepco calls this "Operational Programming" because the control arithmetic closely resembles the equations used to characterize analog operational amplifiers. Like op-amps, operationally programmable power supplies may be used for modeling and simulation of real-world situations. You can use them for amplifying, scaling, inverting, integrating and combining various input signals to produce powerful outputs that can drive motors, light lamps, run heaters, charge and discharge batteries and control machinery of all sorts.

HIGH SPEED

In all power supplies, the design aspect that governs the rate at which the output can follow a fast changing input signal is the output capacitor. Specifically, it is the rate that the capacitor can be charged and discharged. This rate is proportional to the ratio of the output current setting (the current limit) to the value of the capacitor in microfarads. To enable users to calculate the speed, Kepco lists the value of this capacitance in the model table of its operationally programmable models. Those units that have removable capacitors or no capacitors at all (BOP) have the "equivalent capacitance" listed. This is the capacitive value computed by working backward from the observed response. It is not a physical capacitor.

A special technique that uses adjustable lag networks allows certain of our operationally programmable models to function without a conventional output capacitor. This, in turn, allows a relatively wide signal bandwidth for modulation and rapid output slewing. In high speed automatic test applications, this allows for rapid level shifts. Such high speed power supplies (ATE, BOP, BHK-MG,) function better than their conventionally filtered counterparts when in current stabilization mode. Their response to step load transients is up to 1000 times faster.

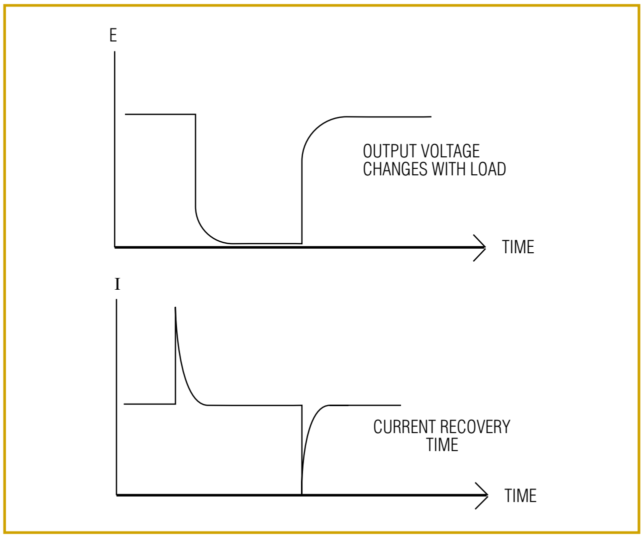

FIGURE 1
The effect of a changing load on a current stabilizer. The output capacitor's charge and discharge time controls the recovery time

CURRENT STABILIZATION

To understand current stabilization one must first stop and consider just what is meant by the idea of both voltage stabilization and current stabilization.

In one sense, these are descriptions of a power supply's expected response to changes in the load. A voltage stabilizer will respond by varying its current along a straight line locus that defines a fixed voltage (Figure 3a) while a current stabilizer does just the opposite (Figure 3b). A plot of the successive operating points created as the load is allowed to vary creates a straight line at a fixed current for the current stabilizer.

We understand resistance or impedance to be the ratio of the change in voltage to the change in current. In the plot of operating points from the voltage stabilizer, we observe a very small change in voltage for a large change in current corresponding to a low source impedance. If the stabilizer were ideal, this impedance would approach zero. The corresponding plot for the current stabilizer suggests a very high impedance and, indeed, the ideal current source would exhibit nearly an infinite source impedance.

The schematic symbol for a voltage source is a battery and the idle condition is an open circuit. The symbol for a current source is an encircled arrow and its idle condition is a short circuit. See Figure 2.

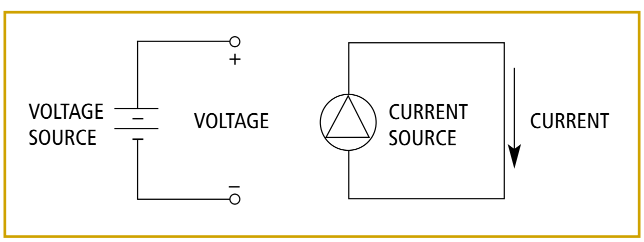

FIGURE 2
Schematic

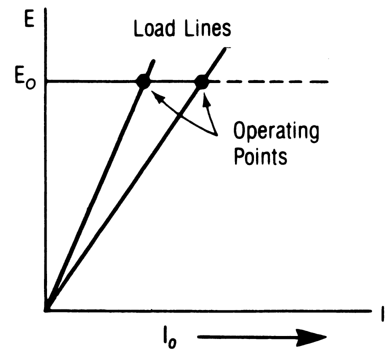

FIGURE 3a
Voltage stabilizer

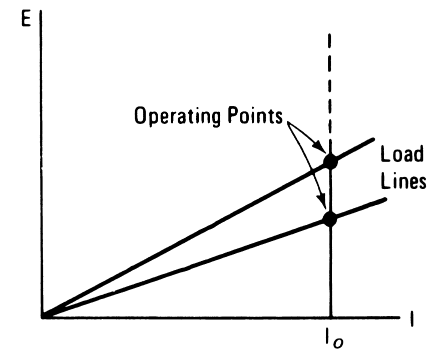

FIGURE 3b
Current stabilizer

Figure 3a and 3b
The concept of "voltage stabilization" or "current stabilization" relates to the locus of points that a varying load will trace if you observe the changing output voltage and current of the power supply being loaded

OUTPUT IMPEDANCE

In this catalog we tabulate the actual source impedance of Kepco's precision analog stabilizers. Impedance values are shown in both voltage and current modes. This is in addition to simply stating the rated degree of stabilization or regulation that the power supply achieves with its high gain feedback amplifier. The figures for resistive inductance and capacitance are in the model tables. One reason for doing this is that output impedance is a widely misunderstood power supply specification that is actually defined at d-c when load effect stabilization is specified. Its significance is apparent at frequencies other than d-c. The output impedance of a power supply is characterized both in terms of a d-c resistance and a reactive element. At high load frequencies, the reactive component dominates the specification.

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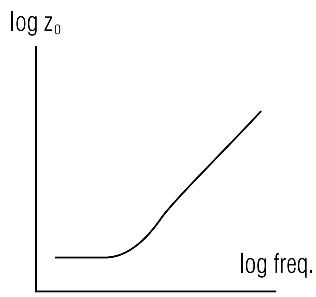

FIGURE 4a
Voltage stabilizer's impedance increases as an equivalent series inductance

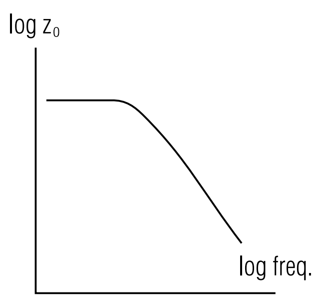

FIGURE 4b
Current stabilizer's impedance decreases as an equivalent shunt capacitance

FIGURE 4a and 4b
Plot of output impedance vs. frequency for a voltage stabilizer and for a current stabilizer

When stabilizing voltage, the reactance is the effective series inductance which, at high frequencies, introduces a significant non-zero component. The impedance rises at 6db/octave as the frequency increases.

When stabilizing current, the reactance is an effective shunt capacitance. This prevents the impedance from being infinite. Indeed, the impedance falls at 6db/octave as the frequency increases.

The impedance table will permit you to plot the reactive impedance of inductors and capacitors. It is a log-log plot. See Figure 5.

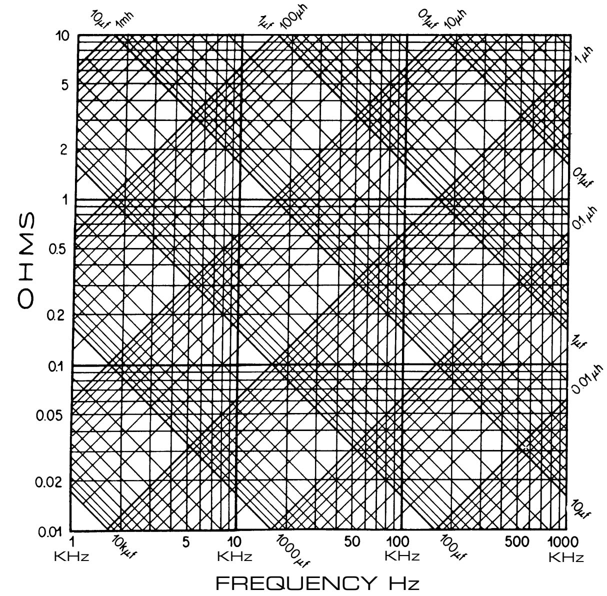

FIGURE 5
Impedance table

EFFECT OF AN OUTPUT CAPACITOR

A conventionally filtered power supply has a quite large output capacitor for energy storage as a voltage stabilizer and for dynamic stabilization. This capacitor shunts the output with its low impedance. This is fine for voltage mode but not-so-good when current is the thing to be stabilized.

A problem arises with power supplies that are dual-mode, attempting to be *both* voltage and current stabilizers. They are called *automatic crossover* designs. The problem is that they can't be very good current stabilizers with a big low impedance output capacitor stuck across the output. The idea of current stabilization mode is that while the current remains fixed as the load changes, the voltage must remain free to vary in proportion to the load resistance. A capacitor inhibits any voltage change across its terminals and thus is incompatible with the voltage agility that must characterize current stabilization.

Kepco's ATE and BHK-MG allow users to disconnect the output capacitor when they wish to optimize performance in current mode. The BOP models have no output capacitors to begin with.

A capacitorless power supply is dynamically less stable than a conventionally filtered design. It is much less tolerant of reactive loads, oscillating if the load reactance is not compensated. Such units and operating modes should not be chosen for conventional use, especially if the load is reactive.

OVERLOAD

The straight lines in Figures 3a and 3b would tend toward infinite voltage or infinite current if not bounded in some way. For the voltage stabilizer, the prospect of infinite current has, traditionally, a host of solutions: fuses, circuit breakers and, in more modern designs, current limiters. For the current stabilizer, the corresponding prospect of infinite voltage is far less familiar, and therefore less intimidating. It is no less a real problem.

Kepco's ATE, BHK-MG, MAT and MST power supplies are "automatic crossover" designs. Common to all of these is the idea that the gain, precision and performance of the current control channel is as close to the performance of the voltage control channel as we can get it. Also, these power supplies have the ability to operate over fully 0-100 percent of the voltage and current rating. The BOP power supplies are 4-quadrant designs. They are fully bounded by a voltage limit when stabilizing current and a current limit when stabilizing voltage. A selector is used to determine whether voltage or current is the parameter being stabilized. It is not automatic. BOP are, therefore, not considered automatic crossover.

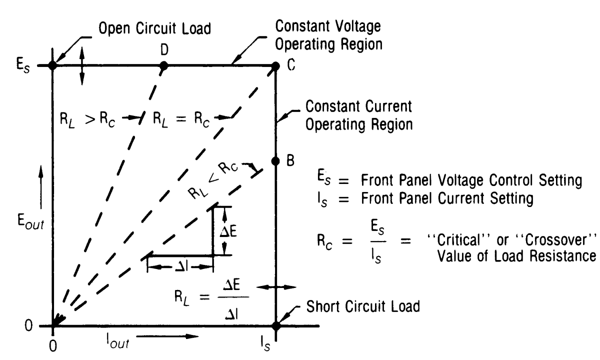

FIGURE 6
The rectangular locus of an automatic crossover design in which the voltage mode serves to protect the current from overload and vice versa

An automatic crossover power supply uses the complementary nature of voltage and current modes to form boundaries for each other. See Figure 6. Here the voltage locus combines with the current locus to produce a closed, fully bounded rectangle whose voltage and current lines can be positioned as the user wishes. The vertical current stabilizing locus provides a maximum current limit for the load current produced by the voltage stabilizer, while the horizontal voltage stabilizing locus provides a maximum voltage limit for the load voltage produced by the current stabilizer.

The opposite of overload is idle. If we understand the difference between what constitutes overload to a voltage stabilizer and current stabilizer, then we can appreciate what it means for them to be idle. For the voltage mode, it is intuitive. Zero current is idle. This can be achieved by opening the circuit to its load with a switch or relay. In Kepco's MAT and MST, the "output-enable" relays open the connection to the load when idling the units in voltage mode. For current mode, it is less intuitive. A current stabilizer is idle when it is producing no voltage. This can be achieved by shorting the output with a switch or relay. The MAT and MST output enable relays do just this when idling the units in current mode. Note: For a power supply to be a real Automatic Crossover design, it MUST be capable of operating indefinitely into a dead short circuit, the current mode's "idle." While the mode is at idle, the power supply, by virtue of its series-pass topology, is working very hard. All Kepco power supplies have sufficient series-pass "horsepower" to do this effortlessly. Many competitive units do not. See the section on HEAT DISSIPATION for an explanation of this. ABC is of course, a switch-mode design.

SOURCE-SINK

The value of a power sinking capability in power supplies lies in two applications: When a BOP is driving reactive loads, particularly in the frequency domain, there will be a part of each cycle when the voltage and current are out of phase and one may be positive where the other is negative. In this situation, the load is supplying power to the power supply for a portion of each cycle and the power supply is a sink.

Another situation is when a power supply is used to exercise batteries, perhaps simulating the light-dark cycle of orbiting solar cells. During the dark, or discharge portion of the cycle, the sink capability draws energy from the batteries. In a sense, such application is like an electronic load.

ONE QUADRANT, TWO QUADRANTS OR FOUR

Power supplies that produce a single voltage polarity and single current polarity are, naturally, single quadrant units. The voltage-current rectangle of an automatic crossover power supply lies in a single quadrant. However, there are actually four quadrants. Voltage can be plus or minus and current can be plus or minus. Kepco's MAT and MST models with their polarity reversal relays can be thought of as two quadrant instruments. See Figure 7.

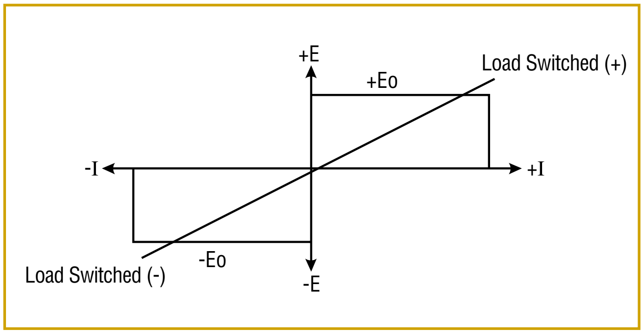

FIGURE 7
Two quadrant operation results when relays are used to provide polarity reversal

When the current (in the conventional sense) flows OUT of the + voltage terminal...as in a battery...we say that it is a SOURCE. When the current flows INTO the + terminal ...as in a resistor...we say that it is a SINK. Power supplies are usually thought of as SOURCES. Loads, electronic or resistive, are thought of as SINKS. It is possible to combine load and power supply in ways that make it behave as both source and sink. See Figure 8.

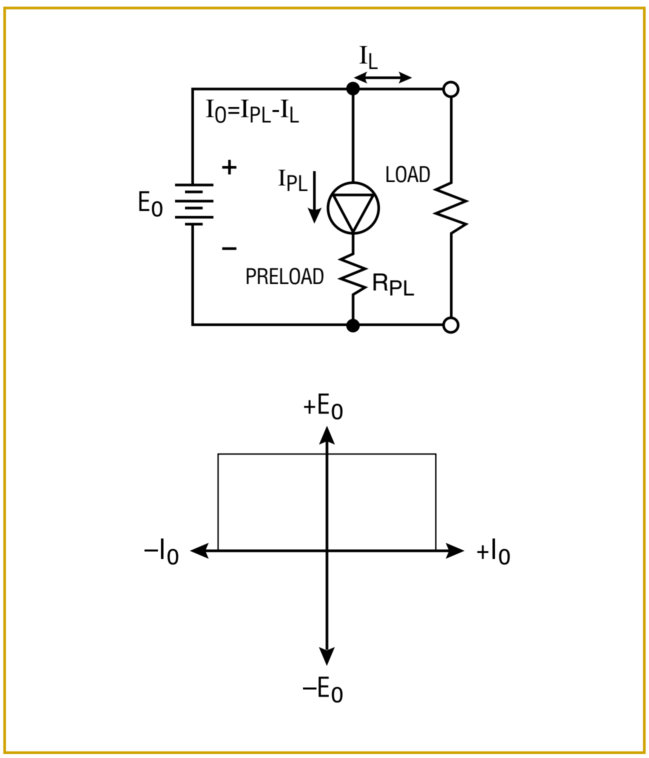

FIGURE 8
Source and sink operation is achieved by preloading the current source in series with the preload resistor, R_{PL}. This makes the preload current, I_{PL} independent of the voltage, E_O. If E_O is a fixed voltage, a simple resistor may be used to create the preload. The sum of $+I_L$ and $-I_L$ is the current rating of the voltage source E_O

Kepco's BOP series, bipolar power supplies, operate in four quadrants. They can produce both positive and negative voltage and current and operate as both source and sink. BOP are true wide-band d-c amplifiers that can reproduce a complex waveform going smoothly and linearly through zero. They are, nevertheless, solid d-c power supplies capable of producing a fixed output for unlimited time which is quite beyond conventional amplifiers. Hence, the phrase "Bipolar Operational Power Supply" (BOP).

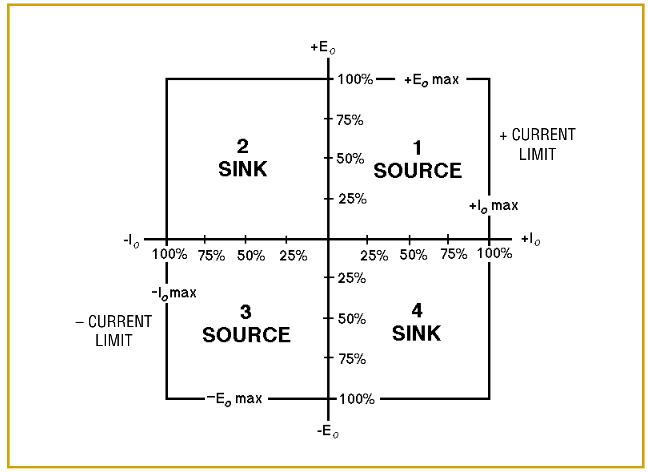

FIGURE 9
Four quadrant operation from a Kepco BOP power supply

BOP are the ultimate analog power supply responding to both amplitude and polarity signals with high speed. When they are harnessed to digital controllers, either their built-in BIT card or an external SN card, their output is, of course, digitized. No longer do they slew smoothly through zero to any voltage or current position in the four quadrants. Digitally controlled by a bus, they stutter step in rigid increments, with a resolution controlled by the digital system.

While the polarity reversal afforded by the relays in MAT and MST power supplies is mechanical, rather than electronic, as in BOP, when the speed limits and resolution constraints of digital control are considered, the net effect is similar. Unless the SINK capability of BOP is required, relay reversal of polarity is a way of obtaining bipolar (two-quadrant only) output.

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HEAT DISSIPATION

The key to being able to function in various quadrants, at high speed, without de-rating, with no limits on duration or load, is an efficient heat dissipating arrangement. The concept of the linear series-pass topology is that the power transistors (or MOSFETs in the high-voltage models) are able to convert unwanted power into HEAT. By so doing, they can meter the flow of power to your load very accurately. Since the power can be quickly switched between dissipator and load, such LINEAR power supplies react very quickly to changing load demands.

The BOP High Power models are four quadrant source-sink power supplies that use switch-mode technology for improved efficiency. Their bandwidth is therefore necessarily smaller than for linear design. To avoid dissipating sinked energy, the BOP High Power models use energy recuperation, passing the load sink back to the a-c power mains

REMOTE ERROR SENSING

If a 4-wire Kelvin connection is made between power supply and load (Figure 10), it is possible to arrange the wires so that one pair carries the load current, and the second pair is made to sense the output voltage without the voltage drop error induced by the flow of current through the resistance of the connecting wires. By this means, power supplies can be designed to compensate for the resistance of the load cables. All of Kepco's linear power supplies have been designed with one extra volt available (a 0-6V supply is really capable of 0-7V); this extra volt allows you to drop as much as 0.5V per load wire and still get full rated output at the load. High current, switch-mode models (BOP High Power) have an extra 0.5V which allows up to 0.25V drop per wire.

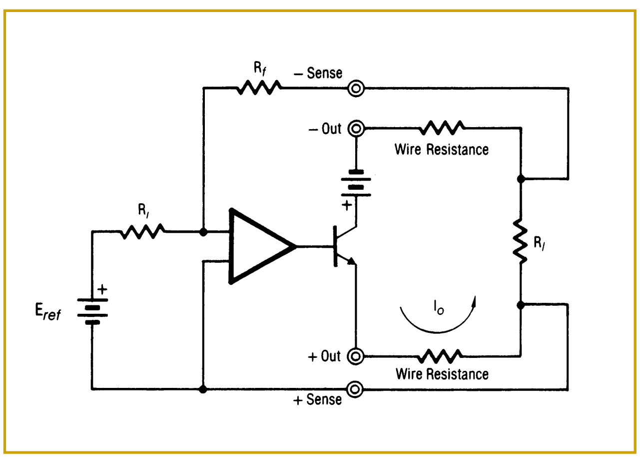

FIGURE 10
Circuit illustrating the use of remote error sensing for voltage stabilization

Some care must be taken when using remote sensing. It is easy to introduce noise through pickup. Wires should be shielded in a noisy environment, and may need to be twisted together, or with the respective load wire to minimize the inductance present in a long run. Most important, care should be taken when connecting, disconnecting, or switching 4-wire load circuits. The load wires must always mate before the sense wires, and the sense wires must break before the load wires. To do otherwise risks running heavy current down light gauge sense leads.

SENSING PROTECTION DIODES

Kepco stabilized power supplies have a special diode connected across each error-sensing link (to the respective output terminal) whose function is to conduct should the connections be inadvertently omitted. These diodes prevent an uncontrolled response when the links are open and a remote connection is missing. See Figure 11.

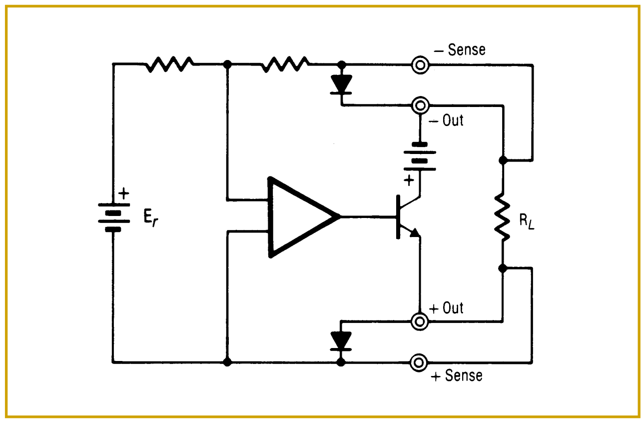

FIGURE 11
Protection diodes

The diodes present a possible hazard to users who wish to switch their loads on and off. If remote error sensing is used, and if the power supply is heavily loaded, a switch that opens only the load wires throws the burden onto the sensing leads. Not only will this likely damage the error sense diodes, but may produce dangerous over-heating in light gauge sense wires used between the power supply and its load.

When switching the load on a power supply that uses a 4-wire connection to its load, the switch must interrupt both the load circuit and the sense circuit. Preferably the sense circuit should be interrupted first and reestablished last.

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DIGITAL PROGRAMMING INTERFACES FOR ANALOG-PROGRAMMABLE POWER SUPPLIES

Analog-programmable power supplies are easily controlled by the d-c voltage generated by a digital to analog converter (DAC). Because Kepco's operationally programmable models have a uniform 0-10 volt, 0-1 mA input, it is possible to design DACs to be able to control all such models.

Kepco's ANALOG PROGRAMMABLE power supplies, notably the operationally programmable models, ATE, BOP and JQE may be interfaced to the IEEE 488 instrumentation bus through a variety of interfaces which function as digital to analog converters. The interfaces implement the AH1 acceptor handshake and L1 listener plus listener-only functions of the IEEE 488 protocol. The interfaces differ mainly in their mechanical aspects and in the number of control channels that are offered. The BOP also accept a talker-listener GPIB card, either BIT 4882 (12-bit) or BIT 4886 (16-bit) which support the SCPI language.

Kepco models with built-in digital capabilities, the ABC, BOP High Power, BHK-MG, MAT and MST series, do not require these digital to analog programming interfaces. The ABC, BOP High Power BHK-MG, MAT and MST implement both talker and listener functions.

Analog programmable models should be used when your application requires analog modeling of a process or simulation or modulation. Except for the BOP High Power and JQE, Kepco's operationally-programmable instruments offer high speed control capabilities that allow for rapid slewing and high-frequency modulation. When used with a digital interface, the relatively slow speed of the computational process will not allow full exploitation of the high speed capability, but they retain the ability to have audio spectrum modulation superimposed on the digitally programmed d-c values.

The Kepco SN series of external digital to analog converters provide listen-only digital capabilities for JQE and ATE power supplies.

An interface card called BIT plugs into an internal slot in the low power low-voltage BOP models (models up to ±200 volts, up to 400 watts). The BIT 488 B/D cards provide a listen-only digital interface with 12 bits of resolution on one channel and 8 bits of resolution on a secondary channel. The user may wire the two channels for either voltage control with a current limit or current control with a voltage limit.

The BIT 4882 (12-bit) and BIT 4886 (16-bit) cards are talker-listeners that support the SCPI command sent over the IEEE 488 bus (IEEE 488.2). Model BIT TMA-27 talker-listener interfaces a BOP power supply to Kepco's single address, multiple instrument, 2-wire, long range serial bus, so that BOP can be integrated into systems with MAT, MST and BOP High Power models.

Kepco's ABC, BOP High Power and BHK-MG power supplies are digitally programmed power supplies with built-in GPIB (IEEE 488.2) interfaces. The BHK-MG, to retain backwards compatibility with earlier BHK high voltage models, contains provision for both analog and digital control.

INPUT DATA FORMAT

The SN and BIT interfaces accept data in either hexadecimal form with a 12-bit binary resolution of $1/2^{12}$ = 1/4095 or 0.0244%, or in Binary Coded Decimal (BCD) format with a 3-digit resolution of $1/10^3$ = 1/999 or 0.1%. In both instances, the host sends character strings to control channel selection, range, polarity and data as a percent of full scale.

VXI

VXI, the "instrument on a card" concept, was developed for signal control and measuring instruments. It has achieved a substantial following in the test and measurements field. Unfortunately, power supplies are not like signal-level instruments in that they create substantial amounts of heat. This is especially true of instrumentation-type programmable power supplies which use linear, dissipative control techniques. Such heat dissipation is not compatible with VXI card cages.

To prevent the heat generated by power supplies from affecting other elements in a VXI card cage, and to minimize the d-c voltage drop between the power supply and its load, we recommend that the power supplies be located close to the load.

To provide VXI support, Kepco offers a single-width, size "C" card to plug into a VXI cabinet and provide an output to the Kepco single address, multiple instrument bus. Models in the MAT, MST, BOP High Power and BOP-TMA lines can directly interface with this card and through it, with other VXI instruments. The power supply's dissipators are remote from the VXI cage so their heat will not interfere with the proper operation of the other instruments in the cage.

VXI plug&play member

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DIGITAL BUS-CONTROLLED POWER SUPPLIES

As distinct from analog power supplies for which digital control is an “add-on” (external or internal), these models are primarily digital. There is no analog control means. Presently, models are available in two forms. One form is intended for multiple instrument applications using a serial bus to distribute a single address to multiple power supplies. These include MAT, MST and BOP (with the serial card). The other form is based on direct GPIB connection. These include ABC, BHK-MG and the BOP with BIT 4882 or 4886 card. The BOP High Power have both the serial bus and GPIB ports.

ABC POWER SUPPLIES

ABC are 100W bench-style power supplies featuring an integrated keypad/GPIB controller with full talk/listen capability. They use zero-up switch-mode topology for efficiency, light weight and small size. They feature power factor correction, universal a-c input and EMI suppression. The challenge in ABC was to replicate the features of traditional linear instrumentation power supplies in a product that uses switch-mode technology for its improved efficiency and all the benefits that flow from that.

ABC integrates a microprocessor to perform several functions, including the power control, keypad interpretation, display and the GPIB interface.

Although designed as bench instrument, ABC can easily be integrated into automatic test systems. The built-in interface permits user control over the voltage, current, overvoltage and overcurrent settings. It reads back the values of voltage, current and the status using SCPI commands (IEEE 488.2).

The ABC has a non-volatile memory in which 40 different combinations of voltage setting, current setting, overvoltage setting, overcurrent setting and time duration can be stored. These can be loaded to form mini-programs or repeating cycles to exercise devices.

Model ABC 10-10DM

BHK-MG POWER SUPPLIES

The BHK-MG are suitable for integration into test systems. The series includes 200 watt full rack models and 40 watt half rack models producing 0-300V, 0-500V, 0-1000V and 0-2000V. The MOSFET output stage is linear and is strappable for high speed operation.

Model BHK 1000-40MG (top) and BHK 1000-0.2MG (bottom)

The output voltage or output current of the BHK-MG may either be analog-programmed (as an operational power supply) or digitally programmed via the GPIB. To take advantage of the fast-programming capabilities of BHK-MG, the analog programming inputs must be used because the speed of control from the GPIB is not sufficiently fast.

As in the ABC, the microprocessor controls the output, monitors the keypad, monitors the built-in IEEE 488.2 control channel and displays the output on a 2-line, 16-character, LCD readout.

MST POWER SUPPLIES

Kepco’s MST combines the small size and efficiency of a high frequency switcher with the gain, stability, accuracy and control of a linear stabilizer. This hybrid approach yields a 200 watt design that can plug in nine (9) abreast into a 4U (7" high by 19") rack housing.

MST is a 200 watt-class programmable instrument-type power supply that combines microprocessor-controlled serial bus communications with high-gain linear stabilization, all driving a 100KHz switcher that incorporates active power factor correction.

MST are packaged in a slender plug-in housing. Each module is self-contained with its own cooling fans, a-c input connector, fuse and d-c terminals. They mount in a special rack adapter, RA 55. One of the slots in this rack adapter or drawer, may be devoted to a plug-in card that provides the bus-format translation between IEEE 488.2 and Kepco’s single address, multiple instrument serial bus. This card is called MST 488-27. Only one such card is needed for every 27 MST modules (three housings of nine each less one slot for the MST 488-27).

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Model MST - 200 Watt

The idea of multiple units in a single housing naturally suggests N+1 redundancy to many engineers and MST incorporates the forced current sharing necessary to implement this. A from-the-front hot-swap capability is also provided.

MST accept a universal a-c input. The user can provide any input from 90 to 264 volts without any form of input selection.

MST have two 3-digit LED output meters and built-in enabling (on-off) and polarity reversal relays. These relays mean that MST will function in two quadrants, providing plus and minus output voltage and current. MST are automatic-crossover voltage and current stabilizers with two 12-bit channels of control; one for voltage, the other for current.

BOP HIGH POWER POWER SUPPLIES

The High Power BOP employs a three-microprocessor architecture. One processor and its attendant programmable logic arrays is devoted to the display and the user-machine interface. A second is responsible for the remote digital interfaces: GPIB (IEEE 488-2), the single-address, multiple-instrument long-range serial bus (IEEE 1118/RS 485) and RS 232. The third processor handles analog functions.

The BOP High Power's display is a 320 x 240 pixel monochrome window that is capable of both analog and digital representations of the actual BOP output. The main channel is displayed along with the appropriate limits. The limit control is selected from the settings menu and allows either a single limit or a pair of limits. The setting that is being controlled by the adjuster is highlighted. The left and right arrow keys are used to move from setting to setting.

The display processor is provided with a separate program memory. The BOP High Power can store settings in 99 memory locations. It supports up to 128 discrete levels and associated dwell times. This permits the creation, storage and recall of arbitrary waveforms which can be run at once or with continuous repetition.

The BOP High Power switching power supplies support three communications protocols. The primary interface is the GPIB (IEEE 488.2). The power supplies also support RS 232 at baud rates of 4.8, 9.6, 19.2 and 38.4 Kilo baud rates. The RS 232 supports both XON-XOFF and CTS/RTS protocols. The RS 485, Kepco's single address, multiple instrument serial bus (IEEE 1118) allows the BOP High Power units to be controlled from and MST 488-27, TMA 488-27 or Kepco's VXI controller, TMA VXI-27. Older models of these programmers may need to be updated to support these new models. Please consult factory.

Model BOP High Power 10-75MG

The GPIB and serial interfaces primarily use the SCPI language: (Standard Commands for Programmable Instruments). The BOP High Power units support the trigger system, including an external trigger input. They also support the LIST and Memory subsystems of the protocol. The SCPI interface is compatible with the BIT 4886 card (see page 55) and supports separate positive and negative limits. CIIL language support is provided for compatibility with the Kepco MAT series and other MATE system instruments. The GPIB interface provides for an SN emulation mode to provide a fast 12-bit control and also supports the IEEE 488.2 commands, which start with the (*) character.

SWITCH-MODE POWER SUPPLIES

How switches work to control large amounts of power efficiently:

The well documented efficiency, size and weight penalties associated with conventional mains-frequency transformer driven a-c to d-c power supplies, has led to an extraordinary array of high frequency alternatives. Known generically as "Switching Power Supplies," SMPS, or "switchers," these designs rely upon the efficiency of a switch to control large amounts of power with relatively little loss.

The switch on your living room wall works in much the same fashion. When it is “off” the current through it is near zero, the open gap supports the full voltage of the utility feeding your home. When you flip it “on” the situation reverses. There is little or no voltage across it and the current flows unimpeded. In either position the switch itself dissipates little power. “On” there is current but no voltage and “off” there is voltage but no current.

If you modulated the ratio of on time to off time by vigorously manipulating the lever you’d be able to control the amount of light (or whatever was connected) without needing much more effort than is required to flip the switch. The switch itself would be controlling quite large amounts of energy with negligible dissipation. This is quite unlike the situation in linear series-pass control systems where power is deliberately dissipated away as the means of control. Switch-mode power supplies work like the wall switch in your living room. They use some form of pulse-width modulation to alter the on time relative to the off time to effect control.

Of course, given the constraints of frequency and the speed of the devices used for switching (now mostly power FETs), there is a limited dynamic range available. The ratio of the shortest pulse (constrained by the speed of the switch turning on and off) and the longest pulse (constrained by the frequency of operation) determines the available dynamic control range. This dynamic range is used for compensating the output against mains variations, load variations and a limited amount of setting control. Switch mode power supplies generally lack the large dynamic range that would make programming a practical matter. Switchers are generally used for fixed output or limited adjustment range output designs.

High frequency operation contributes to the small size of switch-mode power supply designs. Modern units typically operate in the 100-300 KHz range.

With the introduction of instrumentation switch-mode power supplies such as ABC and the BOP High Power series, Kepco has overcome this inherent limitation of switch-mode conversion to produce a true zero-up (to maximum) controllable switch. This allows Kepco to produce programmable d-c outputs in a pure switch-mode topology. The programmable RKW models, though not instrumentation power supplies, also offer zero-up control of a switch-mode power supply.

The use of power FETs with fast turn-on and turn-off characteristics have made switches that operate comfortably at frequencies above 100 KHz practical. Beyond this, the actual choice of operating frequency is driven by consideration of noise generation (EMI), safety issues and the trade-off of size vs. efficiency. Most of the designs in this catalog use one of two topologies, forward converters or flyback circuits operating at a fixed clocked frequency.

TYPES OF SWITCHERS

Forward converters are used in medium and high power applications. They can be recognized by their separate power transformer and output choke. Flybacks are favored for low power applications because they employ a transformer that doubles as the output choke thus saving on one large and expensive component.

TRANSFORMERS STEP-DOWN

Power supplies need a transformer to provide isolation and to shift the level from the voltage of the utility (115V a-c - 230V a-c) to the levels used by modern logic and their associated circuits (typically 5 volts to 48 volts).

The function of the switch, in addition to providing modulation (control) capability, is to convert d-c to a square-wave kind of a-c.

The square wave is necessary to meet two of a power supply’s principal purposes as listed on page 141: the ability to change the output to a different voltage level than the input and to provide isolation. Transformers provide this function. In linear power supplies the transformer operates at mains frequency and is the heaviest and largest part of the unit. In switch-mode designs, the switch is made to operate at high frequencies. Transformers at 100+ KHz can be a small fraction of the size of their mains-frequency counterparts.

The design that does all of this is a composite. The front end is a rectifier-filter that converts the low-frequency a-c to d-c. Operating on North American mains, this circuit functions as a doubler. Operating at European 230-250 volt mains, it functions as a simple rectifier. The resulting d-c is about 300-350 volts. The fast switch chops this so it can pass through a high frequency transformer to be re-rectified and filtered at the secondary to become the output.

OFF-LINE RECTIFIER FILTER

The input rectifier-doubler and filter is called an “off-line” circuit, that is, it operates directly off the line (mains). This “off-line” circuit is a source of a number of problems that have to be addressed by switch-mode power supplies.

For openers, there is little impedance between the filter capacitor that stores the high voltage d-c for the switch and the utility mains, little to impede the surge of current into this capacitor. To keep it under control, surge limiting circuits are required. In low power units this may take the form of a thermistor whose resistance is high when cold and low when hot. In medium power design, a resistor is switched in for start-up and removed once the input capacitor is charged. In high power designs, a sort of soft-start is provided using thyristors to ramp up the voltage.

Another problem is the high voltage itself, which is in the range of 300-350 volts. This must be well isolated from the low (5V) output if users are to connect it to their expensive logic without trepidation.

A third problem is in the discontinuous way in which current is drawn by a capacitor-input filter. This produces both high peak currents and reflects harmonic distortion back to the mains. This is the problem known collectively as poor power factor. Power factor correction (PFC) is used to solve this. Please see the discussion of Power Factor beginning on page 153.

The high voltage created when the a-c mains are directly rectified in off-line designs affords a unique advantage that is incidental to the process but nevertheless, quite valuable. Energy is stored in capacitors as $1/2\ CV^2$.

This means that the energy is proportional to the square of the voltage and the voltage, as we have already seen, is quite high. Thus the energy stored in the input, off-line capacitor, is enormous, sufficient, indeed, to sustain operation of the whole power supply for some time when the mains are interrupted. When the time exceeds a full cycle (20 milliseconds at 50 Hz) a ride-through capability results. The power supply will function uninterrupted through the loss of a part or whole cycle.

The principal advantage of this is to be able to provide some warning to the load that a mains failure is about to occur. This warning can be issued if it is possible to recognize and provide a logic signal when the mains have failed. Since the power supply will continue to operate for some time on the stored energy of its off-line capacitor, this warning can be used to provide an orderly shut-down of the load.

UNIVERSAL OR WIDE RANGE INPUT

The variety of a-c mains that confront power supplies are a logistical headache and sometimes a safety concern...not to mention a complicating factor in the initial design.

Not too long ago, power supplies were produced in two varieties: 115 volt models for the North American market and 230-250 volt models for Europe. Japan, with its 100 volt mains was accommodated either by a low tap on the 115V a-c connection or by extending the input range down to 85V a-c.

As we have seen, these designs use an input circuit that acts as a doubler when in the 115 volt mode and as a bridge rectifier when in the 230 volt mode. A simple jumper selects between them. While this simplified the logistical problem, it did give rise to a potential safety issue...the selection of the wrong input voltage. If a unit set for 115 volts is connected to 230 volts, damage usually results. Also, the selector, though simple, does cost something and so a demand arose for power supplies that would work from any a-c input without user intervention. In low power flyback switchers, this could be accomplished by simply using more of the pulse width modulator's dynamic range for input accommodation and by sizing everything in the input for the extremes. The capacitor had to be sized for the high end voltage while the rectifiers had to be sized for the low end current. Kepco's MRW, KRW and FAW designs are examples of this.

This approach has been very successful up to about 150 watts. Beyond that power level, wide range input is achieved as a fallout of the effort at power factor correction. PFC designs now reach beyond 1.5 KW, so wide range input is available at those power levels too. The Kepco HSP, RKW and HSM designs are examples of this.

Three HSP models shown in RA 60 Housing

Kepco's MST design is a 200 watt product with wide range a-c input that is achieved by using a PFC front end. MST is a hybrid in that it is a switcher that has a linear post-regulator so that it may be programmed over 0-100 percent of its output range. MST are digitally controlled plug-in power supplies that may be combined in groups of up to 1800 watts.

Kepco's ABC design is a 100 watt product with wide range a-c input that is also achieved by using a PFC front end. Unlike MST, the ABC design functions as a "zero-up" controlled switch that can be adjusted to any voltage from 0 to its rated maximum. ABC are bench-style power supplies with keypad/GPIB control.

Kepco's BOP High Power are 1000 watt 4-quadrant products with a bi-directional PFC current that enables it to recuperate energy sinked from an active load.

REDUNDANCY

While power supplies are quite reliable, there are many applications where zero downtime is demanded. This requirement necessitates fault tolerant power systems.

Uninterruptible power sources which address the power integrity question of the utility mains are not a whole solution. Consideration has to be given to the reliability of the power converters themselves. It is possible to employ ultra-conservative design philosophies to minimize the likelihood of failure, but it is not possible to eliminate failure entirely. A more effective approach is to design systems that are fault tolerant in that a single failure does not disable the function. In power supplies, multi-unit assemblies are frequently specified to ensure that internal failure of one power supply does not cause loss of output.

Power supplies may be paralleled with “OR-ing” diodes used to isolate one from the other and to prevent current from being fed back into a failed unit. Thus if one fails, the other may continue to supply the common load.

PARALLELING

It is the nature of voltage sources that only ONE unit can establish the voltage level in a system where several are paralleled. If low source impedance voltage stabilizers are paralleled with no special effort to form a master-slave relationship, the power supplies themselves will sort out who is to be “boss.” Only ONE unit will end up controlling the voltage while the others “overload” into their current mode and merely add their current to the total. The combination of such power supplies always ends up with just one voltage stabilizer. All of the other units operate in current mode.

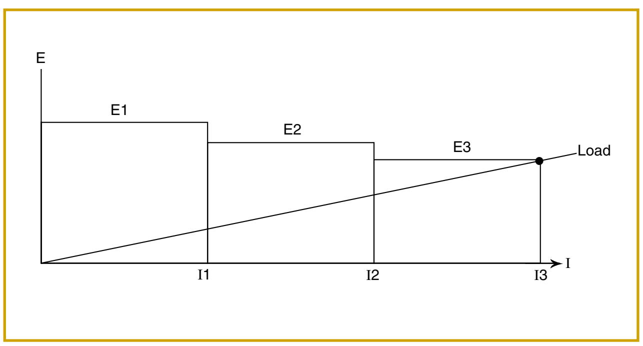

FIGURE 12
Power supplies paralleled without forced sharing.
The voltage is set by the voltage of unit 3 (E3).
Units 1 and 2 merely add current I1 and I2 to the total
and operate in their current limit mode

The principal disadvantage of this method is that the power supplies will be loaded unequally. The one with the highest voltage setting will initially deliver ALL of the current. Only after it goes into current mode, will the next unit assume part of the load and so on. The LAST unit, the one with the smallest voltage setting, ends up controlling the voltage and providing the least current. A further disadvantage is that the voltage seen by the load will change by an amount equal to the difference between the voltage setting of the individual models as each one goes into its current limit, passing voltage control to the next lowest unit.

A complementary situation will prevail if current sources are connected in series. Only ONE current stabilizer can control the current in a single loop. All of the others will overload to their voltage mode, merely supplying voltage to the load, but not controlling the current.

PARALLELED POWER SUPPLIES WITHOUT FORCED CURRENT SHARING

If the voltage stabilizers being used in parallel are poor regulators, with significant non-zero source impedance, then it may be possible to rely on the voltage “droop” afforded by the internal resistance of each unit as a means of causing the current to share. Adjustment is tricky however. All units must be set to the same voltage and readjusted carefully to share the current. This reliance on the internal resistance of poor stabilizers to equalize the current of paralleled power supplies was a “feature” of early power supply designs.

In modern fault tolerant power supply systems, a means is provided for forced current sharing. This ensures that all units carry an equal part of the burden.

The current sharing circuit is a form of master-slave operation in which the current supplied by the master is measured and the other units are controlled to match the current, ensuring that they are equally loaded. Only the master actually controls the voltage to the load.

N PLUS ONE

The basic idea of fault tolerance through redundancy is to size the system so that there is at least one more unit than the minimum required to carry the load. Thus, if a load is 10 amperes, a fault tolerant redundant system might have three (3) 5 ampere units in parallel; one more than is needed, hence: N+1 redundancy. The failure of any one power module leaves sufficient power available to support the whole load.

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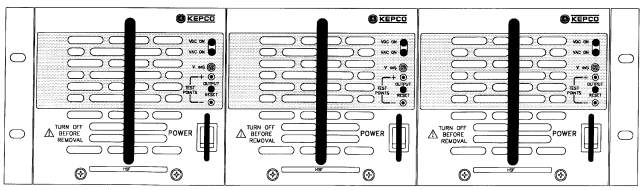
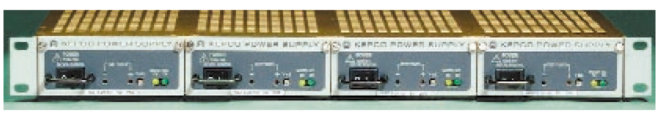
Currently Kepco supports N+1 hot-swap parallel redundancy operation with the 200W MST models, the 50, 100, 150 and 350W HSF models, the 50 and 100 HSF 1U models and the 1000 and 1500W HSP series.

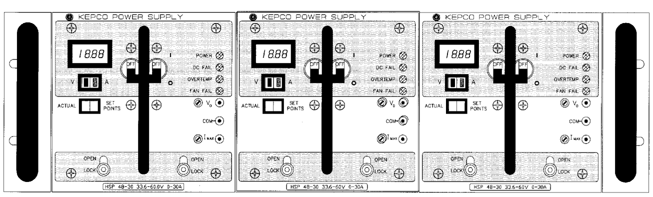
In a “hot-swap” enabled power supply, the idea is to replace bad modules without shutting down the system. This is accomplished by a combination of pre-set adjustments that allow modules to be set off-line and a mechanical arrangement that allows units to be inserted and removed without upsetting the output. When the currents are large, as they are in our 1000W and 1500W HSP hot-swappable modules, the connector to allow the removal and substitution of a new module while the power is live is quite specialized. It is found in the rack adapter, RA 60. A simpler rack adapter without the special hot-swap d-c connectors is available at lower cost. It is called RA 58. The hot-swap rack adapter for the HSF is called RA 19-(X)B and for the MST series, the rack adapter is RA 55.



A 700 Watt N+1 redundant array of three 350W HSF modules



A 300 Watt N+1 redundant array of four 100W HSF 1U modules



A 2000 Watt N+1 redundant array of three 1000W HSP modules

Several other Kepco power supplies offer the kind of built-in forced current sharing that is needed for N+1 redundancy without the plug-in hot-swap capabilities. The RCW 350 and 1500W sizes, the RKW and the HSM are examples.

FORCED CURRENT SHARING

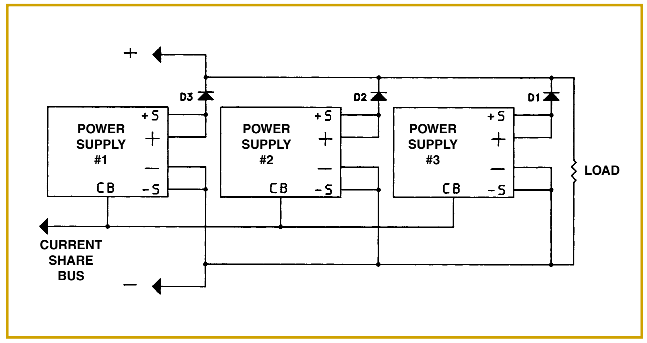


FIGURE 13
Current sharing by means of a current share bus (marked CB)

THE RELATIONSHIP BETWEEN REAL POWER, APPARENT POWER AND POWER FACTOR

Electric power expressed as watts in d-c circuits is the product of the voltage and current (voltage times current). In a-c circuits the calculation is complicated by the need to take into account the shape of the voltage and current waveforms and their relative phase angle.

Real power is mathematically determined by dividing time into a very large number of small segments and multiplying the instantaneous voltage present in each time segment by the instantaneous current flowing and averaging the results.

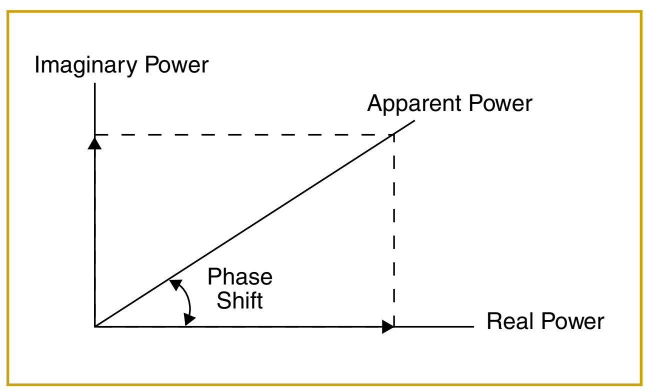


FIGURE 14
Relationship between real and apparent power in a sinusoidal system

A wattmeter gives the same result in a real world circuit because the instrument reacts to the simultaneous effects of the voltage and current present from instant to instant. When separate measurements are made of voltage and current, the product is NOT a-c power since each meter reads an average or rms value of the voltage or current over time without reflecting the phase shift that may be present. If there is a difference in phase between the voltage and current waveforms, the peak current may not be present when the voltage reaches its peak. The apparent power will be the vector sum of the real power and the imaginary power.

The angle is the phase shift. In a non-reactive circuit, the voltage and current will be in phase, the imaginary power is zero and the real power will equal the apparent power. Their ratio is expressed as power factor (PF) and when they are equal, the power factor is unity (1).

Waveform distortion, of the type caused by capacitor input filter circuits following rectifiers, is another source of low power factor. It results from the creation of discontinuous waveforms as the current to the load flows for just the part of the cycle where the voltage from the rectifier exceeds the d-c level across the capacitor. In terms of rms values, there are an infinite number of waveforms that can yield the same rms value. If the current is not sinusoidal, a narrow spike, for example, the rms value may remain the same even though the average value can be quite different. Although the voltage and current are in phase with each other, the power factor can differ from the unity value that two sinusoidal waveforms would produce. A Fourier analysis would show that changing the shape of either the voltage or current waveform reduces the power factor from the unity value that you might expect from the in-phase relationship.

The input off-line capacitors of switch mode power supplies do significantly change the current waveform. As the voltage reaches the stored level in the capacitor, the rectifier diode switches on, forcing the current to flow for a shorter time interval than the voltage. While the load current is drawn from the capacitor continuously, or at the high switching frequency of the converter, the capacitor is recharged only during the interval when the input rectifiers conduct. No current flows into the capacitor from any point along the voltage waveform where its amplitude falls below the capacitor's d-c voltage. Current only flows when it again rises above the d-c value during the next mains half cycle.

Low power factor results when the load current is drawn over only a part of each mains cycle. This is a common result in off-line rectifiers where the input diode does not conduct until the peak of the rectified mains waveform exceeds the d-c level across the input capacitors.

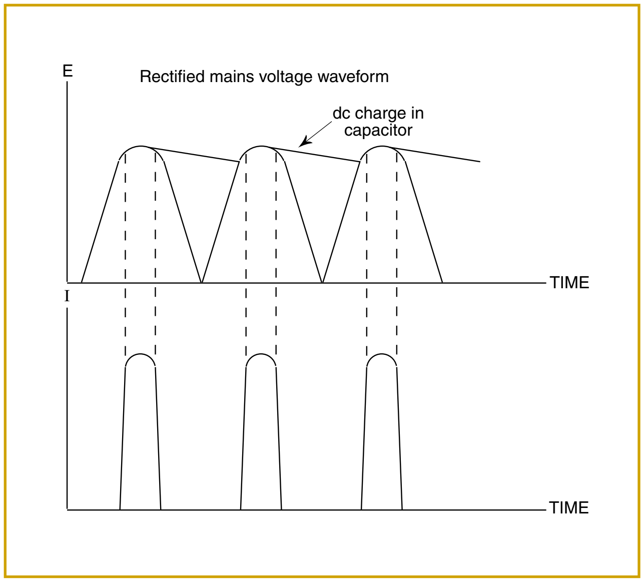


FIGURE 15
A capacitor-input filter as used in off-line power supplies produces discontinuous current flow. a-c current flows only when the a-c voltage exceeds the d-c change in the capacitor

The period of time during which no current flows into the capacitor, expressed in terms of degrees along the voltage waveform, is the rectifier's dead angle. Conversely, the period during which current does flow into the capacitor is the rectifier's conduction angle. The ratio of these angles depends upon the filter's capacitance and how much energy is being withdrawn by the power converter which is the capacitor's load. This, in turn, depends on the amount of power demanded by the output load on the converter. With a light load, the conduction angle may be just a few degrees. At full rated load, the conduction angle will be larger, but even with heavy loads, conduction is not continuous. The current has the form of relatively large, short-duration pulses. Because the a-c mains exhibit a non-zero source impedance, the high current peaks cause some clipping distortion on the peaks of the voltage sinusoid. Fourier analysis would show that this lowers the power factor significantly.

Since power factor represents the ratio of real to apparent power, the high apparent power that yields a low power factor translates into a higher current than the load actually needs to satisfy its real power requirement. The difference between the current that produces the real power consumed by the load and the current measured on an ammeter is known as the circulating current. It is so called because even though it does no real work, it continuously flows back and forth between the mains and the load.

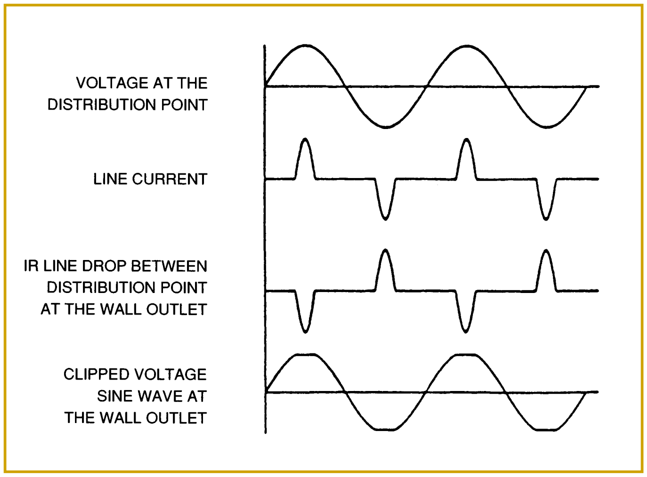


FIGURE 16
Waveforms illustrating the peak flattening effect that the narrow current pulses impose on the mains voltage

A switching converter with 80 percent efficiency and an uncorrected power factor of 0.65 can produce only 717 watts of real power to a load with 12 amperes from a 115V a-c utility mains. (12 amperes is the maximum continuous rating of a standard 15 ampere branch circuit.) Equipping this power supply with power factor correction, despite lower conversion efficiency, allows it to use the full 12 amperes to produce real power for its load. With an overall efficiency of 67.5% the 12 amperes from the 115V a-c branch circuit produces 932 watts to the load, an increase of 30%.

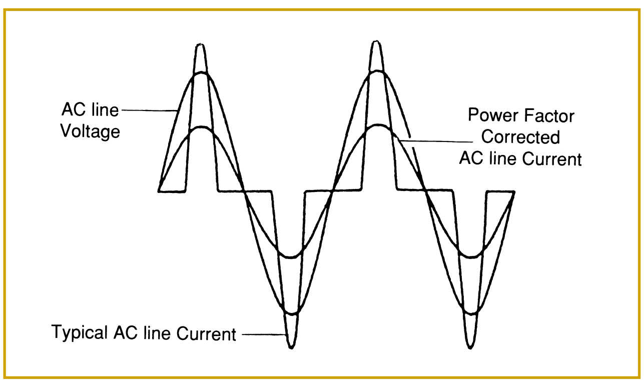


FIGURE 17
Waveforms illustrating the reduced peak current when the current waveform is made to conduct continuously by power factor correction

PROTECTING SENSITIVE EQUIPMENT FROM ELECTRO-MAGNETIC INTERFERENCE

The EMI produced by the high-frequency switching of a switch-mode converter is well recognized and may be dealt with through special filters built into nearly all such power supplies. The discontinuous current pulses created by the charging action of a power supply's input circuit is another form of EMI. As such it can affect the operation of sensitive equipment operated in close proximity to the a-c mains. This interference takes two forms. First, the high amplitude of the current pulses generate electromagnetic fields strong enough to be detected by sensitive amplifiers. Second, as the current pulses occur around the peaks of the voltage waveform, the IR drop in the wiring flattens the voltage waveform producing harmonic distortion. This may adversely affect instruments that depend upon the presence of a normal a-c sinusoid. When more than one power supply operates from such distorted mains, the problem is compounded as each power supply tries to charge its input capacitor from the same peak of the a-c voltage.

THE EUROPEAN VIEW OF POWER FACTOR: EN 61000-3-2

The European electrical system distributes power at 240 volts. This means that the current is half what it would be in the USA for an equivalent load. Because of this, European distribution systems use smaller gauge wire and lower amperage fuses. As a result, they are more sensitive to circulating current than their USA counterparts. With the goal of minimizing circulating current, the International Electrotechnical Committee (IEC) took a look at the discontinuous currents produced by switch mode power converters and other electrical equipment. Any discontinuous waveform consists of a pure sine wave at the fundamental frequency plus sine waves of various amplitudes occurring at each of the fundamental's harmonic frequencies. The IEC codified its findings in IEC 555-2, setting limits for currents at each harmonic frequency through the 40th harmonic. The IEC divided equipment into four classes, each with its own set of harmonic current limits. These limits have been codified into a "European norm," EN61000-3-2.

To meet these limits various power factor correcting (PFC) circuits are employed to actively force the main rectifier(s) to conduct over the whole of each half cycle of the ac power mains. These sometimes take the form of a high frequency boost converter that preceeds the input filter capacitor.

At some sacrifice in efficiency and some loss of simplicity, the PFC boost converter reduces the power factor to something between 0.95 and 0.99 (sufficient to meet the harmonic current limits). Additionally, PFC enhances the energy storing function of the input capacitor. A boost converter can also provide a relatively stable output over a wide range of input voltages. The power factor correcting boost converter produces a constantly high voltage across its input capacitor regardless of the input mains voltage. Thus the hold-up time becomes independent of the mains voltage.

Power supplies with active power factor correction (PFC) include the Kepco ABC (100W), MST (200W), RCW (350, 750 and 1500W), RKW (50, 100, 150, 300, 600 and 1500W), HSP (1000 and 1500W), BOP High Power (1000 and 2000W) and HSM (1000 and 1500W).

Model ABC 10-10DM

Model BOP High Power 10-75MG

Model RKW Programmable - 1500W size

THE CE MARK AND SAFETY AGENCY MONOGRAMS

The CE mark is required by the European Community on certain products. Since January 1, 1997, there are two requirements for the CE mark: Electromagnetic compatibility (EMC) and the Low Voltage Directive (LVD). The EMC standards address both emitted EMI and the susceptibility to RF and electrostatic discharge. The low voltage directive addresses safety issues.

Kepco produces both instrumentation power supplies, which are self-contained products, and modular power supplies which are considered components of a larger assembly. They have different rules. The Low Voltage Directive applicable for our instrumentation power supplies is EN61010-1. The standard currently applicable for component power supplies is EN60950. (The UL standard for the USA is based on the same recommendation of the International Electrotechnical Commission (IEC): IEC 950 and is known as UL60950.)

All component power supplies intended for sale overseas have been CE marked per the Low Voltage Directive (LVD) EN60950. They are NOT certified to the EMC/EMI standards because as components they are intended to obtain their shielding from the larger assembly into which they are mounted. Kepco's component power supplies do, of course, contain input EMI filters designed to reduce conducted EMI below the limits of Class A or B emissions depending on the product. Such filters, however, do not guarantee that the end product into which the power supply is installed will meet all of its EMC/EMI requirements. That remains the responsibility of the end item producer.

Instrumentation power supplies designed to mount within another enclosure or rack are similarly CE marked per the Low Voltage Directive (LVD) EN61010-1, but not the EMC/EMI directives. Those instrumentation power supplies designed for stand-alone bench use are CE marked for both the EMC/EMI directives and the LVD.

Kepco uses the services of Underwriters Laboratories, (UL), the Canadian Standards Association, (CSA), TÜV Rheinland and VDE to perform safety certifications on our products. The LVD test data is on file at Kepco and is available for review by authorized EC port inspectors on request. We can provide, upon request, copies of our certifications by these independent safety agencies or declarations of conformity which indicate the directives for which compliance is declared.

UL RECOGNIZED CSA CERTIFIED CSA CERTIFIED TÜV APPROVED VDE APPROVED

Kepco's facility in Flushing, New York, has received ISO 9001 certificate, number 109592, from Lloyd's Register of Quality Assurance.