D-26

N85 13876

HIGH-EFFICIENCY POWER CONVERSION OPTIONS FOR FLYWHEEL ENERGY STORAGE SYSTEMS

R. L. Hockney
The Charles Stark Draper Laboratory, Inc.
Cambridge, Massachusetts

This presentation includes a discussion of the impact of efficiency on the power system; how efficiency is affected by component types; some ac and dc bus configurations; and systems developed at CSDL; and concluding remarks.

HIGH-EFFICIENCY POWER CONVERSION OPTIONS

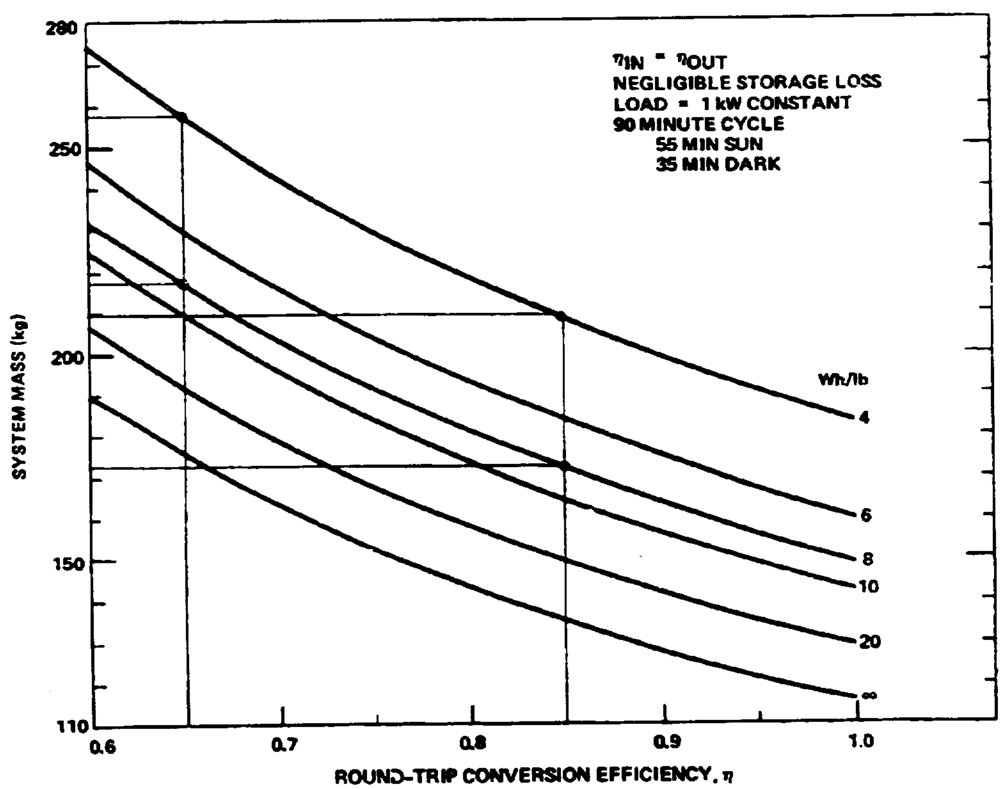
FOR

FLYWHEEL ENERGY STORAGE SYSTEMS

- EFFICIENCY
  - SEMICONDUCTOR
  - MACHINE
- CONFIGURATIONS
- CSDL EXPERIENCE
- CONCLUSIONS

SYSTEM MASS VS EFFICIENCY

This graph (ref. 1) shows the mass of a satellite energy system as a function of conversion efficiency and energy density for a system that supplies a 1-kW steady-state load aboard a satellite in low Earth orbit. The satellite energy system consists of a photovoltaic array and an energy storage element, such as a battery or flywheel. The mass of the photovoltaic array is the product of the required capacity and the power density of the array material. The mass of the storage element is the product of the required storage capacity and the energy density of the storage element.



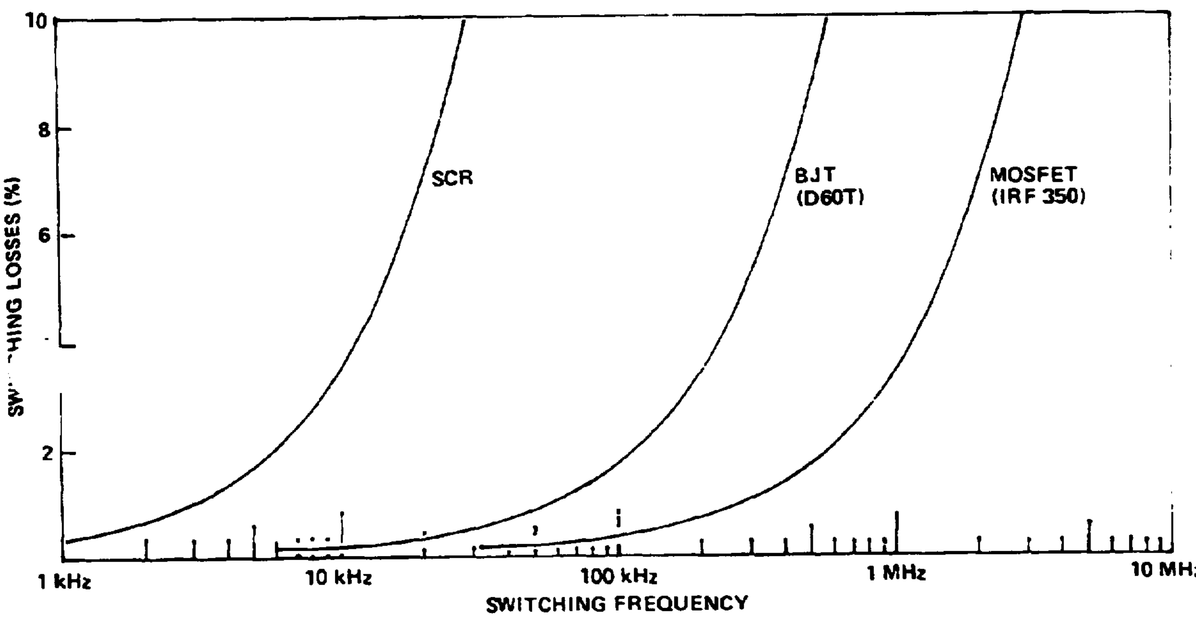
A relative comparison of each semiconductor technology reveals their strengths weaknesses. The IGT is an Insulated Gate Transistor, a relatively new technology.

SEMICONDUCTOR TYPES

	SCR	BJT	FET	IGT
"ON" LOSS	$I \times V_D$	$I \times V_D$	$I^2 \times R_D$	$I \times V_D$
SPEED	SLOW	FAST	VERY FAST	MED
DRIVE	LATCH	CURRENT	VOLTAGE	VOLTAGE
POWER	VERY HIGH	HIGH	MED	LOW

SWITCHING LOSS

The relative switching efficiencies of the three most popular types of power ›iconductors including FETs, bipolar junction transistors (BJT), and silicon con- ›lled rectifiers (SCR) are indicated. The FETs clearly give superior performance ›oughout, and will efficiently operate in regions which are not possible for SCRs › even BJTs.



The design parameters of the candidate machine types can be compared in order to trade off performance with simplicity.

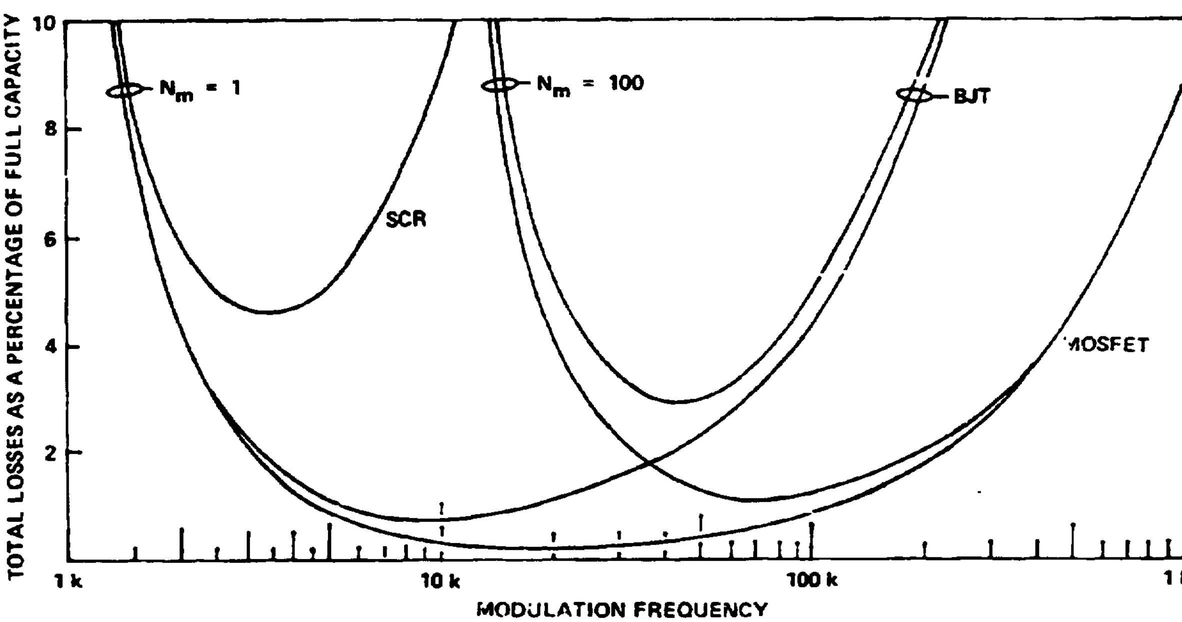
MACHINE TYPES

		PM BRUSHLESS	PM "IRONLESS"	INDUCTION	WOUND-FIELD
TORQUE		KI	KI	KI^2	KI_AI_F
LOSS	IRON	MED	VERY LOW	LOW	MED
	COPPER	I^2R_W	I^2R_W	$I^2(R_S+R_R)$	$I_S^2R_A + I_F^2R_F$
SIDE-LOAD		YES	NEGLIGIBLE	YES	YES
FEEDBACK		POSITION	POSITION	SPEED	POSITION
COMPLEXITY		MED	HIGH	LOW	MED

ALL REQUIRE CONTROLLED-CURRENT, VARIABLE-FREQUENCY DRIVE

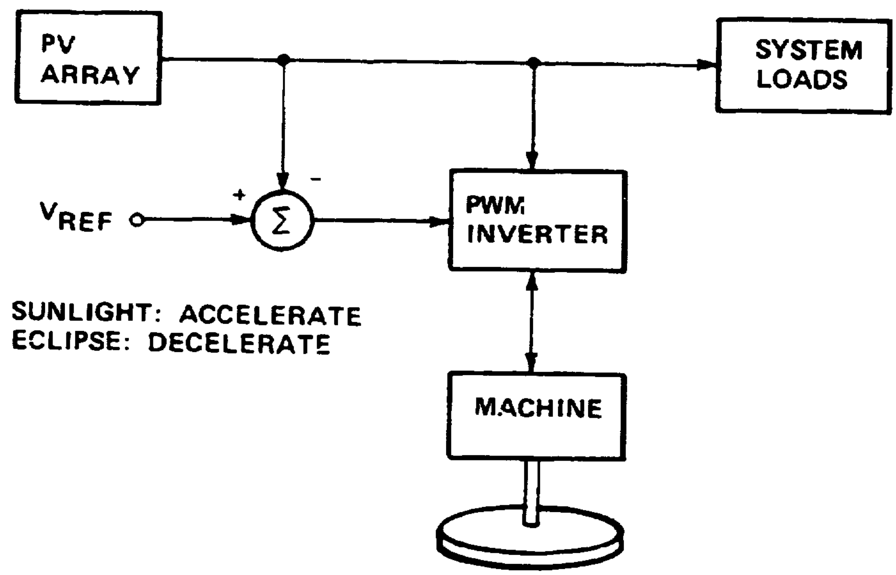
TOTAL LOSS

PWM losses are minimized by selecting a carrier frequency which is a trade-off between the decreasing harmonic losses and increasing switching losses with increased carrier frequency. The combined effect of harmonic and switching losses is plotted for differing values of a machine normalization quantity, N_m (ref. 2). These curves demonstrated that FET devices are advantageous for all applications. They do, however, have particular advantages for high N_m and, therefore, PM motors.



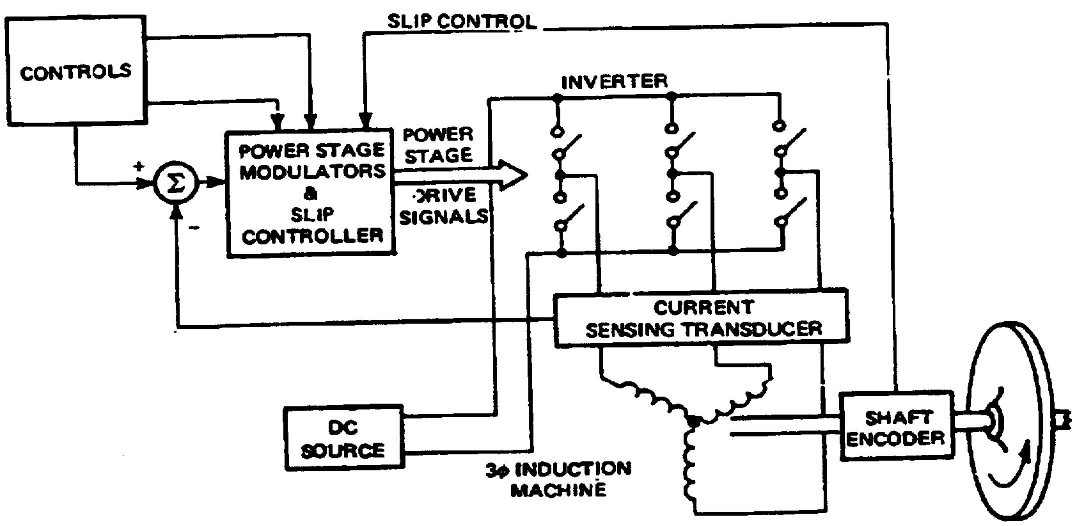
In the first dc configuration, a high-frequency pulse-width modulated inverter controls the rate and direction of power flow. The rate is determined by the voltage regulation control loop.

DC BUS CONFIGURATION



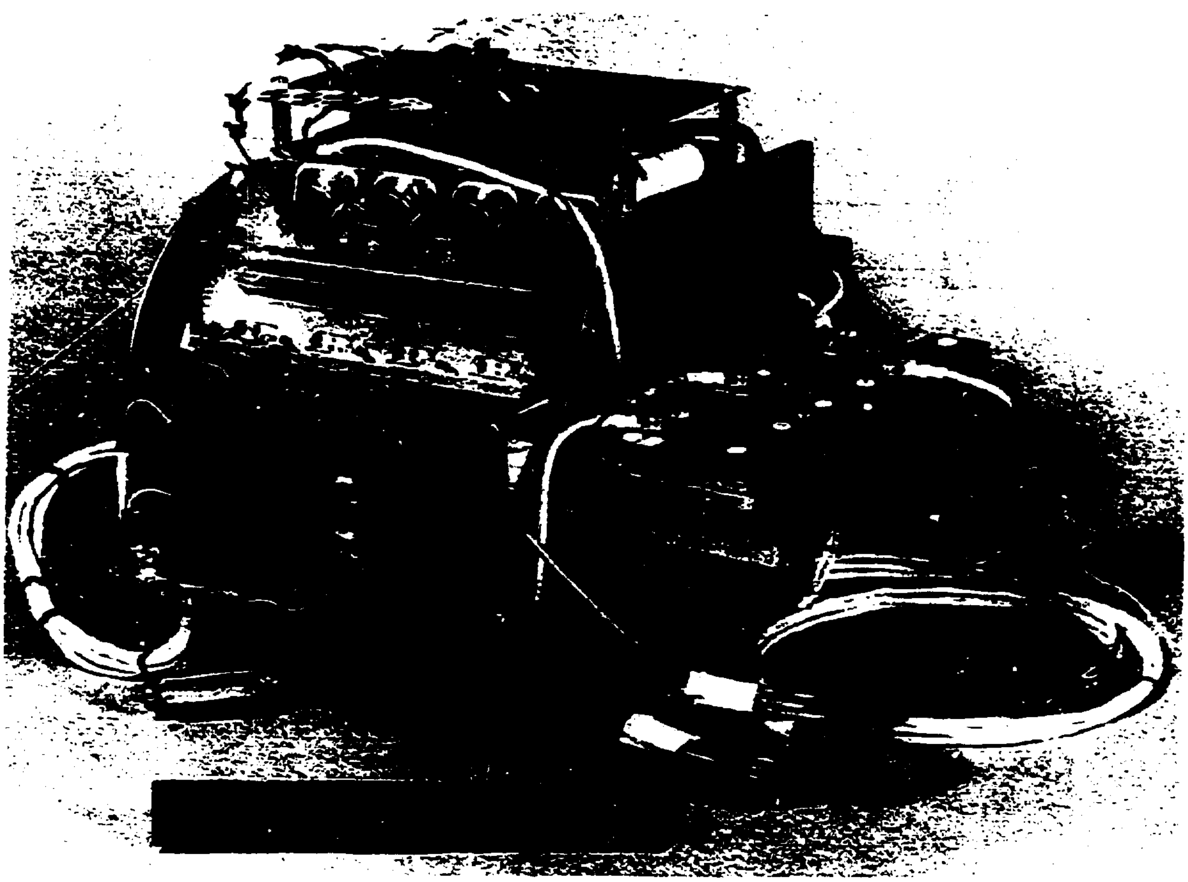
PWM INVERTER

This is the block diagram of a 10-kW three-phase motor controller developed at CSDL (ref. 2). It utilizes MOSFET's in the power stage and employs pulse-width modulation to produce a variable frequency, variable current drive. It was used to develop the slip-control algorithm for optimum-efficiency operation of an induction motor.



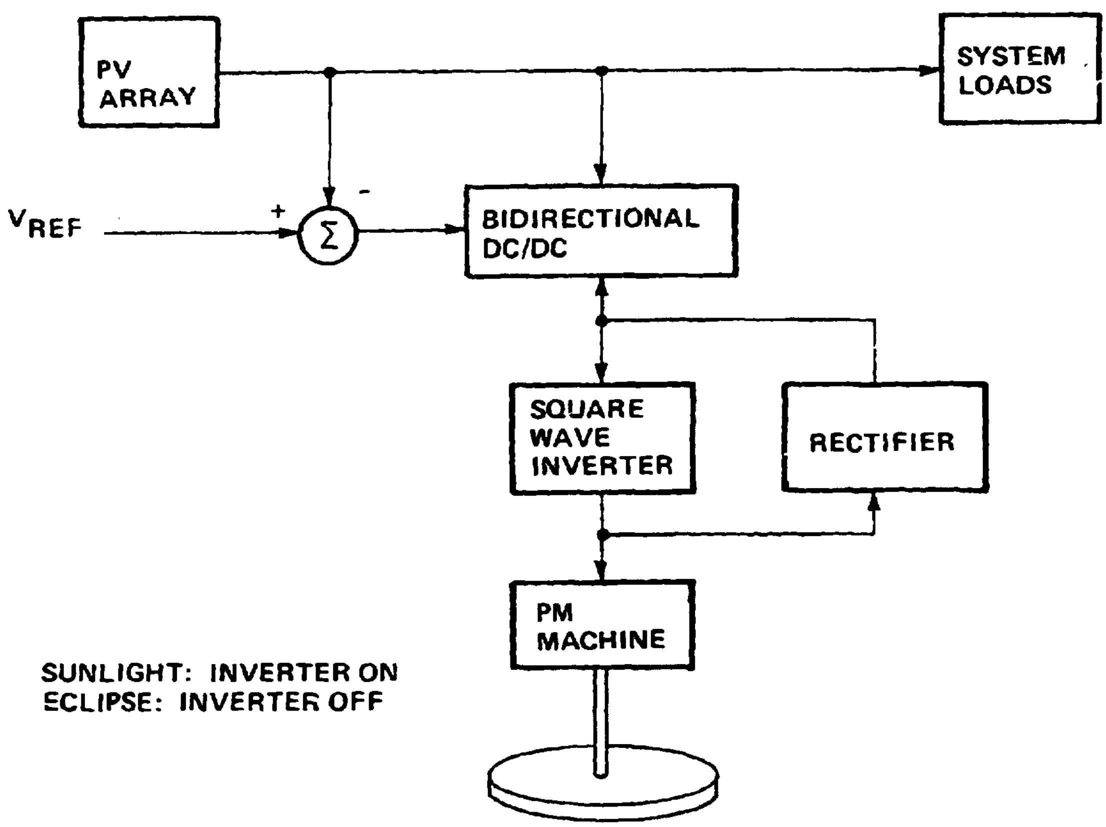
POWER STAGE

The power stage of the 10-kW three-phase inverter comprised 24 MOSFET's and their associated drivers on a forced-air cooled heat sink.



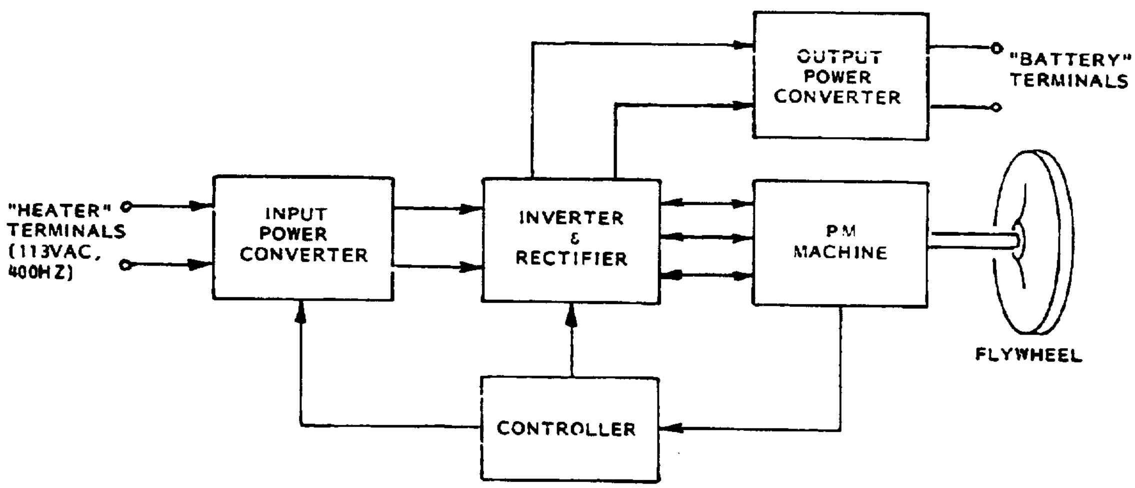
In an alternate dc configuration, the high-speed switching can be performed in a one- or two-switch converter rather than the six-switch inverter.

DC BUS CONFIGURATION



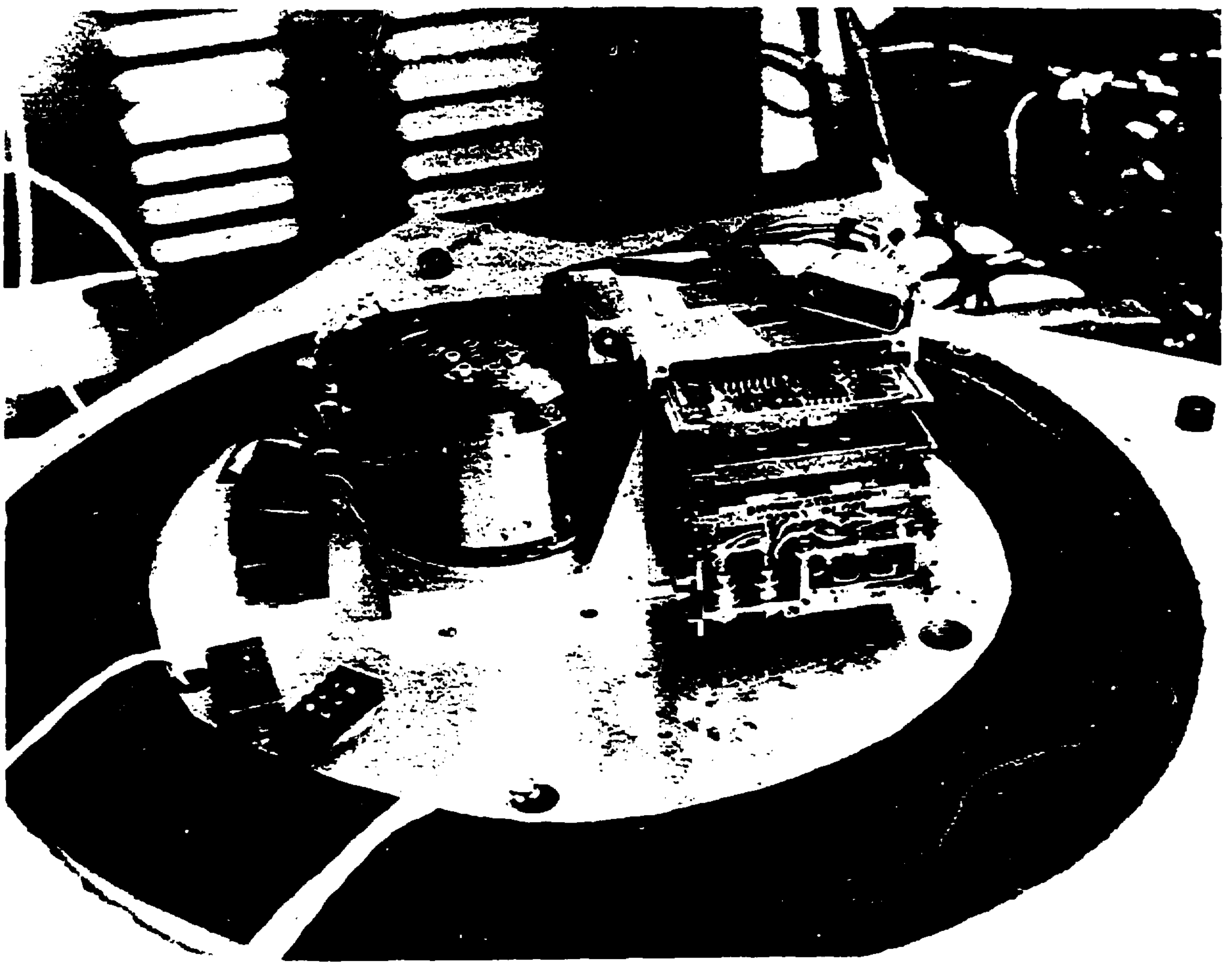
SQUARE-WAVE INVERTER

This figure is the block diagram of the Inertial Power Storage Unit (IPSU) developed at CSDL as a battery replacement. It utilizes a permanent magnet (PM) machine wound to produce square-wave back-EMF and separate input and output converters.



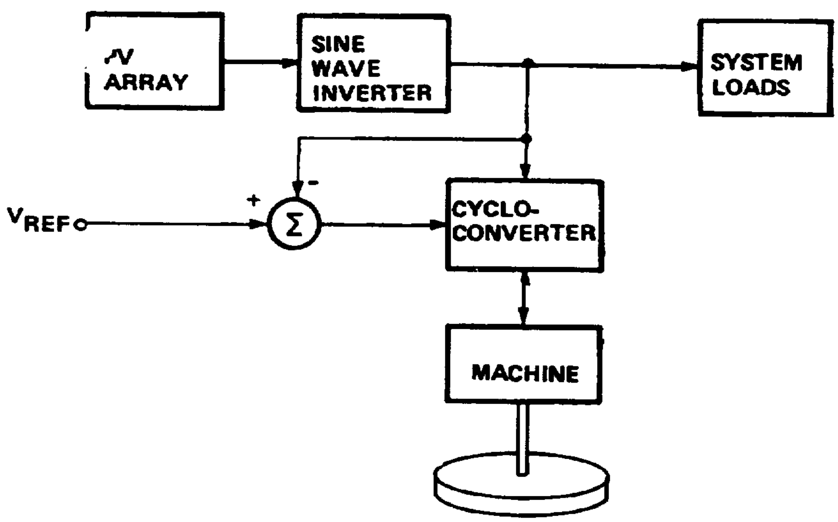
ENGINEERING MODEL

The flywheel/machine module and electronics module for IPSU have to perform as a form, fit, and function replacement for the NiCd battery in fighter aircraft.



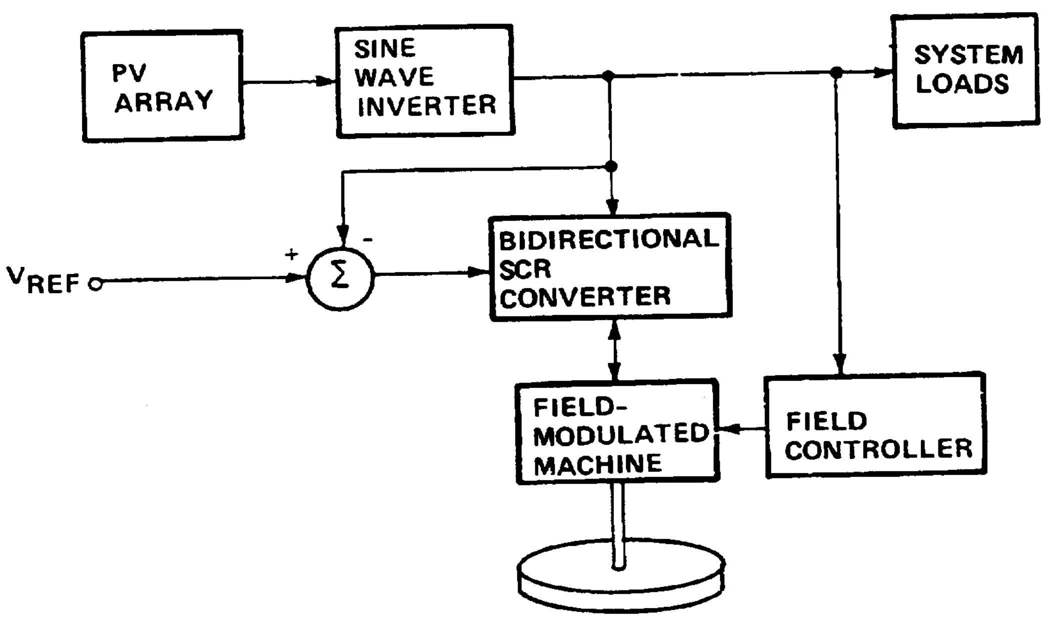
In the first ac configuration, bi-directional power flow through the cyclo-converter will require forced commutation in at least one direction.

AC BUS CONFIGURATION



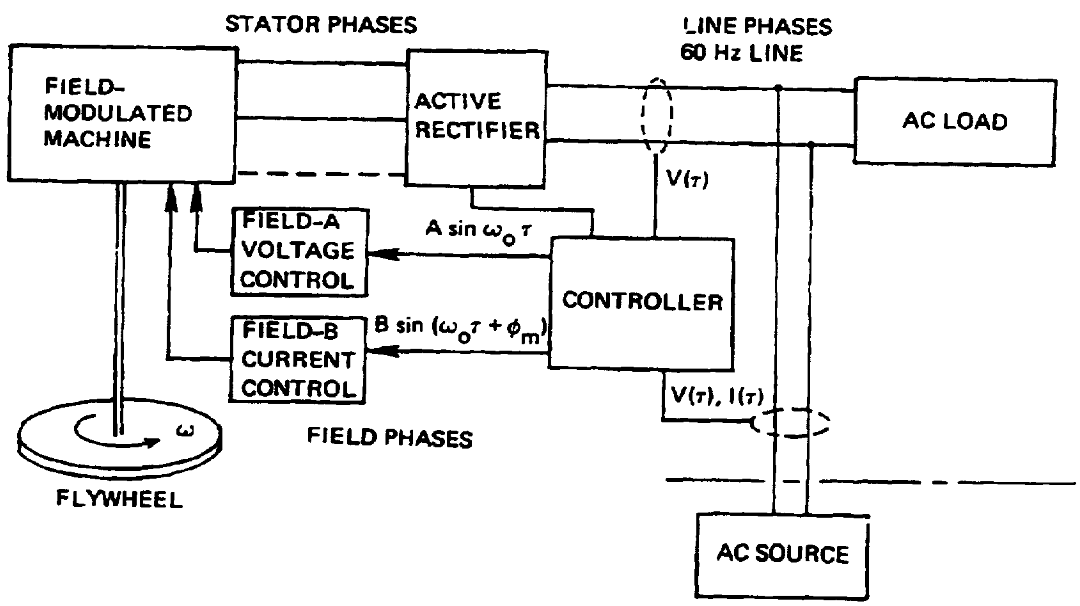
In the alternate ac configuration, a field-modulated machine allows bi-directional power flow through naturally commutated SCR's.

AC BUS CONFIGURATION



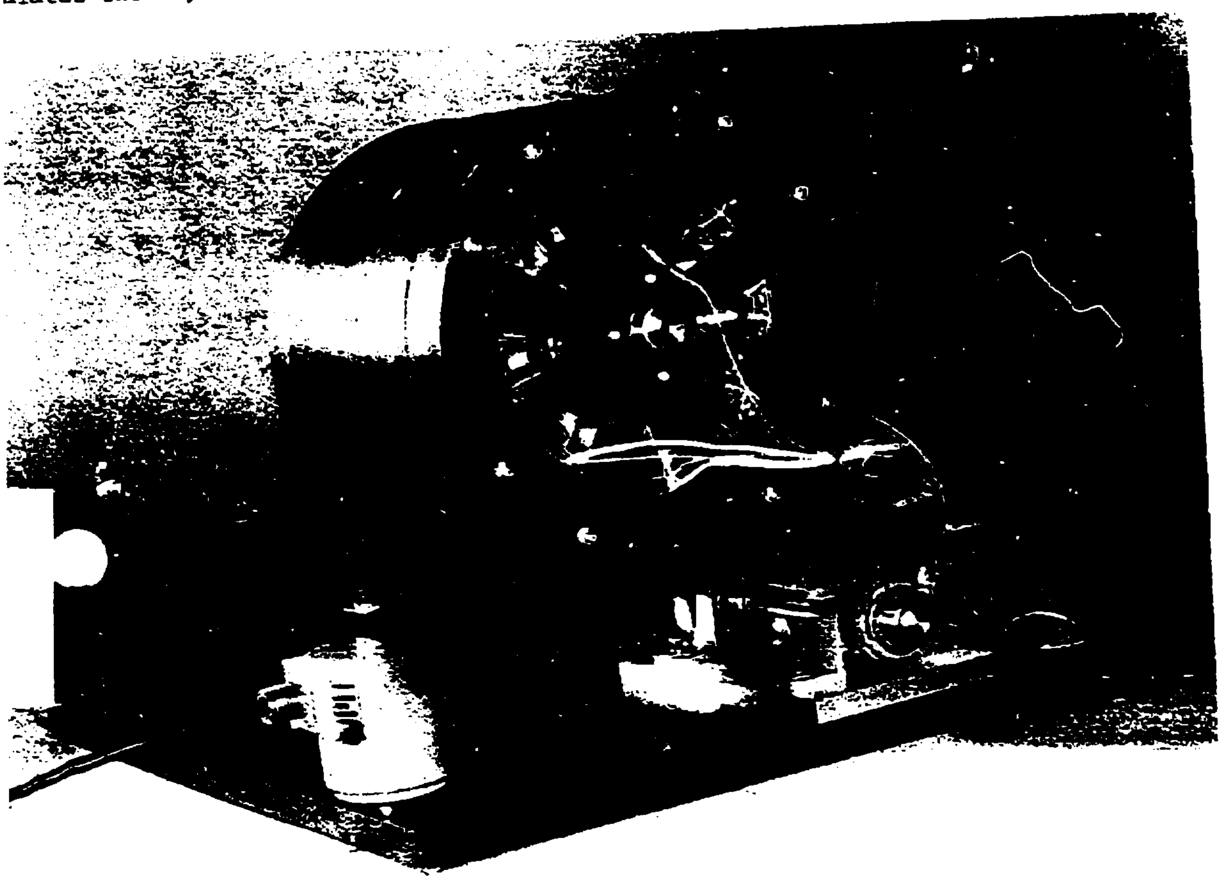
FIELD MODULATION

This power-conversion system uses a CSDL-developed machine (ref. 3) utilizing two independently controlled field windings on the stator. The system includes an SCR switching circuit that demodulates the high-frequency armature waveform to produce the lower-frequency bus voltage.



PROTOTYPE MACHINE

The multi-field machine (right) is shown on its testbed with a dc machine which ulates the flywheel as both load and drive.



Improvements in component technology in recent years have increased the attractiveness of flywheel energy storage. A technology development program is required to determine the optimum configuration.

CONCLUSIONS

- TECHNOLOGY EXISTS FOR PRACTICAL SYSTEM
- RECENT ADVANCEMENTS INCREASE SYSTEM VIABILITY
- SPECIFIC IMPLEMENTATION DEPENDS UPON
  - POWER
  - VOLTAGE
  - AC/DC BUS
- ADVANCED DEVELOPMENT PROGRAM INDICATED

REFERENCES

1. Eisenhaure, D. B.; Downer, J. R.; Bliamptis, T.; and Hendrie, S. D.: "A Combined Attitude, Reference and Energy Storage System for Satellite Applications," AIAA-84-0565, Jan. 1984.

2. Eisenhaure, David; Stanton, William; Hockney, Richard; and Bliamptis, Tim: "MOSFET Based Power Converters for High-Speed Flywheels," 1980 Flywheel Technology Symposium, Rep. No. CONF-801022, Dep. Energy, 1980, pp. 363-370.

3. Eisenhaure, David; Stanton, William; St. George, Emery; and Bliamptis, Tim: "Utilization of Field-Modulated Machines for Flywheel Applications," 1980 Flywheel Technology Symposium, Rep. No. CONF-801022, Dep. Energy, 1980, pp. 353-362.