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EFFICIENT UTILITY EQUIPMENT: POWER DISTRIBUTION SYSTEMS AND POWER CONDITIONING EQUIPMENT

Robert Bernstein

Alfred University
Alfred, NY 14802

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**Efficient Utility Equipment:
Power Distribution Systems and Power Conditioning Equipment**

First Draft Report (May version)

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**Submitted to: Norma Myers
325 Contracting Squadron
501 Illinois Ave., Suite 5
Air Force Contracting
Tyndall AFB, FL 32404-5323**

**Written by: Mr. Robert Bernstein
Alfred University
Alfred, NY 14802**

Management: Provost Ott

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I. INTRODUCTION

Air Force bases, having been constructed many years ago, employ old, inefficient power distribution systems. In order to comply with the Energy Policy Act of 1992, the Air Force must reduce energy consumption. One way of doing this is to install more efficient power distribution equipment, which will cut energy losses during distribution. The first purpose of this paper is to find off-the-shelf power distribution equipment that can be implemented to increase the efficiency.

Air Force bases most likely do not have much in the way of power conditioning equipment. In the past forty years, much equipment that is very sensitive to power disturbances has been developed, including computers and sensitive industrial manufacturing equipment. The present equipment on the Air Force bases probably cannot condition the power to these sensitive loads effectively. This means that equipment can be interrupted or even damaged by the different disturbances, so that business is interrupted and money is lost. These disturbances are also a source of power loss, but can be protected against using certain equipment. The second scope of this project is to find off-the-shelf power conditioning equipment which will protect sensitive loads and increase efficiency.

The different types of disturbances are shown in Table I [1]. Normal power is in the form of a sine wave. All disturbances change some quality of the sine wave. Undervoltage and overvoltage are decreases or increases, respectively, of the voltage, and are usually due to circuit overloads, poor voltage regulation, or brownouts. Sags and swells are momentary (less than a few seconds) decreases and increases in voltage, and are usually caused by starting of heavy loads, lightning, or short circuits. Spikes are similar to swells, but are of very short duration (microsecond to millisecond), and are caused by lightning strikes near lines and switching of

heavy loads. An outage is a complete loss of power and is caused by a fault in system, transformer failure, power line disruption, or generator failure.

The last type of disruption is noise or harmonic distortion, which is a distortion in the normal sine wave. This is caused by radio and radar, fluorescent lights, power electronics control circuits, arcing utility and industrial equipment, and other standard appliances, such as computers, copiers, and laser printers. Harmonic distortion is a major cause of efficiency loss because it causes motor loads, pumps, and disk drives to overheat.

II. WORK PERFORMED

Literature searches in the following areas were performed:

1. Current air base requirements with respect to connected load and power conditioning required.
2. Power distribution and conditioning equipment available off-the-shelf for use to protect equipment on the air base and increase efficiency.

Current Air Base Requirements:

The current base requirements were determined from the Energy Utilities Questionnaire from 1992. Most air bases need a connected load of less than 80 MVA, but some, such as Langley, need up to 195 MVA. The connected load that required conditioning is always less than .8 MVA and the connected load that required an Uninterruptable Power Supply (UPS) is less than .4 MVA.

Power Distribution and Conditioning Equipment:

Because of the many different types of power disturbances, different power conditioning products may need to be used together to minimize the disturbances. A set of custom power products from Westinghouse Electric Corporation[2] can be used either separately or together to provide quality power. Figure 1 shows the Custom Power Distribution System. The Distribution STATCON (DSTATCON) protects the distribution system from a fluctuating, nonlinear load. The basic functions of the DSTATCON are reactive power compensation, voltage regulation, and harmonic load current supply. With the addition of a Solid State Breaker and some type of energy storage, the DSTATCON can also eliminate voltage sags, swells, transients, and power interruptions. The specifications of the DSTATCON are given in Appendix A.

Also from Westinghouse, the Dynamic Voltage Restorer (DVR) protects the sensitive load from disturbances that originate on the distribution or transmission system. The DVR can reduce voltage sags, swells, and transients, provide voltage regulation, limit fault currents, and, with the addition of shunt solid state breaker and some type of energy storage, prevention of power interruption. Appendix B shows two uses of the DVR as well as the specifications of the DVR.

The Solid State Breaker (SSB) from Westinghouse instantaneously interrupts the current when a disturbance is detected, protecting sensitive loads. It can be used in a few different ways, as shown in Fig. 2. Appendix C shows the specifications of the SSB.

The Solid State Transfer Switch (SSTS), the last custom power product from Westinghouse, instantaneously transfers sensitive loads from a normal supply that experiences a disturbance to an alternate supply that is unaffected by the disturbance. The SSTS can be

obtained with voltage ratings between 4.16 and 34.5 kV and current ratings between 300 and 1200 Arms continuous. Figure 3 shows the application of the SSTs.

A magneto-optic current transducer, developed by ABB Power T & D Co. and used by Commonwealth Edison Co., can be used to detect cable faults [3]. A polarized light signal is sent through the magnetic field of the line to a sensor. The magnetic field alters the polarization. The amount of change in polarization is directly proportional to the strength of the magnetic field. This, in turn, is directly proportional to the current of the line. A change in the signal from the sensor indicates a change in the current.

For many of the previous systems, it was mentioned that energy storage of some type was needed to provide an Uninterrupted Power Supply (UPS). A UPS can also be used as a separate system. This has been most commonly a battery of some type, but with the development of superconductor technology, a new type of UPS has been developed. This is Superconducting Magnetic Energy Storage (SMES). A diagram of the principle of operation of the SMES is shown in Fig. 4. The SMES is very efficient, can be mobile and can be scaled to almost any size requirement. However, very low temperatures are presently needed and the large magnetic field could be harmful to the environment. A system developed by Superconductivity, Inc. [4] is capable of providing 750 kW for about 2 seconds, but costs \$1 million and uses 50 kW of power continuously for the refrigerator, since it must be cooled to about 4 K.

A SMES system developed by Babcock & Wilcox [5] is for a 1800 MJ, 50 MVA application. The power from the SMES can be used to support the system frequency until the generator can support the system.

Other UPS systems that can be used are batteries, flywheels, and compressed air systems.

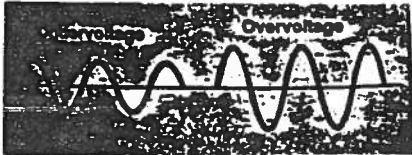
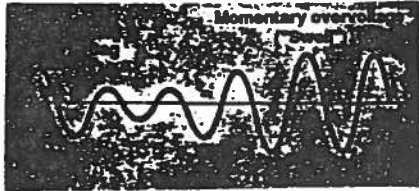
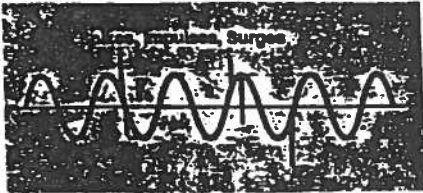


III. PLAN FOR NEXT PERIOD

A continued literature search will be undertaken in the areas of power distribution and conditioning equipment. More off-the-shelf equipment will be found and literature on these systems will be studied.

REFERENCES

1. U.S. Department of Commerce, National Institute of Standards & Safety. "Power Quality." NIST SP768A. Oct. 1990.
2. N.H. Woodley. "Solid State Custom Power Products for Distribution Feeder Power Quality Improvement." Westinghouse Electric Corporation, March 2, 1995.
3. T.J. Meno and H.S. Gilleland. "138 kV Cable Fault Detection Using Magneto-Optic Current Transducers and a New Digital Differential Relay." Proceedings of the American Power Conference, Chicago, IL, 1995.
4. T.P. Sheahan. "Introduction to High Temperature Superconductors." Plenum Publishing Corp.: 1994.
5. S.F. Kral, M. Aslam, P.F. Ribeiro, X. Huang, and M. Xu. "Superconducting Power Delivery Systems for Transmission and Distribution Applications." Proceedings of the American Power Conference, Chicago, IL, 1995.

Table I. The different types of power disturbances [1].

Type of Disturbance	Sine Wave	Description of Disturbance	Causes
Undervoltage and Overvoltage		Abnormally low or high voltage lasting for more than a few seconds.	circuit overloads, poor voltage regulation, brown outs
Sags or Swells		Momentary decrease or increase in voltage outside the normal tolerance.	starting and stopping of heavy loads, lightning, and power system faults
Spikes or Surges		Very short duration voltage increases.	lightning, switching of heavy loads, short circuits, and power system faults
Outages		Complete loss of power that may last from several milliseconds to several hours.	power system faults, accidents involving power lines, transformer failures, generator failures
Electrical Noise or Harmonics Distortion		Distortion of the normal sinewave power.	radar and radio transmitters, fluorescent lights, power electronics control circuits, arcing utility and industrial equipment, loads with solid state rectifiers, and switching power supplies typically used in computers

Custom Power Distribution System

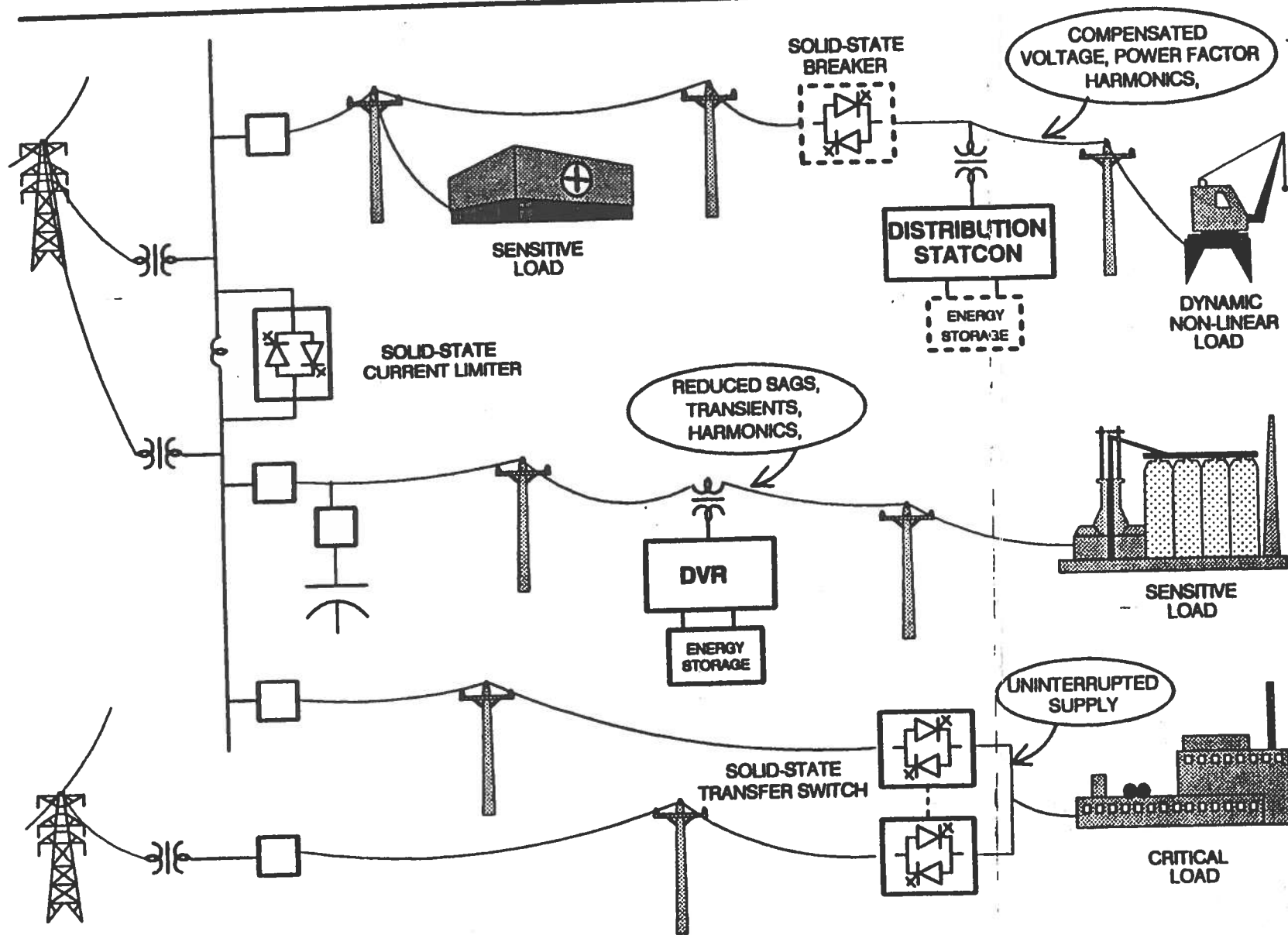


Figure 1. The Custom Power Distribution System from Westinghouse Electric Corporation.

Solid-State Breaker Applications

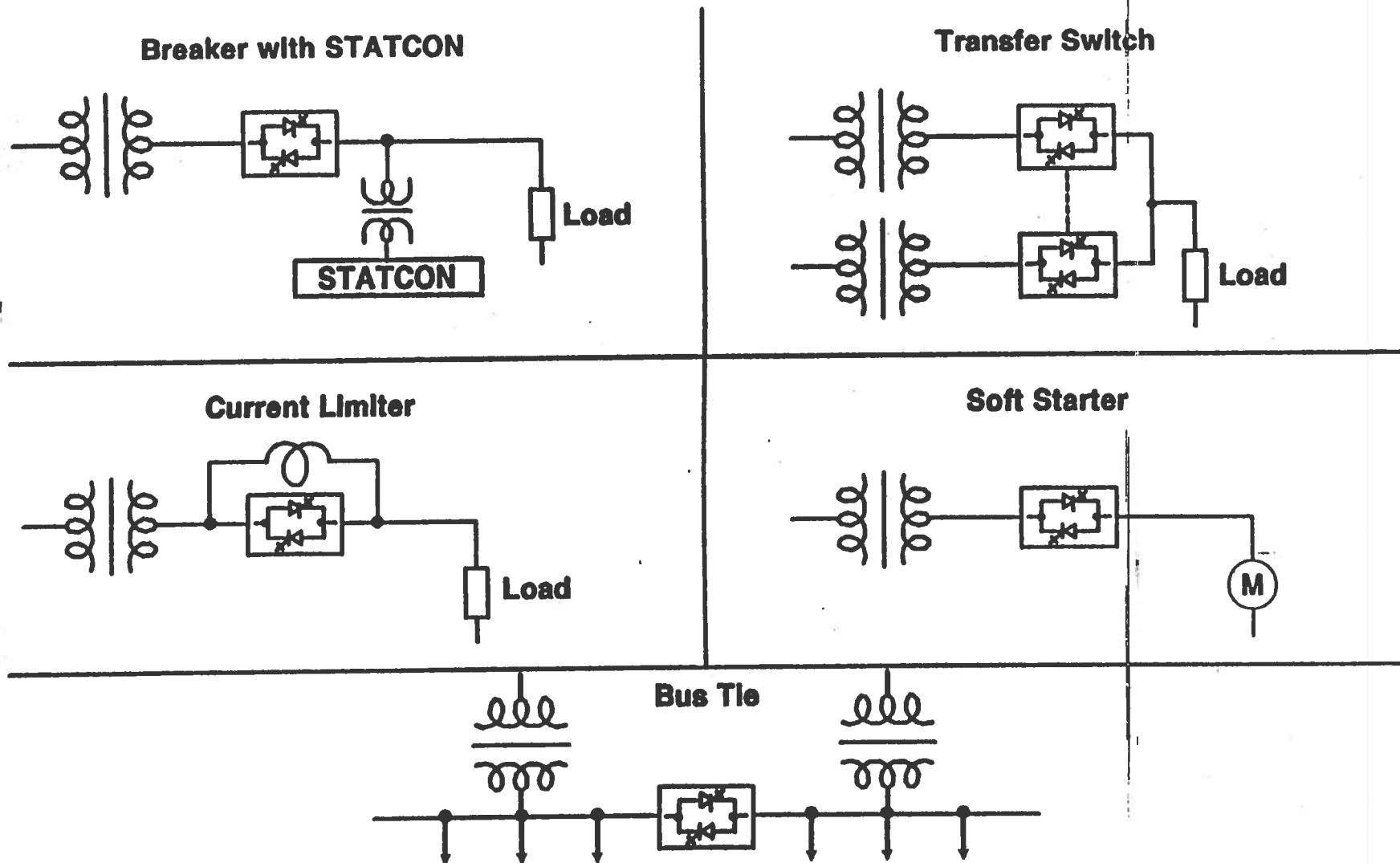


Figure 2. Some different uses of the Solid State Breaker.

Solid-state distribution transfer switch

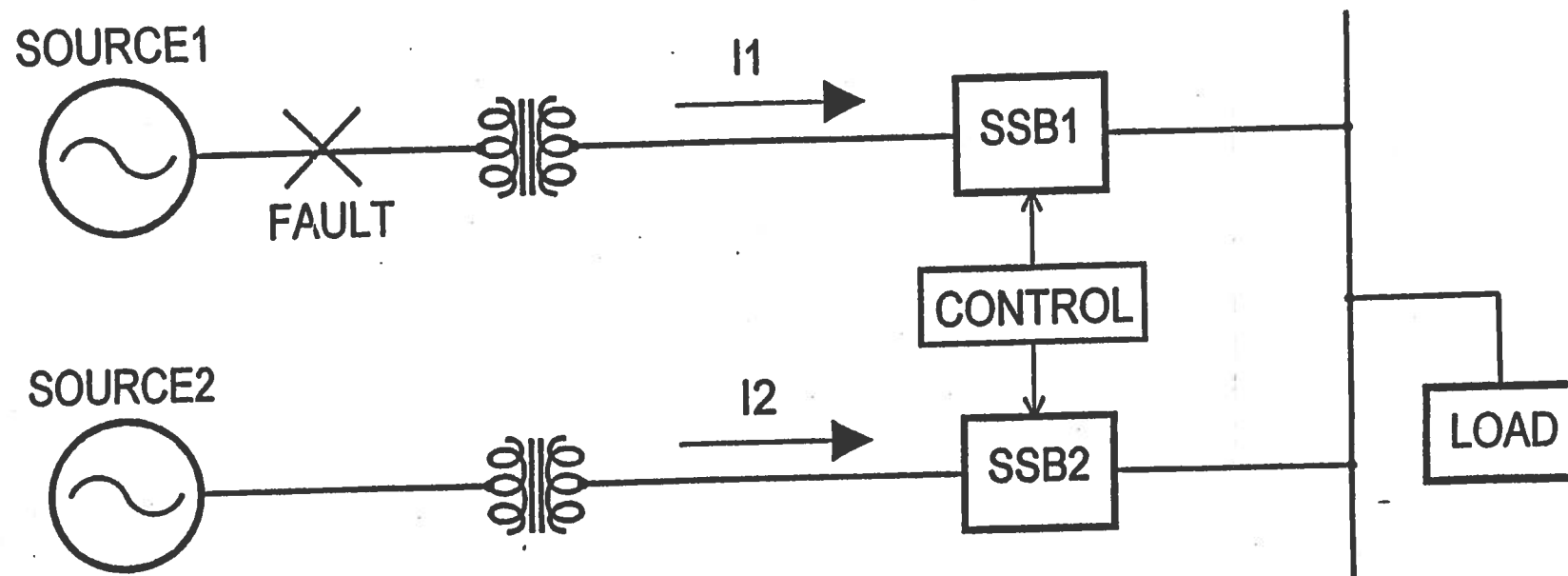


Figure 3. Some applications of the Solid State Transfer Switch.

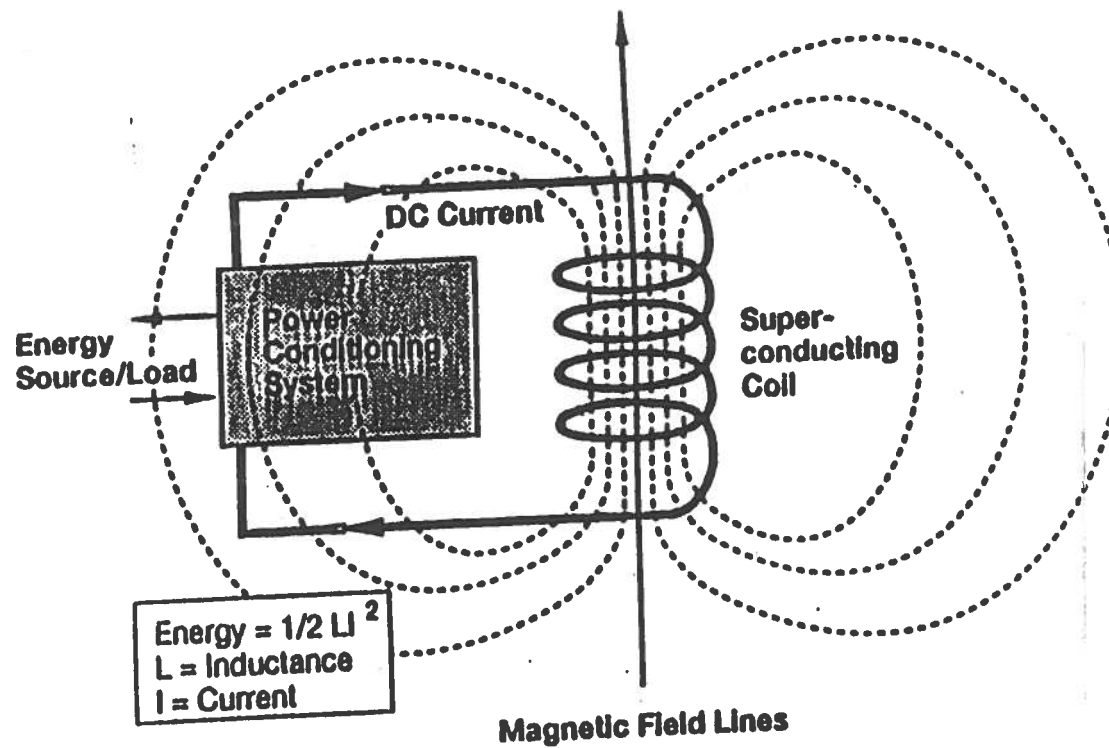


Figure 4. The principle of operation of the Superconducting Magnetic Energy Storage.

Ⓜ Distribution STATCON (DSTATCON) Specification

1) Purpose:

- A) Automatically regulate the Distribution line Voltage by supplying continuously variable lagging or leading VARs to the distribution line within the operating range of the DSTATCON.
- B) Automatically correct the Distribution line Power Factor by supplying continuously variable lagging or leading VARs to the distribution line within the operating range of the DSTATCON.
- C) Automatically reduce Harmonics produced by non-linear loads by supplying the distribution line with the appropriate current waveform to cancel the waveform of the non-linear load.

2) Nominal MVAR Ratings:

Any rating from "0 to +/- 1 MVAR" to "0 to +/- 10" MVAR

3) Nominal Connection Voltage:

4.16 KV to 69 KV (Note that the DSTATCON is connected to the distribution line via a Step-up Transformer)

4) Overload:

Operate at steady-state system voltages from 15% to 110% of nominal and provide rated output current (hence MVAR) proportional to the system voltage.

(Example:

at 105% of nominal voltage, the MVAR output will be 105% of nominal)

Example:

at 25% of nominal voltage, the MVAR output will be 25% of nominal)

5) Speed of Response:

17 Milliseconds (1 cycle) to go from full lagging to 90% of full leading MVAR output (or vice versa) in response to a voltage magnitude step.

6) Control Accuracy:

Maximum error in the set parameter (voltage or power factor) is "+/-" 1 % of the set point value.

7) Losses:

Less than 2 % of the MVAR rating (for units without Storage Subsystems)

8) Availability:

98% availability, including both forced and scheduled outages

Ⓜ Distribution STATCON (DSTATCON) Spec. (Continued)

9) Harmonics:

The harmonic current produced by the DSTATCON as a Percentage of the rated maximum continuous current of the DSTATCON will not exceed the following:

- 1.0% for any odd Harmonics
- 0.5% for any even Harmonics
- 1.5% for the RMS total of all Harmonics

In addition the DSTATCON is designed to avoid resonance with any other distribution system device, such as: capacitor banks, filters, etc.

10) Negative Sequence System Voltages:

The DSTATCON is designed to operate with a Steady State Maximum Negative Sequence System Voltage of 4.0%

11) Redundancy and Maintainability:

- A) 10% redundancy in the individual Power Electronic devices in each Phase
- B) 25% redundancy of the cooling system fans (or blowers)
- C) Replacement of individual Power Electronic devices requires no more than 2 Hours.

Ⓜ Distribution STATCON (DSTATCON) Specification (with Energy Storage Subsystem)

The Distribution STATCON with Energy Storage is the same as the Specification without Energy Storage except for the following additions:

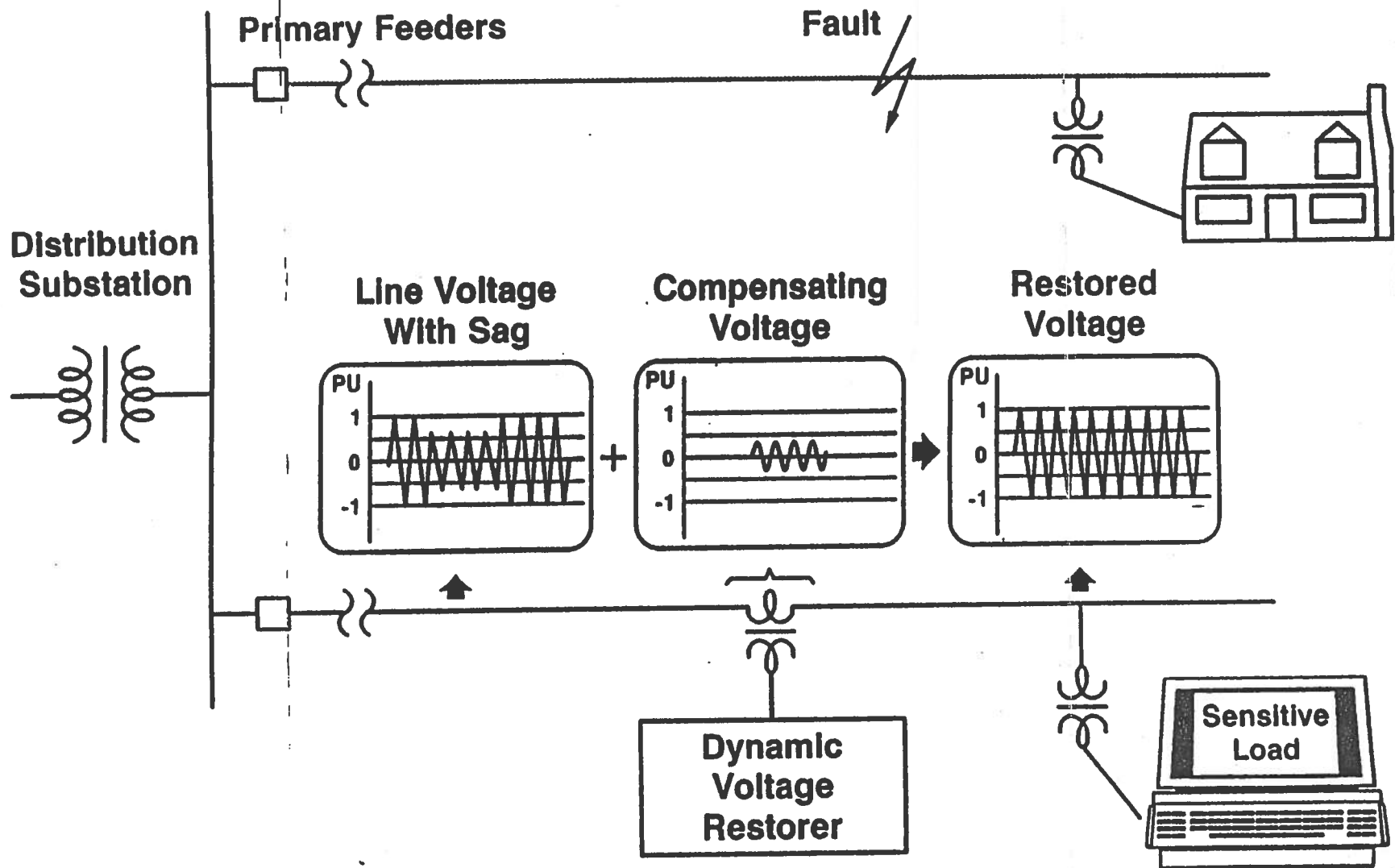
1) Purpose:

- A) With the addition of an Energy Storage Subsystem and a Solid-State Bkr., automatically Supply or Absorb continuously variable Real Power to the distribution line to eliminate Voltage Sags, Swells and Transients within the capabilities of the Storage Subsystem.
- B) With the addition of an Energy Storage Subsystem and a Solid-State Bkr., automatically prevent power interruptions by supplying the appropriate amount of continuously variable Real Power to the distribution line during the interruption period within the capabilities of the Storage Subsystem.

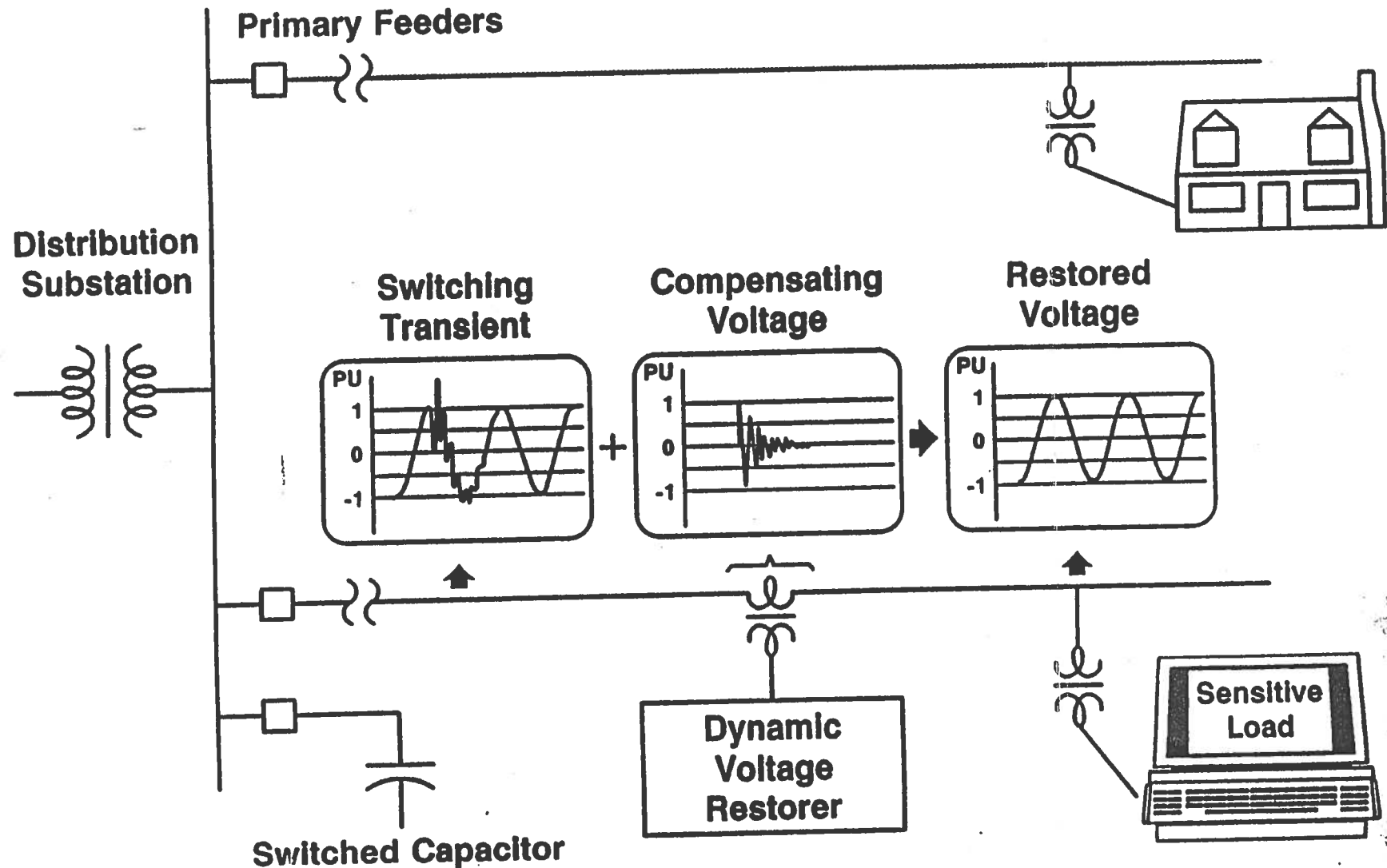
2) Typical Storage Subsystems Sizes:

1 to 100 Megajoules
(or 1 to 100 Megawattseconds)
(or 0.3 to 30 Kilowatt-hour)

DVR Restores Line Voltage During Sags



DVR Compensates Switching Transients



Ⓜ Dynamic Voltage Restorer (DVR) Specification

1) Purpose:

- A) Automatically restore the Distribution line Voltage to normal, following a voltage variation; such as a sag, dip, or swell, by injecting continuously variable voltage in series with the line.
- B) Automatically reduce Harmonics produced by non-linear loads by supplying the distribution line with the appropriate voltage waveform to cancel the waveform of the non-linear load.
- C) Automatically reduce fault currents on the load side, by injecting leading quadrature voltage (with respect to the line current) to temporarily limit the fault current within the operating range of the DVR.

2) Nominal MVAR Ratings:

Any rating from "0 to +/- 1 MVAR" to "0 to +/- 10" MVAR

3) Nominal Connection Voltage:

4.16 KV to 69 KV (Note that the DVR is connected to the distribution line via a series Insertion Transformer)

4) Normal Operating voltage Range:

Operate at steady-state system voltages from 15% to 110% of nominal.

5) Speed of Response (In voltage regulation mode):

Less than one (1) Millisecond when restoring a 0.5 per unit voltage sag to normal.

6) Control Accuracy:

Maximum error in the set parameter (voltage or power factor) shall be "+/-" 1 % of the set point value.

7) Losses:

2% of the MVAR rating (for units without Storage Subsystems)

8) Availability:

98% availability, Including both forced and scheduled outages

9) Harmonics:

The DVR is designed to avoid resonance with any other distribution system device, such as: capacitor banks, filters, etc.

Ⓜ Dynamic Voltage Restorer (DVR) Specification (Cont.)

10) Negative Sequence System Voltages:

The DVR is designed to operate with a Maximum Negative Sequence System Voltage of 4.0%

11) Required design Features

- A) 10% redundancy in the individual Power Electronic devices in each Leg
- B) 25% redundancy of the cooling system fans (or blowers)
- C) Replacement of individual Power Electronic devices shall require no more than 2 Hours.

Ⓜ Dynamic Voltage Restorer (DVR) Specification (with Energy Storage Subsystem)

The DVR with Energy Storage is the same as the Specification without Energy Storage except for the following additions:

1) Purpose:

- A) With the addition of an Energy Storage Subsystem and a Solid-State Bkr., automatically Supply or Absorb continuously variable Real Power to the distribution line to eliminate Voltage Sags, Swells and Transients within the capabilities of the Storage Subsystem.
- B) With the addition of an Energy Storage Subsystem and a Solid-State Bkr., automatically prevent power interruptions by supplying the appropriate amount of continuously variable Real Power to the distribution line during the interruption period within the capabilities of the Storage Subsystem.

2) Typical Storage Subsystems Sizes:

1 to 100 Megajoules
(or 1 to 100 Megawattseconds)
(or 0.3 to 30 Kilowatt-hours)



Ⓜ 13.8 KV Solid-State Circuit Breaker Specification

1) Purpose:

- A) Instantaneously interrupt the current in a 13.8 KV three phase, grounded neutral distribution line
- B) After the initial instantaneous current interruption, limit the Fault current to a predetermined value to allow downstream Coordination.

2) Nominal Voltage Class:

13.8 KV

3) Nominal 3-Phase MVA Class:

1000 MVA

4) Rated Maximum Voltage:

15 KV RMS

5) Rated Continuous Current Ratings:

670 Amperes RMS

6) Maximum Peak Current Interruption Level:

2,500 Amperes Peak

Note: The Solid-State Breaker Interrupts Instantaneously thereby preventing the Fault current from exceeding the Max. peak current Interruption level.

7) Fault Let-through Current Rating:

8000 Amperes RMS for	15 Cycles, followed by
open for	15 Cycles, followed by
8000 Amperes RMS for	15 Cycles, followed by
open for	15 Cycles, followed by
8000 Amperes RMS	15 Cycles, followed by
open	

8) Rated Interrupting Time:

30 Microseconds (Approx. 1/500 of a cycle)
(Conducting to Non-conducting)

9) Maximum Number of Fault Interruptions:

Unlimited

10) Rated Closing Time:

1 Cycle