Flexible Ship Electric Power System Design

Abstract

This paper discusses new techniques which will reduce manning requirements and increase the reliability of continuous service through automation of functions related to the ship's electrical system. Its functions include monitoring and control, automated system failure analysis and identification, automated intelligent system reconfiguration and restoration, and self-optimizing power system architecture under partial failure.

New materials such as high energy magnets and high temperature superconductors are either available or on the horizon. New technologies are an important driver of new power system concepts and architectures.

This paper also introduces new approaches for designing ship power systems by using several new technologies.

text

Introduction

The first electrical power system was installed on the USS Trenton in 1883 (Ykema 1988). The system consisted of a single dynamo supplying current to 247 lamps at a voltage of 110 volts d.c. Until the 1914 to 1917 period, the early electrical power systems were principally d.c. with the loads consisting mainly of motors and lighting. It was during World War I that 230 volt, 60 hertz power systems were seriously introduced into naval vessels. Since World War II the ship’s electrical systems have continued to improve, including the use of 4,160 volt power systems and the introduction of electronic solid-state protective devices.

Protective devices were developed to monitor the essential parameters of electrical power systems and then through built-in logic, determine the degree of configuration of the system necessary to limit the damage to components and equipment and to enhance the continuity of electric service for the vessel (Ykema 1988).

Fuses are the oldest form of protective devices used in electrical power systems in commercial systems and on navy vessels. Circuit breakers were added around the turn of the century. The first electronic solid-state overcurrent protective device used by the Navy was installed on the 4,160 power system in Nimitz class carriers.

Navy systems of today supply electrical energy to sophisticated weapons systems, communications systems, navigational systems, and operational systems. To maintain the availability of energy to the connected loads to keep all systems and equipment operational, the navy electrical systems utilize fuses, circuit breakers, and protective relays to interrupt the smallest portion of the system under any abnormal condition.

The existing protection system has several shortcomings in providing continuous supply under battle and certain major failure conditions. The control strategies which are implemented when these types of damage occur are not effective in isolating only the loads affected by the damage, and are highly dependent on human intervention to manually reconfigure the distribution system to restore supply to healthy loads.

This paper discusses new techniques which aim to overcome the shortcomings of the protective system. These techniques are composed of advanced monitoring and control, automated failure location, automated intelligent system reconfiguration and restoration, and self-optimizing under partial failure.
These new techniques will eliminate human mistakes, make intelligent reconfiguration decisions more quickly, and reduce the manpower required to perform the functions. It will also provide optimal electric power service through the surviving system. With fewer personnel being available on ships in the future, the presence of this automated system on a ship may mean the difference between disaster and survival.

**Shipboard Power System Structure**

Navy Ships use three phase power generated and distributed in an ungrounded delta configuration. Ungrounded systems are used to ensure continued operation of the electrical system despite the presence of a single phase ground. The voltages are generated at levels of 450 volts a.c. at 60 hertz. The most popular topology used in Navy electrical system is a ring configuration of the generators which provides more flexibility in terms of generation connection and system configuration. In this type of topology, any generator can provide power to any load. This feature is of great importance in order to ensure supply of power to vital loads if failure of an operating generating unit occurs.

Generator switchboards are composed of one or more switchgear units and are located close to their associated generators. Further the generator switchboards are composed of three sections: one section contains the generator breaker, generator controls, breaker controls, and protective devices; the other two sections contain a bus tie breaker, load center breakers, and breakers for major loads.

Figure 1 illustrates a three generator system in the ring configuration; in typical operation two of the generators would be used for normal operation with the remaining generator serving as emergency supply. Bus tie circuits interconnect the generator switchboards which allows for the transfer of power from one switchboard to another.

In general, the Navy distribution system consists of switchboards, transformers, power panels, bus transfer units and interconnecting cable used for delivering power to the loads. A shipboard electrical distribution system contains loads that require power at 440, 115, and 4,160 volts at 60 hertz, and 440 and 115 volts at 400 hertz. The loads requiring 400 hertz are typically part of the command and surveillance systems, weapons systems, and aircraft and aviation support equipment. The 4,160 volt loads are typically associated with aircraft carriers. The interfaces used between the 60 hertz and 400 hertz systems are either motor-generator sets or static solid-state frequency converters.

Load center distribution, which is a modification of radial distribution, is used below the generator switchboard level. This configuration is illustrated in Figure 2 for one generator switchboard. One or more load center switchboards are connected to each generator switchboard to supply power to load concentrations in various areas of the ship. The load center switchboards supply power to power panels or individual loads, either directly or via automatic bus transfers (ABTs) or manual bus transfers (MBTs). Power distribution panels are centrally located to the loads that they feed.
They provide control and protection of selected portions of the power or lighting distribution systems and special power distribution systems.

![Diagram of Load Center Distribution]

**Figure 2. Load center distribution**

Reconfiguration and Restoration

System faults must be quickly resolved by removal of the faulted portion of the system from the remainder of the system. These faults could be due to material casualties of individual loads or widespread fault due to battle damage. In addition to load faults, casualties can occur to cables, power generating equipment, or power distribution buses which can lead to conditions of having inadequate power generation capacity for all attached loads.

Some equipment failures and battle damage may lead to large overcurrent conditions. Battle damage can also generate multiple faults concentrated in contiguous areas. For example, a single missile hit during battle could cause multiple, simultaneous faults on multiple cables served by the same load centers. The ship should be able to survive and continue to fight under a single hit. When faults other than single line to ground occur, the protective devices reconfigure the connections to isolate the faulty sections or perform automatic load shedding to adjust the load demand to match reduced generation capacity due to faulted generation capabilities.

After the protective devices generate an automatic reconfiguration action, certain automatic actions are performed to restore power. In certain situations, ABTs are used to transfer power in critical equipment where the potential loss of power, even for a few minutes, would cause the equipment to be inoperative or would cause a personnel or ship safety hazard. Also for the loads with MBTs, personnel manually operate the transfer switch to select the alternate power source. Further electrical personnel must manually close breakers to loads which were unnecessarily isolated during the automatic load shedding.

**PROTECTIVE DEVICES**

Protective devices are used in electrical power systems to prevent or limit damage during abnormalities and to minimize their effect on the remainder of the system (Ykema 1988). Protective devices consist of three separate but interrelated stages, which are: monitoring stage, the logic stage, and the tripping actuation stage. The monitoring stage monitors, at all times, the electrical system parameters such as current, voltage, frequency, and temperature. The logic stage makes decisions regarding the normal or abnormal conditions. The tripping stage rapidly switches to reconfigure the system to avoid or limit damage to the system and the components.

**CURRENT STATUS OF MONITORING AND CONTROL**

Table 1 characterizes the current status of the monitoring, control, and protection functions of protective devices in shipboard electrical systems. Remote operation in the table refers to operations at the control center. The table shows that below the load center, the protective devices are locally controlled and monitored which does not permit remote automation of those devices.
### TABLE 1

**Present Monitoring, Control, and Protection Functions**

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>MONITORING</th>
<th>CONTROL</th>
<th>PROTECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data Available</td>
<td>Parameters</td>
<td>Device</td>
</tr>
<tr>
<td>Generator</td>
<td>local and remote</td>
<td>current, voltage, phase angle, power, frequency, CB status</td>
<td>local and remote</td>
</tr>
<tr>
<td>Bus Tie Breaker</td>
<td>local and remote</td>
<td>voltage, current, power, CB status</td>
<td>local and remote</td>
</tr>
<tr>
<td>Load Center</td>
<td>local and remote</td>
<td>current, voltage</td>
<td>local and remote</td>
</tr>
<tr>
<td>Power Distribution Panels</td>
<td>local and remote</td>
<td>current, voltage</td>
<td>local and remote</td>
</tr>
<tr>
<td>Frequency Conversion Unit</td>
<td>local and remote</td>
<td>voltage, current, power, frequency, phase angle, temperature</td>
<td>local and remote</td>
</tr>
<tr>
<td>Bus Tie Breaker</td>
<td>local and remote</td>
<td>current</td>
<td>local</td>
</tr>
<tr>
<td>Non-vital Loads</td>
<td>local and remote</td>
<td>current</td>
<td>local</td>
</tr>
<tr>
<td>Non-vital Loads (Part of load shedding scheme)</td>
<td>local</td>
<td>current</td>
<td>local, automatic</td>
</tr>
<tr>
<td>Vital Loads</td>
<td>local and remote</td>
<td>current</td>
<td>local</td>
</tr>
</tbody>
</table>
PROBLEMS WITH PRESENT APPROACH FOR RECONFIGURATION / RESTORATION

When simultaneous faults occur, each feeder breaker sees the overcurrent fault that is resident on its line. Also the upstream breakers in the load centers see the cumulative of the individual feeder overcurrents. Presently, under some fault situations, the affected feeder breakers have problems coordinating their operations, the load center breakers eventually open and disconnect healthy as well as faulted feeders. When this occurs the operator has no accurate knowledge of which cables or equipment have failed which complicates the problem of restoring power to the healthy portion of the electrical system.

Ground detectors are provided on ship service, emergency and special frequency switchboards and at the initial point of distribution on large systems isolated from the main distribution system. Presently after a fault is detected, the operators perform a manual, trial and error method to locate the ground fault. They typically start at the feeder where the ground fault has been indicated. They isolate one phase of the feeder at a time until the faulted phase is identified. Next they traverse downstream of the phase to the next level of the distribution system. The process continues until the fault is located. This process has been reported to take as long as 24 hours on some occasions.

A load shedding system is incorporated into the 60 Hertz electrical system to ensure that loss of an operating paralleled generator will not cause the complete loss of electric power. Selected circuit breakers connected to non-vital loads are remotely opened when generator overload is sensed. With this approach, a fixed set of loads are shed which in most cases means that more loads are disconnected than necessary to meet the reduced generation capacity. Also the circuit breakers to these loads must be manually closed during restoration.

Under emergency conditions to the vital loads, a casualty power system is the temporary distribution system that provides the means to bridge damaged sections of the ship. The system is made of bulkhead mounted terminals, risers, pre-cut cable lengths between terminals, terminals on switchboards, various distribution panels, and vital equipment controllers. To establish the system, portable cables are provided to connect between permanently installed terminals and permanently installed vertical riser cables. With the pressures that face the operators during an emergency situation, there is a high probability that human error may occur during the manual rigging of the casualty power system. Further it is possible to overload the system to the point of catastrophic failure.

In general the present Navy electrical system provides the capability to remotely close only large size breakers (down to the load center level). Hence it is impossible to dynamically reconfigure or restore on a load by load basis from the control center. An automated intelligent reconfiguration / restoration system can provide speed in locating and isolating faults, more efficient load shedding, faster reconfiguration and restoration, a decrease in the manpower required for operation, and a decrease in human intervention and mistakes. In the next section, the new automated reconfiguration / restoration system is discussed.

Automated Intelligent Reconfiguration / Restoration

The intelligent reconfiguration system includes remote monitoring and control of all circuit breakers and relays, a geographical database, an accurate failure location technique, and a technique for performing reconfiguration and restoration.
FAILURE LOCATION

The geographical database contains a database entry for each piece of major equipment in the distribution system such as generators, loads, breakers, cables, bus transfer units, transformers, and frequency changers. Each database entry contains the associated geographical location of the component. The chart below represents the information stored in the database for each load. Similar formats are used for the other type of equipment.

- Load #
- Type of Equipment (radar, lighting, etc.)
- Voltage Level (440 V, 115 V)
- Frequency Level (60 Hertz, 400 Hertz)
- Priority Level (non-essential, semi-essential, essential)
- Operating Load Factor in Emergency Condition
- Location

Battle damages typically result in at least a brownout in the damaged region of the electrical system. When relay actions occur in response to these types of situations, monitored data and protective devices’ status information are coordinated to determine the type of protective device in use and the portion of lines and equipment they protect, using the geographical database. The resulting information represents the nature and extent of damage.

The fault contributing to the relay action is localized. A list of disconnected loads is developed by matching the lines in the system which are not energized to their geographical location in the distribution system. The critical loads in the list are identified. These disconnected critical loads are said to have experienced catastrophic failure.

Using the list of disconnected loads, an automated technique reconfigures the system and restores power to damaged loads. The reconfiguration technique generates control signals for alternative cables or switchboard arrangements in restoring interrupted load or generating equipment to service. The reconfiguration subsystem searches for alternate paths around the damaged area to supply all equipment which was energized before the blackout and was not damaged. Then a demand analysis is performed to determine if generation capacity can meet the load demands of the configuration. The selection of reconfiguration options is performed using an intelligent (expert-system based) scheme which seeks a near-optimal solution to match generation capacity to a maximum number of loads. The vital loads are given the highest priority in the process.

Once the reconfiguration topology has been established, the geographical database is used to determine which breakers must be closed or opened. The sequence of control actions to the breakers is performed to restore power in a manner which prevents the initiation of new faults or blackouts.

Many of the advanced concepts presented in this section rely on accurate information on the state of the system. They require real-time data such as currents, voltages, and sequence of events for protective devices which can be acquired with distributed monitoring through remote sensing. The Navy presently is developing the Smart Ship Project which aims to develop, evaluate, and select solutions to demonstrate that reduction in the crew’s workload for a surface combatant can be achieved. One of the technologies to be implemented on the Smart Ship is a distributed information system on a fiber-optic backbone throughout the ship which supports the instantaneous sharing of information across a shipwide local area network (LAN). This redundant LAN network enables monitoring and control functions from many locations such as integrated condition assessment of machinery systems and a shipboard machinery control system. With this fiber optic LAN technology available as the infrastructure for monitoring and control on ships, the automated failure identification and intelligent reconfiguration / restoration system can be implemented easily.
Modeling and Simulation Methodology for Ship Design

This paper also discusses new software tools which were developed to perform detailed steady-state and transient failure analysis of ship electrical systems. These new tools provide a user-friendly and modular methodology for modeling a shipboard electrical system. They were originally developed to provide a methodology to design ship-like electrical systems for testing the failure location and reconfiguration / restoration subsystems. However they also have been found to be useful for the Navy to train ship personnel on a ship-like electrical system in a simulation platform, performing new ship design or retrofitting ship design of electrical systems, or performing failure simulation studies to test new protection schemes or devices.

The tools include two techniques: the first which uses EMTP-ATP to model and simulate a ship's electrical system for transient analysis of components or systems, and the other which uses PSpice to model and simulate a ship's electrical system for steady state analysis.

More Advanced System Designs

As commercial and military use of electrical power expands, increasing demands are placed on the electric power systems. These demands may be summarized as follows.

1. Increasing load power
2. Single power bus rather than multiple buses
3. More efficient use of power generation units
4. High power densities (weight and volume)
5. Improved system stability and survivability
6. Reliability

This section discusses the fundamental search for new power systems to meet these demands (Capel et al. 1988, Chetty 1987, Nelms and Grisby 1989, Krauthamer 1990).

Available technology is generally used as the starting point for developing new power systems. The initial starting point in searching for new possible architectures for new power systems was the superconductors. The fundamental design in conventional power systems is based on near perfect insulation technology and imperfect conductors. However, in the salt water environment insulators behave far from perfect and this imposes severe limitations on the magnitude of available voltages. Furthermore, the presence of conductive contaminants, which is unavoidable in salt water environments, adversely affects high voltage structures, causing power losses. Therefore, efficient use of high currents is an attractive candidate for building high power systems in ships which necessitates the use of superconductors. To the authors' knowledge an architectural study to optimally utilize superconductors on shipboard electrical systems has not appeared in the literature up to now. At the present time there is intensive research in superconductors all over the world. Also, there is a strong belief that room temperature superconductors will be a reality in the not too distant future. Therefore, conceptual design of superconductive power systems for ship applications seems timely.

The most common justification for using superconductors in power systems is the elimination of conductor losses. However, superconductors are not merely perfect conductors; they have other useful properties. These are high current carrying capability, magnetic shielding, quenching and Meissner effect. One of the major benefits of superconducting power systems is that at a given voltage the power capacity of a superconducting cable is much higher than that of a conventional cable. Also the superconducting cable can be built to operate at surge impedance loading and the transmission problems related to reactive power can be eliminated (Forsyth 1984).
One of the architectures (Current Source Current Intensive System) discussed in this paper utilizes the first benefit while another architecture (Articulate System) incorporates the second benefit.

**BASIC ARCHITECTURAL STUDY**

Electric power is the product of voltage and current. In general, to transmit a given power the amplitudes, shapes, and frequencies of voltage and current can be selected in many different ways. Voltage-current sizing generally depends on the available technology. Table 2 is a classification of power system architectures based on V-I amplitudes and source behavior. This table shows the positions of the first power system in the U.S. (DC), high voltage AC (HVAC) and high voltage DC (HVDC) systems. Superconducting Magnetic Energy Storage (SMES) is a new architecture and occupies a new place in the table. An extension of the SMES concept leads to the Current Source Current Intensive (CSCI) System which is a subject of this study. Furthermore, given total freedom in V-I source behavior, afforded by the modern power electronics technology, the Articulate power system would be selected. The Articulate power system is feasible with extensive use of modern power electronics and microcomputer control technologies (Ehsani and Kustom 1988, Ehsani et al. 1990).

**TABLE 2**

Power System Architectures

<table>
<thead>
<tr>
<th>V-I INTENSITY</th>
<th>MODERATE V-I</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIGH VOLTAGE</td>
<td>HIGH CURRENT</td>
</tr>
<tr>
<td>AC</td>
<td>AC</td>
</tr>
<tr>
<td>DC</td>
<td>DC</td>
</tr>
</tbody>
</table>

- **CURRENT SOURCE**
  - High Voltage AC (FACTS)
  - High Voltage DC
  - Articulate Power Systems (AC and DC)
  - Articulate Power and Space Power Systems

- **VOLTAGE SOURCE**
  - Voltage Source Current Intensive
  - Current Source, Current Intensive
  - Articulate Power Systems (AC and DC)

**FACTS** - Flexible AC Transmission Systems
**SMES** - Superconductive Magnetic Energy Storage

There are many possible power system architectures; however, only three or four of these possible architectures are presently used due to technological and historical reasons. Table 3 shows the historical development of new system architectures based on the available technologies at the time. This table also suggests that power systems history is on the verge of another major leap forward.

**TABLE 3**

Historical Development of Terrestrial Power System Architectures

<table>
<thead>
<tr>
<th>TECHNOLOGY</th>
<th>ARCHITECTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery, DC Generator, DC Motor, Indacendent Lamp</td>
<td>First Electric Power System, Pearl Street, New York, 1882</td>
</tr>
<tr>
<td>Transformer, Induction Motor, Synchronous Generator</td>
<td>First 3-Ø AC Power Supply, Germany, 1891</td>
</tr>
<tr>
<td>High Power Rectification and Inversion</td>
<td>First HVDC Power System, Sweden, 1954</td>
</tr>
<tr>
<td>Superconductors, High Power Processing, New Generators, Computers</td>
<td>?</td>
</tr>
</tbody>
</table>

The quantum leap in power system design will be based on superconductors, power electronics, and computer control. Ships may be among the first to benefit from these new developments due to their unique combination of high constraints and increasing performance demand.

**THE CURRENT SOURCE CURRENT INTENSIVE POWER SYSTEM**

This new concept has a single line (one conductor) power transmission and distribution configuration. A Current Source Current Intensive (CSCI) system with Superconductive Magnetic Energy Storage (SMES) is shown in Figure 3. It is seen that there is only one current path in this series system. When the SMES is not used it is crowbarred (short circuited). When the circuit operates without SMES, its current is controlled by one of the converters. Each converter can be either a rectifier or an
inverter. Converters can easily be added or removed by shorting out and power can be quickly reversed. Therefore, direct current circuit breakers are not needed. However, in a CSCI system, an open-circuit fault would be catastrophic, and circuit makers (crowbars) would be needed to clear such faults.

**Figure 3. CSCI Power System Architecture**

Independent power control is achieved at each terminal without the requirement for a high speed load dispatch control. Power variations at various terminals are automatically compensated for at the current controlling terminal. However, in the series system without SMES enough inductance should be added in the loop to help stabilize the loop current.

When a SMES is used in the series system for energy storage it can be connected without an interface converter. In this case short term current can be controlled by the SMES. The SMES will be charged when the power demand is lower than generation and will be discharged when the demand is higher. Therefore load leveling is possible. This will help reduce the size of generating units. For example, when a rotating generator is used it can be operated at its most efficient power rating.

A CSCI system with SMES will not operate at constant current over a long period of time. In general, current will change very slowly with time. However, a ratio of one to three current change is enough to discharge 90% of the SMES energy because the solar energy is proportional to the square of the system current.

\[ W = \frac{1}{2} LI^2 \]  

(1)

The performance of the system can be characterized by the equations below for the configuration in Figure 3 where power electronic voltage variations are assumed almost instantaneous in comparison with \( I_d \) variations.

\[ P_1 = V_1 I_d \]  

(2)

\[ P_2 = V_2 I_d \]  

(3)

\[ P_3 = V_3 I_d \]  

(4)

\[ P_s = V_s I_d \]  

(5)

\[ P_1 + P_2 + P_3 + P_s = 0 \]  

(6)

\[ L_s \frac{dI_d}{dt} = \frac{P_s}{I_d} \]  

(7)

**SHIP APPLICATION OF CSCI**

In certain applications, such as on a ship platform, the superconductive transmission line can also serve as an integral superconductive magnetic energy storage device for the system. Thus, the CSCI power system can supply large variable loads from a small continuous power source. Furthermore, the inherent magnetically stored energy of the system can be used to supply pulsed loads for civilian and military applications.

However, the intense magnetic field near the CSCI conductor may create safety and technical problems. These problems can be eliminated by superconductive shielding of the conductor (Ehsani et al. 1990). The shielded CSCI power system loses its inherent ability to store energy. However, this can be remedied by discrete
SMES units which can be connected to the system without any power electronic interface.

PROBLEMS WITH SUPER HIGH CURRENTS

Superconductors might be well utilized for high currents. However two main problems arise:
1. Switching of high currents for power transfer to and from the CSCI loop is problematic. Semiconductor switch losses become significant due to conduction voltage drops. One solution to this problem may be to use superconductive switches [Ariga and Ishiyama, Mawardi et al.]. A superconductor can be operated as a switch in two ways: heat injection technique and magnetic quenching method.

2. High magnetic field due to high currents may be hazardous to the personnel and instruments around. As in the switching problem, superconductivity can offer a solution to this problem (Rose-Innes 1978). Using superconductive shielding techniques most of the magnetic effects can be eliminated. Shielding the superconductor can be accomplished in a coaxial structure. The example circuit given in Figure 3 is modified to a coaxial transmission as shown in Figure 4.

Figure 4. Shielded CSCI Power System

ARTICULATE POWER SYSTEMS

This architecture can be applied with or without superconductive technology. In the articulate system, voltage, current, and frequency are all flexible and can be controlled, in real time, to optimize the power system performance under varying conditions. For example, in an AC Articulate Power System, it may be desirable to operate the transmission line with continuous natural loading, even as the load varies randomly and the system frequency is varied to continuously minimize the generation losses. In this case, the voltage and current are as shown below.

\[
V(t) = \sqrt{Z_0 \cdot P(t)} \quad (8)
\]

\[
I(t) = \frac{P(t)}{\sqrt{Z_0}} \quad (9)
\]

where \( V(t) \) and \( I(t) \) are the power system operating voltage and current, \( Z_0 \) is the distribution line surge impedance and \( P(t) \) is the load power demand. Therefore, the system voltage and current is continuously optimized (by power electronic means) in accordance to the above expressions. The system frequency is independently optimized in response to the generator state vector and the load demand.

EXAMPLE OF AN ARTICULATE SYSTEM

An example AC articulate power system is shown in Figure 5. When the transmission voltage and current satisfy equations (8) and (9), the generator at the sending end has to supply only the real load power. Transmission voltage can be adjusted by controlling the field winding current of a synchronous generator or by a sending end power converter. At the receiving end a Unity Displacement Factor Frequency Charger (UDFFC) (Gyugyi and Pelly 1976) presents a unity displacement factor load (resistive load) to the receiving end transformers and a constant frequency and voltage to the load.
regardless of the load power factor. Since the line voltage is set at an optimal value, a wide range tap changing transformer is required to regulate the output voltage or this task may also be performed by the receiving end converter. Thus, the generator sees pure resistance. Furthermore, line reactance does not affect the stability margin. A communication link between the receiving end and sending end may be necessary to control the total power system. System control will be more robust compared to the conventional systems.

The articulate system may be a viable option for providing quick and efficient reconfiguration by self-optimizing the distribution cables under partial failure.

**Summary and Conclusion**

This paper discussed a new automated intelligent reconfiguration / restoration system for shipboard electrical systems. The system automatically assesses a shipboard power system's fault conditions for damage, identifies catastrophic failure, localizes the affected cables and loads, and then reconfigures and restores power to vital loads and as many of the remaining loads as possible. This new technique makes the system more reliable in providing continuous electric supply and reduces the manpower required to operate the system under faulted conditions.

Two new architectures for designing ship power systems have been introduced: the current source current intensive (CSCI) and the articulate system. The basic characteristics of these systems have been discussed. It appears that the CSCI is the more ambitious of the two architectures. By this virtue it will also be realizable in a more distant future. However, some aspects of the articulate system architecture, as discussed in this paper can be implemented in the short term. A flexible AC distribution systems, within the context of flexible AC transmission systems (FACTS) (Hingorani 1993) which are now undergoing rapid development and implementation, can be regarded as a subset of the family of control methodologies which constitute the realm of articulate systems. Undoubtedly as the CSCI and articulate system designs progress, problems will arise; however, the developments in superconductors, superconducting magnetic energy storage, and power electronics will provide a wide technical base to solve these problems.
These advanced system architectures suggest better ways for implementing the power distribution system in next generation ships. They also provide ways to bring new technologies, better system operation, to existing ships during its retrofitting for service life extension.

References


Acknowledgments

Part of this research was supported by the Office of Naval Research Grant #: N00014-96-1-0523.

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