Journal of Polish CIMAC
Gdansk University of Technology
The Faculty of Ocean Engineering and Ship Technology

POWER PLANTS MAIN SWITCHBOARDS CONFIGURATION OF MULTI-MODE SHIPS

Jerzy Herdzik

Gdynia Maritime University
ul. Morska 81/87, 81-225 Gdynia, Poland
tel.: +48 58 6901430, fax: +48 58 6901399
e-mail: georgher@am.gdynia.pl

Abstract

It was presented the main switchboards' configurations of multi-mode ship power plants. It has dominated diesel-electric propulsion systems. The development of main switchboards has an aim the increasing of power system reliability from main engines, through generators and electrical network to electric motors of main propulsion and dynamic positioning thrusters. This is a way of increasing redundancy and reliability of propulsion system. The superior aim is the fulfillment of DP class 2 and DP class 3 dynamic positioning requirements.

Keywords: *multi-mode ship, main switchboard, configuration, propulsion system, diesel-electric propulsion*

1. Introduction

All ships ought to have minimum two electric generators driven by two independent engines. One of them has been reserved generator and one has covered the maximum demand for electric energy in the all exploitation conditions. Often it would be met more complicated electric network. In that case the main switchboard may be made in different configurations. The solution of switchboard configuration may influence on many other power elements.

The distribution system is the vital link connecting the generators that produce electric power to the equipment that uses it. It transmits electric power from the power source to the power user. The distribution system also protects (by means of circuit breakers and fuses) itself, and its generators from damage that might otherwise be caused by faults in the system or connected equipment.

The simple switchboard configuration is presented on Fig.1.

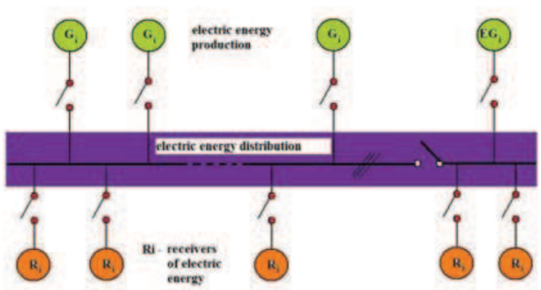

Fig.1. An example of simple switchboard configuration with parallel work of generators

There are three auxiliary and one emergency generators. During parallel work of auxiliary generators the overloading or other failures may result in the domino effect. The trip-out of one generator working on electric network may cause the overloading of the other generators, following the trip-out of next generator and black-out in all electric network. This is a dangerous situation for ship safety. For this reason an emergency generator is installed on ships. It gives the electric energy in time maximum 30 seconds after black-out but supplies only receivers from the emergency switchboard. It allows to recover the electric energy in main switchboard.

2. The development of ship main switchboards

A main switchboards (MSB) is a switchboard directly supplied by the main source of electrical power or power transformer and intended to distribute electrical energy to the unit's services or switchboards not being directly supplied by the main source of power will be considered as main switchboards when this is found relevant from a system and operational point of view [2,4].

The electric energy distribution system can be divided into *feeder side* and the *load side*. The feeders are the generators, the loads are various ship's consumers.

Due to reliability of supplying in electric energy and an avoidance of fully black-out it may be met more complicated configurations of main switchboards (Fig.2). In normal condition the all bar bus-ties are in closed position. In a necessary it may work on electric network more than one auxiliary generator. It needs the parallel work of them. In case of necessity the bus bus-ties may stay in opened position and each the auxiliary generator works only on a part of receivers (consumers). In this situation only partially black-out might occur.

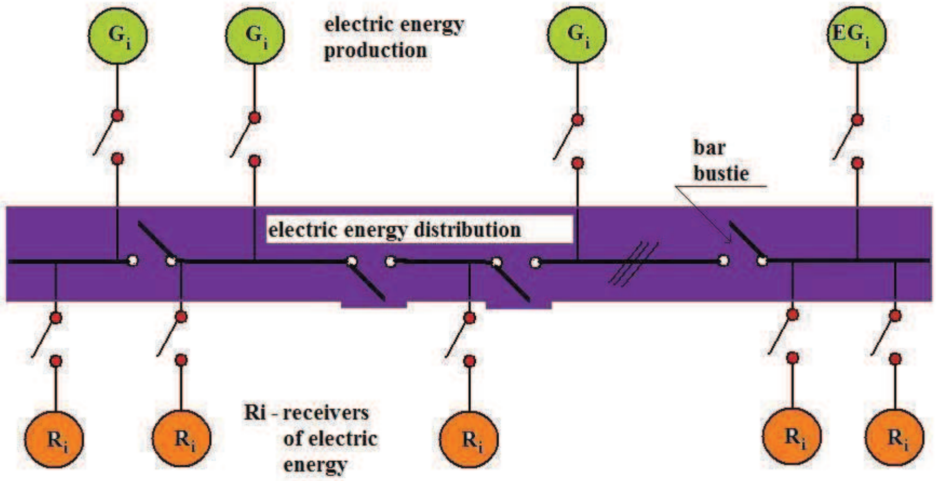

Fig.2. Main switchboard configuration with parallel or independent work of generators

The configuration presented on Fig.2 gives only a few possibilities of generators work on electric network. The partially black-out might occur and in that case it is impossible to supply the chosen section of receivers from the other generator. This is a serious imperfection. On ships with dynamic positioning DP class 2 it is used as requisite the ring switchboard configuration like presented on Fig.3. Due to ring (possible two smaller rings on Fig.3) there are possible configuration where all consumers may be supplied when a section of bars in the switchboard is out of order (a failure or other system faults). The failure of any single circuit or bas-bar section shall not endanger for the services necessary for the offshore unit's maneouvrability. For DP class 2 it is accepted that the bas-bar sections are arranged in one switchboard. The bas-bar control and protection system shall be designed to work both open and closed bus-tie breakers [5].

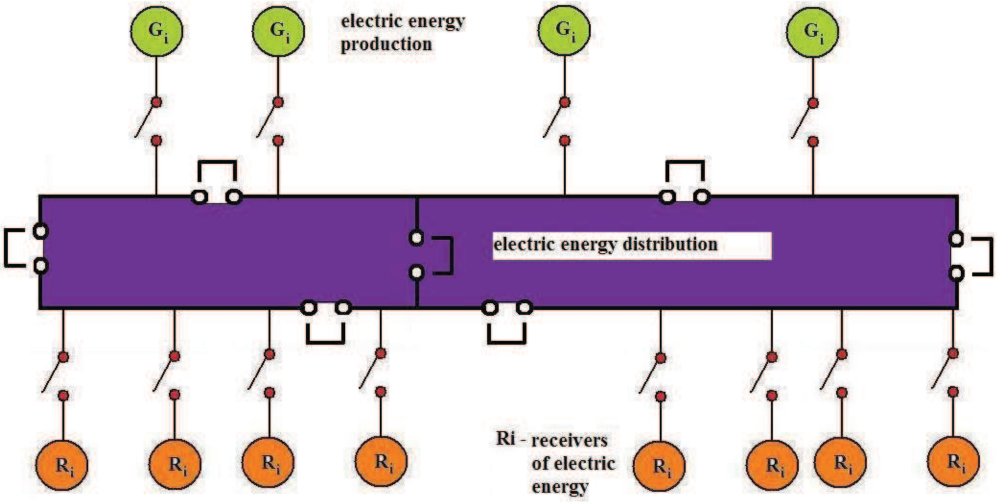

Fig.3. An example of the ring configuration of main switchboard

In DP class 2 or above, any single failure must not render the system inoperable. The philosophy is applied throughout the vessel design including the switchboards, propulsion and power generation. On ships with DP class 3 it is required that each bas-bar section is isolated from other by watertight A-60 partitions. There shall be a bas-tie breaker on each side of this partition [1,5]. Class 3 of DP provides triple redundancy in terms equipment failure and must also remain operable in case of fire and flooding. The vessel with minimum two engine rooms has A60 bulkhead separation. The power and propulsion system must be design such that adequate power and thrust is available even under failure conditions [4,5,6]. An example of switchboard configuration for DP class 3 was presented on Fig.4.

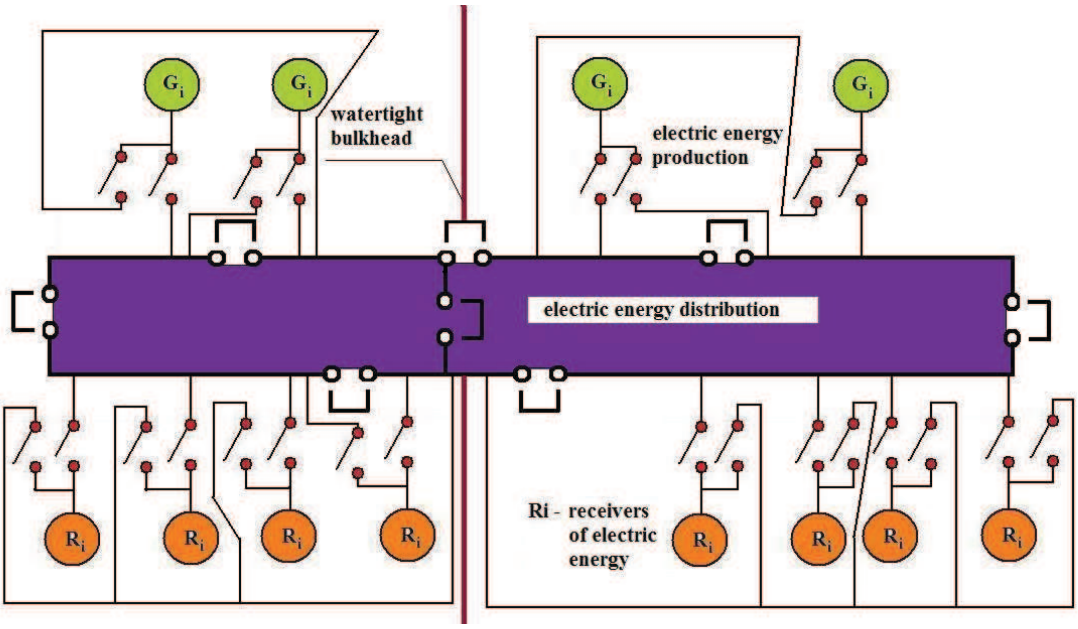

Fig.4. An example of the ring configuration of main switchboard with watertight bulkhead for ships with DP3

An example of existing ship mv. Solitaire with two separated engine rooms, eight main generators, eight thrusters and switchboard configuration is presented on Fig.5. This is ship with DP class 3 for pipe-laying.

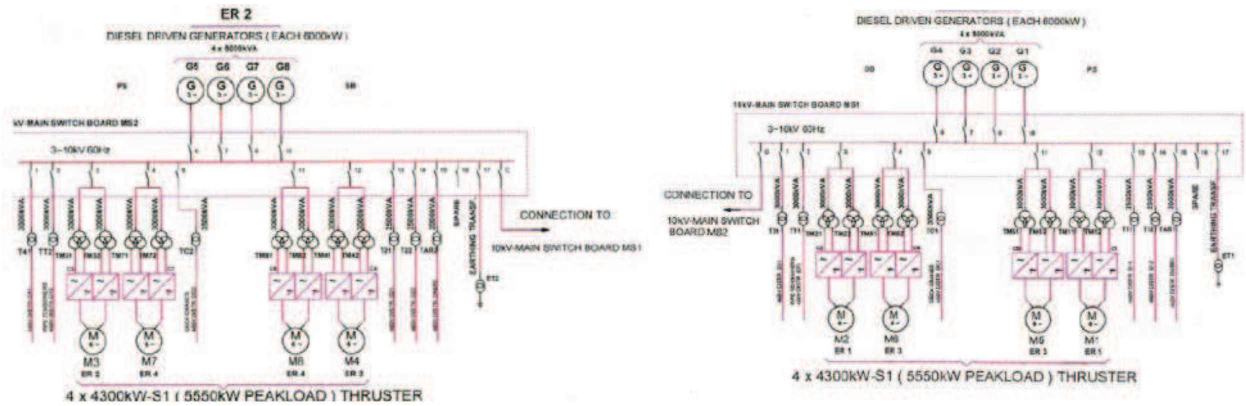

Fig. 5. Power system configuration with two engines rooms of mv. Solitaire [7]

The thrusters driven by electric motors have each nominal power of 4300 kW, but in a necessary the power may increase to 5550 kW, of course with load limiting time up to 5 minutes for that thruster. It was used a synchroconverter with parameters: current strength AC 1225 A, voltage 2*1454 V and frequency 35 Hz, 520 RPM of thruster propeller.

3. Control arrangement

Engine control power is typically 24V DC. It may be derived from a DC power supply (battery backup, UPS, voltage converter). Switchboard control supplies 24V DC and sometimes other DC power. The engine control and safety system should have separate power supplies. It ought to be from separate sources, sometimes may accept separate fuses from the same distribution. The normal source of supply should be the main power system.

Electrical protection schemes are designed to prevent the uncontrolled release of energy associated with power system faults, thus protecting life and limiting damage to equipment [1,3]. For DP vessels with DP class 2 and 3 the power system protection scheme must also ensure continuity of supply to essential consumers such as thrusters and other auxiliary systems. The primary protection function is over current protection, which is intended to prevent excessively high currents causing cables to catch fire.

The overall electrical protection scheme can be divided into three following sections:

- generator protection;
- bus-bar protection;
- feeder protection.

Due to costs many ship-owners try to resign with the bus-bar protection. This fault has very small probability of event but gives very serious damage and/or fire if occurs. Bus-bar protection is designed to isolate the effects of short circuits and earth faults acting directly to bus-bars or their connections. Bus-bar protection can take the following forms, depending on the number of bus sections that have to be protected:

- over current protection;
- differential protection;
- directional over current protection;
- optical arc detection;
- pressure detection;
- earth fault protection.

When electric propulsion is utilised (popular solution on multi-mode vessels), the electric power generation and distribution system shall be equipped with an automatic control system having at least the following functions [1]:

- ensure adequate power for safe manoeuvring is available at all times;
- ensure even load sharing between on-line generators (to protect over load);
- execute load tripping and/or load reduction when the power plant is overloaded;
- execute that adequate power for safe manoeuvring is available also if one running generator is tripped (for example: by way by tripping of non-essential consumers);
- control the maximum propulsion motor output;
- if the automatic system fails, in that case that is no start or stop of generators shall occur as an effect of a failure, so no changes in available power shall occur.

4. Control power arrangement

The power management systems (PMS) or energy management systems (EMS) are used to avoid the ship's electric network before the partially or fully black-outs. These systems are still developed and fulfill more functions.

A power system is in a fault if any of its critical parameters are out of tolerance for more than an acceptable time period, also during expected power system transients. The parameters which must remain within tolerance include: voltage, current, frequency, levels of harmonic distortion, line current balance, phase voltage balance.

The basic faults conditions on three phase system are [1,3]:

- short circuit – on one or more phases;
- open circuit – on one or more conductors;
- earth fault;
- over/under frequency;
- over/under voltage;
- over load – rating of engine exceeded;
- over current – rating of alternator, bus-bar, cables, motors, transformer or other consumer exceeded;
- severe active power sharing imbalance;
- severe reactive power sharing imbalance;
- excessive regeneration of power;
- severe waveform distortion;
- loss of synchronization or crash synchronization.

On Fig.6 is presented typical control power arrangement with separate sources of supply: DCA and DCB. If the emergency distribution is from UPS – the UPS battery endurance should be a minimum of 30 minutes. On Fig.6 all engines (generators) on one bus share a control power supply.

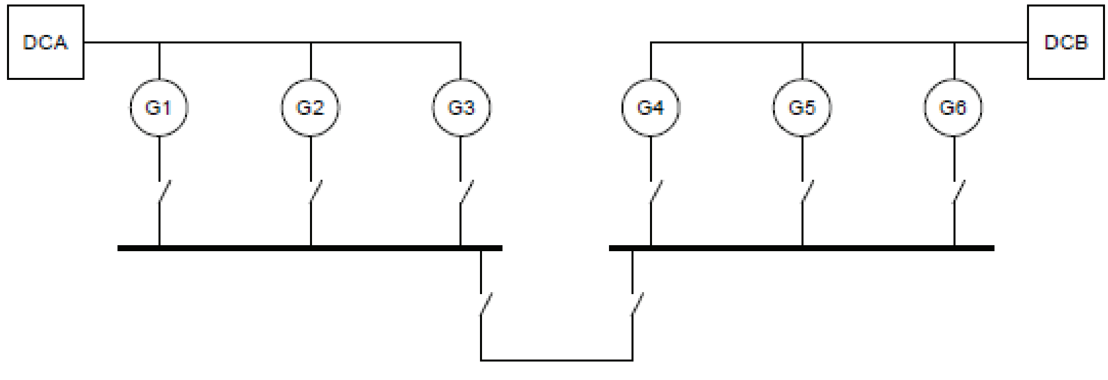

Fig.6. Typical control power arrangement [1]

Losing multiple generators as the result of a single failure (causing black-out) is extremely destructive and dangerous to the power system. On Fig.7 was shown the alternators with permanent magnet generator system. There is only one source of control power but each generator is independent of the external control power source.

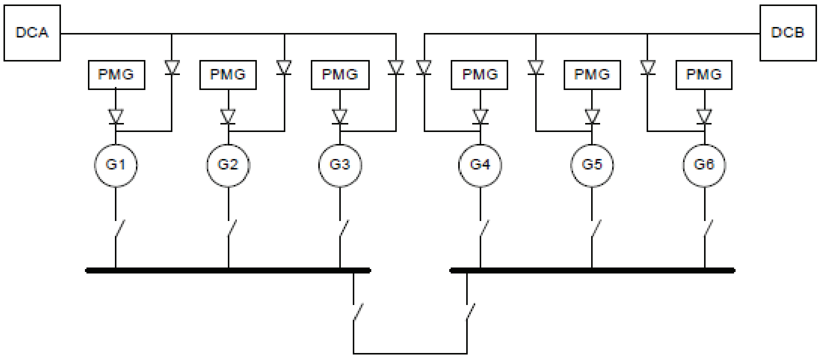

Fig. 7. Engine control power with permanent magnet generator (PMG) backup [1]

These solutions are unsatisfactory for power system of multi-mode and electric propulsion ships. Alternatively each generator can be supplied from its own power system (Fig.8).

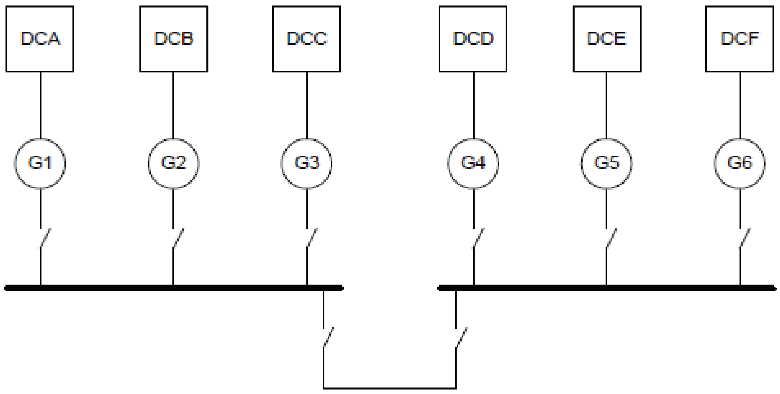

Fig.8. Independent engine control supplies [1]

The redundancy concept of using only two control supplies is presented on Fig.9 with diode isolated system. It is not recommended for multi-mode vessels due to a voltage dip associated a fault in one control power system shall be seen by all control systems. It is not recommended as a way of improving reliability too.

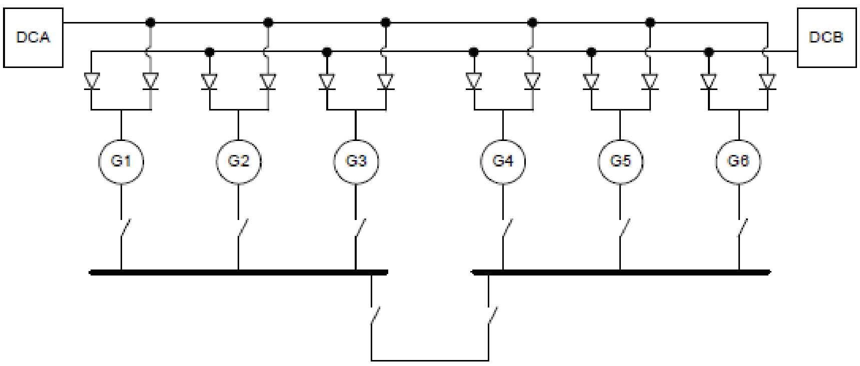

Fig.9. Diode isolated dual supplies [1]

If the voltage dip ride through is insufficient then all running engines may malfunction. The second problem is dependent on the selectivity of the fuses at the generator and power supplies to ensure a fault in one engine supply does not blow the main fuses at each DC supply output.

5. Basic requirements of the generators control

A typical malfunction generator protection relay is shown in Tab.1. and on the other way the requiring generator protective functions for ships with DP systems.

Tab. 1. Generator protective functions [1](X – yes, N – no) [1]

Function	Generator trip	Quick trip of bus-tie	Excitation trip	Start all generators	Generator lockout	Alarm
Phase current differential	X	N	X	N	X	N
Negative current sequence	X	X	N	X	N	X
Under voltage	X	X	N	X	N	X
Over voltage	X	X	X	N	N	X
Reactive power	X	N	N	X	N	X
Phase reversal	X	N	N	N	N	N
Under frequency	X	X	N	N	N	X
Loss of excitation	X	N	N	N	N	N
Reverse power	X	N	N	X	N	X
Phase over current	X	N	N	N	N	N
Over frequency	X	X	X	N	N	X
IAS/PMS E-stop	X	N	X	N	X	X
IAS PMS CB open	X	N	N	N	N	X
High set over current	N	X	N	N	N	N
Trip coil monitor	N	N	N	X	N	X
VT fuse failure	N	N	N	X	N	X
Diode failure	N	N	N	X	N	X
Generator winding high temp.	N	N	N	X	N	X
Generator bearing high temp.	N	N	N	N	N	X
Field current	N	N	N	X	N	X
Relay fault	N	N	N	X	N	N
ESD emergency shut down	X	N	N	N	X	X
Earth fault	X	X	N	X	N	X

IAS – Integrated Automation System

The rules and requirements of classification societies for ships with DP systems are similar. Presented in Tab.1. generator protective functions are implemented as a standard.

6. Accumulators of energy

The main reason of black-outs is overloading when the accessible power from working generators is less than the power demand from consumers. The possibility of accumulating energy in AC network is limited. The UPS battery endurance should be a minimum of 30 minutes but only for control power.

A global and marine industry exists for Uninterruptible Power Supply (UPS) systems. It was needed a source of high energy in the emergency situations: inefficiency, failure, peak of power demand, etc. For multi-mode vessels the needed energy storage is about 100-250 kWh with possibility of feeding during 1-2 minutes with the power up to 5 MW. This is a challenge for energy storage devices. It was presented in the Tab.2 the storage devices and theirs basic parameters. In marine appliances only the first three would be taken into consideration but only flywheels are the best for high cyclic and high power applications.

Tab.2. Energy storage devices and basic parameters [8]

type	storage mechanism	common duration	cycles
capacitor	electrical charge	seconds or minutes	100,000's
flywheel	kinetic energy	seconds or minutes	1000's-100,000's
battery	electro-chemical	minutes or hours	100's-1000's
pumped hydro	potential energy	hours	1000's
thermal	ice, molten salts	hours	1000's

A large number of applications (ship power plant as well) exist that collectively can be categorized under "peak power support". For example, drilling vessels and drilling platforms maintain a number of diesel engines as D-E systems to meet the peak power needs. The generators working parallel loads the engines at idles or at low capacity factor due to irregular power demands of drilling units and/or DP operations. A flywheel system could augment the capacity of the diesel generators, making possible to meet the peak power demand requirements with smaller number of working gensets. In that case it will be the ability to reduce needed investment cost due to application of smaller total number of installed gensets. The added value of that application may derive from reduced wear and tear on generating equipment and reduced air emissions, especially important on ECA areas (mandated air pollution limits or taxes).

The dimensions of 100 kWh ARPA-E flywheel and mass (about fifteen tons) are convenient for marine appliances (omitting small ships below 60 m of length). The Beacon POWER proposition was given to naval ships with smaller units. The biggest one is a flywheel of 10MW power with the energy storage of 27.8 kWh.

7. Final remarks

The development of main switchboards configuration and marine power plant protection have been made in recent years. The greatest improvement has come in the form of protection systems for example able to identify which generator is responsible for causing a severe active or reactive imbalance. The system faults in functions of generator protective system are common in multi-mode vessels. In fact the incorrect response of traditional generator protection is usually responsible for causing the black-out. The protection system are now available from several sources.

Now new functions of advanced generator protection (AGP) system are coming into use like: core protection functions, predecessors of modern AGP and two basic principles of operation: voting system and conformance to predicted generator behavior [1].

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