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AUTOMATIC MARINE GENERATING PLANT

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I. INSTRUCTION

Because of the lack of manpower, efforts are now being made to improve working condition in ships through labor saving measures in the engine room and the unmanned condition in the engine room during ocean navigation at night (commonly known by the abbreviations "M0" or "E0" standing for machine room and engine room zero respectively). To achieve this, considerable enphasis is being placed on continuous marine power sources which are operated completely by automated and labor saving devices. Therefore, in recently built ships, efforts are being made to obtain continuous marine power supplies by automating the generating equipment in the ship, and also to make the power supply plant more economical by reducing the supply fluctuations caused by a fluctuating load and by employing only the mininum number of required units appropriate for the load. Especially in recent diesel ships for ocean navigation, systems are often used in which the power is supplied by turbo-generators which employ the exhaust gas of the main diesel engines for economic reasons, but changes in the amount of exhaust gas due to speed control of the main diesel engines has a great influence on the turbo-generators and changes in the power source are major factors in interruption of the power source. Even in such systems, stable power can be supplied by automating the marine diesel generator.

Fuji Electric is making efforts to automate marine electrical equipment on the basis of its rich experience in marine electrical equipment and the Siemen's techniques which Fuji has introduced into Japan. This article outlines Fuji Electric's automatic generator control system, including the newly developed automatic paralleling unit and automatic sequential starter.

II. AUTOMATIC POWER SUPPLY SYSTEM

1. Basic system design points

1) When accidents or other troubles arise in the unmanned engine room, they are handled automatically more quickly, economically and stably than with former systems.

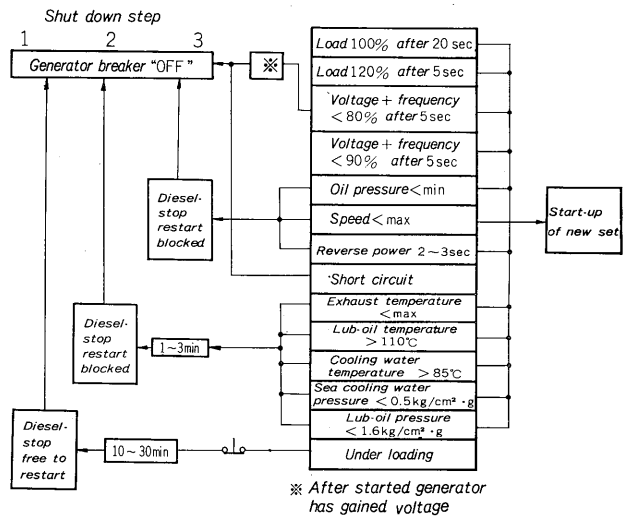

Fig. 1 System block diagram of automatic marine generating plant

2) The functions of the former generating plant and incoming switching device have been retained as much as possible and the various special functions of this system have been added so that former equipment could be remodelled into equipment with these functions.

3) The various components which make up this system can be separated both in terms of function and construction so that each part can function independently and can be drawn out from the panel. Therefore, when there is an accident, the faulty part can be bypassed manually and the other parts used automatically.

4) There is a check lamp and check board on the front of each part to facilitate maintenance and inspection. Inspection is also possible during operation.

5) Considering the characteristics of each part (environmental conditions and application conditions), contactless integrated circuits are used as much as possible. The logic elements used in the marine data logger, main engine remote control device, etc. are the Fuji Electric F-MATIC N silicon transistor switching elements which have already proven their excellence.

2. Functions

Fig. 1 is a block diagram of this system. In this equipment, the various abnormal elements which arise in the power generating system and the way of obtaining these are not only abnormalities appearing in the generator output, i. e. voltage and frequency fluctuations as in the former systems, but also abnormalities which appear in the diesel engines. Therefore, the abnormalities can be quickly detected and will not lead to major faults. In addition, the means for handling abnormalities are as practical as possible and include three trip levels in the generator circuit breaker and the time differences in issuing start instructions of the new generator equipment in respect to load capacities. Therefore, the abnormal values of the detecting points shown in *Fig. 1* are based on the type and characteristics of the diesel engines as well as the type of the generator and the inherent specifications of the ship, and the various variations are considered in such a way that the values are adjustable. Besides these indicated in *Fig. 1*, functions generally required for the automation of generators, i. e. sufficient automation of the compressed air tank needed when starting the diesel engine, automation of the daily fuel supply tank and automatic adjustment of the cooling water temperature are also necessary, and must be considered separately.

3. Equipment construction

This equipment consists of the following components:

1) Automatic diesel starter
2) Automatic paralleling unit
3) Automatic sequential starter
4) Underload and system voltage monitor
5) Other accessory components

Fig. 2 shows an external view of a typical marine switchboard equipped with the above equipment.

III. AUTOMATIC PARALLELING UNIT FPU

1. Outline

Fig. 3 shows an external view of this unit. In this equipment, the functions of the former automatic synchronizing unit and the automatic load sharing unit are included in a single unit, and other auxiliary functions are also present.

When this unit is used as a part of the "automatic generating system", a starting instruction is received from the sequential starter descrived in section IV, and operation is completely automatic. When there is absolutely no network voltage assuming that all generators in the ship have been tripped, this unit gives a breaker closing instruction at the time the generator voltage is established. In addition to being used as a single unit, the FPU is standardized for used only with automatic synchronizing operations or with automatic load sharing operation.

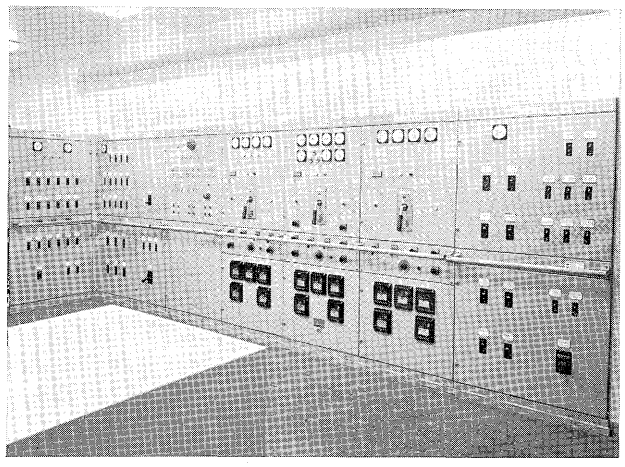

Fig. 2 Main switch board equipped with marine generating plant

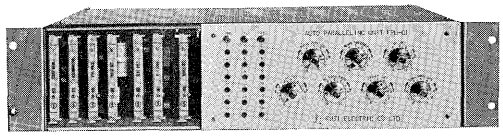

Fig. 3 Fuji automatic paralleling unit FPU

Besides the features listed in II. 1, this unit also possesses the following features:

1) The input and output signal of the equipment are all insulated by means of a relay, potential transformer and current transformer and there is strong resistance to erroneous operation or damage due to external noise or contact with outside lines.
2) The functions are suitable for an "automated ship" such as the NK "M0" ship.
3) Since the functions of the former automatic synchronizing and automatic load sharing units have been included in a single unit, it is not only more compact but also more economical.
4) In addition to the automatic synchronizing and load sharing functions, this equipment has the following auxiliary functions.

(1) Self circuit breaker throw-in operation.
(2) Increasing pusle initiated operation when synchronizing is delayed.
(3) Response threshold operation.
(4) Load detect and auto-load-shift operation.
(5) Mutual interlock operation with synchronizing pulses.

(1) Automatic synchronizing operation

Adjustable range of frequency difference at synchronization: ±0.15 to ±0.5 Hz (adjustable)
Adjustable range of voltage difference at synchronization: ±7.5% or less
Limit of adjustable frequency: ±0.1 Hz
Pulse duration for governor motor operation instruction: 0.15 to 1.0 seconds (adjustable)
Maximum permissible frequency difference for normal operation: ±10 Hz
When frequency difference is less than ±0.06 Hz if synchronization is delayed, increasing pulses are initiated.

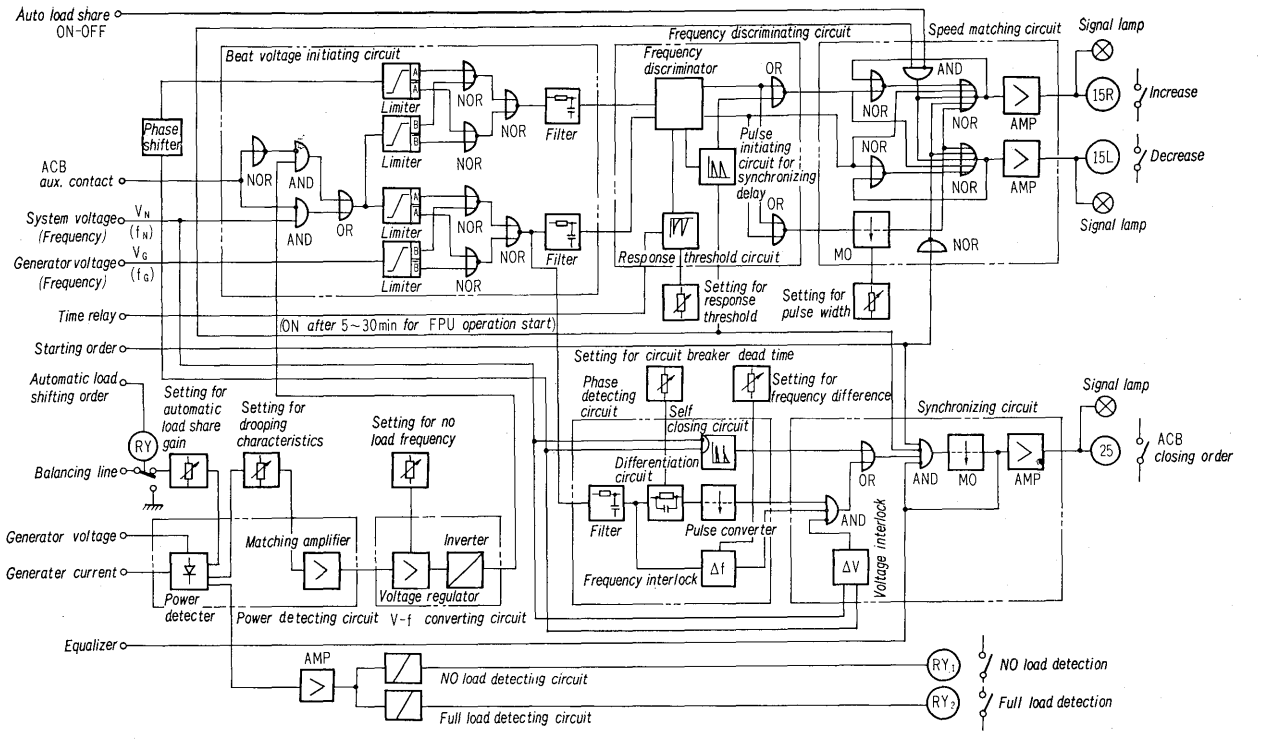

Fig. 4 Block diagram of FPU

(2) Functions for independent operation

System voltage confirmation value:

pulse occurs every 2 sec. after confirmation of 10% or less

Generator voltage confirmation value:

pulse occurs every 2 sec. after confirmation of 85% or more

(3) Load sharing operation

Load sharing accuracy:

±10% or less (pf=0.8 at generator rating)

Adjustable range of no-load frequency:

63~59 Hz or 53~49 Hz (adjustable)

Frequency droop adjustment:

0 to 4 Hz at full load variation (adjustable)

Adjustable range of response threshold:

no sensitivity at load variations of 2.5 to 5% or less after 5 to 30 minutes after starting

(4) Permissible ambient temperature range: 0 to 50°C

2. Components and operation of equipment

A block diagram of the FPU is shown in *Fig. 4*. As is shown in the diagram, this unit is divided into modules which depend on functions. There are a total of 7 printed boards for the beat voltage initiating circuit, frequency discriminating circuit, speed matching circuit, power detecting circuit, V-f converter, phase detecting circuit and synchronizing circuit. In addition there are also a few accessory devices. In other words, these modules are appropriately assembled so that they can be used as independent operation units as shown in *Table 1*. The operation of these units is as described below.

1) Automatic speed matching

Table 1 **Circuit combination of FPU**

	Overall FPU-02 function	Function of automatic speed matching and synchronizing unit	Function of automatic load sharing unit
Beat voltage initiating circuit	○	○	○
Frequency discriminating circuit	○	○	○
Speed matching circuit	○	○	○
Power detecting circuit	○		○
V-f converter	○		○
Phase detecting circuit	○	○	
Synchronizing circuit	○	○	

When there is a frequency difference between the system and the generator during synchronization, a pulse signal for increasing or reducing the speed is given to the governor motor of the generator so as to match the generator frequency with that of the system. The speed matching rate can be adjusted by the pulse duration (adjustable). The operating principle utilizes the beat voltages (all saw-tooth waveforms) of the "system-generator" and "system-generator phase advancing voltage". As is indicated in *Fig. 5* and *6*, the rate of delay of the generator in respect to the system is evaluated and the correction pulse signal is generated.

2) Automatic synchronizing operation

When the generator is synchronized with the system, the voltage and frequency differences between the system and the generator are brought within the permissible values. When the phases of both agree (however, only the dead time of the breaker is ahead

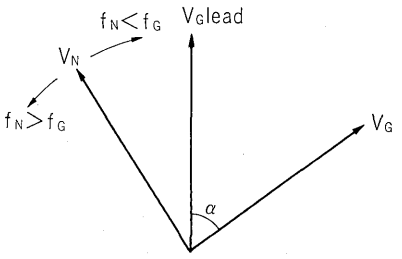

Fig. 5 Vector diagram of beat voltage

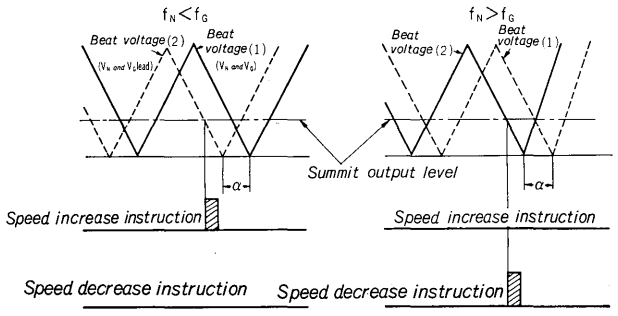

Fig. 6 Operational mode of $\triangle$f discriminator

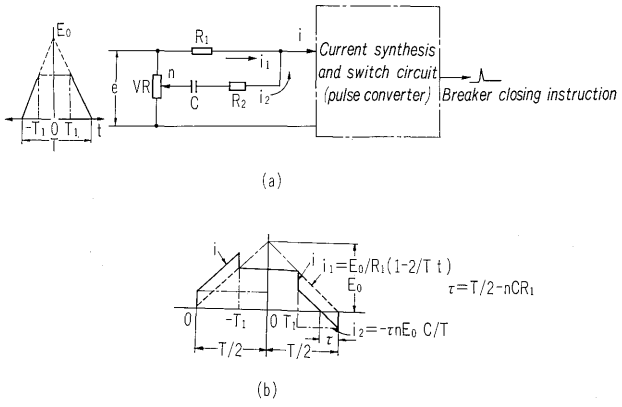

Fig. 7 Operational mode of detecting the dead time of circuit breaker

of phase) the generator breaker closes and the generator is completely connected to the system. In this case, during the dead time of the breaker the input of the circuit shown in *Fig. 7* (a) is the base form wave voltage of a beat voltage consisting of the generator voltage and the system voltage (left of *Fig. 7* (a)). As can be seen in *Fig. 7* (b), the output current i is obtained and the constant time τ which is not related to the beat frequency is utilized. Therefore, it is possible to adjust this time over a wide range.

3) Automatic load sharing

This equipment is installed in each generator and the standard frequency oscillating circuit (no-load frequency setting) in each of these units automatically shares the actual power proportionally among the various generators connected to the system. The actual power of each generator is detected by the circuit in *Fig. 8*, the vector diagram of which is shown in *Fig. 9*. The detection voltage acts to give

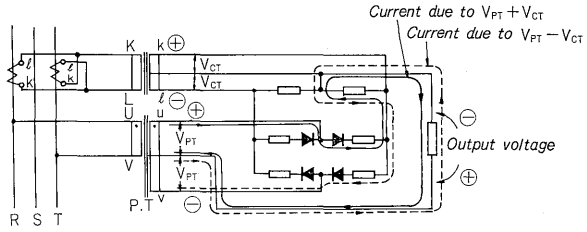

Fig. 8 Detecting circuit of actual power

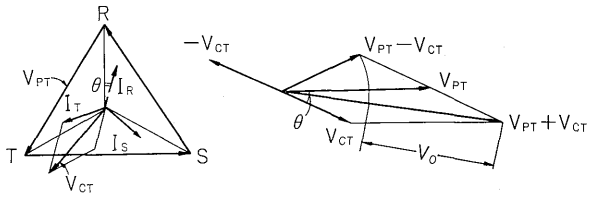

Fig. 9 Vector diagram for detecting of actual power

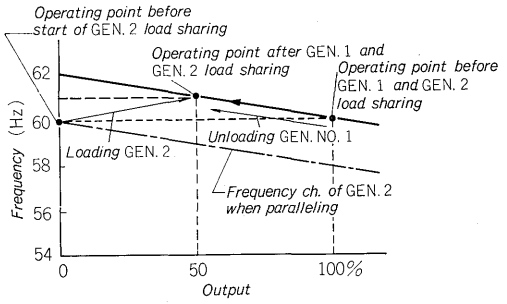

Fig. 10 Operational mode of load sharing (at drooping characteristic)

drooping characteristics to the basic frequency and also regulates the basic frequencies if they differ by comparison with the power detection voltage of another generator. This basic frequency is proportionally combined with the system frequency, the beat voltage is generated, the previously described speed matching circuit and the correction signal is transmitted to the generator governor. In other words, the generator with the relatively low percentage of load sharing has its speed increased by the governor, while that with a high percentage has its speed decreased. Load sharing can be achieved by keeping the frequency constant as in the former systems but this equipment provides stable load sharing related relatively to the load and the frequency by means of the drooping characteristics.

The load sharing modes of this equipment are as shown in *Fig. 10*.

4) Others

(1) Self circuit breaker throw-in operation

When there is no voltage in the system, the generator breaker is automatically closed if the newly started generator voltage is established.

(2) Increasing pulse initiated operation when synchronization is delayed

In the case of the automatic speed matching and synchronizing operations occurring, when the

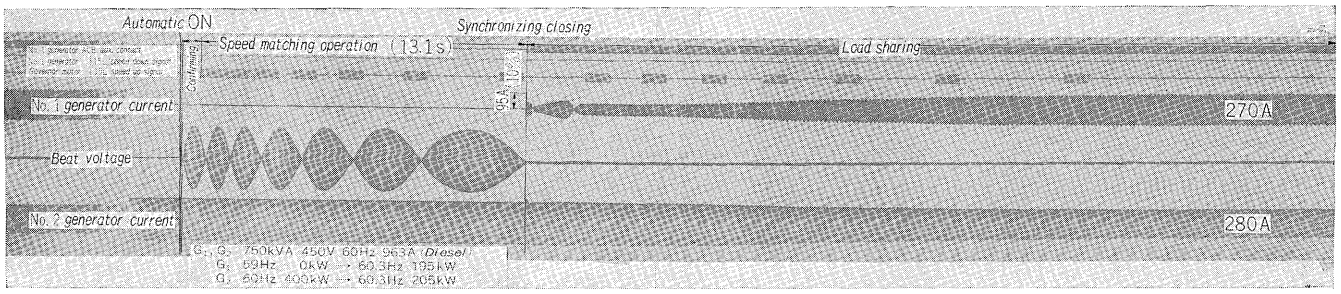

Fig. 11 Operational oscillogram of FPU

frequency of the system and generator voltage is agree with and not be co-phase, the synchronization time is extended considerably. In order to prevent this, a delay pulse for speed increase is given to the governor motor only when the breaker is off. A synchronization delay due to frequency number and unbalance is prevented.

(3) Response threshold operation

Five to thirty minutes after the equipment starts, load sharing sensitivity is complete so that load sharing is locked for very small load unbalances and the operating duty of the governor drive circuit is minimized. When there is a load unbalance which exceeds this complete sensitivity, this operation is promptly reset, sensitivity becomes high and load sharing is performed.

(4) Load detection and load shifting

In this equipment, the actual power sharing of the generators is detected and a corresponding signal is given to the exterior. The load can also be shifted to another generator automatically. For example, when there is parallel operation of two generators with the loads balanced, the load is automatically shifted to the other generator and if the complete load is shared sufficiently only with this one generator, the generator with no load can automatically be separated from the system. At this time, when the load is divided among more than one generator, it is possible to the original load conditions. In additions, various types of operation are possible by combinations with external sequences.

(5) Test results

Fig. 11 shows an oscillogram obtained during testing of this marine equipment. After a constant time has passed after the starting signal entered, speed matching is performed first. Next comes synchronization and then the load sharing operation is clearly evident from the figure. In addition, in actual examples, satisfactory results have also been confirmed in respect to static operation.

IV. AUTOMATIC SEQUENTIAL STARTER

1. Outline

This equipment has the main function of evaluating the automatic generating system, and all start and

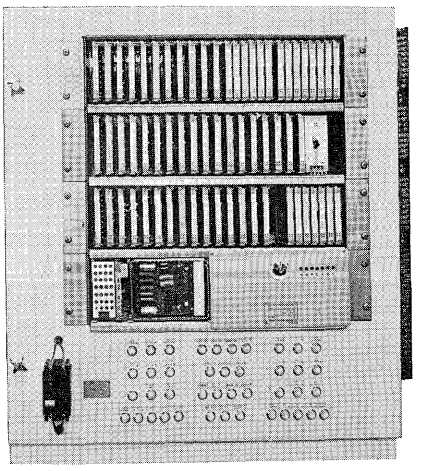

Fig. 12 Selecting equipment for automatic staring

stop instructions for the system blocks come from this equipment. In other words, when abnormalities occur in the power system, an automatic start instruction is transmitted to the preset generator engine and if the generator is running, a start instruction is given to the automatic paralleling unit described in section III. Whenever there is any sort of abnormality, a trip signal is transmitted to the air circuit breaker of the generator concerned and the abnormal generator is cut off from the system. All of these operations are completely automatic. The reliability is high because of the contactless F-MATIC N logic elements used for the silicon transistors of the control circuits and the contact type relays used in the input/output circuits. An external view of this unit is shown in *Fig. 12*. This unit is designed in accordance with the basic principles given in section II. 1 but in addition it has the following features:

1) This system is designed with priority given to the manual operation so that manual operation has priority at all times.

2) This equipment has been broken down into units according to function and the optimum control system can be achieved by combining various types of generators in the system.

3) A fail-safe system has been adopted and operation is stable in respect to error signals and faults within the equipment.

4) Since the construction is compact and light weight, it can be accomodated in the synchronizing

panel of the main switchboard or the generator control panel. (*Fig. 2*)

2. Functions and operation

Since there is only one generator system when the ship is on the sea, it is necessary to have a reserve generator in the marine generator system to comply with regulations. Generally, there are usually either 2 generators (one in use and one reserve), or 3 generators (two in use and one reserve). However, in cases where power consumption is especially high such as in refrigerated container ships or trawlers, 4 or 5 generators are sometimes used. This equipment effectively controls all of these generators, maintains a continuous power supply on the ship and operates economically. Since the equipment is divided into units according to function, sufficient functions can be provided for any number of generators. In this article, an example will be explained in detail where there are 3 diesel generators with one generator normally in use. A flow chart of this system is shown in *Fig. 13.*

1) Standby setting circuit

This circuit determines in which way faults should be handled automatically in accordance with marine generator operating conditions by means of the push button switches on the switchboard. There are two push button switches for each generator: one for standby setting and one for resetting. When one generator is set to " ST-BY ", the other is automatically set to " RESERVE ". If the generator is at ST-BY, it is automatically started first whenever an abnormality arises in the generator in operation. The generator set at RESERVE is started immediately when the automatic starting of the generator set at ST-BY fails or the air circuit breaker can not be automatically closed. As described above, this is a " one-touch " system.

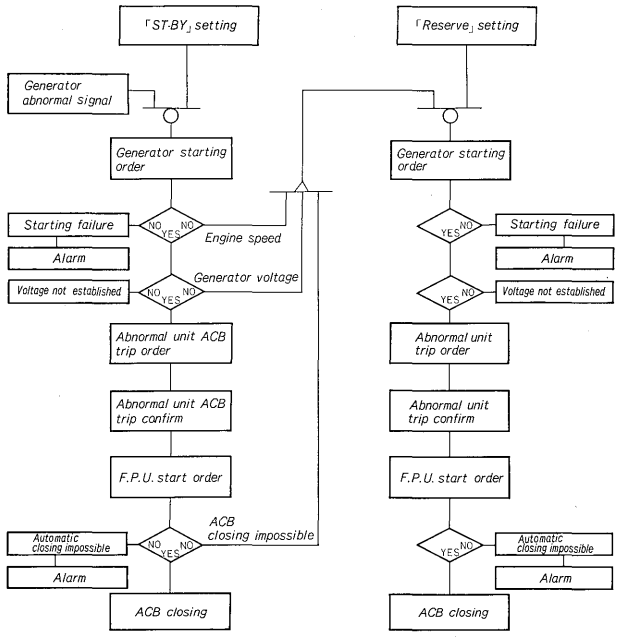

Fig. 13 Operating flow chart of sequential start control device

For standby setting of this equipment, it is necessary to automatically set other automated devices such as the generator/engine automatic starting devices and the automatic paralleling unit. The ST-BY or RESERVE conditions can be set automatically by one push button switch but when one of the generators is cut off from the system, the reset push button switch of this generotor can be pushed. If the ST-BY generator is reset at this time, the generator in RESERVE is automatically changed to ST-BY. When two generators are automatically started at the same time due to some abnormality, both can be set to ST-BY by the addition of a simple circuit.

2) Automatic starting instruction

When abnomalities occur while a generator as shown in *Fig. 1* is in operation, an automatic starting instruction for the ST-BY generator is given by the sequential start control device and the generator engine is automatically started. If this automatic starting fails, this signal is sent back to the equipment and an automatic starting instruction for the RESERVE generator is given immediately. Abnormalities are detected by means of automatic monitoring and alarm devices.

3) Automatic change

If the ST-BY generator is operated and the voltage is established, the air circuit breaker of the generator in operation trips after a fault in the generator in opration has been confirmed. Then the air circuit breaker of the ST-BY generator automatically closes. After the ST-BY generator is in parallel operation with the generator in operation, the faulty generator is cut off by the so-called " non-black out change " system. When the ST-BY generator is started, the RESERVE generator is immediately set to ST-BY.

4) Automatic setting block

Since this system emphasizes continuous power supply and automatic protection of the system when faults occur (when a fault occurs in the unmanned engine room, the fault is automatically processed and an alarm is given to the engineer), manual setting and resetting is performed after the optimum measures have been taken by this equipment for the fault and the next fault can be treated from the beginning. The automatic setting block described below is used for this.

(1) The generator in operation becomes the automatic setting block and standby setting is not possible.
(2) After standby setting is once performed, there can be no change in the ST-BY generator even if another ST-BY push button switch is pushed. When making a change, a new ST-BY setting can be performed after once resetting.
(3) When automatic operation fails, the automatic set block takes effect and that generator is cut off from the system.

(4) When manual operation takes place duriug automatic operation, the automatic condition of this equipment is reset.
(5) If the reset push button switch is not pushed in the automatic setting block condition, there can be no new standby setting.

5) Checking circuit

In order to facilitate maintenance and inspection, all input and output signals of this equipment are displayed on indicators. Therefore, by looking at the check panel, it is possible to tell immediately if the equipment is operating correctly or not. Test elements are provided for checking the F–MATIC *N* circuit and with these, it is possible to confirm normal operating conditions. Test jacks are attached as accessories for inspecting the interior of the printed boards and when required, a faulty board can be removed from inside the cubicle and its operation can be tested.

6) Applications

In addition to the above-mentioned functions, this equipment can be adopted for the following functions be adding or changing simple circuits.

(1) Supply from ST–BY generator before starting a heavy consumer load

After there is automatic parallel operation of the ST–BY generator before starting a heavy consumer load, this equipment can decide if supply by one generator is possible when the load begins or is stopped and when possible, one generator is automatically stopped.

(2) Automatic stoppage of ST–BY generator by regulating load capacity

When the power system load is increased during generator operation and the generator is over-loaded, the ST–BY generator can be automatically started and put into parallel operation. If the load becomes lighter, the generator can be automatically stopped.

V. CONCLUSION

In order to raise the reliability of marine power generation systems, it is necessary not only to increase the reliability of the various units within the system, but also to effectively combine the various units, i. e. the diesel engines (or turbines), generators and distribution panels and produce a system which completely matches actual operating conditions. These recently developed automatic paralleling units and sequential start control units have all operated stabily after installation on the ships and their very high reliability has been determined. In order to produce such a high reliability system, close cooperation with the ship owners and the dockyards is needed and from now on, Fuji Electric will endeavor to supply systems with greater reliability and more easily used through cooperation with owners and dockyards.