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THE USE OF A FREQUENCY CONVERTER FOR THE ACTIVATION OF A STAND-BY DIESEL GENERATOR OF A SHIP'S POWERPLANT

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Abstract. The paper considers the ways of accelerating the activation of a ship's stand-by diesel generator by using advantages of a vector controlled frequency converter during the activation for obtaining additional power reserve in ship's automated electrical powerplants. The activation of the stand-by generator and putting it into operation can often be needed for startup of ship's powerfull consumer, in the cases of failures in running equipment, accidents, in an emergency, or changes in navigation conditions, as well as while fixing the vessel location during the dynamic positioning. The main obstacle to such an activity is the fact that the complete sequence of operations (stages) should be performed for this: pre-start preparation of a diesel engine, the activation and acceleration of the unit to a certain speed, the synchronization of the started generator with the other running generators through the fuel regulating devices of the diesel engine and sharing the load among the generators in case of successful connection of the standby one to the bus bars of the powerplant main switchboard. The duration of listed stages can be from 15–20 seconds to several minutes, and therefore such delay may be unacceptable.

Existing methods of speeding up the mentioned stages are not considered together as a whole. The proposed solution is to organize the inverter activation of the stand-by diesel generator controlled by a specialized device or by the part of the power plant control system, at the end of which all previously listed stages of putting the unit into operation will be completed and the ship's powerplant will be ready for accepting the additional load. The specialized device should be accommodated to processing input data in real time during the activation. It forms control commands for the frequency converter, generator voltage regulator, regulator of diesel engine speed and air circuit breaker of the generator. The device also calculates (determines) the moment of switching on a breaker, as well as the magnetic flux of the generator and the torque moment of the diesel engine by predicting the load of any of the running in parallel generators from the assumption that the standby generator is connected and sharing of active and reactive load components between all generators are over. In other words, the spatial position and magnitude of the EMF vector of generator which will be connected to bus bar immediately before the breaker is closed must match the values that have been determined as a result of the forecast of the power plant operating mode with the stand-by generator already in operation, taking into account changes caused by transition processes. Redistribution of active load components of generators to equal levels after closing the breaker will occur due to a certain supply of kinetic energy of the unit rotating parts. The proper amount of kinetic energy is provided by the commands of the specialized device during the controlled activation of the disel generator based on the forecast of load changes.

Key words: ship's electric powerplant, stan-by generator activation, specialized control unit, synchronization, load sharing.

1. Introduction

Switching on the powerful consumer or the equivalent powerful consumers' group causes negative consequences in the ship's electrical power supply leading even to powering down and failure of generating units when there is insufficient stock of the so-called rotating power of the working generators. To prevent these and other negative consequences, the ship's powerplant control system and powerful consumers have been equipped with devices that allow the activation only with the appropriate power reserve. If the total power of the running generators is insufficient when the power consumer asks for the activation, the control system starts the stand-by diesel generator (SbDG). However, if the power reserve is considered sufficient, the start of powerful consumer is provided manually by an operator or automatically. In practice, the necessity of urgent activation of the SbDG and putting it in operation may occur in other situations, such as failures in running equipment, accidents, in an emergency, or changes in navigation conditions, as well as while fixing the vessel location during the dynamic positioning.

The main obstacle to such an activity is the fact that the complete sequence of operations (stages) should be performed for this: pre-start preparation of a diesel engine, the activation and acceleration of the unit to a certain speed, the synchronization of the SbDG with the other running generators through the fuel regulating devices of the diesel engine and the load sharing between the units in the case of successful connection of the generator to the bus bars of the powerplant main switchboard (MSB). According to estimates [1], the time interval between the coming of a SbDG starting command and the moment when the SbDG is connected to the MSB bus bar and load sharing between the running generators is completed can be from 15–20 seconds to several minutes for ships' automated power-plants (SAPP). Depending on the specific situation, the duration of such delay may be unacceptable.

The reduction of the durations of the particular stages of putting the SbDG in operation can be achieved in the following ways. The first one is the creation of an activation queue and keeping the diesel-generators (DG) in a "hot standby" mode, which, on the one hand, gives the opportunity not to wait for the completion of the diesel engine warming up after its activation, and on the other hand leads to inefficient expenditure of energy and fuel consumption for maintaining the DG readiness to activation. The second one is the use of the accelerated generator connection to the MSB bus bar using the modes of rough- or self-synchronization which require devices and automation additional to the standard configuration of the SAPP [1, 5, 6]. Particularly noteworthy mode is the so-called electromechanical actuation [5], being a kind of self-synchronization mode, wherein the connection of the non-working generator to the network and the primary engine start are performed almost simultaneously. Fig. 1 shows the results of processing the oscillograms of the electromechanical activation of the generator of an unmanned power station, where:

Curve 1 is network voltage U_N; curve 2 is stator current I_{ST} and the envelope of its maximum $I_{ST\,MAX}$ and minimum I_{ST_MIN} values (dashed curves); curve 3 is rotor voltage U_{ROT}; curve 4 is a rotation rate n/n_{nom} at electromechanical start; 5 is the same rate at a normal start.

Being faster than at the normal start, the acceleration of the unit and its getting the synchronism are provided by the connection of a rotor winding directly to the exciter which is located on a generator shaft. Devices controlling rotor current are adjusted in such a way that when the rotation frequency becomes close to the synchronous, the generator has been excited and able to get the synchronism. The rotating part of the unit is affected not only by the torque of turbine but also by the asynchronous torque of the generator, which is especially noticeable when there is a damper winding on the rotor.

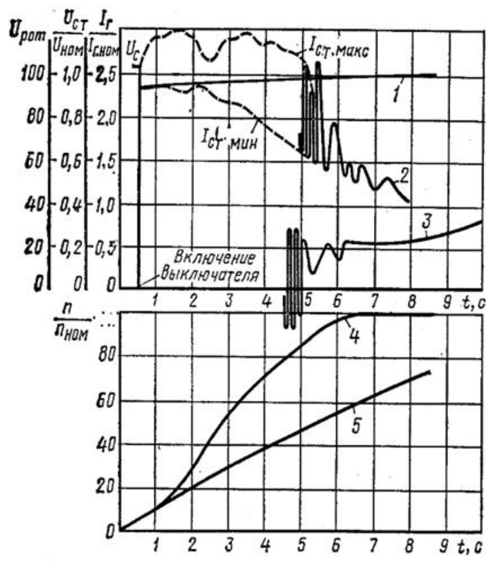

Fig. 1. Processes at electromechanical activation of the hydro generator 3.5 MW [5].

It can be noted that with this method of activation the automation of the unit is simplified and the processes taking place in the generator are similar with the processes in the asynchronous activation of synchronous motors with the connected exciter. Along with the advantages (quick acceleration, no need of synchronization), the method discussed has the following drawbacks. In this case, the activation is not controllable and this facilitates the automation of the unit; the issue of loading the generator after entering in synchronism is not considered, while the load sharing stage between generators takes some time.

Widespread introduction of power semiconductor converters, in particular, two-directional frequency converters (FC), both in the power part of the SAPP and in auxiliary subsystems of the ships [1, 13], brings a new perspective to the problem of time reduction necessary to put the SbDG into operation for obtaining the required reserve of generated power.

For reducing the activation time of the diesel engine, the so-called inverter or frequency start [2, 11] can be used due to the rotating torque of the synchronous generator working in the motor mode and supplied from the FC. Power supply for the FC, in turn, can be provided from either MSB bus bar or from a separate energy storage unit, such as a supercapacitor bank. This method allows abandoning the generally accepted variants of the diesel engine activation unit, such as an electric or pneumatic starter or a separate system of providing starting air to diesel cylinders. At the same time, the presence of a regular activation unit allows it to be used for the activation as an additional one to overcome the inertia of moving masses during the acceleration of the DG. Assuming that the power of the starter is the power of the synchronous generator itself in the starter mode, the duration of diesel acceleration to some required speed can be significantly reduced.

The examples of inverter activation of the DG of diesel locomotives with AC-DC or AC current transmission are presented in [2, 3]. Fig. 2 demonstrates the oscillograms of transition processes at the inverter starter of the DG consisting of a diesel engine 12LDG500 with a synchronous generator GS567U2 at various values of output current of the starter inverter.

The starter system includes ST22-2000 starter inverter with the power module of field winding power supply, cumulative-boost converter ST23-500 DC with the capacitor drive on supercapacitors and a starter accumulator battery.

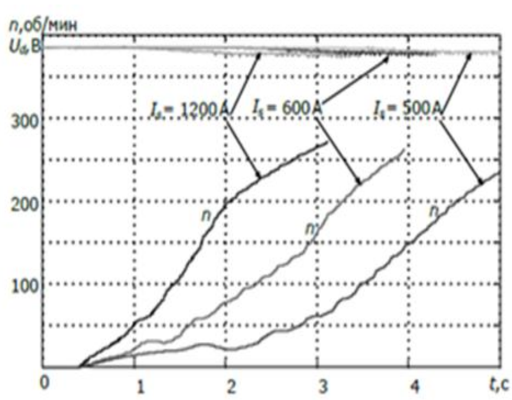

Fig. 2. Transitional processes at the activation of the DG 500 kW invertor [8].

It is noted that in this case the inverter activation allows maintaining the useful capacity and life cycle of the battery by eliminating discharge current jumps occurring during the normal activation of the DG by a regular starter-generator; the rapid achievement of the DG shaft speed 210 rpm at which further operation is sustainably controlled by the diesel engine regulator is provided by the optimal adjustments of the vector-controlled starter inverter; activation time is minimal.

The mathematical model and block diagram of vector control of the synchronous machine (SM) in the starter mode is proposed in [3]. One of the research results is obtaining the estimated relations between the torque and power of the SM and the shaft speed for the unit containing a diesel with capacity of 6000 hp shown in Fig. 3.

The following basic parameters of the SM are used in the simulation: nominal power 4500 kW, linear voltage 1450 B, phase current 1900 A, shaft speed 1000 rpm, current frequency of 100 Hz, time constant of exciting winding 1.4 s. It should be emphasized that the structure of the vector control of the invertor contains a functional converter of the torque setting FCT forming the output signal as a function of the rotation speed, and the functional converter of the excitement current setting FCE forming the output signal for field current control. The signal on the initial and real-time angular position of the SM rotor comes from an appropriate sensor or is calculated implicitly. The task of vector control is to control the torque (current) as the function of the rotation speed which provides the maximum effective use of storage energy taking into account the maximum current limit of the stator. So, an example shows the possibility of implementing of the activation controlled according to certain criteria, one of them being the reduction of the time necessary for putting the SbDG into operation.

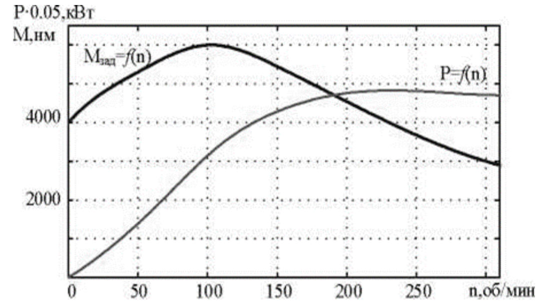

Fig. 3. Estimated relation of the torque and power of the SM at the activation of the DG of 6000 hp [3].

The use of FC for the activation of powerful turbo generators is described in the works of [9–11] and is considered to be well-established and tested method. However, when it was implemented, the problem of reducing the time of putting stand-by generator into operation was not considered. Therefore, in order to solve it, in the case of the SAPP, this method requires further development.

2. Propositions concerning the reduction of the activation time of the SbDG

The proposed solution is to organize the inverter activation of the DG by controlled specialized device (CSD) or by the part of the SAPP control system, at the end of which all previously listed stages of putting the SbDG into operation will be completed and the SAPP is ready for loading, in particular, for activating the powerful consumer. The input signals of the specified CSD should be: the rotation speed of the SbDG and the magnetic flux of the generator, the mutual location and vector values of the EMF and voltage on the MSB bus bars, the number of running generators and the power of each of them, as well as their total power in real-time mode. As a result of processing these data, during the activation process the CSD forms control effects on FC, the generator voltage regulator (GVR), the diesel engine speed regulator and the generator air circuit breaker (ACB). The moment of the switching on the ACB, as well as the magnetic flux of the generator and the torque of the diesel engine should be determined by the CSD by predicting the load of any of the running in parallel DGs from the assumption that the SbDG was connected and sharing of the active and reactive load components between all generators is over. In other words, the spatial position and magnitude of the EMF vector of generator being connected to the bus bar at the moment when its ACB is switched on must match the values that have been determined as a result of the forecast of the SAPP operating mode with the SbDG already in operation, taking into account changes caused by transition processes.

Redistribution of the active components of loads of generators to their uniform distribution after the ACB switching on should occur due to a certain supply of kinetic energy of the unit rotating parts which is provided by the CSD control during the controlled SbDG activation based on the forecast of load changes.

Thus, it is possible to eliminate the time spent on the synchronization and load sharing and, in addition, to reduce the acceleration time of the unit, considering the power of the starter as the synchronous generator itself in the starter mode.

Let us consider some aspects of the rationale behind the proposed solution.

The rules of the Register provide for DG tests which are developed to check the settings and actions of engine controllers and AVRs by applying and resetting 50–100 % of the generators load. Ship's DGs are found to be under similar conditions at permitted activations of consumers which power corresponds with the power of the generator. Therefore, the design of DGs provides for these changes in the mode of operation without deterioration in performance.

In most modern SAES, the SbDG activation is performed by means of the automatic or manual (with synchronoscope) synchronization for minimizing the equalizing currents and voltage and frequency deviations in the network. The analysis of instructions for connecting generators in parallel manually and the characteristics of devices providing automatic synchronization [15] leads to the conclusion that the command for ACB closing can be sent when the angle δ between vector of generator EMF and vector of voltage on the MSB bus bar is +/- 25^o ... +/- 30^o or “at the position of the synchronoscope arrow relative to the phase match mark in the sector from “11 o’clock” to “13 o’clock”. At the same time, it is considered that the current jump and the transition parameters of redistribution of active loads will be within acceptable limits. Immidiately after the ACB closing, the angle δ will correspond to the angle of the load – of the connected generator. It is known [1] that the value □ of about 30^o corresponds with the nominal active load of synchronous generators.

Let us suppose that the CSD has determined the switching angle of ACB δ during the SbDG activation; the SbDG has the proper stock of kinetic energy to the moment of connection to the bus bar due to acceleration and after connection the active load would been distributed evenly between the generators. Then let us determine the loads of SAPP generators for several options using these considerations. Let us assume that the values of nominal power Pn of the generators are equal and only one generator is running with a load of 50 (100) % of Pn which in relative units is 0.5 (1). Here and further in brackets another appropriate load level is pointed out. In parallel with the running DG the SbDG should be put in operation. For the even distribution of loads, the SbDG must abruptly take 0.25 (0.5) of the Pn, and the running generator must abruptly give 0.25 (0.5) of the load remaining in operation with 0.25 (0.5) Pn. Then let us assume that there are two DGs running with a load of 0.5 (1) Pn each and the SbDG should be connected in parallel with them. For an even distribution of the load, the SbDG must abruptly take about 0.34 (0.68) Pn; after that the loads on each of the three generators will be about 0.33 (0.66) Pn. Considering the options with three and four generators in operation and SbDG connection, the values of 0.38 (0.75) and 0.4 (0.8) respectively can be obtained.

Thus, depending on the load of generators in the standard configuration SAPP, the SbDG load taken abruptly will be (0.25.. 0.8) Pn. If changes in SbDG parameters are not satisfactory for the bigger values among those in terms of existing requirements, then the limit of accepted load taken at the moment of ACB switching on can be limited due to the process controlability. A slight discrepancy in the distribution of the load in this case will be corrected in the short time after the SbDG connection by compensating actions from SAPP controlling system. Studies of electromechanical processes under varying levels of non-observance of the conditions of precise synchronization for various reasons [5–8, 12] show that the generator shock current and the mechanical moment arising on the rotor due to non-synchronous closing of ACB with switching angles δ of no more than 30^o are within the limits acceptable in practice and depend on several significant factors such as: the resistance of the network to which the generator is connected; the slip of the rotor $s = \Delta\omega = d\delta/dt$ on which the DG kinetic energy and the value of taken active load depends; magnetic flux and, accordingly, the EMF of generator idle mode at the activation moment. In support of above mentioned, the simulation results [7, 8] of the connection into the network by means of precise synchronization of 10 kW synchronous generator can be considered. The simulation was carried out with the use of the developed models in the Matlab-Simulink/ SimPowerSystem software package and using the physical model, then the results was implemented practically. To confirm the feasibility of our proposed solution, it is planned to carry out similar research for a real and promising SAES, as well as to develop the algorithm of operation and structure of the CSD.

3. Conclusions

In practice, the necessity for urgent putting ship's stand-by diesel-generator into operation may occur in a variety of situations, such as: connection of a powerful consumer, failures in working equipment, alarm, accident or changes in navigation conditions, ship retention located with dynamic positioning. The main obstacle to this is waiting for the sequence of technological operations (stages): pre start preparation of diesel engine, activation and acceleration of the diesel to preset revolution speed, synchronization of the generator to the switchboard bus bar, load sharing between generators after closing the breaker. Existing methods of acceleration of some of listed stages do not address the problem in a complex which could take into account all stages together. The proposed solution is to organize the inverter start controlled by the specialized device, at the end of which all stages of putting stand-by diesel-generator into operation will be completed and the power plant ready to receive the load. For the confirmation of feasibility of the proposed solution a further research on real and prospective ship's powerplant models is needed, as well as developing the structure of the specialized device and the algorithm of operation.

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ВИКОРИСТАННЯ ПЕРЕТВОРЮВАЧА ЧАСТОТИ ПРИ ВВЕДЕННІ В РОБОТУ РЕЗЕРВНОГО ДИЗЕЛЬ-ГЕНЕРАТОРА СУДНОВОЇ ЕЛЕКТРОСТАНЦІЇ

Сергій Самонов, Віталій Дубовик

У статті розглянуті шляхи прискорення введення в роботу суднового резервного дизель-генератора з використанням переваг перетворювача частоти з векторним управлінням у період запуску для забезпечення додаткового резерва електричної потужності в судновій електростанції. Запуск і введення в роботу резервного генератора можуть часто бути потрібними для пуску потужного споживача, а також необхідними в таких ситуаціях, як: несправність працюючого обладнання, тривога, аварія або зміни навігаційних умов, при утриманні судна в позиції при динамічному позиціонуванні. Головними перешкодами для цього є необхідність очікування повного завершення послідовності технологічних операцій (стадій): передстартової підготовки дизеля, пуску і прискорення дизеля до встановленої швидкості, синхронізації генератора з іншими працюючими генераторами впливом на паливо-регулюючі пристрої дизеля, розподілу навантаження поміж генераторами в випадку вдалого включення генератора на шини головного розподільного щита. Тривалість перелічених стадій може сягати від 15–20 секунд до декількох хвилин, у зв'язку з чим подібна затримка може стати неприйнятною.

Існуючі методи прискорення завершення перелічених окремих стадій в одному комплексі не розглядають їх у сукупності. Запропановано організацію контрольованого спеціалізованим пристроєм інверторного запуску резервного дизель-генератора, наприкінці якого всі перелічені стадії будуть завершені і суднова електростанція буде готова прийняти додаткового навантаження. Вказаний спеціалізований пристрій має бути пристосованим для обробки в реальному часі необхідної вхідної інформації впродовж запуску і формування керуючих команд до пертворювача частоти, регулятора напруги генератора, регулятора частоти обертання дизеля і автоматичного вимикача генератора. Момент включення автоматичного вимикача, а також магнітний потік генератора й обертовий момент дизеля мають бути розраховані спеціалізованим пристроєм шляхом прогнозування навантаження будь-якого одного з паралельно працюючих генераторів із припущення, що резервний генератор уже підключений, і рівномірний розподіл активної частини загального навантаження поміж всіма генераторами завершений. Іншими словами, просторова позиція і величина вектора електро-рушійної сили безпосередньо перед увімкненням автоматичного вимикача генератора, який буде під'єднано до шин, мають бути визначені як результат прогнозування режиму електростанції в складі з резервним генератором, який уже працює, приймаючи до уваги зміни, пов'язані з перехідними процесами. Перерозподіл активної частини навантажень генераторів до однакових рівнів після включення автоматичного вимикача резервного генератора відбудеться за рахунок визначеного запасу кінетичної енергії частин, що обертаються. Величина необхідної кінетичної енергії має бути забезпечена командами пристрою протягом керованого запуску дизель-генератора, який грунтується на прогнозі змін навантаження.

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