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Operation Planning of Standalone Maritime Power Systems Using Particle Swarm Optimization

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Abstract— **This paper presents the power management system (PMS) that relies on optimal power planning and maximum energy efficiency in dynamic positioning (DP) drilling vessel. Nowadays, it is becoming an improving demand for higher precision and decreases ship motion induced by environmental disturbance such as wind, waves, and sea current, which leads to the use of power generation more efficient. According to this, an efficient strategy solution and schedule have increased significantly for power management of diesel generator (DG) units on marine vessels as an independent microgrid to the utility grid. Thus, the power management system (PMS) of vessels is proposed to monitor and prevent the blackout by using the model predictive controller (MPC) based on optimal control method in order to estimate the future power demand in the hostile environment. Due to nonlinear characteristics of diesel generators, such as power ramp rate limits and non-smooth cost functions, a particle swarm optimization (PSO) is applied to solve the economic dispatch (ED) problem for a dynamic system. The simulation results demonstrate that the proposed method can improve ED operation problems more efficiently while meeting DGs constraints.**

Keywords—Power management system, economic dispatch, particle swarm optimization, the dynamic positioning system

I. INTRODUCTION

Exploration oil and gas in offshore is an expensive and high-risk operation, especially in deep water. A dynamic positioning system (DPS) is an advanced piece of technology, which is widely used in vessels, platforms, and other ocean structures to maintain a vessel's or a platform's by applying its thrusters automatically [1]. In hydrocarbon fields, a drilling vessel or semi-submersible rig is continuously exposed to environmental disturbances such as wind, waves, and seawater current to keep the position and heading of drilling rigs. The majority of these modern vessels are equipped with diesel-electric power generation plants, renewables energies storage, and variable speed thrusters for positioning. Hence, one of the worst scenarios for DP vessel is a loss of the power or blackout for drilling oil and gas in heavy condition [2]. A crucial part of the blackout prevention functionality is found in the Power Management System. Therefore, the ship owners make a significant effort to increase the power system stability against failures while drilling operation are subjected to complicate environmental disturbances. Station keeping of a vessel is required to maintain a position near to the desired location of the vessel. DP uses available control devices such as rudder, propeller, and vector thrusters to compensate the environmental forces and keep the vessel as close as possible to the desired position. DP has many advantages over other conventional station keeping methods such as mooring lines, for deepwater operations. The electric power system is crucial for conducting advanced operations in most of the modern marine vessels such as oil and gas rig, pipe and cable laying, crane, and passenger ships with the dynamic positioning system (DPS). The ability to perform maintaining and maneuvering stations depending on current loads, waves, and wind depend on the capacity of the power plant. Inadequate power may result in lower DP performance, loss of position, full power, which is called shutdown [3].

The excessive load in generator capacity units and distribution are the probabilities of the risk of power system fault. Therefore, redundancy costs are expensive and cost-effective is increasing significantly, in terms of investment in equipment, maintenance, emissions, and fuel consumption due to diesel generators running hours. Therefore, flexibility in the operation of power generation and distribution systems for producing oil and gas resources by using (PMS) is very vital. For example, the uncertainties in a load of drilling, cable, and pipe laying in operation are made challenges to supply power for DPS. Thus, PMS should determine the optimal power flow base on future operating load profile [4].

Accordingly, unknown load demand in future will predicate base on DP effect of load profile by optimizing the algorithm. Besides, PMS is used for generator control, power failure prevention, power limitation, load distribution, and load shedding. The positioning system receives the available energy from the energy management system. If the desired pitch rpm setting gives a total load higher than the available power in the system, the thruster setpoint is decreased. Under normal circumstances when no operating limit is exceeded, the DP system will reduce power consumption sufficiently to avoid activation of load delivery [5].

The main challenge for DP ship power system is that the essential dynamic load, such as thrusters in heavy condition, may have a higher power ramp rate DP demand than the power generators capability. Therefore, in this condition, it causes uncompensated power between demand and increases the risk of blackout. Therefore, to avoid blackout in critical

TABLE I. SUMMARY OF DP DRILLSHIP PROPULSION PARAMETERS

Parameters	Value
Machinery: 6×Diesel Generator	
Population system:	7 MW
2× Azipod Propellers	1200 kW
2× Bow Thrusters	1750 kW
2×Azimoth Thrusters	1000 kW

situations, DPS should be allowed to use maximum power, which is available on busbars, and have higher priorities than the other heavy consumers. In normal conditions, when there is no over the operating limit, the DP system reduces power consumption reasonably to prevent load profile and power generation oscillation [6]. However, in operation conditions, the DP system should be able to use maximum energy and prioritize the main consumers. In principle, this is an optimization problem, and its purpose is to reduce the cost of unit production while satisfying is limited. Previous methods have been made to solve economic dispatch problems by using different mathematical programming and optimization techniques. These conventional methods include Lambda repeat and participation methods [7],[8]. These nonlinear features of a generator include unauthorized prohibited areas, ramp rate limits, and cost functions that are not flat or curved. Moreover, for a large scale mixed generating units, the conventional method has proposed for the fluctuating problem due to more extended solution in time.

To solve the optimal operation planning for generator units, artificial intelligence techniques based on Hopfield neural network have been employed successfully for quadratic fuel cost function and prohibited zones constraint [10-13]. However, an inappropriate sigmoid function taken at Hopfield model may sustain from exceeding repetition, as a result, in large calculations. Researchers in [14], [15] explored model predictive control (MPC) because of computer science advances and algorithms that make it feasible to combine positioning control and thrust allocation into a single algorithm. These papers compared the advantages and disadvantages of using MPC with the conventional algorithms and dedicated to nonlinear model predictive control application for (DP) problem. Moreover, the authors in [16],[17] proposed PSO method for the MPC controller and mixed-integer nonlinear programming for solving an optimization problem, respectively. However, they have not considered the power generation constraints practically, such as ramp rate limits for DGs unit as a critical issue in the drilling operation.

Regarding the above, the main objective of the research project is to investigate the economic dispatch problem of power management using the PSO methodology, when the operational limitation is exceeded by DPS power consumption. In this paper, we developed a power management system methodology within the DP ship and described it as an optimal dispatch problem. Thus, the objective of the proposed method is the optimization of power generation within a specific time horizon. The system under study, which is adapted from the estimated MVDC system, includes 6 generators and two propulsion and four thrusters load is shown as Table I. The rest of the paper is prepared as follows: Section II demonstrates the concept of a dynamic positioning system; Section III interduces the operation and planning concept for DGs; Section IV shows the simulation results in Matlab/Simulink, and Section V the paper conclusions.

II. DYNAMIC POSITIONING SYSTEM

For many marine activities, a ship must be kept in a fixed position. Dynamic positioning systems automatically control the position and flow of the ship using main engines that are always dynamic and create a hostile ability to deal with environmental disturbances such as waves and wind. Disruptions in the marine environment are the ship, while the DP controller automatically compensates for these forces and keeps the ship using propellers and engines. In general, a ship with six degrees of known freedom (surge, sway, yaw, roll, heave, and pitch) is shown in Fig. 1. However, the DP system can only control three horizontal movements of (surge, sway, and yaw) and design the motion control of (roll, heave, and pitch) are neglected. These parameters are proposed for navigation and antennas systems.

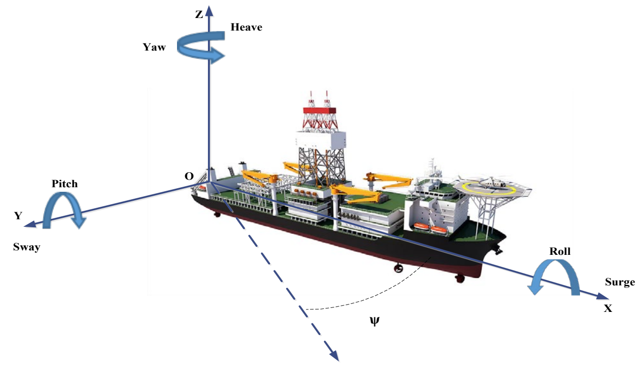

Fig. 1. Motion components of the vessel with six degrees of freedom.

The DP system consists of some subsystems are defined as follows:

1) Power system

The power system of a vessel includes generators, distribution system (switchboards), transformers, variable frequency drives (VFD), and motors control center, energy storage system and uninterruptable power supply (UPS) for using sensitive equipment monitoring and automation systems. They comprise of all necessary components to supply the DP system with the power system.

2) Signal processing

All data send by environmental sensors, such as gyrocompass, wind sensors, motion reference units, must be thoroughly analyzed in a separate signal processing module to feed the controller or computer with information about the position of the vessel. Then, the DP computer calculates the required thrust, which will be applied by the thrusters in order to maintain the deviation of the vessel into the right position.

3) Control system

The control system consists of:

- Computer/joystick systems console
- Sensors such as gyrocompass, wind sensors, motion reference units, etc.
- Position reference systems include:

a) Global navigation satellite systems (GNSS),

b) Hydroacoustic systems, taut wires,

c) Microwave systems, laser systems, etc
d) The interface unit of input and output
e) Monitoring system and operator panels

4) Thruster system

Thrusters system enclose the essential mechanism to supply the DP system by allocating thrust force and tracking the pass. The thruster system consists of electric drive units, main propellers, and rudders that are supervised by the DP control system. In [3], [4], the authors proposed the high-level positioning controllers in order to calculate the commanded forces in surge and sway and moment in yaw. Also, the thrust allocation module that computes the corresponding force and direction commands to each thruster device has been introduced. Moreover, they highlighted the importance of low- level thruster control in normal and extreme conditions for avoiding the wear and tear mechanical parts and risk of blackout and harmonic distortion in power systems, respectively.

III. PROBLEM DEFINITION

The economic dispatch and optimal planning is a nonlinear programming optimization of a DP ship power system. Especially, for DP load demand in heavy condition. Accordingly, the planned integration units at each specific period of DP operation must be scheduled for economic dispatch performance. Dispatching optimal generation among operational units to ensure the demand for DP system, spinning reserve capacity and applied operation restrictions of generators that consist of the ramp rate limit and the prohibited operating zone is formulated as follows:

A. Operation restrictions of shipboard generation

For solving the economic dispatch of the shipboard generates unit; it is expected that the output of the generator is adjusted smoothly and immediately. Technically, the operating range of all main diesel generator (DG) units is constrained by their ramp rate limits for forcing the operation of the unit frequently [11],[15]. Hence, the two restrictions of DG operation must be taken between up ramp (UR_i) and down ramp (DR_i) rate limits of generator changes as follows:

$$P^0_{DG,i} - DR_i \le P_{DG,i} \tag{1}$$

$$P^0_{DG,i} + UR_i \ge P_{DG,i} \tag{2}$$

where $P_{DG,i}$ is the present output power, and $P^0{}_{DG,i}$ is the previous output power of i the generator (MW/time-period).

B. Objective function

The objective function of economic dispatch is to minimize the cost of operation rate and to meet the DP load demand of a shipboard power system over various limitations. The total cost function for generators, which is defined by the quadratic curved cost function as follow:

$$Min\ J = \sum_{t=1}^{n}\sum_{i=1}^{m} \alpha_i P^2_{DG,i}(t) + \beta_i P_{DG,i}(t) + \gamma_i. \tag{3}$$

C. Generators operation Constraints

The cost function j should be minimized to solve the optimization problem under the power balance, and generator constraints at a particular operating interval, which can be represented as:

$$\sum_{i=1}^{m} P_{DG,i} = P_D + P_L, i = l,...,m. \tag{4}$$

$$M\,\mathrm{ax}(P_i^{\min}, P^0_{DG,i} - DR_i) \le P_{DG,i} \le M\,\mathrm{in}(P_i^{\max}, P^0_{DG,i} + UR_i) \tag{5}$$

where P_L is the ohmic losses between generators and distribution network, and P_D is the total load demand include DP load profiles.

D. Particle Swarm Optimization

To solve the optimization problem, Kennedy and Eberhart are introduced the Particle Swarm Optimization (PSO) technique in 1995 [13], which is inspired by the society of animals behavior such as fish schooling and bird flocking. PSO is one of the most modern heuristic algorithms that are continuous the linear/nonlinear optimization problems solution. The proposed method provides a population based on the search process in which individuals are known as particles to modify their positions with the time.

During the optimization period, each particle changes its position corresponding to their neighboring particles experience, and the individual experience, creating the best position encountered by itself and its neighbors. The swarm course of a particle is determined by the collection of particles neighboring and its historical particles experience. The optimization method can be found by Equations (6) and (7) for particles, where the i -th is demonstrated as particle position $x_i = (x_{i1}, x_{i2}, ..., x_{ik})$ and $v_i = (v_{i1}, v_{i2}, ..., v_{ik})$ is particle speed (velocity) in the k dimensional space respectively.

The i -th best previous position of particles, which is recorded and formulated as $x^i_{pbest} = (x^{i1}_{pbest}, x^{i2}_{pbest}, ..., x^{ik}_{pbest})$. Moreover, the best particle position between global particles is presented by the x_{gbest} . The formulated equations of speed and position of each particle can be defined via the current speed and the distance from x^{ik}_{pbest} to x_{gbest} as shown in the following calculations:

$$\begin{aligned} v_{ik}^{(t+1)} &= \omega.v_{ik}^{(t)} + c_1.rand_1().(x^{ik}_{pbest} - x_{ik}^{(t)}) \\ &+ c_2.rand_2().(x_{gbest} - x_{ik}^{(t)}) \end{aligned} \tag{6}$$

$$x_{ik}^{(t+1)} = x_{ik}^{(t)} + v_{ik}^{(t+1)}, i = 1,2,...,n,\ k = 1,2,...m \tag{7}$$

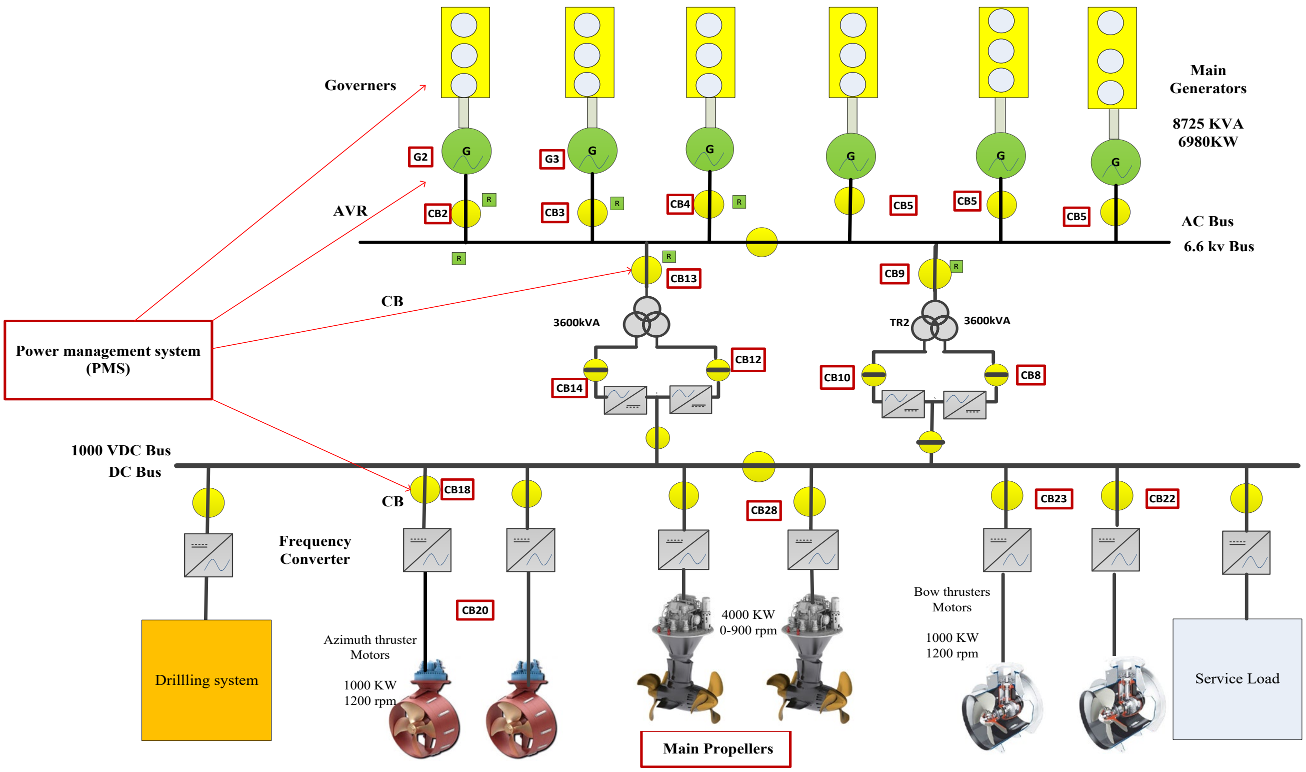

Fig. 2. Configuration of DP drilling vessel.

where

n	number of particles in a group
m	number of members in the article
t	pointer of iteration (generations)
w	inertia weight factor
$rand_{1,2}$	random number in the range [0 1]
c_1, c_2	acceleration constant;
$v_i^{(t)}$	the velocity of a particle at iteration
x_{pbest}^{ik}	the personal best position of particle i
$x_i^{(t)}$	the current position of the particle at iteration
x_{gbest}	the global best position of the swarm

In order to provide compensation among global and neighbor identifications, appropriate inertia weight w is proposed to find a satisfactory optimal solution. Generally, the inertia weight w can decrease linearly from 0.9 to 0.4 during the iteration and defined by the following equation:

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter \qquad (8)$$

where $iter_{\max}$ is the maximum number of generations and $w_{\max}$ and $w_{\min}$ are the maximum and the minimum number of inertia weight, respectively.

IV. SIMULATION RESULTS

The proposed optimization algorithm is tested in simulation on the case of study in [5] where a typical DP drill-ship should be drilling economically in a steady-state position. As mentioned, Table I shows a summary of DP drillship thrusters and technical propulsion specifications [18]. The drillship power plant is designed for 6 diesel generators of 7 MW of nominal active power that connected to two buses by AC to DC and DC to AC converter by two three-phase transformer with a nominal power of 3600 KVA and several feeders with circuit breakers which connected to azimuth thrusters, azipod propellers, drilling and service load. Fig 2, illustrates the configuration of power generation and distribution of a DP drillship. In this simulation, DGs have operated in the generators constraints and fuel cost functions coefficients, as shown in Table II, which, power outputs are generated randomly. Furthermore, It Should be considered that the simulation and PSO algorithms are written in MATLAB software and executed on an Intel i7-235G RAM.

TABLE II. GENERATING POWER PLANT CAPACITY AND COEFFICIENTS

Unit No.	P_i^{min}	P_i^{max}	α ($)	β ($/MW)	γ ($/MW^2)	P_i^0	URi (MW/h)	DRi (MW/h)
1	0	7	450	10	0.0135	3.5	2.9	2.1
2	0	7	430	12	0.013	3.5	2.9	2.1
3	0	7	460	12	0.0135	3.5	2.9	2.1
4	0	7	390	58	0.056	3.5	2.9	2.1
5	0	7	370	57	0.054	3.5	2.9	2.1
6	0	7	370	52	0.052	3.5	2.9	2.1

The power demand in different drilling operation under the normal and heavy DP maneuvering, are simulated by MATLAB software. For an overview of DP ship power plant simulation, the sequence of events during DP operation is presented by Fig 3 and implemented as:

- T1:10 minutes drilling Load disconnected and normal DP maneuvering.
- T2: 20 minutes drilling Load connected and Propulsion begins ramping up
- T3: 60 minutes drilling Load connected and normal DP maneuvering.
- T4: 40 minutes Propulsion and drilling begins ramping down
- T5: 50 minutes regular drilling and Bow Thrusters startup
- T6: 30 minutes Full power ahead (heavy drilling and DP maneuvering)

Correspond to the simulation result, during 30-40 seconds; full power load demand is raised ahead. Therefore the power load demand is exceeding from power generations, and it has required a suitable strategy for optimal unite commitment in the power generation during DP operation.

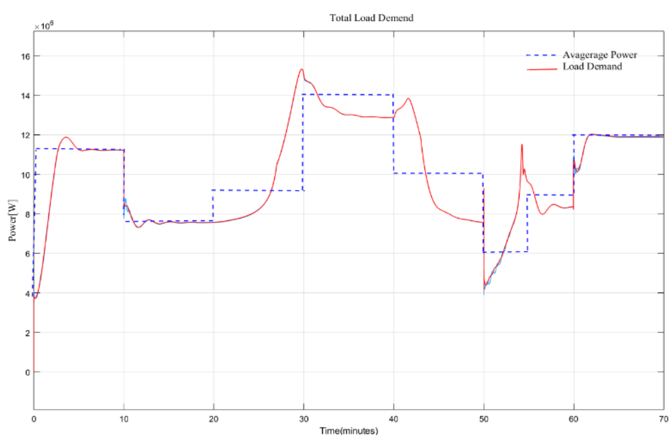

Fig. 3. Power load demand of the DP drilling vessel for several time intervals.

Due to many experiences of the PSO method, it is susceptible to adjusting individual weights or parameters. The following PSO parameters, which are used in this simulation [11].

- MaxIt=200; Maximum Number of Iterations
- nPop=100; Population Size (Swarm Size)
- w=1; Inertia Weight
- wdamp=0.99; Inertia Weight Damping Ratio
- c1=2; Personal Learning Coefficient
- c2=2; Global Learning Coefficient

Fig. 4 demonstrates the convergence trend of the evaluation values of the average power demand by using PSO method. It illustrates that the PSO has suitable convergence property, consequently resulting in good evaluation value and minimum generation cost function.

The optimal economic dispatch of generation units simulation results in different power plants generating during time intervals by considering the load demand is shown in Fig. 5. As experimental results from the MATLAB simulations, we can be observed on the bar chart that the proposed optimization method shares the power generation by considering DGs constraints to meet the economically dispatches. During the time intervals (T1, 2, 3, 4), the DGs optimum generations are approximate 1.4 MW, which are 12% of the total nominal value of power generation per each DGs. However, at time T5,6, the shipboard power plants are under the massive DP and drilling operation. Furthermore, economic dispatching of generations for DGs1,2, and 3 has adjusted near to 36% and 37%, and 27% respectively, while the total generation raised for the system's objective cost function. The information in Fig. 6 shows that the total operating cost function of the electric power plants for the different mentioned period in DP maneuvering and drilling operation at the time intervals (T1…T6).

According to experimental and computational time results, the minimum total cost function will belong to DG1,2and3 at times (T1,2,3,4) approximately 1250 $/MWh, and the maximum total cost at times (T5,6) due to the heavy operation are calculated 3100$/MWh, and 5400 $/MWh respectively, meanwhile the total cost for DGs 4,5,6 during operation has computed and remained nearby 5500$/MWh.

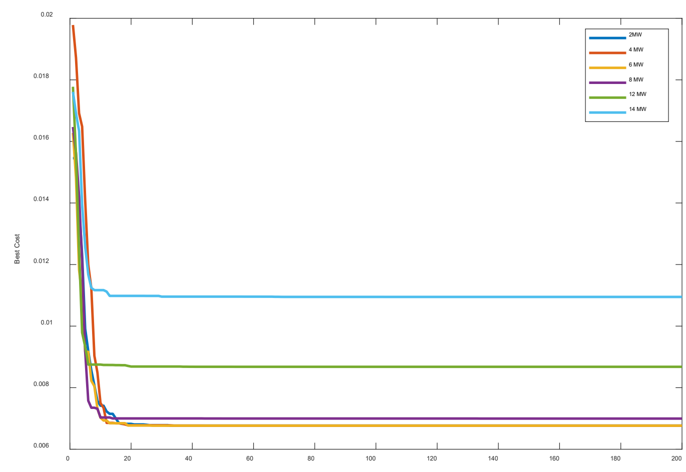

Fig. 4. Convergence property of average DGs cost using PSO method.

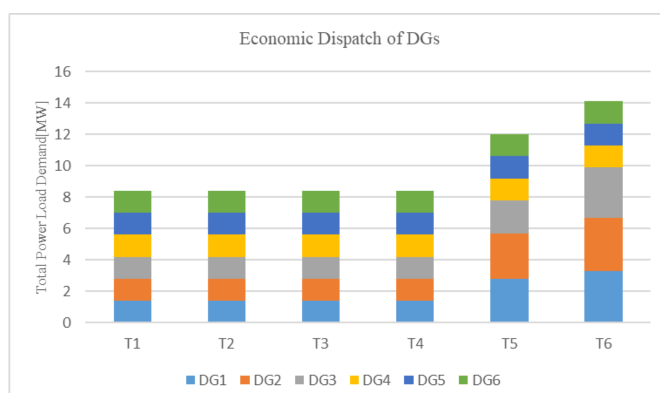

Fig. 5. Economic dispatch of DGs intervals (Ti) power generation.

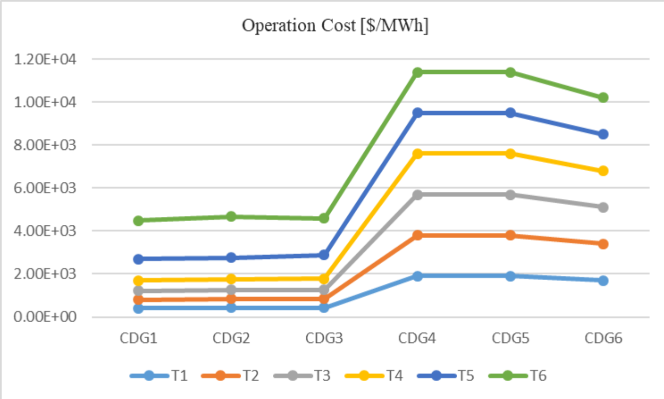

Fig. 6. Distribution of power DGs generated cost function.

V. CONCLUSION

In this study, an optimal strategy based on the PSO method to solve the economic dispatch problem of a DP drillship with considering generators constraints is successfully analyzed. The PSO algorithm has been shown to have an excellent performance during the DP and drilling operation by containing a superior solution, steady convergence properties, and quick computation efficiency. Due to the nonlinear characteristics of DGs, such as generators ramp rate limitations and non-smooth cost functions, the proposed method has a certain quality to achieve higher solution efficiency to optimize DGs cost function and better performance in operation planning problems.

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