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Research Article

Integration of PV in Shipboard Power Systems for Optimal Power Management

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Abstract

From the past few years, inaccessible offshore systems optimal electrification has become significant and got broad consideration from the marine industry. The complete electrification belonging to ship-board power systems called All- electric ships (AESs) is exposed to the introduction of electric propulsion has lead to the requirement for more cost-effective solutions. With the increase of demand in energy, present-day ships whether with the developing requirements for good energy conservations and protection of the environment have planned to seek after AES (All-Electric Ship) designs. AES is imagined to turn into a fascinating innovation with extraordinary potential for both emission and fuel reductions when it is contrasted with conventional ship power systems. But, such onboard systems are inclined to abrupt load variations because of a fluctuating mission profile due to climatic conditions, in this way they have a need for efficient PMSs (Power Management Systems) for working optimally. Here taking into account this paper, facilitated the optimal power management at the end of the supply of a given All-Electric Ship is examined. This paper put forward a Differential Evolution Algorithm, for Shipboard Power Management. To exhibit the effectiveness of the exhibited Power Management Systems (PMS), the outcomes are compared with the Classical methodology.

***Keywords*:** All-Electric-Ship; constrained optimization; coordinated energy management; Power management system**.**

I. INTRODUCTION

This A shipboard electrical system is small in size and has fewer parts than a run of the commercial business power system. A classic soldier ship may have 3 or 4 generators with an aggregate limit of (80-100) MW. Most extreme of this limit is used by drive engines, for which a two-shaft boat will be evaluated with the scope of (35-40) MW each. These loads are enormous concerning the complete producing limit has made the investigation of onboard transport power systems riskier than commercial power systems. The greater part of the rearranging suppositions made in the investigation of the commercial power systems is invalid with that of present-day ship power systems. This inconvenience requires a precise model of whole systems including the applicable elements of every part.

A reliable supply of electrical power is extremely basic nowadays. With the expanding requirement for improved energy conservation, the activity to seek after an AES (all- electric ship) arrangement has developed [1]. All-Electric Ships (AES) significant challenge is to structure

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and integrate
PMS (Power Management System) intended for the optimal scheduling concerning installed onboard ship power plants [2]. Power Management Systems can be built on basis of economic dispatch and unit commitment traditional economic load dispatch deals with minimizing power generation cost while satisfying set of equality and inequality constraints. On the other hand, some toxic gasses are emitted polluting environment because of the operation of fossil fuel plants. Thus conventional minimum operation cost cannot be made on the mere basis for generation dispatch, emission minimization to protect environment must also be taken care of.

Many algorithms were proposed to solve power management problem in shipboard power system. Classical methods to solve the proposed problem are lambda iteration method, Merit order loading, gradient methods for optimal dispatch and priority list method, dynamic programming methods for optimal combination of units. Apart from these classical methods we have different optimization techniques for the economic operation of generators, which have fast convergence and capability of finding global minimal regardless of the initial parameter values. The optimal power management in an All-Electric Ship concerning various objectives, related technical and ecological limitations can be figured as a mixed-integer nonlinear programming model [3]-[7]. Here in this paper, optimal management issues can be explained by a heuristic methodology utilizing differential evolution.

The DE algorithm is propelled by sociological and natural inspirations and can deal with optimality on intermittent, harsh, and multi-modular surfaces. Differential Evolution is one of the straightforward yet ground-breaking population- based stochastic optimizers for managing an assortment of optimization issues including multi-modular, obliged, nonlinear, non-differentiable, and multi-objective. DE for the most part has three favorable circumstances, finding the genuine worldwide least regardless of the initial parameter values, fast convergence, and utilizing a couple of control limitations.

Renewable energy sources, like photovoltaic energy systems have been increasingly incorporated into shipboard power systems also the applications of renewable energy sources has become a global trend. The photovoltaic energy systems on shipboard power systems are to be installed for producing electricity and can be used for supplementing the generators of diesels and reducing the power required as of these units installed. The proposed PMS performance is analyzed on the basis of RO-PAX ferry by means of incorporated complete electric propulsion and practical constraints. These results are to be compared with the TNE outcomes obtained by the classical method.

The rest of the paper is structured as follows: Section II particularizes on the features of Shipboard power system and Power management along with the technical and

$$To\ Ce = \sum_{j=1} \sum_{i=1} (Stij\ (SFC(Pij)) + MCi)\ .\ Pij.\ \Delta Tij + SCij|Stij - Sti.j-1\ |) \qquad (2)$$

environmental constraints, Solution of power management problem in shipboard systems with classical method in Section III, Section IV extends to obtain solution of power management problem with differential evolution optimization method, In Section V, optimal power management problem in shipboard systems including solar PV generation system to meet load along with diesel generating units is discussed , Appendix, Analysis of the results obtained from projected PMS applied in the direction of AES are presented in Section
Finally Section VII gives the conclusion of the paper.

II. Ship Board Power Systems and Power Management

A completely electrified shipboard power system is thought of, where generated electric force supplies mostly electric drive engines and boat service loads. The propulsion of Ship is given with enormous electric engines driven by means of power electronic converters which empower ceaseless variable speed of shaft activity in a broad speed range, operational adaptability along with efficiency. Likewise, the main requirement for enormous shafts for prime movers and propellers coupling as well as the utilization of gearboxes “Where T is the total time period under study, SFC_i is the specific fuel consumption, St_{ij} is 1 if the operating unit is i, otherwise it is 0 and N_E is given as the total number of electric generators.”

$$SFC_i(P_i) = FC_i(P_i)/P_i \qquad (3)$$

“The key objective of the problem is minimizing the total cost of operation of AES. This minimization of cost ought to be done subjected to various constraints.”[12] Constraints which are technically considered in this cost function minimization while solving power management problem are

(1) Generator loading limits

$$P_{i.min} < P_{ij} < P_{i.max} \qquad (4)$$

Where, P_i, min, P_i, max are minimum and maximum power generating limits of i^{th} generator (MW)

(2) Power-balance-constraint

Ng

which are mechanical has been removed [8].Customary ships just as AES must utilize an all-around

$$\sum St_{ij}.P_{ij} = L_j + \Delta P_{prop.j} i=1 \qquad (5)$$

planned Ship Energy Efficiency Management Plan (SEEMP) [9]. In future, significant focuses belong to SEEMP would be activity minimization of cost and emission of gas restriction. Up to now SEEMPs have concentrated on CO2. Nonetheless, the detailing of the issue can be effortlessly summed up and different pollutants past CO2 can be remembered for what's to come. The objectives of activity cost minimization and GHG discharge restriction may struggle with one another, building the optimal management of power in AES is a demanding issue. Here in specific circumstance, if the propulsion power be properly in a balanced manner to meet up

AES operation constraints, which can incredibly add toward the confinement of GHG emissions progressively.

In the considered shipboard power system there are five generator units headed for meeting the propulsion and ship service loads [10]. The formulation of onboard thermal units i and j subscripts denotes the i-th 'generator' and the j-th 'time interval', respectively.

(3) Minimum up/down time constraint

$t_{OFF,i} - t_{ON,i} \geq T_{ON\ min,i}$ ---Up Time (6)

$t_{ON,i} - t_{OFF,i} \geq T_{OFF\ min,i}$ ---Down Time (7)

$t_{OFF,i}, t_{ON,i}$ are termed as the points of time which i-th generator stop or start operating. $T_{ON\ min,i}, T_{OFF\ min,i}$ are given as the allowable minimum time for i-th generator's non-operation time.

(4) Prevention of Blackout constraint

Fuel consumption (FC) can be estimated precisely by a second order polynomial of the delivered power Pi as follows

$$FC_i(P_i) = c + b.P_i + a.P^2 \qquad (1)$$

$$\sum_i S_{ij}.P_{i,m} - L_j - \Delta P_{prop,j} \geq m\{P_{i,max}\}$$

max$\{P_{i,max}\}$: maximum power of the committed units (8)

P_i is the power generated, i is i[th] generator

Problem formulation

A. Objective function:

Total variable cost of the power plant (ToCe) be determined by means of considering the fuel cost (FCi), the maintenance cost per unit power (MCi) and also the start- up / shut-down cost (SCij) of the i-th generator, creating active power P_{ij} during a time interval ΔT_j [11].

(5) Generator's ramp-rate constraint

$$\frac{|P_{ij} - P_{i,j-1}|}{\Delta T_j} \leq Rc_{i,max} \qquad (9)$$

Where $Rc_{i,max}$ is change of power at the maximum rate developed by means of i-th generator.

Apart from the technical constraints considered in the cost function minimization while solving power management problem emission constraint is also considered in order of reducing emissions.

(6) Emission constraint

In order to reduce CO_2 emissions, n'p: the number of passengers,

n'v: the quantity of conveyed vehicles, and

The term FLD is the Full load displacement of ship in (tns).

$$\frac{\sum_{i=1}^{Ng} c_i . St_{ij} . SFC(P_{ij})}{LF . V_j} \leq EEOI_{max,sea}$$

$$\frac{\sum_{i=1}^{Ng} c_i . St_{ij} SFC(P_{ij})}{LF} \leq EEOI_{max,port}$$

III. SHIPBOARD POWER MANAGEMENT USING CLASSICAL METHOD

The Power management issue in Shipboard power systems can be explained by utilizing Classical methods. In this paper, the Unit commitment issue is illuminated by the Priority list Method by thinking about specialized technical limitations. Unit-Commitment is a mathematical optimized issue accustomed to decide the different schedule of operation of

Where c_i: the factor of conversion for emissions of gas estimation for i-th generator (gCO_2/gFuel), P_{ij} is the produced Power by i-th thermal-unit in j-th time-interval (MW), SFC_i : Specific-fuel-consumption of the i-th generator (gFuel/kWh), V_j is speed of the ship in the j-th time interval (kn), LF is Ship loading factor (tns).

$EEOI_{max, sea}$: upper limit of EEOI (when ship is on the sea) and $EEOI_{max, port}$: upper limit of EEOI (when ship is at the port).

B. EEOI

EEOI is characterized as follows,

those units that are generating at each time interval by varying loads producing the cost of minimum operation under various requirements and conditions.

The preference of every unit for committing or de- committing before the schedule of unit has been resolved based on the characteristics of the unit. Priority list of the units are readied dependent on the cost of fuel acquired from average cost of the fuel of every generator unit working at the most extreme yield power of it. The average production-cost of full load of each unit is characterized by the cost for every unit power (Rs/MW), when each unit is working at full limit of it. The cost of fuel of each unit be communicated as

$$EEOI = \frac{mC0_2}{\;}$$

(12) f

ai

$+ b + c.$

(16)

Transport work

"The mass-created by CO_2 is termed as m_{co2}during the ship

i($pmax$)

FCi = i =

$pmax$

i

P^{max} i

i i

$pmax$ i

power system operation. EEOI is termed as the proportion of mass radiated by CO_2 and work done by transport. Indirectly it gives the efficiency of operational ship, as indicated by the definition of efficiency i.e; the consumed energy that is required for delivering the vehicle relative work ought to be utilized. The mass of CO_2 is to a degree corresponding to that expended fuel (energy). Thus, operational efficiency of the ship and emissions of CO_2 both are given within EEOI in a decent way". $EEOI_S$ and $EEOI_P$ i.e; when the ship sailing on open sea or else ship at the port are given as follows

The units have been positioned by its FCi in the order of ascending. Along these lines, priority-list of all the units would be figured dependent on the order of the FCi, by which each unit with the most minimal FCi will be having the most priority to share the load to be dispatched.

Optimal scheduling of the load among the generators is comprehended by the lambda iteration strategy. The motivation behind financial dispatch is to decide the optimal power generation of the units partaking in providing the load. The total of the absolute power generation ought to be equivalent to the load demand at that specific time. The

$EEOI =$

$mCO_2 =$

$\sum_i c_i . P_{ij} . SFC_i(P_{ij})$

(13)

economic dispatch issues is an obliged advancement issue and it very well may be numerically communicated i.e., total

$s.j \quad LF.V_j.\Delta T_j$

LF is loading factor

mCO_2

$LF.V_j$

$\sum c.P.SFC(P)$

(14)

production cost.

$$= \sum_{i=1}^{n} c_i + b_i.P_i + a_i.P^2$$

(17)

$EEOI = \_\_\_\_\_\_ =$

$p.j \quad LF.\Delta T_j$

i i ij i ij

LF

i=1

is minimum, subject to constraint

Loading factor of the Ship LF relies upon a sort of the analyzed ship, e.g., traveller RO-PAX ship, and so forth. Here, LF is given to a RO-PAX ship and it's determined as

$$\sum_{i=1}^{ng} P_i = PD \quad (18)$$

Where

$L.F =$

$$\frac{n'_P \cdot 0.1 + n'_V}{n'_P \cdot 0.1 + n'_v} \quad (15)$$

A typical methodology is to expand the constraints into objective function by utilizing the Lagrange multipliers np: the greatest number of the travellers,

nv: the number of maximum vehicles conveyed,

$$L_i = Ct + (PD - \sum_{i=1}^{ng} P_i)$$

(19)

IV. SHIPBOARD POWER MANAGEMENT USING DIFFERENTIAL EVOLUTION

The solution for power management in Shipboard power

$$\frac{\partial L}{\partial P_i} = 0 \qquad (20)$$

where the constrained function is minimum.

From the above equation the condition for optimum dispatch can be obtained as

systems aims to optimize a selected objective function with subject to different technical and environmental constraints. Mathematically, the power management problem can be formulated as mentioned in Section II.

A. Differential Evolution

$$\frac{\partial C_i}{\partial P_i} = \lambda$$

i=1,2,………,ng, which results in

(21)

By and large, the greater part of the classical methods for optimization applies the analysis of sensitivity and also the algorithms which are gradient-based with the linearized objective function as well as the limitations of system around

P_i can be calculated as

$$b_i + 2a_iP_i = \lambda \qquad (22)$$

a working point. Tragically, Optimal Power management issue is nonlinear and is detailed as a mixed-integer nonlinear optimization issue. Henceforth, classical optimization

$P =$

$\lambda - b\mathrm{i}$ (23)

methods are not reasonable for such an issue. In addition, it's absolutely impossible for choosing whether the local i 2ai

After obtaining the optimal schedule of powers we check for power balance constraint, generator loading limits of units which are operating in that time interval and generator ramp up/down rates for calculating total cost.

A. Methodology

The procedure for implementing Shipboard Power Management using classical method is given below

Step 1: Specify the minimum and maximum generator loading limits of each unit. Specify the fuel cost of each unit, load even.

Step 2: Determine the average production full load cost of each-unit and arrange them in the order of ascending (as in the Priority list order).

Step 3: Obtain optimal combination of units for the load in that particular time interval. Optimal combination of units (unit status) is obtained by following priority list scheme.

Step 4: Check if any violations in blackout prevention constraint, minimum up/down time constraint for the optimal unit status generated.

Step 5: If there are any violations repair the system until the constraints are satisfied and obtain a set of optimal combination.

Step 6: Specify the load requirement in each time interval.

Step 7: Distribute the Powers to be generated in order to meet the load in that time interval, among the operating units at that time (which we know from the unit status obtained).

Step 8: Optimal combination of power output (economic dispatch) of all generating units which are operating in that time interval is obtained by using Lambda Iteration Method.

Step 9: Check for the technical and environmental constraints and repair if any violations.

Step 10: Calculate total cost from the objective function which includes fuel cost, startup/shut-down cost and maintenance cost.
optimum is also a global optimum. Along these lines, conventional optimization techniques that utilize derivatives and slopes will be unable to recognize the global optimum [13].

Also, here are just a couple of control parameters which are worn to refresh the DE population, in this way it's simple to execute and tuning of a parameter. The three primary evolutionary operators such as mutation, crossover, and the selection operator, normally applied in the DE for refreshing the population. The two initial operators (mutation and the cross-over operator) have been utilized for producing the preliminary vectors, whereas the other operator (the selection-operator) decides the enhanced one among the objective vector and also its preliminary vector for cutting edge dependent upon its wellness esteems. The standard algorithm of DE and a large portion of improved variations been worked upon its genuine qualities.

B. Methodology

The procedure for implementing Shipboard Power Management by using Differential Evolution is given below

Step 1: Specify the minimum and maximum generator loading limits of each unit.

Step 2: Obtain the Unit status randomly. Units are randomly committed by considering a variable h, whose value is assigned by rand () function. Range of the rand () function will be (0, 1). If the value assigned for h is more than 0.5 then we consider the unit to be 1(ON). If the value assigned for h is less than 0.5 then we consider the unit to be 0(OFF).

Step 3: Check for the Blackout prevention constraint and minimum up/down time constraint by following the repair algorithms.

Step 4: Unit status is updated if any constraints are violated by using repair strategies employed respectively.

Step 5: For this updated unit status, obtain the optimal schedule of power outputs (economic dispatch) in order to get optimum cost.

Step 6: Check for the power-balance constraint, generator power limits and ramp rate limits of generating units.

Step 7: If there are any violations in the constraints go to repair strategy to satisfy them.

Step 8: Calculate total cost and fitness from the objective function which includes fuel cost, startup/shut-down cost and maintenance cost.

Step 9: Create a new population by using differential evolution and calculate cost which satisfies all the technical and environmental constraints.

Step 10: By following the DE cycle of mutation, cross-over and selection obtain the best set of schedule.

Step 11: Obtain the optimal cost by using this optimal schedule of power outputs from DE (as the control variable is power).

Step 12: Check whether all the constraints are satisfied and thus obtained cost is the best cost.

V. SHIPBOARD POWER MANAGEMENT WITH PV USING DE

Apart from solving Power management problem in Ship power system and obtaining the Optimum cost by using the proposed Differential evolution algorithm, we are incorporating PV to reduce the use of fossil fuels and to reduce emissions. As the present day world is moving on to renewables for generation of electricity, we have considered solar as one of the reliable source of energy. A PV system is a power system designed for supplying solar power which is utilizable by methods of photovoltaic. Designing reliable and effective PV systems requires understanding both the art and science of photovoltaics and applying the strategies, skills and techniques necessary to meet specific goals and objectives. [14]

Here we are installing three PV generating units of 100KW capacity each [15]. We consider the actual generation capacity from PV with efficiency of 18.75percent i.e,(0.0563MW) and perform the optimal power scheduling with DE to solve power management problem .

A. Methodology

The procedure for implementing Shipboard Power Management with PV using Differential Evolution is given below

Step 1: The power generation from PV (solar) is considered to be some value.

Step 2: At each time interval load can be considered as the difference of the total load and the power generated from solar in that particular time horizon.

Step 3: Specify thus obtained load for the Optimal combination of units and Optimal schedule of power generation among the operating units

Step 4: Check for any violations in technical and environmental constraints and repair them.

Step 5: Rest of the procedure for obtaining optimal combination and optimal schedule which results in optimum cost and fitness follows the steps as in DE

B. Appendix

The ship technical parameters as well as the on-board power systems are introduced here. Ship parameters rely upon the kind of ship. Here we have considered RO-PAX ship containing two huge electric drive engines provided by a set of total 5 electrical generators.

Table-I: Cost coefficients of generating units

Generator number	A	B	C
1	5.40	61.5	390
2	5.40	63	400
3	5.60	65	420
4	13.1	12	430
5	13.5	10	450

Table-II: Ship parameters

PARAMETER	SPECIFICATION
TYPE	RO-PAX ferry
Nominal speed (kn)	24
Maximum no of passengers	2500
Number of the vehicles (nv)	700
Displacement of Full-load (tns)	70,000
EEOImaxs (gCO2/tn.kn)	27.5
EEOImaxp (gCO2	165

/tn.kn)	

Table-III: Pay load data of the ship

Portion of the inspected Route	No. of Passengers, n_{P1}	No. of vehicles, n_{V1}	Loading Factor of Ship, [LF] (tns)
Departure -Intermediate port	1955	600	58,616
Final destination- Intermediate port	1720	500	49515

Table-IV: Parameters of units

PARAMETERS OF UNITS	GENERATOR				
	1	2	3	4	5
Minimal UP time (Hours)	1	1	1	1	1
Minimal DOWN time (Hours)	1	1	1	1	1
Start- Up / Shut- Down cost (m.u.)	0	0	0	0	0
Emissions of CO_2 (gCO_2/g fuel)	3.2	3.2	3.2	2.5	2.5
Ramp up rate	8	8	2	1	1
Ramp down rate	7	7	2	1	0

6	37	22.5
7	34	22
8	32	20.5
9	29	19.8
10	6	0
11	22	17.5
12	28	18.5.
13	29	19.8
14	30	20.2
15	30	20
16	29	20.2
17	27.5	18
18	21.5	17
19	6	0

Table-V: Power Generation limits of units

TECHNICAL - PARAMETERS	GENERATOR				
	1	2	3	4	5
Maximum power (MW)	15.0	15.0	15.0	9.0	9.0
Minimum power (MW)	3.0	3.0	3.0	2.0	2.0
Nominal power (MW)	15.0	15.0	15.0	9.0	9.0

Power systems of ship are inclined to load variations which

Table-VII: Data for Installation of the PV (100 KW capacity)

Capacity of Power Plant	100KW
Generation per year	2,70,000
Cost of Electricity per unit	Rs.1.8
Investment Cost per MW	68 Lakhs
Operation and Maintenance cost per year	60,000
Payback period	25 years

VI. Analysis of Results

The proposed optimization method is applied on RO-PAX ferry with five generators supplying two electric propulsion motors. The power management problem in ships is solved by using Classical method and Differential evolution method.

occurred suddenly because of the change in climate conditions just like the profile of the mission. Shipload (MW) during all the time intervals and Ship speed during the whole route made a trip as indicated by the time interval during the total travelled route is in Table-6.

Table-VI: Ship Load data and speed

Time interval	Load (MW)	Speed (kn)
1	19.9	17
2	27	19
3	33	20.5
4	35	21.2
5	36	21

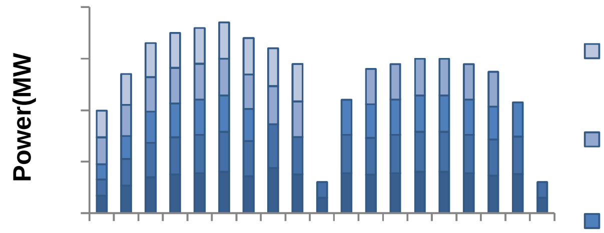
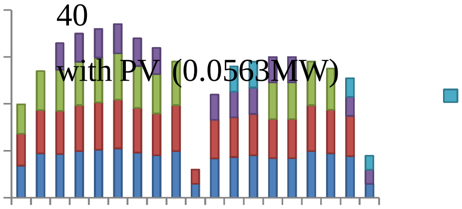


Fig. 1 Power generation schedule by classical method



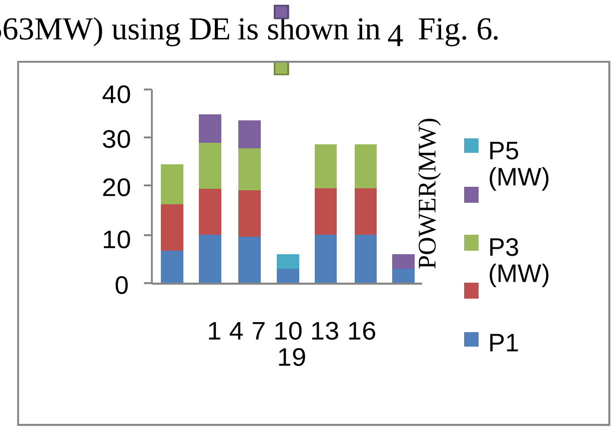
7.1 Analysis of Results with PV

Optimal power generation scheduling

15 17 19

5 using DE is shown in Fig. 5 and Convergence characteristics P of cost function with PV (0.0563MW) using DE is shown in 4 Fig. 6.

P 3



Time (hours)

Fig. 2 Power generation schedule by DE method

Optimal Power Schedule among the operating units in that time interval according to the unit status obtained by classical method is presented in Fig.1 and by DE method in Fig.2

Convergence characteristics of the cost function by DE is shown in Fig.3

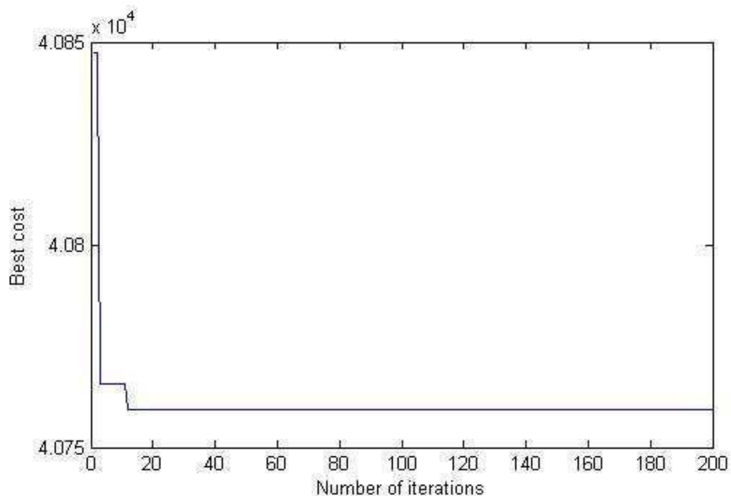


Fig.3 Convergence of cost function using DE

In the above Fig. we can see the convergence of cost which is drastically changing from the start to end and became steady after certain iterations which we take as a fixed cost value by using DE.

Operation cost during all time intervals obtained by Classical and DE are presented in Fig. 4

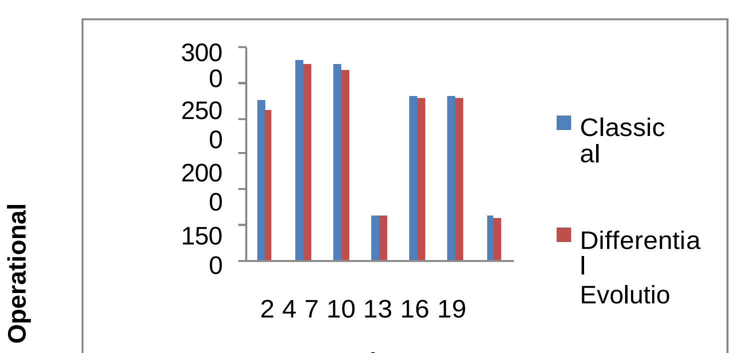


Fig. 4 Operating cost by both Classical and DE method

Fig. 5 Power generation schedule with PV (0.0563MW) using DE

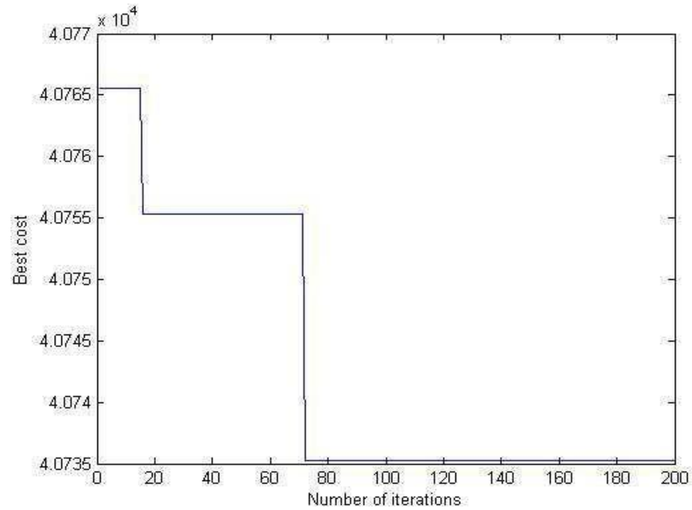


Fig.6 Convergence of cost function with PV (0.0563MW) using DE

In the above convergence graph we can clearly see the optimized cost function of shipboard power system with PV using DE.

VII.CONCLUSIONS

From the results it can be concluded that Power management problem in ship power systems comprises of UCP and optimal scheduling. Unit commitment problem and optimal power scheduling (economic dispatch) problem are solved by utilizing Differential evolution method and Classical method. Operating cost is calculated by satisfying all the technical constraints. The total obtained operation cost by classical method is 41,770.4986, whereas the obtained total operation cost by differential evolution optimization method is 40,759.4049. Thus we can observe the optimum cost obtained by DE method is smaller when compared with classical method by 2.42%. The load sharing of generating units is analyzed and presented under Case study and discussion section. Operation cost with respect to time horizon is calculated and is presented in section VI. Emission constraint is also been satisfied. In order to obtain optimal power management, power is generated by incorporating PV system. The results are been analyzed by considering the PV generation of 0.0563MW. The total operation cost has been

reduced by 0.061% in case of 0.0563MW PV generation using DE and the cost is 40,735.2914 in comparison with DE method. By this analysis we can conclude integration of PV generation system in ship power system is advantageous and reduces the emissions apart from cost optimization.

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