6TH INTERNATIONAL CONFERENCE ON ELECTROMECHANICAL AND POWER SYSTEMS
October 4-6, 2007 - Chişinău, Rep.Moldova

OPTIMIZATION OF LOAD DEPENDENT IN NAVAL POWER SYSTEM

Vasile DOBREF, Octavian TĂRĂBUŢĂ

"Mircea cel Bătrân" Naval Academy Constantza, Romania,
dobref_vasile@yahoo.com

Abstract **– This paper describes optimization of operational procedures embedded in the power management system with regards to an overall ship´s safety and optimization of fuel consumption. Proposed method reflects issues important in the marine power system design; the problem is formulated for the influence of generating sets inertia on overall blackout risk when using fast load reduction technology.**

The proposed method can be applied to any vessel that requires more generating sets installed and special consideration of related safety issues in operations. With a properly addressed risk, the vessel can operate with closed bus-tie and have a maximum flexibility in operations in order to achieve the maximum fuel savings.

Keywords: *ship power management, fuel consumption, blackout prevention*

1. INTRODUCTION

Various methods to improve operability and safety of marine vessels have been developed and applied in recent years, [1] to [10].

The traditional power management system (PMS) monitors the total power demand and compares it to the available supply. The system can automatically start and stop generator sets to coincide with the load changes in accordance with the pre-set load dependent start-stop tables; an overview of marine power management has been given in [3] to [8]. In case of one generator set sudden failure, the power system loading will be transferred to the remaining generators online. According to the class rules, transient frequency after step load for marine power system is limited to. Hence, the online generators must be unloaded before reaching the under frequency limit.

Traditional PMS functions, such as load shedding can disconnect non-essential consumers and unload the network, but in some cases with limited success. The goal in this paper is to propose the optimization of the load dependent start table in order to minimize the fuel consumption and to increase the resistance to blackout by efficient use of fast load reduction technology. With optimized load dependent start tables it is possible to have lower fuel consumption while running the engines with safe operating margin in the event of single point failures. Dynamically positioned (DP) operated anchor handling tug support vessel (AHTS) vessel is used as a case study [12].

2. SAFETY AND BLACK-OUT PREVENTION

The traditional PMS automatically starts and stops generator sets to coincide with the load changes in accordance with the pre-set load dependent start-stop tables. The load dependent start table usually is defined to allow the generator sets to carry a maximum of 110% load in a failure situation. With two engines running, at or above 55% load for longer than some prescribed time, for instance 10 seconds, a third generator set will automatically start and synchronize to the network.

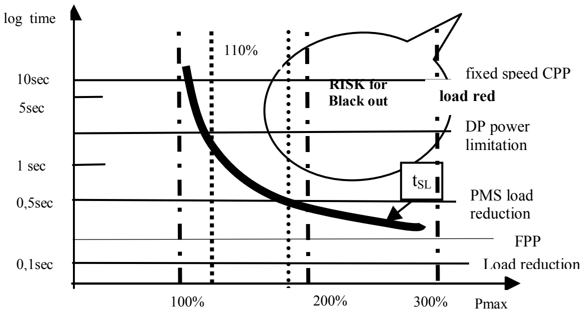


Figure. 1. Regulation time responses for power reduction, with response time of fast load reduction.

Figure 1 shows the Diesel engines capability to maintain the frequency for the load step overload associated with the loss of a parallel running engine [1]. In typical installations, it has been seen that the actions of load reduction and blackout prevention must be effective within less than 500ms in order not to compromise the power system stability and limit the flexibility of operation. For the blackout prevention functionality some common conclusions can be made on what is typically required [1]:

a)Thruster and thruster drives: Variable speed FPP thrusters can have a load reduction scheme, either monitoring the network frequency and/or receiving a fast load reduction signal from the PMS. Fixed speed

CPP thrusters do not have fast enough response time for blackout prevention. Therefore fixed speed CPP thrusters must be included in the PMS load shedding scheme;

b)PMS: By class requirements, the PMS must include blackout prevention with load reduction/load shedding functionality. It was observed earlier, that the response time in this system was too long to obtain the desired level of fault-tolerance without a fast acting, stand-alone load reduction scheme in the thruster drives. With the knowledge of today, this has been claimed solved by use of fast acting, and possibly event-trigged load reduction algorithms;

c) DP system: The DP system is also equipped with a power limitation function, normally based on a permitted maximum power consumption signal from the PMS. Generally, this has shown to be effective in avoiding overloading of the running plant, but not fast enough to handle faults and loss of generator sets. Of importance is also the power limitation in manual and joystick control of the thrusters.

In case of one gen-set sudden failure, the power system loading must be transferred to the remaining generators online. If two equally rated generators are online, each loaded on 80% of rated power, the failure of one generator will result in load increase to 160 % on the remaining one. 110 % is a typical Diesel engine limitation. Hence, the frequency will start to drop on the remaining generator. Activating the under frequency limit at –10% of the generator normal speed will initiate opening of circuit breaker and remaining generator will be disconnected. That will have a blackout as a consequence. In order to avoid a blackout, the fast load reduction must act faster than frequency drop. The time before under frequency limit can be determined from the swing equation [11]:

$$\dot{\omega} = \frac{1}{2\ I} T_a \qquad (1)$$

where ω is generator shaft speed, I is inertial time constant and T_a is the accelerating torque. For Diesel generators, the inertial time constant I is typically between 1.5 and 2 seconds [13,14]. Solving eq. (1), the time before under frequency is reached or safe time limit can be determined with the following equation:

$$t_{SL} = \Delta\omega \, . \, \frac{2 \cdot I}{p_{\max} - 100\%} \qquad (2)$$

3.Optimization problem formulation. Case study.

Assuming j equal rated units are connected online, the optimization problem is to find the received load PL(j) in the moment of starting the next unit j+1 in order to achieve the minimum difference in total instantaneous fuel consumption with j and j+1 units, according to following formulation:

$$\min\left(\sum_{i=1}^{j} ICFi\left(\frac{P_L(j)}{j}\right) - \sum_{i-1}^{j+1} ICFi\left(\frac{Pc(j)}{j+1}\right)\right) \geq 0 \qquad (3)$$

where $ICF_i(P_L(j)/j)$ is the instantaneous fuel consumption on each unit i when heaving j equal rated units online, usually indicated in tons per hour. $P_L(j)$ is the received load with **j** units online and has the same value for j+1 units online. A case study vessel with diesel electric propulsion, tug ship, as fig.2 show, will be used to explain the proposed method [12,13]. In this case :

- basic configuration is similar to any offshore supply vessel;
-the bollard pull (BP) is approx.10^5daN;
-total installed load of all consumers is approx 7800 kW;
-installed generating capacity is equal to the total installed load of all consumers and losses;
-the prime movers are medium speed diesel engines,
- the number of the gen-sets is four;
- all the gen-sets are-equally rated ;
- for equally rated units of the same BSFC curve, equal load sharing has been used.

Figure 2 represents typical operational profile of an anchor handling tug support vessel.

A typical offshore supply vessel is most of the time in DP low or high operating mode. The vessel spends just 1% time per year in the BP (bollard pull) mode which is the operating mode with the highest loading.

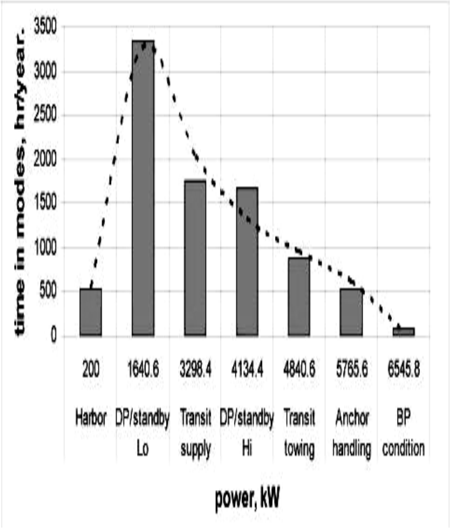
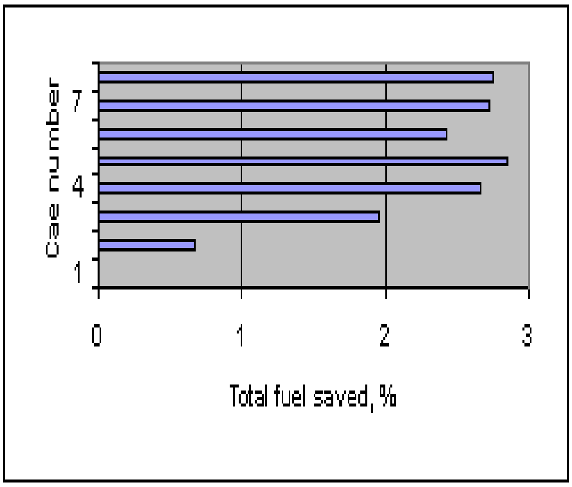


Fig. 2 Typical operational profile of the anchor handling tug support vessel

Table and diagram of results for eight cases with different load depending start tables are presented in fig. 3.



Case no.:	1	2	3	4	5	6	7	8
Gen. online	Gen.set loading in the moment of starting the next unit, $P_{start,i}(j)$,%							
2	55	60	70	80	89	90	90	100
3	68	70	80	85	85	100	90	100
	Total fuel savings (per year, %)							
	0	.67	1.9	2.6	2.8	2.4	2.72	2.75

Fig. 3. Table and diagram of results

Notice that the highest fuel consumption per year is for the case no. 1 which corresponds to the safest case since sudden fail of one generator can not cause more than 110% loading on others, see fig. 1. The minimum time for fast load reduction system to reduce the load on consumers i.e. thrusters is claimed to be 500 milliseconds. Various fast load reduction systems can vary in speed.

Case number 5, shown of fig. 3, corresponds to the unconstrained optimum, when eq. (3) is set equal to zero. However, cases no. 1 to 4 are allowable. Cases no 5 to 8 are not allowable since they are above the safe operational limit set to 80 %. Case 4 can be selected as an optimum with an active blackout constraint $P_{start}(j=2)=80\%$ for both generating sets.

It is important to notice that the optimization method gives an insight into the costs of the increased safety which means that increasing the blackout resistance can affect the fuel consumption on different ways. For instance, perturbation of the $P_{start,i}(j)$ around selected optimum (for the case 4) will give different cases: +9% for j=2 (case 5) the fuel savings can be increased, but just for 0.19% and would shift the system to unsafe region, , $t_{SL} = 0.46$ sec.

- –10% (case 3) will decrease the fuel savings but just for a 0.69 % and increase the safety of the system, $t_{SL} = 0.9$ sec. The value of t_{SL} is two times higher than for the case 5. An interesting feature would be to change the safety limit according to the operational risk, and hence to switch between cases 1 to 4. Installed generating capacity does not need to be equal to the total installed load of all consumers, see assumption 2 at the beginning of the section. The results of optimization study have been shown in the fig. 4. The cases correspond to the first five cases represented in the load dependent start table on fig. 3. The risk limit may not be changed since the flywheel inertia of the gen-set can be selected to keep approximately the same values of the inertial time constant I for different power ratings, as done in ref. [14]. 6550 kW is a maximal loading according to the vessel's operational profile for BP mode whereas the 7800 kW covers all consumers that operate on 100 %. Results show that installing 6550 kW to cover only expected consumption in the bollard pull mode of operation could save from 0.5 to 1 % of fuel per year. Reduced installed power will impose higher risk for vessel to perform high load operations on very bad weather conditions. Hence, obtained low fuel savings might not be justified with regards to operability and safety.

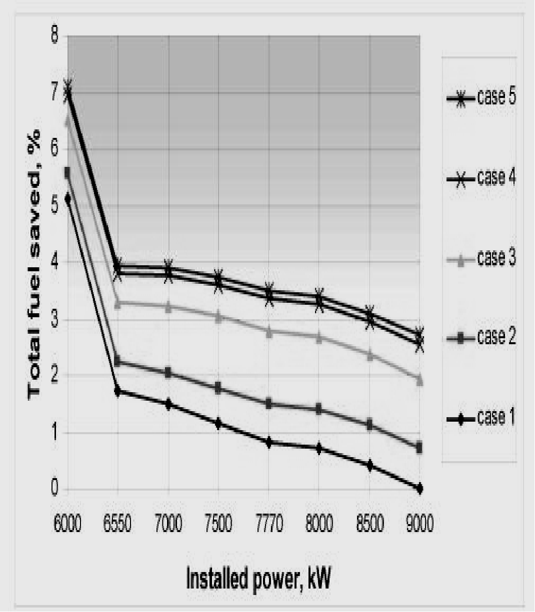


Fig.4.Optimization with different installed generating power

4. CONCLUSIONS

This paper has presented an optimization of load dependent start tables to minimize the overall fuel consumption and to improve the operability and blackout prevention of DP vessels. The method describes efficient use of fast load reduction system and outlines possibilities to use energy storage devices which can control the inertia of the power system.

With operational risk properly addressed, several issues embedded in the power management system and power system design can be optimized and decisions can be based on clear defined criteria. One of the possibilities that might be achieved is that the vessel can operate with closed bus-tie to obtain the maximum savings in fuel consumption. Safe operation with closed bus-tie can give more flexibility to different possible configurations in power system design regarding fault–tolerance and reconfiguration.

The optimization method has been tested in simulation for an AHTS vessel and can be applied to any vessel that requires several generating units installed and special consideration of safety issues in operations.

References

[1] Sørensen, A. J., Ådnanes, A.K., Reconfigurable Marine Control Systems and Electrical Propulsion Systems for Ships. ASNE Reconfiguration and Survivability Symposium, February 16-18 (RS 2005), Florida, US

[2] Sørensen, A. J., Quek, S.T., Nguyen, T. D., Improved Operability and Safety of DP Vessels Using Hybrid Control Concept, International Conference on Technology & Operation of Offshore Support Vessels-OSV, 20-21 September, Singapore 2005

[3] Lauvdal, T., Ådnanes, A.K., Power Management System with Fast Acting Load Reduction for DP

[6] Sørensen A. J., Marine Cybernetics: Modeling and Control, Fifth Ed., UK-05-76, Dept. Marine Technology, NTNU, Trondheim, Norway

[7] Hansen, J.F., Modeling and Control of Marine Power Systems, PhD thesis, Report 2000:9-W, Dept. Eng. Cybernetics, NTNU, Trondheim, Norway, 2000

[8] Radan, D., Power Management Of Marine Power Systems, Report, Dept. Marine Technology, NTNU, Trondheim, Norway, 2004

[9] Sørensen, A.J., Structural Issues in the Design and Operation of Marine Control Systems. IFAC Journal of Annual Reviews in Control, Vol. 29, Issue 1, pp. 125-149, 2005, Elsevier Ltd

[10] Changben Jiang, Brian Forstell, David Lavis, and Oen Ritter, "Ship Hull and Machinery Optimization using Physics Based Design Software", Marine Technology, Vol. 39, No. 2., April 2002, pp. 109-117.

[11] Anderson, P.M., Fuad, A.A., Power System Control and Stability, IEEE Press, John Wiley and Sons, 2nd Ed., 2003

[12] Ådnanes, A. K., Small size Ancor Handling and Support Vessel- AHTS, Tech. Report, ABB

[13] Radan, D.,T.A..Johnansen, A.J. Sorensen, A.K.Adnanes, Load dependent start tables in Marine Power Management Systems with Blackout Prevention;WSEA Transactions,2005

[14] MAN B&W, Project Guides for Marine Plants, Dual-fuel Engine 48/60DF, L+V 48/60 B, L+V 32/40.