ETAP BASED LOAD FLOW AND SHORT-CIRCUIT ANALYSIS OF A 42 M FAST CREW BOAT ELECTRICAL POWER SYSTEM UNDER PEAK LOADING CONDITIONS.

Abstract:

This paper models and evaluates the electrical power distribution system of a 42 m fast crew boat under peak operating conditions using ETAP. The study focuses on arrival and departure scenarios, which represent the highest electrical load as manoeuvring and auxiliary systems operate simultaneously. The system is designed in compliance with marine industry standards, namely IEC 60092, IEC 61363, and SOLAS. Load flow analysis is performed using the Newton-Raphson method to assess voltage stability, power distribution, and generator loading. Simulation results show that the optimised generator capacity of 250 kW operates at 82.1% load under peak demand, providing satisfactory operational margin and system reliability. Short-circuit analysis indicates a maximum short-circuit current of approximately 4.8 kA, allowing selected protection devices to safely interrupt faults. Calculated results were compared with ETAP simulation results and showed good agreement, with a design margin below 10%, confirming the validity of the modelling approach. The proposed methodology demonstrates how conventional design calculations can be combined with simulation-based verification to provide a reliable framework for marine electrical power system design.

Key words:-
ETAP Simulation, Load Flow Analysis, Fast Crew Boat, SOLAS, Short Circuit Analysis, IEC 60092, IEC 61363

Introduction:-

For modern marine vessels, reliable electrical power distribution is essential to the safe and continuous operation of the vessel, especially for fast crew boats in harsh, dynamic and demanding operating conditions. These ships are required to provide consistent power to propulsion systems, navigation equipment, safety critical load and onboard services in all operational modes. The most challenging of these are the arrival and departure conditions because high power manoeuvring equipment like bow thrusters are all operating at the same time. Compliance with the maritime regulations set by the International Maritime Organization (IMO) in accordance with SOLAS Convention as well as the requirements of the International Electrotechnical Commission (IEC 60092 and IEC 61363) is necessary to assure the safety of the system, redundancy and operational reliability [1-3]. Load flow analysis becomes an important tool for electrical system performance analysis to determine voltage profile, power distribution, and electrical losses under various operating conditions [4]. But, conventional manual calculations would not capture the complex interactions like impedance effects and reactive power flow and therefore require the use of advanced simulation platforms like ETAP [5–7].

In recent research, both theory and simulation based methods for electrical load flow have been explored at great length. Although multiphase load flow analysis is well developed for classical works like Bernstein et al. [4] is limited to not account for vessel-specific operational constraints, limiting the applicability to marine electrical systems. Simulation based studies with ETAP have been reported in abundance [5] – [7] which showed that their modelling was more accurate than analytic methods, but these had been applied to terrestrial power systems and did not meet maritime regulatory requirements.

Within the marine field, Doerry et al. and Prousalidis and Hatziargyriou et al. have made significant contributions in the area of conceptual modelling of shipboard power systems with a focus on power system design and analysis, but their contributions have not been primarily focused on detailed validation of shipboard power systems under extreme operating conditions [8, 11]. Recent studies have focused on integrated shipboard microgrids and ship renewable energy systems, including hybrid configurations, in contrast to traditional ship configurations [9, 20]. Although these studies contribute to the knowledge of future maritime power systems, they tend to ignore important operational conditions like arrival or departure modes, where the peak electrical demand results from multiple activations of manoeuvring and auxiliary loads.

Moreover, the protection studies like Nguyen et al. [10] emphasize on fault analysis and load shedding, but there is no explicit association of the two with steady-state load flow validation. However, this work aims to overcome these limitations by incorporating modelling that meets the standards, Newton–Raphson (NR) load flow analysis and short circuit analysis in the study scope. In this work, the most important contributions are the simultaneous use of load flow and short circuit analysis in the same framework, the focus on peak operational conditions and the validation of the simulation accuracy by comparison with analytical results which show the deviations within the allowable engineering tolerance.

Study Vessel Description:-

The study vessel is a 42 m aluminium fast crew boat designed for offshore personnel transport and light cargo operations, capable of accommodating up to 100 passengers and operating at speeds of 20 to 30 knots. The onboard electrical system adopts a split-bus configuration consisting of two main switchboards interconnected via a bus-tie breaker, allowing balanced load sharing and operational flexibility. This configuration enhances system resilience by enabling fault isolation and maintaining continuity of supply during partial system failures. An emergency generator and dedicated emergency switchboard ensure uninterrupted power supply to critical loads in compliance with SOLAS requirements. The details of the vessel are presented in Table 1 and the corresponding illustration of the designated vessel is shown in Fig. 1.

Table 1. Details of the vessel used for this simulation study

No.	Principal Dimensions	Size (m)
1	Length Overall (LOA)	42
2	Length Waterline (LWL)	40
3	Length Between Perpendiculars (LBP)	39
4	Beam MLD (Moulded Beam)	7.6
5	Depth MLD (Moulded Depth)	3.5
6	Design Draft @ 60 DWT	1.65
7	Maximum Draft @ Full Load	1.90

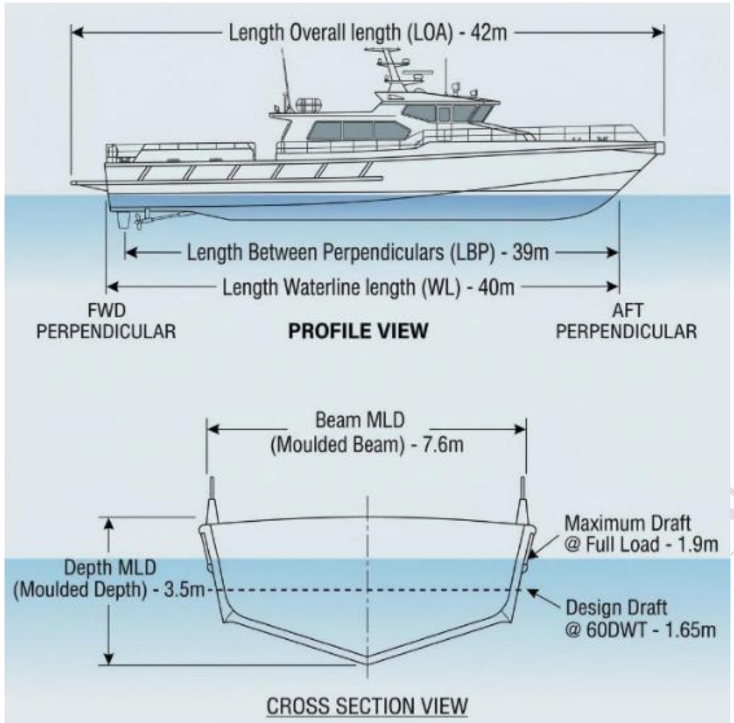

Fig. 1. Illustration of designated vessel of study.

Methodology:-

Before simulation with ETAP, electrical load analysis was conducted manually to estimate the total power needed for this ship for the maximum load at arrival or departure. The loads are divided into six sections: the main switchboard (163.89 kW), the main deck distribution board (2.97 kW), below main deck distribution board (9.32 kW), wheelhouse distribution board (10.04 kW), 24V DC power loading panel (0.47 kW DC), and 24V DC radio panel (1.15 kW DC). For all loads, the diversity factors used were of the order of 0.6 to 0.8. The total power needed when arriving or departing was estimated to be 186.19 kW diversified (AC) and 1.62 kW (DC). Considering a design margin of 5-10%, the total demand power was estimated as 195-205kW AC. The number of generators needed to be matched with the corresponding load (80% operating) was 250 kW × 2 units (including standby generator), which satisfied the requirement of SOLAS II-1/41.

Next, the electrical power system of the ship was modeled using Single Line Diagram (SLD) compiler used in ETAP, which is a digital representation of the ship's electrical power distribution system. The SLD was created from the conceptual block diagram in Fig. 2, which is a schematic representation of the flow of power from the power sources to the final distribution points. Generators, busbars, switchboards, transformers and distribution boards were represented based on their electrical rating, operating voltage and protection schemes. Newton–Raphson (NR) algorithm was used to perform load flow analysis.

The 42 m fast crew boat is designed to meet SOLAS and IEC 60092-201 requirements with a split-bus structure comprising of two Main Switchboards (MSB-A and MSB-B) connected via a normally closed bus-tie breaker. This setup allows for fault isolation and load sharing, flexibility of operation, supply continuity in case of generator failure or maintenance and automatic fault isolation. Critical loads are carefully arranged, Steering Gear 1 is supplied by MSB-A and essential emergency equipment is supplied via the Emergency Switchboard (ESB). The selection of cables was carried out following the IEC 60092-352 with marine grade EPR/XLPE insulated cables.

The electrical network was broken down into 4 main zones to take into account the layout of the vessel and the voltage drop behaviour. The Main Engine Room comprises the Main Generators and Main Switchboards.

Emergency Generator and Emergency Switchboard are located in a fire-protected compartment in the Emergency Station. The wheelhouse distribution board (DB-WH) which provides the power to the navigation equipment, emergency lighting, and communication systems is connected via an approximately 20 m feeder cable that was identified as a critical feeder branch for voltage drop analysis. The habitation is supported by DB-MD (Main Deck) and DB-BMD (Below Main Deck).

There were several assumptions used. All loads were given a uniform PF of 0.8 lagging. Protection coordination and margins for motor starting currents were based on Full Load Amperage (FLA) values. For communication systems (Radio/GMDSS) the diversity factor was 1.0 for all operating modes. Demand for Steering Gear 2 was assumed to be the same as that of Steering Gear 1. Circuit breakers of Type B and Type C were chosen, but sensitive instrumentation circuits were protected by the use of Type Z circuit breaker. The design margin for a generator was assumed as 1.2 (around 80% continuous loading) according to IEC 60034. Rectifiers were represented in the load as independent loads with a DC power rating and not included in AC demand calculations.

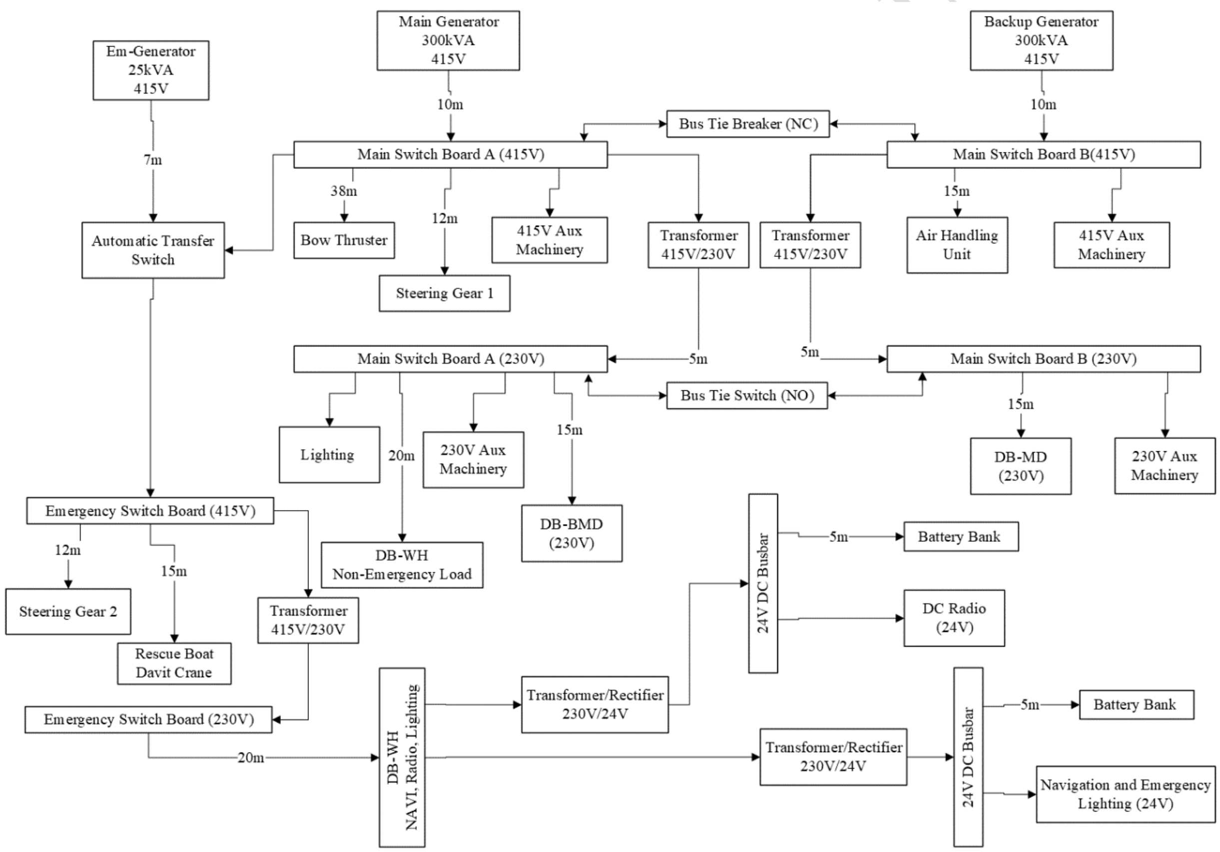

Fig. 2. Block diagram of electrical system design on the intended study vessel of a 42 m Fast Crew Boat.

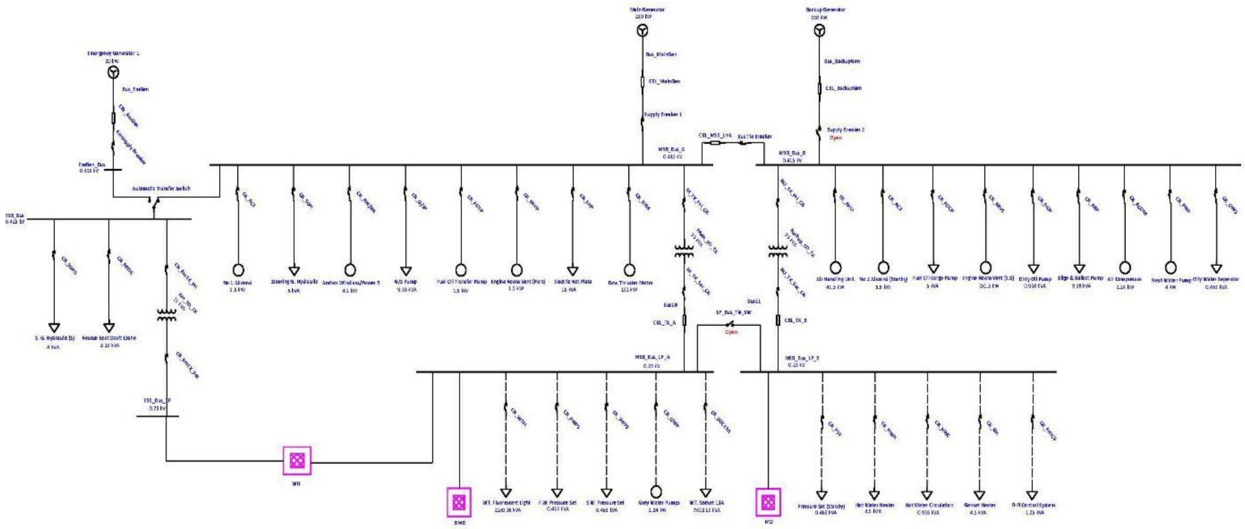

Fig. 3. Corresponding Single Line Diagram (SLD) for the study vessel MSB.

Results and Discussions:-

Simulated Newton–Raphson (NR) load flow results are shown for arrival and departure operating modes for all the AC sections in the figures. The load distribution shown in Table 2 summarizes the loads shown in 4-7. As expected, the results show that electrical load for the vessel is highly dependent on propulsion support and HVAC systems, and a considerable portion of the auxiliary electrical loads are intermittent and standby. The highest loading condition is the motor power of the bow thruster which requires about 128 kW and 49.27 kVAR, indicating that the maneuvering operation is the most critical loading condition of the vessel [8, 11]. In this operating mode, the total diversified load demand that is simulated is 187.35kW, which is within the acceptable deviation of 9.42% from the manual estimation of the diversified load demand using spreadsheet from engineering practice [6, 7, 12]. The short circuit analysis was carried out according to IEC 61363-1:1998 [3]. Motor contributions were taken into consideration for the total fault current, and the alternator fault contribution was calculated using the motor ratings and sub-transient reactance. Comparisons between the manual calculations and the simulation from ETAP reveals an error of 8.70% in the alternator fault level and 2.12% in the total short circuit current.

The higher simulation values are in line with ETAP's conservative modelling approach [8, 10]. Along with the bow thruster, other major contributors are the air handling unit (41.47 kW and 17.02 kVAR) and the No. 1 air conditioning unit (5.99 kW and 4.50 kVAR). Other machinery in service is the anchor windlass/power unit (4.60 kW), engine room ventilation fans (1.80 kW and 3.59 kW) and fuel oil transfer pump (1.35 kW). In the mode, the several major auxiliary systems including standby air-conditioning systems, bilge and ballast pumps, steering gear hydraulic systems, cargo pumps, refrigerators, and washing machines were not in operation and reported zero demand. The results provide good agreement with previously published work. Arrival and departure conditions are considered in a focused manner, which results in generator sizing and system reliability considerations under the most challenging conditions, consistent with regulatory requirements to ensure safe marine operations [1-3]. This is the most critical operational condition for the design of marine electrical systems, and it is conservative for the sizing, protection coordination, and system reliability evaluation of the generator [8, 10].

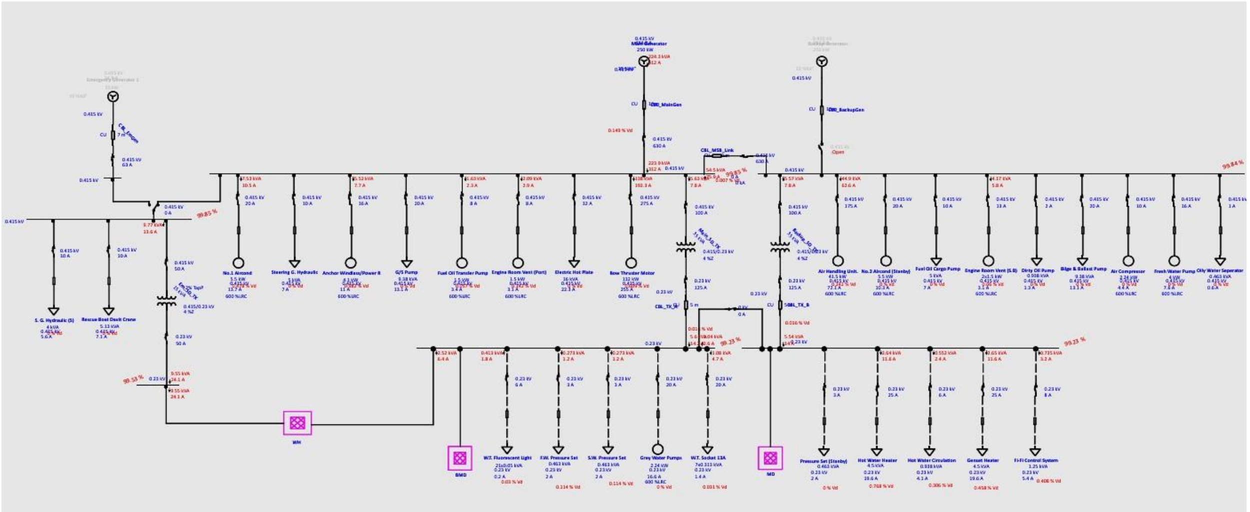

Fig. 4. Main switchboard power flow diagram in arrival/departure condition.

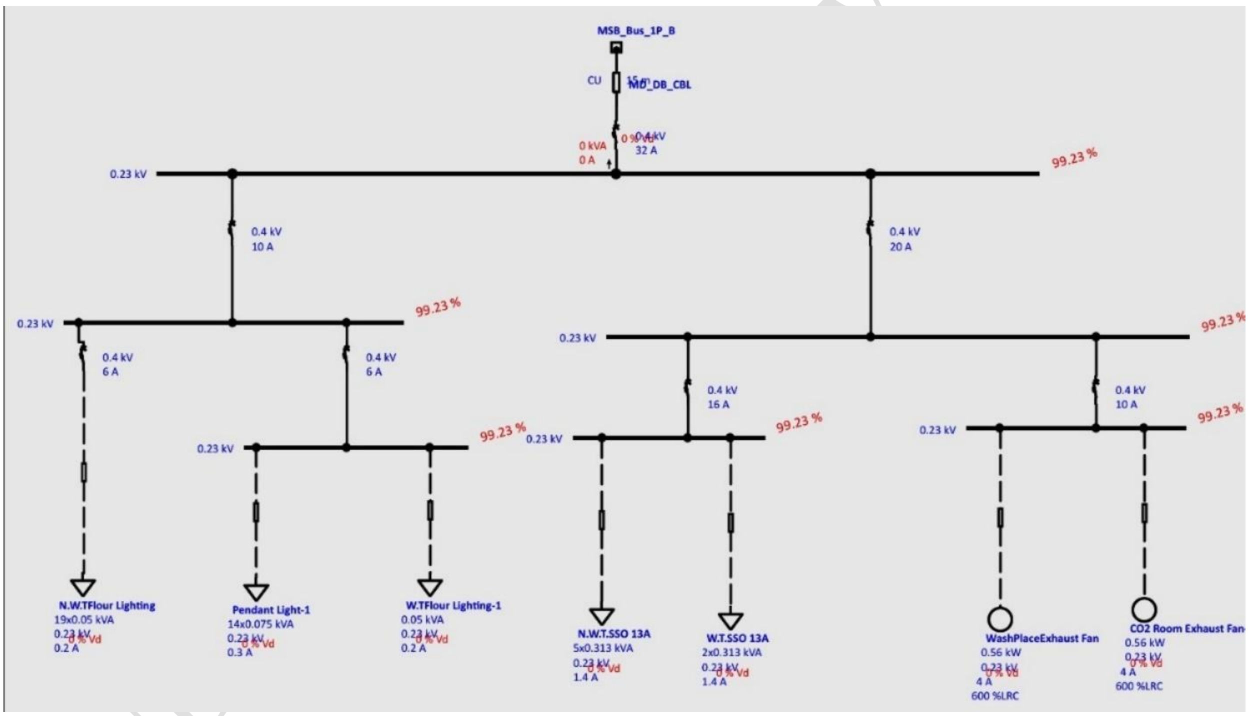

Fig. 5. Main deck power flow diagram in arrival/departure condition.

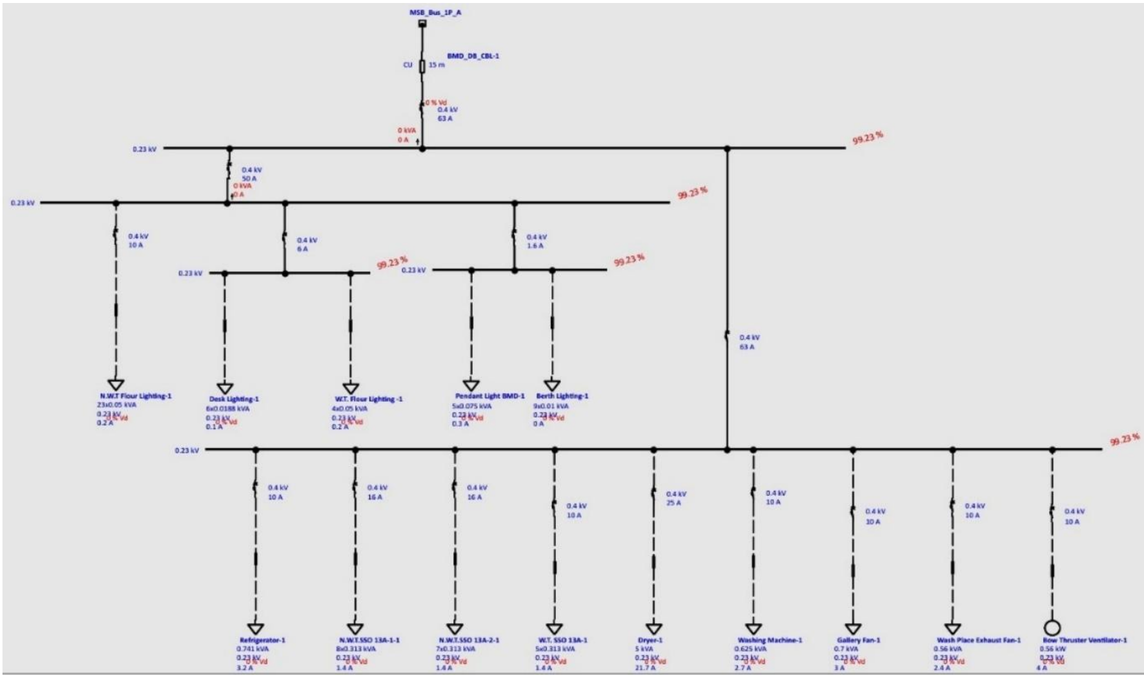

Fig. 6. Below main deck power flow diagram in arrival/departure condition

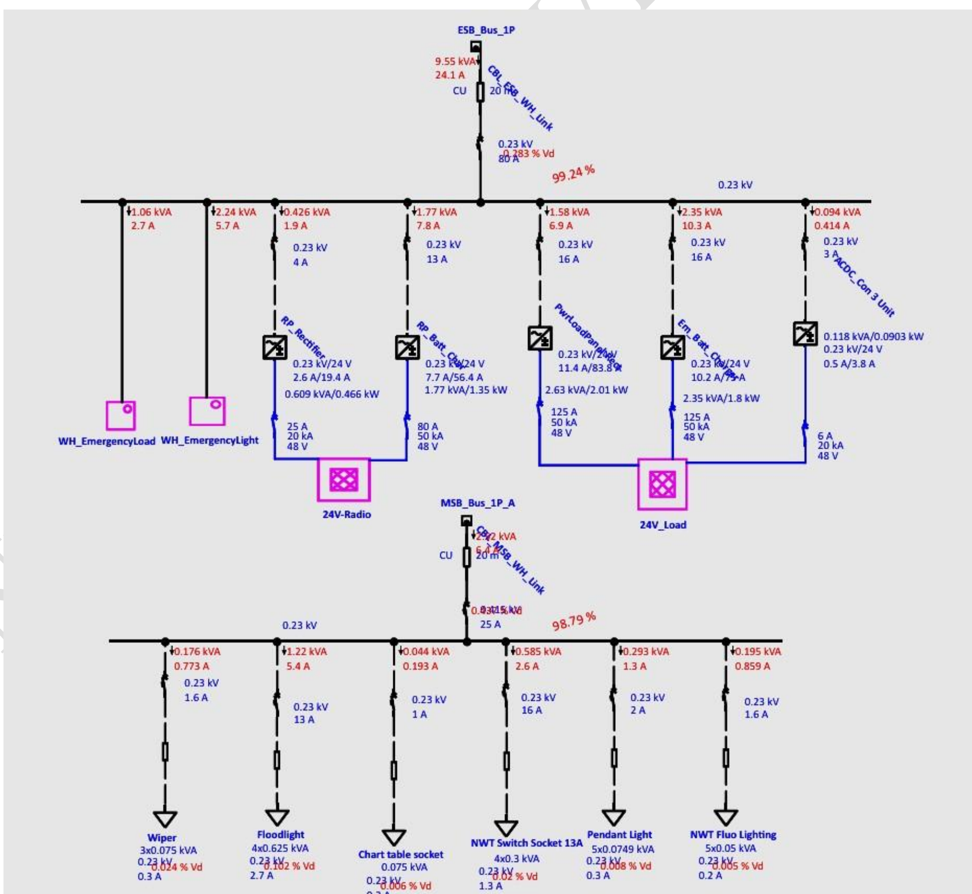

Fig. 7. Wheelhouse power flow diagram in arrival/departure condition

Table 2. NR resultant load flow analysis for each component in arrival/departure condition

Component ID	Rating/Limit	Rated kV	kW	kvar
Air Compressor	2.24 kW	0.415	0	0
Air Handling Unit	41.5 kW	0.415	41.47	17.02
ALDIS Light	0.075 kVA	0.23	0.0354	0.0266
Anchor Windlass/Power R	4.1 kW	0.415	4.6	2.96
Berth Lighting-1	0.09 kVA	0.23	0	0
Bilge & Ballast Pump	9.38 kVA	0.415	0	0
Bow Thruster Motor	132 kW	0.415	128	49.27
Bow Thruster Ventilator-1	0.56 kW	0.23	0	0
Chart Table Socket	0.075 kVA	0.23	0.0352	0.0264
CO2 Room Exhaust Fan-1	0.56 kW	0.23	0	0
Desk Lighting-1	0.113 kVA	0.23	0	0
Dirty Oil Pump	0.938 kVA	0.415	0	0
Dryer-1	5 kVA	0.23	0	0
Electric Hot Plate	16 kVA	0.415	0	0
Engine Room Vent (Port)	1.5 kW	0.415	1.8	1.06
Engine Room Vent (S.B)	3 kW	0.415	3.59	2.12
F.W. Pressure Set	0.463 kVA	0.23	0.219	0.164
FI-FI Control System	1.25 kVA	0.23	0.589	0.442
Fi-Fi Control System	1.25 kVA	0.23	0.585	0.438
Fire Alarm Panel	0.125 kVA	0.23	0.0984	0.0738
Floodlight	2.5 kVA	0.23	0.976	0.732
Fresh Water Pump	4 kW	0.415	0	0
Fuel Oil Cargo Pump	5 kVA	0.415	0	0
Fuel Oil Transfer Pump	1.5 kW	0.415	1.35	0.916
G/S Pump	9.38 kVA	0.415	0	0
Gallery Fan-1	0.7 kVA	0.23	0	0
Genset Heater	4.5 kVA	0.23	2.1	1.58
Grey Water Pumps	2.24 kW	0.23	0	0
Hot Water Circulation	0.938 kVA	0.23	0.44	0.33
Hot Water Heater	4.5 kVA	0.23	2.09	1.57
Navigation Light Panel	0.3 kVA	0.23	0.189	0.142
No. 1 Aircond	5.5 kW	0.415	5.99	4.5
No. 2 Aircond (Standby)	5.5 kW	0.415	0	0
NWT Fluo Lighting	0.25 kVA	0.23	0.156	0.117
NWT Switch Socket 13A	1.2 kVA	0.23	0.469	0.352
Oily Water Separator	0.463 kVA	0.415	0	0
PA System	0.125 kVA	0.23	0.0985	0.0738
Pendant Light	0.375 kVA	0.23	0.235	0.176
Pressure Set (Standby)	0.463 kVA	0.23	0	0
Refrigerator-1	0.741 kVA	0.23	0	0
Rescue Boat Davit Crane	5.13 kVA	0.415	0	0
S.G. Hydraulic (S)	4 kVA	0.415	0	0
S.W. Pressure Set	0.463 kVA	0.23	0.219	0.164
Search Light	2.5 kVA	0.23	1.57	1.17
Shaft Tachometer	0.1 kVA	0.23	0.063	0.0473
Steering G. Hydraulic	5 kVA	0.415	0	0
W.T. Fluorescent Light	1.05 kVA	0.23	0.331	0.249
W.T. Socket 13A	2.19 kVA	0.23	0.864	0.648
WashPlace Exhaust Fan	0.56 kW	0.23	0	0
Washing Machine-1	0.625 kVA	0.23	0	0
Wiper	0.225 kVA	0.23	0.141	0.106

Conclusion:-

A detailed and verified evaluation of 42 m fast crew boat electrical power system is carried out in ETAP simulation under peak loading. The results validate the ability of the system to satisfy performance, safety and reliability requirements with sufficient generator size, steady voltage profiles and tolerable fault levels. Manual calculations along with simulation based analysis provides a sound and useful approach to marine electrical system design. Future works should be done to extend this study to transient analysis, harmonic study, and advanced protection coordination to further improve the system reliability and performance under real operating conditions. In the critical perspective, this study shows important strengths, such as using analytical and simulation approaches, and taking into account the international standards and highlighting the conditions of peak load. The good correlation between the manual and simulation results confirms the reliability and usefulness of the model.

This analysis, however, is restricted to steady-state operation and ignores transient phenomena such as motor starting currents, voltage dips etc., and frequency stability which are important to actual shipboard operation.

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