Unbalance load analysis on closed bus electrical system under ship dynamic positioning scenario

S Sarwito¹, Semin¹, M B Zaman¹, Soedibyo² and I Fawaiz¹

¹ Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
² Department of Electrical Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

Abstract. Dynamic Positioning (DP) operation on offshore auxiliary vessels emerges as a challenge in need of ensured high-powered bow thruster stability. DP operation is widely adopted under an open electrical system (open bus). Open bus-configured DP usually has low electricity disturbance. However, open bus-configured DP is always attributed to its low efficiency. Our study revealed that DP ships using closed bus configuration are prone to the unbalance three-phase electric load problem. Unbalanced load, which always results in the unbalance three-phase voltage problem, can affect the performance of the motor or another electrical component. Our simulation successfully showed the effect of unbalance load on the ship’s electric stability. By using commonly electric ship configuration as simulation testing, the ship grid configuration with the power supply of two generator thruster and one diesel generator with the 2-bow thruster and a static load can indicate unbalanced load on AHTS vessels with variations up to 75%. By minimizing the variation of percentages of the bow thruster operating point and other loads, minimum allowable three-phase deviation of the unbalance, which indicated by the three-phase voltage operating point could be met. The simulation study was done using MATLAB as a tool.

1. Introduction

AHTS Vessel has a different system to the other type of vessels as its purpose is mainly for offshore activity [1]. This type of ship vessel is usually having a dynamic positioning system, a system that serves to control the ship movement during, for instance, open-sea oil-drilling operation.

Unbalance load is a condition where each load on phase experiences inequality of load values between one phase and another phase due to several factors that make a significant difference in load values between other phases [2]. This unbalanced load can occur in dynamic positioning. Unbalance voltage can also be defined as the difference in phase angle values that do not correspond to different values between phase angles, each of which is worth 120° [3–6].

The addition of a large powered bow thruster can affect system stability if the system does not have resistance to transient disturbances that are temporary [7]. In the event of a transient disturbance and the system cannot maintain its stability [8,9], there will be a loose synchronization of the generator and more fatal will cause the failure of the electrical system [10,11].

The study of the unbalanced load will provide an assessment of the stability of the ship’s electrical system so that practitioners can mitigate out of the problem [12–14]. Several methods to prevent the occurrence of unbalance load problems is by applying load-shaving scenario, by distributing one-phase loads to another phase or adding compensator.
2. Methods
Upon conducting unbalance load simulations, the single line diagram of the AHTS vessel must be formulated as a reference. From referring to the designed single line diagram, the system operation is simulated in accordance with the specifications of the equipment used. Our study carried out three steps as a method, which is described in detail below.

2.1 Formulating Simulation Parameter
Upon preparing the Simulation Parameter, the data is needed. Those are the power of the generator, diesel generator, the load profile each phase, the cable impedance and the volatility of the equipment installed on the ship to input data in MATLAB simulation.

2.2 Unbalance Load Testing
After the system is fully formulated, the simulation of the unbalanced load can be done by using an unbalance load module in the MATLAB software. The results obtained from the simulation are in the form of currents and angles per phase. This data will then be processed and analysed to provide an assessment of the dynamic positioning condition of the vessel.

The simulation is carried out by doing the evaluation on five different configuration scenarios as stated in Table 1.

| Scenario | Power Supply | Load | Load Variations |
|----------|--------------|------|-----------------|
| 1        | 2 Generator Thruster | 2 Bow Thruster | 60% - 75% | 100% - 80% | 100% - 100% | 110% - 110% |
| 2        | 1 Generator Thruster | 2 Bow Thruster | 40% - 40% | 50% - 50% | 60% - 60% |
| 3        | 2 Generator Thruster, 1 Diesel Generator | 2 Bow Thruster & Ship Equipment Load | 60% - 75% | 100% - 80% | 100% - 100% | 110% - 110% |
| 4        | 2 Generator Thruster, 2 Diesel Generator | 2 Bow Thruster & Ship Equipment Load | 60% - 75% | 100% - 80% | 100% - 100% | 110% - 110% |
| 5        | 1 Generator Thruster, 2 Diesel Generator (Closed Bus) | 2 Bow Thruster & Ship Equipment Load | 75% - 75% | 80% - 80% | 85% - 85% |

Simulation of unbalance load on AHTS ships is done using the MATLAB program, as illustrated in Figure 1. After performing the calculation process for the five predefined scenarios, then the process of designing a programming language into the programming application is used.
2.3 Validation
In this research, we adopt the Unbalance Load benchmarking standard from IEC Standard (International Electrotechnical Commission). IEC's rules have regulated many matters relating to electrical installations and electrical equipment such as requirements that applied to installations relating to electricity efficiency. One part that is regulated by IEC is the quality of stress on an electrical installation and electrical equipment.

### Table 2. IEC Standard

| Type of Installation                                      | Lighting % | Other uses % |
|-----------------------------------------------------------|------------|--------------|
| A – Low voltage installations supplied directly from a public low voltage distribution system | 3          | 5            |
| B – Low voltage installation supplied from LV supply *    | 6          | 6            |

*as far as possible, it is recommended that voltage drop within the final circuits do not exceed those indicated in installation type A.

When the main wiring systems of the installation are longer than 100 m, these voltage drops may be increased by 0.005 % per metre of wiring system beyond 100 m, without this supplement being more significant than 0.5 %

Voltage drop is determined from the demand by the current – using equipment, applying diversity factor where applicable, or from the values of the design current of the circuits.

The voltage quality of an unbalance load in electrical installations, and electrical equipment is also considered. The amount of current unbalance can be measured and calculated by the maximum deviation ratio of the average values of the three averaged phases. As such, the maximum deviation from the

![Figure 1. Simulation using MATLAB.](image-url)
average is expressed as a percentage of the average unbalance. In IEC / TR 61000-3-14 chapter 10-Unbalance Emission Limits for unbalanced LV systems are shown in Table 2 below.

### 3. Results

After conducting research based on the research methodology described in the previous chapter, there are several results based on the process that has been carried out.

#### 3.1 Result for Simulation.

**3.1.1 Scenario 1**

Scenario 1 has a configuration, power supply 2 generator thruster with load 2 bow thruster and uses load variations 60% -75%, 100% -80%, 100% -100%, 110% -110%.

**Table 3. Current and voltage in calculation Scenario 1**

| Load Variation | Phase R (A) | Degree (°) | Phase S (A) | Degree (°) | Phase T (A) | Degree (°) |
|----------------|-------------|------------|-------------|------------|-------------|------------|
| 60%–75%        | 614.7       | 24.1       | 614.2       | 144.1      | 614.7       | 264.1      |
| 100%–80%       | 820.7       | 24.1       | 820.8       | 144.1      | 820.8       | 264.1      |
| 100%–100%      | 912.5       | 24.1       | 911.6       | 144.1      | 912.5       | 264.1      |
| 110%–110%      | 1004.4      | 24.1       | 1003.3      | 144.1      | 1004.4      | 264.1      |

From the results of simulations and calculations in Scenario 1, as shown in Figure 2 and Table 3, the greater the use of bow thruster power or the greater the value of variation in loading on the bow thruster. From the graph, it can be concluded that the current value in each phase is proportional to the value of the variation of the power of the bow thruster. In Scenario 1, after the calculation is done with the results

![Figure 2. (a) Current phasor diagram Scenario 1 variation 60%-75%](image)

![Figure 2. (b) Voltage phasor diagram Scenario 1 variation 60%-75%](image)

**Table 4. Standard unbalance Scenario 1**

| Load Variation | Calculation According to IEC Standard | IEC Standard | Inf |
|----------------|--------------------------------------|--------------|-----|
| 60%–75%        | 0.02                                  | 5%           | Yes |
| 100%–80%       | 0.03                                  | 5%           | Yes |
| 100%–100%      | 0.03                                  | 5%           | Yes |
| 110%–110%      | 0.04                                  | 5%           | Yes |
of the four variations that meet the IEC standard, which is equal to 0.03%. In Table 4, shows that in Scenario 1, the four variants meet IEC standards which show a number below 5%. Therefore, in Scenario 1, it is said that the load is balanced.

3.1.2 Scenario 2
Scenario 2 has a configuration, power supply 1 generator thruster with load 2 bow thruster and uses load variation 40% -40%, 50% -50%, 60% -60%.

Table 5. Current and voltage in calculation Scenario 2

| Load Variation | Phase R (A) | Degree (°) | Phase S (A) | Degree (°) | Phase T (A) | Degree (°) | Phase R (A) | Degree (°) | Phase S (A) | Degree (°) | Phase T (A) | Degree (°) |
|----------------|-------------|------------|-------------|------------|-------------|------------|-------------|------------|-------------|------------|-------------|------------|
| 40%-40%        | 364.57      | 24.96      | 364.57      | 144.96     | 364.57      | 264.96     | 412.88      | 0.41       | 412.88      | 120.41     | 412.88      | 240.41     |
| 50%-50%        | 456.31      | 25.17      | 456.31      | 145.17     | 456.31      | 265.17     | 412.35      | 0.51       | 412.35      | 120.51     | 412.35      | 240.51     |
| 60%-60%        | 548.28      | 25.37      | 548.28      | 145.37     | 548.27      | 265.37     | 411.83      | 0.61       | 411.83      | 120.61     | 411.83      | 240.61     |

![Figure 3](image)

(a) Current phasor diagram Scenario 2 variation 40%-40%
(b) Voltage phasor diagram Scenario 2 variation 40%-40%

Table 6. Standard unbalance Scenario 2

| Load Variation | Calculation according to IEC standard | IEC Standard | Inf. |
|----------------|--------------------------------------|--------------|------|
| 40%-40%        | 0.00%                                | 5%           | Yes  |
| 50%-50%        | 0.00%                                | 5%           | Yes  |
| 60%-60%        | 0.00%                                | 5%           | Yes  |

From the results of simulations and calculations in Scenario 2, as shown in Figure 3 and Table 5, it can be seen that the greater the use of bow thruster power or the greater the value of the variation of loading on the bow thruster, the greater the current flowing in each phase. The current value generated in each variation undergoes a significant change, but the resulting angle is the same for each variation. From the graph, It can be concluded that the current value of each phase is proportional to the value of the variation of the power of the bow thruster. In Scenario 2, after the calculation is done with the results of the four variations that meet the IEC standard, which is equal to 0.00%. In Table 6, shows that in Scenario 2, the three variants meet IEC standards which show a number below 5%. Therefore in Scenario 2, it is said that the load is balanced.
3.1.3 Scenario 3
Scenario 3 has a configuration, power supply 2 generator thruster and 1 diesel generator with a load of 2 bow thruster and the load of the ship that is run using load variations 60% -75%, 100% -80%, 100% -100%, 110% -110%.

Table 7. Current and voltage in calculation Scenario 3

| Load Variation | Current per Phase | Voltage per Phase |
|----------------|-------------------|-------------------|
|                | Phase R (A)       | Degree (°)        | Phase S (A)       | Degree (°)        | Phase T (A)       | Degree (°)        | Phase R (A)       | Degree (°)        | Phase S (A)       | Degree (°)        | Phase T (A)       | Degree (°)        |
| 60%-75%        | 722.52            | 25.31             | 1218.94           | 145.51            | 565.92            | 265.21             | 413.18            | 0.35             | 412.14            | 120.56             | 413.66            | 240.26             |
| 100%-80%       | 1032.92           | 25.53             | 1632.20           | 145.80            | 756.12            | 265.40             | 412.58            | 0.47             | 411.20            | 120.74             | 413.22            | 240.35             |
| 100%-100%      | 1218.77           | 25.61             | 1820.33           | 145.88            | 940.85            | 265.48             | 412.15            | 0.56             | 410.77            | 120.83             | 412.79            | 240.43             |
| 110%-110%      | 1342.42           | 25.71             | 2006.21           | 146.01            | 1036.00           | 265.57             | 411.87            | 0.61             | 410.36            | 120.91             | 412.58            | 240.48             |

Figure 4. (a) Current phasor diagram Scenario 3 variation 60%-75%  
(b) Voltage phasor diagram Scenario 3 variation 60%-75%

Table 8. Standard unbalance Scenario 3

| Load Variation | Calculation according to IEC standard | IEC Standard | Inf. |
|----------------|---------------------------------------|--------------|------|
| 60%-75%        | 5.37%                                 | 5%           | No   |
| 100%-80%       | 5.39%                                 | 5%           | No   |
| 100%-100%      | 4.65%                                 | 5%           | Yes  |
| 110%-110%      | 4.66%                                 | 5%           | Yes  |

From the results of simulations and calculations in Scenario 3, as shown in Figure 4 and Table 7, it can be seen that the greater the use of bow thruster power or the greater the value of the variation of loading on the bow thruster, the greater the current flowing in each phase. The current value generated in each variation undergoes a significant change, but the resulting angle is the same for each variation. From the graph, it can be concluded that the current value of each phase is proportional to the value of the variation of the power of the bow thruster. In Table 8 above shows that in Scenario 3, for Scenario 3 after simulation, the variations are 60% - 75% and 80% - 100% exceeding the IEC standard while for variations that have the same loading value 100% - 100% and 110% - 110% have a value below the IEC standard of 5%. So, for variations of 60% - 75% and 100% - 80%, repairs need to be done.
3.1.4 Scenario 4

Scenario 4 has a configuration, power supply of 2 generator thruster and 2 diesel generators with a load of 2 bow thruster and the load of the ship being run using load variations 60% -75%, 100% -80%, 100% -100%, 110% -110%.

Table 9. Current and voltage in calculation Scenario 4

| Load Variation | Phase R (A) | Degree (°) | Phase S (A) | Degree (°) | Phase T (A) | Degree (°) | Phase R (A) | Degree (°) | Phase S (A) | Degree (°) | Phase T (A) | Degree (°) |
|----------------|-------------|------------|-------------|------------|-------------|------------|-------------|------------|-------------|------------|-------------|------------|
| 60%-75%        | 771.25      | 25.79      | 1215.80     | 145.97     | 565.23      | 265.21     | 413.48      | 0.30       | 412.61      | 120.48     | 413.88      | 240.22     |
| 100%-80%       | 1215.49     | 26.42      | 1812.98     | 146.67     | 938.89      | 265.40     | 412.64      | 0.48       | 411.50      | 120.71     | 413.17      | 240.37     |
| 100%-100%      | 1215.49     | 26.42      | 1812.98     | 146.67     | 938.89      | 265.48     | 412.64      | 0.48       | 411.50      | 120.71     | 413.17      | 240.37     |
| 110%-110%      | 1338.41     | 26.61      | 1997.16     | 146.88     | 1033.60     | 265.57     | 412.42      | 0.53       | 411.17      | 120.78     | 413.00      | 240.41     |

Figure 5. (a) Current phasor diagram Scenario 4 variation 60%-75%  
(b) Voltage phasor diagram Scenario 4 variation 60%-75%

Table 10. Standard unbalance Scenario 4

| Load Variation | Calculation according to IEC standard | IEC Standard | Inf. |
|----------------|----------------------------------------|--------------|------|
| 60%-75%        | 5.36%                                  | 5%           | No   |
| 100%-80%       | 5.38%                                  | 5%           | No   |
| 100%-100%      | 4.64%                                  | 5%           | Yes  |
| 110%-110%      | 4.64%                                  | 5%           | Yes  |

From the results of simulations and calculations in Scenario 4, as shown in Figure 5 and Table 9, the greater the use of bow thruster power or the greater the value of variation in loading on the bow thruster, the greater the current flowing in each phase. The current value generated in each variation undergoes a significant change, but the resulting angle is the same for each variation. From the graph, it can be concluded that the current value of each phase is proportional to the value of the variation of the power of the bow thruster. In Table 10 above shows that in the scenario, for Scenario 4 after the simulation is done the variation is 60% -75% and 80% -100% exceeds the IEC standard while for variations that have the same loading value 100% -100% and 110% -110% has a value below the IEC standard of 5%. So, for variations of 60% -75% and 100% -80%, repairs need to be done.
3.1.5 Scenario 5
Scenario 5 has a configuration, a power supply of one generator thruster and two diesel generators with a load of 2 bow thruster and the load of the ship being run using a load variation of 75% -75%, 80% -80%, 85% -85%.

Table 11. Current and voltage in calculation Scenario 5

| Load Variation | Current per Phase | Voltage per Phase |
|----------------|-------------------|-------------------|
|                | Phase R (A) | Degree (°) | Phase S (A) | Degree (°) | Phase T (A) | Degree (°) | Phase R (A) | Degree (°) | Phase S (A) | Degree (°) | Phase T (A) | Degree (°) |
| 75% -75%       | 912.55     | 26.25      | 1361.78     | 146.53     | 704.72      | 266.14      | 412.28      | 0.55       | 410.96      | 120.81      | 412.89      | 240.42     |
| 80% -80%       | 974.12     | 26.36      | 1454.11     | 146.66     | 752.14      | 266.25      | 412.10      | 0.59       | 410.70      | 120.87      | 412.76      | 240.45     |
| 85% -85%       | 1035.78    | 26.47      | 1546.14     | 146.79     | 799.62      | 266.35      | 411.93      | 0.62       | 410.44      | 120.92      | 412.62      | 240.48     |

(a) $I_g = 1354.01 \angle 147.591°$

(b) $V_g = 410.69 \angle 119.157°$

Figure 6. (a) Current phasor diagram Scenario 5 variation 75%-75%
(b) Voltage Phasor Diagram Scenario 5 Variation 75%-75%

Table 12. Standard unbalance Scenario 5

| Load Variation | Calculation according to IEC standard | IEC Standard | Inf. |
|----------------|----------------------------------------|--------------|------|
| 75% -75%       | 4.64%                                  | 5%           | Yes  |
| 80% -80%       | 4.65%                                  | 5%           | Yes  |
| 85% -85%       | 4.65%                                  | 5%           | Yes  |

From the results of simulations and calculations in Scenario 5, as shown in Figure 6 and Table 11, the greater the use of bow thruster power or the greater the value of variation in loading on the bow thruster, the greater the current flowing in each phase. The current value generated in each variation undergoes a significant change, but the resulting angle is the same for each variation. From the graph, it can be concluded that the current value of each phase is proportional to the value of the variation of the power of the bow thruster. In Table 12 above shows that in Scenario 5 the third variation meets the IEC standard, which shows a number below 5%. So that in conditions of 5 loading variations produce a current value whose imbalance is still permitted.

3.2 Proposed Solution
Based on the results of simulations that have been carried out, our study proposes 3 approaches as an alternative to overcome or protect activities on the electrical system of the vessel from unbalanced disturbance.
3.2.1 The first approach
Operate the bow thruster in the scenario and under load variation below the standard unbalance load. In Scenario 3 and Scenario 4, there is a result of the value of the load imbalance that exceeds the standard value of the imbalance that is permitted on the closed bus system. If Scenarios 3 and 4 are implemented, it should be noted in the variation value of bow thruster loading, wherein certain variations of load, the value of imbalance produced is more than the standard value of imbalance. Then the method of improvement is to do a scenario under the IEC standard by equating the value of the variation of loading, with the same variation of the load, the resulting value is below the value of the IEC standard.

3.2.2 The second approach
Reducing the amount of unbalance. To repair the unbalance that occurs on the AHTS vessel by reducing the value of the unbalance, that is by balancing the source load because basically, the 3-phase load is balanced but because of the load of 1 phase it results in an unbalance.

3.2.3 Third approach
Installing compensator. The use of Static Var Compensator (SVC) can be used to compress unbalanced loads on unbalanced loads on the distribution system. This can be done by adjusting the variable reactance contained in the compensator. This arrangement can be achieved by operating the controlled compensator Thyristor at a certain conduction angle. With the conduction angle asymmetry in the thyristor, the reactivity of the asymmetric delta relationship is obtained. SVC can absorb or produce reactive power to balance closed electrical systems and reduce the presentation of imbalances that arise in closed electrical systems. SVC is installed in parallel with the load, with the SVC expected to be able to balance the current in the electrical system covered by the AHTS BNI Castor, that is by reducing the current value per phase that appears on an unbalanced system, as shown in Table 13.

Table 13. Comparison of unbalance values before and after using the proposed approaches.

| Variation    | Before repair | Repair Variation | Install Compensator | IEC Standard | Inf. |
|--------------|---------------|------------------|---------------------|--------------|------|
| 60%/-75%     | 5.36%         | 4.62%            | 3.89%               | 5%           | Yes  |
| 100%/-80%    | 5.38%         | 4.62%            | 3.86%               | 5%           | Yes  |
| 100%/-100%   | 4.64%         | 4.64%            | 3.85%               | 5%           | Yes  |
| 110%/-110%   | 4.64%         | 4.64%            | 3.84%               | 5%           | Yes  |

4. Conclusions
Based on the results of simulations unbalance load using MATLAB, conclusions can be drawn as follows:

1. There is a relationship between the unbalance condition and the variation of loading, which is when the loading variation increases, the current value will also increase. In Scenarios 3 and 4, there is a load unbalance that exceeds the IEC standard where the IEC maximum limit for an allowable load imbalance is 5%; this occurs because the loading conditions are not as large so that the loading variation is 60%/-75% and 100%/-80% and need repairs.

2. In order to repair the unbalance disturbance of the closed bus-configured circuit, three ways can be done, namely by operating the bow thruster and the load of the ship in the same variation of loading, reducing the value of unbalance and installing compensator.

Acknowledgements
Authors wishing to thank Dr Akbar Swandaru (Power Sector Analyst from ASEAN Centre for Energy) for providing his view on power electrical problem relevancy to the marine engineering research spectrum to aid better the construction of this research paper.
References

[1] Roa, M. (2016). “Demonstration of fault ride-through capability for closed bus operation on dynamic positioning vessels”. 2016 Petroleum and Chemical Industry Technical Conf. (PCIC), Philadelphia, PA, USA, pp. 1–10.

[2] Sarwito, S., Koenhardono, E.S. and Martha, K.P.T. (2018). “Analysis of transient response and harmonic disturbances on the tanker’s electrical system based on simulation”. Int. J. of Marine Eng. Innovation and Research 3(1).

[3] Sarwito, S. and Sulaiman, M.A. (2018) “Analysis of electric propulsion performance on submersible 60 M with motor Dc 2 x 1850 kW 380 V using ohmformer at voltage 190 Vdc 10260 Ah and without using ohmformer at voltage 115 Vdc 10260 Ah”. Int. J. of Marine Eng. Innovation and Research 2(3).

[4] Sarwito, S., Prananda, J., Koenhardono, E.S. and Kurniawan, A.W. (2017). “Study of calculation of degaussing system for reducing magnetic field from submersible vehicle”. Int. J. of Marine Eng. Innovation and Research 1(2).

[5] Sarwito, S. and Hanif, M. (2017). “Analysis of unbalanced load effect of three-phase transformer feedback 61-103 performance on the various connection windings”. 2017 Int. Conf. on Advanced Mechatronics, Intelligent Manufacture, and Industrial Automation (ICAMIMIA), pp. 146–150.

[6] Nounou, K., Charpentier, J.F., Marouani, K., Benbouzid, M. and Kheloui, A. (2018). “Emulation of an electric naval propulsion system based on a multiphase machine under healthy and faulty operating conditions”. IEEE Transactions on Vehicular Techno. 67(8): 6895–6905.

[7] Sarwito, S. (1995). Perencanaan Instalasi Listrik Kapal. Departemen Pendidikan dan Kebudayaan Proyek Peningkatan Perguruan Tinggi ITS, Surabaya.

[8] Sarwito, S., and Zaman, M.B. (2019). “Transient stability analysis on ahts vessel electrical system using dynamic positioning system”. Int. J. of Mechanical Eng. and Techno. (IJMET) 10(2): 461–475.

[9] Kusuma, I.R., Sarwito, S. and Irawati, R.A.W.A. (2017). “Analysis of electric propulsion performance on submersible with motor DC, supply power 10260AH at voltage 115VDC”. Int. J. of Marine Eng. Innovation and Research 1(2).

[10] Sarwito, S., Semin, S. and Suherman, A. (2017). “Analysis of three phases asynchronous slip ring motor performance feedback type 243”. Int. J. of Marine Eng. Innovation and Research 2(1).

[11] Chanif, M.M. and Sarwito, S.S. (2014). “Analisa pengaruh penambahan kapasitor terhadap proses pengisian baterai wahana bawah laut”. J. Teknik ITS 3(1): G70–G75.

[12] Silalahi, E.K., Sarwito, S. and Kurniawan, A. (2017). “Analisa teknis dan ekonomis automatic stacking crane di PT. Terminal Teluk Lamong PELINDO III”. J. Teknik ITS 5.

[13] Kurniawan, A., Adam, F., Fitri, S.P. and Sarwito, S. (2016). “Experimental study of magnesium anode voltaic cell as electrical source of impressed current cathodic protection for ship hull”. Int. J. of Applied Eng. Research 11(24): 11647–11650.

[14] Andoyo, L., Sarwito, S. and Zaman, B. (2015). “Analisis human error terhadap kecelakaan kapal pada sistem kelistrikan berbasis data di kapal”. J. Teknik ITS 4(1): G10–14.