Electrical Systems Design of a Maritime Search and Rescue Vessel

“A report submitted to the School of Engineering and Energy, Murdoch University in partial fulfilment of the requirements for the degree of Bachelor of Engineering”

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Abstract
This thesis report documents an investigation into the electrical engineering aspects and design considerations pertinent to the maritime industry and, in particular, to ship building. The investigation is a review of the electrical power systems of a 35 metre search and rescue (SAR) vessel designed and constructed for the Philippines coast guard by BAE Systems at its Henderson shipbuilding facility in Perth, Western Australia. The purpose of reviewing the electrical systems of the 35M vessel is to provide a platform from which future vessels of similar class, size and operational purpose can be designed.

The electrical engineering design aspects include an introductory description of the rules for classification for which vessels are constructed and in particular that of the 35M SAR vessel and the structure of project management and the interrelationships between different engineering and design departments which are involved in the 35M SAR shipbuilding process. The re-validation of the electrical engineering systems includes the use of the existing 35M SAR vessels load demand to determine generator sizing, three phase motor starting arrangements, cabling, protection and DC emergency power systems, all of which are referenced against classification rules and international standards requirements where applicable.

The document is constructed in a systematic way which allows the reader to identify the design processes involved in the 35M SAR vessel. Its order may not specifically represent the order for which the electrical design is carried out; additionally it does not include specific mechanical or architectural design detail. However generalised detail is included, where applicable, in order to provide background information.

It has been shown that a systematic approach to shipbuilding and a constructive and professional relationship between various engineering and design departments is paramount to the successful construction of a maritime vessel. It was additionally identified that during the electrical engineering design process, assumptions are made based on past experiences and practical appreciation for vessel load demands during normal operational conditions, which ultimately ensures system loading is reduced while still maintaining operational requirements of the vessel. It is however identified that over-sizing of some items, such as cables, is deliberate in order to reduce installation errors and potential product availability issues.
Acknowledgements

BAE Systems for the opportunity to review the 35M Search and Rescue Vessel at the Henderson facility in Perth, Western Australia and providing access and usage of drawings throughout this report. Special thanks to Stelios Daniels, Senior Electrical Engineer at BAE Systems for ongoing assistance and advice throughout the project and Murdoch University supervisor Dr Gregory Crebbin.
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Introduction

1.1. Shipbuilding Design Rules
The majority of marine infrastructure, which includes ships and offshore structures, are built and maintained to established technical standards in relation to their design, construction and survey. These standards are defined by classification societies.

Classification societies themselves have been in existence since the second half of the 18th century when the first recorded and arguably most well known society, Lloyds Register, was established. Historically it is accepted that marine insurers, being based at Lloyd’s coffee house in London, developed an independent hull and equipment inspection system which could be used to establish the condition of ships presented to them for insurance cover. In 1760 a committee was established for this sole purpose, which resulted in the first recorded survey standards being Lloyd’s Register Book for the years 1764-65-66 (IACS 2006).

In all, it is accepted that there are now 50 or more classification societies worldwide. However eleven of these organisations collectively class more than 90% of all commercial shipping tonnage involved in international trade. These eleven member organisations, including an associate member, make up the IACS (The International Association of Classification Societies) which was established in 1968; however its origins date back to the international load convention of 1930 (IACS 2006).

The ten member societies which make up IACS are:

- ABS American Bureau of Shipping
- BV Bureau Veritas
- CCS China Classification Society
- DNV Det Norske Veritas
- GL Germanischer Lloyd
- KR Korean Register of Shipping
- LR Lloyds Register
The society additionally includes the following associate:

- IRS: Indian Register of Shipping

The purpose of a classification society is to establish and apply standards to ships and other marine related facilities and structures in relation to design and construction, including electrical systems. These established rules are not design codes and cannot as such be used for specific design purposes, however the rules are intended to assess structural strength and integrity of essential parts of a ships hull, appendages and the reliability and function of other equipment to maintain essential services on board (IACS 2006). Reliability and function of other equipment includes propulsion systems, steering systems, power generation etc. Therefore the use of classification societies in the construction of marine infrastructure provides owners, insurers, financiers and ports, through which vessels transit, the confidence that vessels and infrastructure having met classification society rules are fit for purpose and pose minimal risk to cargo, life and the environment (IACS 2006).

The implementation of classification rules includes a number of processes which start with a technical review of the design for a new vessel followed by a visual inspection of the vessel during the construction phase which includes attendance at relevant production facilities that provide key components such as engine, generators etc and on satisfactory completion of the above a certificate of classification is issued. Once in service the vessel must undergo periodic class surveys and meet the relevant rule conditions in order to maintain class certification. It should be noted that a classification survey is a visual examination that consists of an examination of the items intended for survey, detailed checks of selected parts, witnessing tests, measurements and trials (IACS 2006).

A Classification society by its nature is “self-regulating, independent and externally audited” and “has no commercial interests related to ship design, ship building, ship ownership, ship
operation, ship management, ship maintenance or repairs, insurance or chartering” (IACS 2006, p.3).

It is fundamentally classification societies and design rules that determine the electrical power systems on-board marine vessels including the 35M search and rescue reviewed in this report.
Vessel Background

2.1. Det Norske Veritas (DNV) Classification
The 35M Search and Rescue (SAR) vessel, which is investigated throughout this report, uses the Det Norske Veritas (DNV) rules for classification of high speed, light craft and naval surface craft. The choice of one classification standard over another is generally dependent on the customer preference which may be based on classifications for other vessels within a fleet or the location for which the vessel is predominantly located. Additionally it may be a preference to the ship builder or design consultancies. In the case of the 35M SAR vessel it was a customer preference based on the existing use of the DNV classification; DNV is a Norwegian classification society originally formed in 1864.

DNV rules for classification of high speed, light craft and naval surface craft cover a number of topic areas which include:

- Part 0 Introduction
- Part 1 Regulations
- Part 2 Materials and Welding
- Part 3 Structures, Equipment
- Part 4 Machinery and Systems – Equipment and Operations
- Part 5 Special Service and Type – Additional Class
- Part 6 Special Equipment and Systems – Additional Class
- Part 7 HSLC in Operation

Each part is subsequently divided into a number of chapters with Part 4 (Machinery and Systems – Equipment and Operation) being relevant to electrical systems. Part 4 is divided into the following chapters:

- Part 4 Chapter 1 Machinery Systems, General
- Part 4 Chapter 2 Rotating Machinery, General
- Part 4 Chapter 3 Rotating Machinery, Drives
- Part 4 Chapter 4 Rotating Machinery, Power Transmission
2.2. Standards

DNV classifications and indeed all classifications are related to technical requirements which are based on international standards. Therefore, classification societies rules for electrical installations on ships use the IEC (International Electrotechnical Commission) standards; IEC is a world wide organisation for standardisation whose objective is to promote international cooperation on all questions concerning standardisation including the electrical and electronic fields (IEC 92).

IEC60092 –Electrical Installations in Ships is the primary standard referenced by DNV and must be adhered to. The society does however allow standards other than IEC60092 for ship design if
they are found to represent an overall safety concept equivalent to that of the rules. In other words standards such as the Australian Standards which are not directly referenced by DNV can be used to augment the class rules if required, and therefore can be used if the content adequately reflects that of the equivalent IEC standard; however this is at the discretion of the classification society and on request must be provided to the society for review on demand. Generally Australian Standards are used only if the IEC standards do not provide sufficient design information or are not accessible. An example is the use of AS1150 for lighting compliance on ships as detail within this standard facilitates minimum lux requirements and design guidelines which are not directly specified or available in the rules or IEC standards. The use of Australian Standards additionally facilitates electrical equipment and component selection and purchases as these items must, as a minimum, meet Australian Standards for sale in Australia.

Table 1 below outlines the Society Classification Rules, International Standards and Australian Standards referenced during the electrical systems design of the 35 metre search and rescue vessel.

In addition to the standards and rules specified in Table 1 below, which are electrically specific in nature, the 35M SAR vessel is built to the following international convention, regulation and standards:

- IMO International Code of Safety for High Speed Craft (HSC Code)
- SOLAS 1997 (Safety Of Life At Sea)
- International Load Line Convention 1966 (The stability of ships is seriously affected by overloading; the load line is a line or number of lines marked on the side of a hull to indicate how low a vessel may rest in the water)
- International Tonnage Convention 1969 (Universal tonnage measurement systems of vessels)
<table>
<thead>
<tr>
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<th>Title</th>
<th>Year:</th>
</tr>
</thead>
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<td>Ships/High Speed, Light Craft and Naval Surface Craft – Part 4, Chapter 8 Electrical Installations</td>
<td>January 2001</td>
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<tr>
<td>IEC60092</td>
<td>Electrical Installations in Ships</td>
<td>1994-08</td>
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<tr>
<td>AS3000</td>
<td>Wiring Rules</td>
<td>2007</td>
</tr>
<tr>
<td>AS1150</td>
<td>Artificial Illumination in Ships</td>
<td>1983</td>
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Table 1: Classification Rules, International and Australian Standards - Electrical
Shipbuilding Design Process

3.1. Project Management
Similar to other construction processes, shipbuilding requires the integration of a number of engineering, design and management disciplines to successfully complete project requirements. The aim of any design is fundamentally to meet all identified user requirements while still maintaining cognisant understanding of applicable platform or project constraints. The meeting of user requirements can be subsequently divided into a number of key requirements including function, performance, environmental, construction, safety, reliability, availability and maintainability requirements while ensuring compliance with regulatory and statutory authorities.

3.1.1. Shipbuilding Disciplines
The shipbuilding process at BAE Systems is divided into a number a key design sections with each section being the responsibility of a particular design discipline, with the coming together of each section resulting in a finished vessel. Design specifications in themselves are dependant on the customer and can be developed by independent naval consultants, or, if adequate technical knowledge is available within the vessel customer’s organisation, then specifications are created internally. Alternatively, a customer will approach a ship builder such as BAE Systems and request the creation of a specifications document based on general guidelines. These design specifications mentioned above are referred to as technical specifications.

The specific vessel technical specifications are generally divided into the following sections:

- General
- Hull Structure and Outfit
- Air Conditioning and Ventilation
- Electrical
- Mission Systems
- Passenger and Crew Fitout
- Main Machinery
- Vessel Systems
- Life Saving, Fire and Safety

General technical construction specifications typically includes details such as climatic conditions, in which the vessel will operate, certificate and classification build rules, sea trial guidelines and language and measurement units used for construction. Structural design specifications can include steel thickness for deck plating, skegs and keel plate etc. while accommodation and outfit design specification covers everything from acoustic installation, windows, pipe work colouring, cathode protection and power supply format.

The design disciplines are divided into the following:

- Naval Architecture - Generally naval architecture is involved in hull structure and fitout, life saving and fire safety, and ride control systems, which come under main machinery. Additionally naval architects are involved in documentation, design parameters and sea trials. Figure 1a shows a scaled model of the 35M SAR vessel hull under test at various speeds as designed by the naval architecture discipline.

- Electrical Engineering - Electrical engineering is fundamentally responsible for the electrical systems of the vessel including power generation, power distribution, protection, control, lighting and all associated alarm systems.

- Mission Systems - Mission systems account for the navigation and communication systems required by class rules including navigation lighting requirements although connection and protection etc is a responsibility of electrical engineering.

- Mechanical Engineering - Mechanical engineering is involved in vessel systems such as fuel, sanitary, water and exhaust. Additionally mechanical engineers design HVACs and selects and installs main machinery equipment including engines, gear boxes and steering gear etc. (Figure 1b shows the main propulsion plant installed in the as-built vessel)
- Design Drafting - Design drafting is responsible for the technical drawings across all disciplines.

Figure 1: (a) Scale model of 35M SAR hull under performance testing; (b) Port side main propulsion engine – 3508B Caterpillar marine diesel (BAE Systems n.d)

Appendix B includes a general arrangement drawing of the 35M SAR vessel. The intention of this drawing is as a background reference only to general vessel arrangements.

3.1.2. Electrical Systems Design Process
The design of a ship’s electrical system is an iterative process in which the interrelationship between varying design disciplines is fundamental to final completion. The flow chart of figure 2 below defines the design process and shows the interrelations between various disciplines in order to successfully complete the electrical system design of the 35M SAR vessel. It can be seen from the flow chart that the design process includes the creation of a tender document. The tender documentation is included as part of the electrical design as BAE Systems does not maintain electrical personal at its Henderson facility which is used for the sole purpose of ship
maintenance and construction and therefore electrical contractors are employed for the electrical fit-out duties. The development and details of the tender documentation will not be covered in this report.
Figure 2: Electrical engineering design process flow chart

- Client Request
  - Naval Architecture – Estimated Load
  - Projects and Fit-out – Estimated Load
  - Mechanical Engineering – Estimated Load

Ship Requirements
  - Hull design specifications
  - Type of vessel

Load Demand Profile
  - Load requirements extrapolated from ship requirements
  - Ongoing
  - Generic sizing of equipment load (create load envelope – over estimate)
  - Estimate number of GPO’s, lighting and electronics load
  - Initial single line diagram created
  - DC system load identified

Tender Estimate
  - Major design issues addressed (Motor starters, number of generator sets and size)
  - Equipment ratings (switchboards, DB’s etc.)
  - Consultation on load changes
  - Vendor packages

Vendor Package Specifications
  - Load envelope revised (based on experience or more detailed design analysis i.e. single line diagram)
  - Vendor package input and delays identified

Electrical Sub-Contractor Specifications
  - Load envelope revised (mechanical load errors accounted)
  - Ongoing process
  - Galley equipment load generally an issue (excessive load from original specs)

Detailed Electrical Design Begins

Load Demand Updated
  - Loads confirmed in conjunction with mechanical, naval, projects and fit-out
  - Circuit breakers, Cable sizes confirmed

Electrical Contract Award Stage

Single Line Diagram
  - Distribution Board Design & Diagrams
  - Emergency Supply Design & Diagrams
  - Motor Starter Diagrams
The Electrical System

4.1. Power and Distribution

The AC distribution system of the 35M SAR vessel is designed to the following characteristics:

- 440V three phase ac / 60Hz / 3 wire without neutral + earth
- 220V single phase ac / 60Hz / 2 wire without neutral

The relationship between 440V and 220V is not through normal phase and line voltages which occur when a generating system has a grounded neutral, as can be seen from figure 3a below, but is an historical convention for ship electrical systems and created through the use of a transformer, as shown in figure 3b.

![Diagram of 440V and 220V relationship](a)

![Diagram of 440V and 220V relationship achieved through transformer action](b)

Figure 3: a) 440V and 220V relationship (note 220V phase voltage is not related to 440V line voltage). b) 440V and 220V relationship achieved through transformer action.

The selection of the 440V / 60Hz three phase distribution system is due to the following reasons:

- 440V systems draw relatively small current resulting in less distribution loss
- Increase in frequency (above 50Hz) results in physically smaller equipment for same power rating
- 440V / 60Hz is the standard power systems characteristics used extensively in military and Para-military vessels and is the standard for low voltage distribution used by NATO.
- DNV (Det Norske Veritas) class acceptable voltage and frequency values.

An addition feature of the electrical system characteristics is the type of distribution system incorporated on the 35M SAR vessel. The project vessel uses what is known as an insulated neutral system. An insulated neutral system can be best described by first identifying an earthed neutral system. Earthed neutral systems are widely used in land based power generation and distribution networks and in simple terms refer to the connection of a power system neutral point to earth via a grounding conductor and grounding electrode as shown in figure 4a below. In comparison an insulated neutral system has no direct connection from the power system neutral point to earth as shown in figure 4b.

![Figure 4: (a) Earthed neutral (system) grounding; (b) Insulated neutral system](image)

The major advantage of an insulated neutral system is related to reliability during a phase to ground fault. During a phase to ground fault, which can occur with insulation breakdown, there is no path for the fault current to return to the source, as a result the load is unaffected and
continues to operate normally; this is evident in figure 5 below. For completeness, however, a capacitive coupling effect does exist between each active conductor and ground which results in a circulating current path for the fault current. However due to the very high reactive value of this capacitive coupling effect, while currents do actually flow, they are small.

Figure 5: Insulated neutral system during phase to ground fault.
4.2. Load Demand

The calculation of load demand is achieved by the interrelations between the various engineering and design disciplines with each providing the electrical size of items relevant to their discipline that meet design requirements. The easiest way to accommodate these loads from an electrical engineer's perspective is by use of a load analysis spreadsheet which allows the easy tracking and modification of electrical equipment and their respective power requirements. Table 2 below provides a sample of the load analysis spreadsheet constructed for the 35M SAR vessel.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>220V kW</th>
<th>440V kW</th>
<th>220V kVA</th>
<th>440V kVA</th>
<th>Connected Load kW</th>
<th>Connected Load kVA</th>
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</thead>
<tbody>
<tr>
<td>Bilge Pump</td>
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<td></td>
<td></td>
<td></td>
<td>1.40</td>
<td>6.36</td>
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<td>Desalination Unit</td>
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<td>2.2</td>
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<td>0.2</td>
<td></td>
<td>0.2</td>
<td>0.91</td>
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Table 2: Load analysis spreadsheet – sample of loads for 35M SAR vessel as constructed.

The load analysis spreadsheet divides loads into 220V and 440V connections with 220V being single phase and 440V being three phase. In addition to the division of loads between three phase and single phase, equipment is divided into resistive (input) and reactive (motor) which allows for the identification of equipment that have a reactive component and those that do not.

During early design stages name plate data and specifications for motors and other electrical equipment is not always available when load demand calculations are being performed so the selection of power factor and efficiency for motors are based on a generic load table (see Table 3 below). It is preferable however to use actual motor specifications, if available, as actual power factors and efficiencies of smaller motors including single phase motors can be very low.
Load demand of the 35M SAR vessel is determined from its operational status and not the full load characteristics of all electrical equipment and machinery operating simultaneously. As the 35M SAR is a patrol type vessel it can therefore, effectively, operate in one of four electrical power modes which are cruising, harbour, fire monitor and shore.

- Cruising mode operation is considered the normal operating condition of the vessel and, as the name suggests, relates to the electrical power consumed when the vessel is under transit or cruising conditions. The determination of load under this mode of operation is dependent on the functionality of electrical equipment, experience of the design engineer

<table>
<thead>
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<th>3PH-KW</th>
<th>PF</th>
<th>EFF</th>
<th>1PH-KW</th>
<th>PF.X.EFF</th>
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<tr>
<td>4</td>
<td>0.84</td>
<td>0.82</td>
<td>1.6</td>
<td>0.59</td>
</tr>
<tr>
<td>5.5</td>
<td>0.85</td>
<td>0.83</td>
<td>2.2</td>
<td>0.55</td>
</tr>
<tr>
<td>7.5</td>
<td>0.86</td>
<td>0.85</td>
<td>3</td>
<td>0.65</td>
</tr>
<tr>
<td>11</td>
<td>0.86</td>
<td>0.87</td>
<td>3.75</td>
<td>0.67</td>
</tr>
<tr>
<td>13</td>
<td>0.86</td>
<td>0.87</td>
<td></td>
<td></td>
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<tr>
<td>15</td>
<td>0.86</td>
<td>0.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18.5</td>
<td>0.86</td>
<td>0.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>0.87</td>
<td>0.89</td>
<td></td>
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</tr>
<tr>
<td>30</td>
<td>0.87</td>
<td>0.9</td>
<td></td>
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<tr>
<td>37</td>
<td>0.87</td>
<td>0.9</td>
<td></td>
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<tr>
<td>45</td>
<td>0.88</td>
<td>0.91</td>
<td></td>
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<tr>
<td>55</td>
<td>0.88</td>
<td>0.91</td>
<td></td>
<td></td>
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<tr>
<td>75</td>
<td>0.88</td>
<td>0.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>0.88</td>
<td>0.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>0.88</td>
<td>0.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>132</td>
<td>0.88</td>
<td>0.92</td>
<td></td>
<td></td>
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<tr>
<td>160</td>
<td>0.88</td>
<td>0.93</td>
<td></td>
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<tr>
<td>200</td>
<td>0.88</td>
<td>0.93</td>
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<tr>
<td>250</td>
<td>0.88</td>
<td>0.93</td>
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<td>315</td>
<td>0.88</td>
<td>0.93</td>
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<tr>
<td>400</td>
<td>0.89</td>
<td>0.96</td>
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<td></td>
</tr>
</tbody>
</table>

Table 3: Generic motor power factor and efficiencies (BAE Systems n.d.)
and practical appreciation for load demand of equipment, such as lights and power outlets used specifically by the crew.

- Harbour operations are a representation for when the vessel is performing in-shore duties and may include in-shore anchorage with crew living on-board.

- Fire monitor is the operational mode for the vessel when performing ship to ship or ship to shore fire fighting duties.

- Shore mode does not involve operations of the types mentioned previously but relates to the load consumed by the vessel when along-side. While along-side the vessel may be undergoing maintenance or preparing for departure.

Table 4 is an example of various load demands of equipment as a percentage value over all operation modes.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Connected Load</th>
<th>Cruise</th>
<th>Cruise</th>
<th>Harbour</th>
<th>Harbour</th>
<th>F/Monitor</th>
<th>F/Monitor</th>
<th>Shore</th>
<th>Shore</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kVA</td>
<td>%</td>
<td>kVA</td>
<td>%</td>
<td>kVA</td>
<td>%</td>
<td>kVA</td>
<td>%</td>
<td>kVA</td>
</tr>
<tr>
<td>Bilge Pump</td>
<td>1.40</td>
<td>100</td>
<td>1.40</td>
<td>100</td>
<td>1.40</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Desalination Unit</td>
<td>3.27</td>
<td>60</td>
<td>1.96</td>
<td>0</td>
<td>60</td>
<td>1.96</td>
<td>60</td>
<td>1.96</td>
<td></td>
</tr>
<tr>
<td>Sewage Treatment</td>
<td>3</td>
<td>60</td>
<td>1.80</td>
<td>0</td>
<td>60</td>
<td>1.80</td>
<td>60</td>
<td>1.80</td>
<td></td>
</tr>
<tr>
<td>Antifouling System</td>
<td>0.2</td>
<td>100</td>
<td>0.2</td>
<td>100</td>
<td>0.2</td>
<td>100</td>
<td>0.2</td>
<td>100</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Table 4: Load demands of equipment in various operational modes

Table 5 below identifies the load demand of the 35M SAR vessel as built in each operational mode and the total load of the vessel. Future vessels will inevitably have different load values.

<table>
<thead>
<tr>
<th>Total</th>
<th>Cruise</th>
<th>Harbour</th>
<th>Fire Monitor</th>
<th>Shore</th>
</tr>
</thead>
<tbody>
<tr>
<td>kVA</td>
<td>194.83</td>
<td>71.11</td>
<td>65.62</td>
<td>86.57</td>
</tr>
</tbody>
</table>

Table 5: 35M SAR load demand at various operational modes
4.3. **Sizing Generator Sets**

The sizing of generator sets for the 35M SAR vessel, and indeed all vessels, is based on IEC60092 standard, Pt.201- Electrical Installations in Ships. Section 2 of Pt.201 stipulates that every ship shall be provided with a main source of electrical power that consists of at least two generator sets and is capable of suppling all auxiliary electrical services for maintaining the ship in normal operating conditions without the use of emergency power facilities. The normal operating conditions for the 35M SAR vessel is cruising mode. Additionally the capacity of the generator sets shall be such that if one is rendered inoperable then the remaining unit must be capable of suppling the electrical services necessary to provide normal operational conditions of propulsion and safety, minimum habitability conditions with respect to comfort, and preservation of cargo if applicable (IEC92 1994).

As is seen from Table 4 above (Sec 4.2) the load demand in cruising mode of the 35M SAR vessel is approximately 71kVA, which equates to 56.8kW for a 0.8 power factor. Therefore, based on this load demand, each of the generators must be at least 71kVA in size.

As generator sets are usually only available in a number of discrete sizes, it is at the discretion of the electrical engineer to determine what capacity of alternator is finally chosen. Final sizing generally depends on the following:

- **Temperature Class F** – thermal classification in accordance with DNV Pt.4, Ch.8 Sec.5 – Rotating Machines: temperature rise in windings of alternator units having output of less than 5000kVA. Options are available, however BAE Systems selects Class ‘F’ due to ability of HVAC systems to control vessel internal temperatures, and ambient temperature operating conditions for vessel.
- **Operational Load demand** – must meet operational load demand as defined by DNV Pt.4, Ch.8, Sec.2 – Main Electrical Power Supply System. A design margin may be included depending on the detail to which load demand has been calculated.
- **Electrical System Distribution Requirements** - 440V three phase ac / 60Hz
- **Diesel Engine Requirements** – generator sets cannot be oversized with respect to load conditions. Diesels operating in an unloaded state, typically less than 40-50% of rated capacity, experience combustion related issues resulting in premature failure or excessive maintenance outcomes of the engine.
Based on the normal operational load demand for the 35M SAR vessel, two (2) Caterpillar 3304B generating sets, each rated at 65kW were used. Typically the engine manufacturer is selected by the mechanical engineering discipline in alignment with mechanical build specifications, and therefore options for a particular alternator manufacturer may be limited.

As the model of generators used on the 35M SAR may not be available for future vessel of this class and design, the ‘Stamford’ model UCM274C alternator has been selected for design revalidation purposes as it is a common alternator with capacities which meet voltage, frequency and load demands currently specified for the 35M SAR.

Figure 6 below identifies the alternator ratings at various class temperatures, frequency and winding configurations for the Stamford UCM274C alternator. Based on the ‘F’ class temperature rating, 60Hz frequency requirements, 440V level and 71kVA load demand it is seen that an alternator rated at 74kW or 92.5kVA base continuous rating is required. Base continuous rating, also known as basic continuous, continuous running duty or continuous duty is the specified (kVA) rating at specified ambient temperature and power factor for continuous use without overstressing the insulation (Stamford 2006).

With a basic calculation it is shown that an alternator rated at 92.5kVA will be loaded to approximately 77% of its rating under normal operating conditions thus meeting diesel engine operating condition requirements as discussed above.

\[
\text{Diesel Engine Loading (\%)} = \frac{\text{Load Demand (kVA)}}{\text{Alternator Rating (kVA)}} \times 100\% = \frac{71.11}{92.5} \times 100\% \approx 77\%
\]
### RATINGS

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>50 Hz</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Series Star (V)</td>
<td>380 400 415 440</td>
<td>380 400 415 440</td>
<td>380 400 415 440</td>
<td>380 400 415 440</td>
</tr>
<tr>
<td>Parallel Star (V)</td>
<td>190 200 208 220</td>
<td>190 200 208 220</td>
<td>190 200 208 220</td>
<td>190 200 208 220</td>
</tr>
<tr>
<td>Series Delta (V)</td>
<td>220 230 240 254</td>
<td>220 230 240 254</td>
<td>220 230 240 254</td>
<td>220 230 240 254</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KVA</td>
<td>65.0 65.0 65.0 N/A</td>
<td>67.5 67.5 67.5 N/A</td>
<td>77.5 77.5 77.5 N/A</td>
<td>81.5 81.5 81.5 N/A</td>
</tr>
<tr>
<td>KW</td>
<td>52.0 52.0 52.0 N/A</td>
<td>54.0 54.0 54.0 N/A</td>
<td>62.0 62.0 62.0 N/A</td>
<td>65.2 65.2 65.2 N/A</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>91.6 91.8 92.0 N/A</td>
<td>91.5 91.8 91.9 N/A</td>
<td>91.0 91.4 91.6 N/A</td>
<td>90.6 91.2 91.4 N/A</td>
</tr>
<tr>
<td>kW Input</td>
<td>56.8 56.8 56.5 N/A</td>
<td>59.0 58.8 58.8 N/A</td>
<td>68.1 67.8 67.7 N/A</td>
<td>71.6 71.5 71.3 N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>60 Hz</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Series Star (V)</td>
<td>416 440 460 480</td>
<td>416 440 460 480</td>
<td>416 440 460 480</td>
<td>416 440 460 480</td>
</tr>
<tr>
<td>Parallel Star (V)</td>
<td>208 220 230 240</td>
<td>208 220 230 240</td>
<td>208 220 230 240</td>
<td>208 220 230 240</td>
</tr>
<tr>
<td>Series Delta (V)</td>
<td>240 254 266 277</td>
<td>240 254 266 277</td>
<td>240 254 266 277</td>
<td>240 254 266 277</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KVA</td>
<td>72.0 72.5 75.0 75.0</td>
<td>75.0 77.5 80.0 80.0</td>
<td>90.0 92.5 97.5 97.5</td>
<td>93.8 102.5 102.5 108.8</td>
</tr>
<tr>
<td>KW</td>
<td>57.6 58.0 60.0 60.0</td>
<td>60.0 62.0 64.0 64.0</td>
<td>72.0 74.0 78.0 78.0</td>
<td>75.0 82.0 82.0 87.0</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>91.9 92.2 92.3 92.5</td>
<td>91.8 92.0 92.2 92.4</td>
<td>91.2 91.5 91.7 91.9</td>
<td>91.1 91.2 91.5 91.6</td>
</tr>
<tr>
<td>kW Input</td>
<td>62.7 62.9 65.0 64.9</td>
<td>65.4 67.4 69.4 69.3</td>
<td>78.9 80.0 85.1 84.9</td>
<td>82.4 89.9 89.6 95.0</td>
</tr>
</tbody>
</table>

Figure 6: Stamford model UCM274C alternator with selection indicated (Stamford UCM274C Technical Data Sheet 2006)

Figure 7: Stamford alternator 12 lead connection types (Stamford UCM274C Technical Data Sheet 2006)
4.4. Fault Level Calculations

There are two independent means of providing electrical power to the 35M SAR vessel, one through the onboard generating capacity and the other through a shore supply connection. With respect to the 35M SAR the two independent power sources cannot be paralleled, as such electrical power is either supplied by the onboard generation or shore connection only. To ensure that paralleling is not enacted an interlock connection internal to the main switch board is installed.

Fault level calculations are performed in order to correctly size buses, protective equipment and cable fault rating. Due to the interlock arrangement of the power sources, on the 35M SAR, and the shore supply limited at 60A, the fault level calculations use the onboard power sources.

Calculations are based on a symmetrical three phase short circuit fault. When a symmetrical short circuit fault occurs on a synchronous generator the ac component of the fault current can be divided into three periods, sub-transient period (X''), transient period (X') and steady-state period (X) as seen in figure 8 below. From figure 8 it can be seen that the maximum fault current occurs during the sub-transient period.

![Figure 8: Symmetric ac component of fault current (Stevenson 1992)](image)

There are number of ways in which the sub-transient fault current can be determined such as:

- Calculations using the sub-transient reactance value provided by alternator manufacturers
- Obtaining short circuit values direct from alternator/Genset manufacturers
The sub-transient fault current will be calculated using the MVA and per-unit methods (for comparison purposes only) based on the sub-transient reactance value as specified from the UM274C Stamford alternator data sheet. Full specifications sheets for the UCM274C Stamford alternator are given in Appendix C.

<table>
<thead>
<tr>
<th>TELEPHONE INTERFERENCE</th>
<th>50 Hz</th>
<th>60 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>COOLING AIR</td>
<td>0.216 m/sec 458 cfm</td>
<td>0.204 m/sec 595 cfm</td>
</tr>
<tr>
<td>VOLTAGE SERIES STAR</td>
<td>360/220 400/231 415/240 440/254</td>
<td>416/240 440/254 460/266 480/277</td>
</tr>
<tr>
<td>VOLTAGE SERIES DELTA</td>
<td>220/110 230/115 240/120 254/127</td>
<td>240/120 254/127 266/133 277/138</td>
</tr>
<tr>
<td>KVA BASE RATING</td>
<td>71.5 71.5 71.5 62.7</td>
<td>84.5 87 91 92</td>
</tr>
<tr>
<td>Xd DIR. AXIS ASYNCHRONOUS</td>
<td>2.04 1.85 1.72 1.48</td>
<td>2.40 2.20 2.11 1.96</td>
</tr>
<tr>
<td>Xd DIR. AXIS TRANSIENT</td>
<td>0.16 0.14 0.13 0.12</td>
<td>0.18 0.17 0.16 0.15</td>
</tr>
<tr>
<td>X'y' DIR. AXIS SUBTRANSIENT</td>
<td>0.11 0.10 0.09 0.08</td>
<td>0.13 0.12 0.11 0.11</td>
</tr>
<tr>
<td>X'y' QUAD. AXIS REACTANCE</td>
<td>0.94 0.85 0.70 0.69</td>
<td>1.10 1.01 0.96 0.90</td>
</tr>
<tr>
<td>X'y' QUAD. AXIS SUBTRANSIENT</td>
<td>0.14 0.13 0.12 0.11</td>
<td>0.14 0.12 0.12 0.11</td>
</tr>
<tr>
<td>X Leakage Reactance</td>
<td>0.06 0.05 0.05 0.04</td>
<td>0.07 0.06 0.06 0.06</td>
</tr>
<tr>
<td>X2 NEGATIVE SEQUENCE</td>
<td>0.13 0.12 0.11 0.10</td>
<td>0.14 0.12 0.12 0.11</td>
</tr>
<tr>
<td>X2 Zero Sequence</td>
<td>0.09 0.08 0.08 0.06</td>
<td>0.10 0.09 0.09 0.08</td>
</tr>
</tbody>
</table>

Reactances are saturated at values are per unit at ratings and voltage indicated.

4.4.1. Fault level calculation: MVA method
The MVA method is a useful method when performing field calculations as it is quick and easy to perform with accuracy within 5%.

![Figure 9: Stamford UCM224G alternator specifications extract (Stamford UCM274C Technical Data Sheet 2006)](image)

![Figure 10: Single Line Diagram – fault at main bus](image)
Fault MVA = \( S/X \).................................................................(1)

\( S = 3\Phi \) Apparent Power, \( X = \) sub-transient reactance

\[ \text{Gen 1 Fault MVA} = \frac{0.0925}{0.12} = 0.7708 \text{MVA} \]

\[ \text{Gen 2 Fault MVA} = \frac{0.0925}{0.12} = 0.7708 \text{MVA} \]

\[ \text{Fault MVA Total} = \text{Gen1 Fault MVA} + \text{Gen 2 Fault MVA} = 0.7708 + 0.7708 = 1.542 \text{MVA} \ldots (2) \]

Therefore:

\[ \text{Sub-transient fault (I'')} = \frac{\text{Fault MVA Total}}{\sqrt{3.V}} = \frac{1.542 \times 10^6}{\sqrt{3.440}} = 2023 \text{A} \]
4.4.2. Fault level calculation: Per-Unit method
Reference should be made to figure 10 above.

\[
Impedance \ Base \ (Z_B) = \frac{V_B^2}{S_B} = \frac{(440)^2}{92.5 \times 10^3} = 2.09
\]

\[V_B = Line \ Voltage, \ S_B = 3\Phi \ Apparent \ Power\]

\[
Impedance \ Equivalent \ (Z_{eq}) = Z_B \times Z_{pu} = 2.09 \times 0.12 = 0.2511
\]

\[Z_{pu} = Per-Unit \ sub-transient \ Impedance\]

\[
Gen \ 1 \ Fault \ Current \ (I') = \frac{V}{Z_{eq}} = \frac{440}{\sqrt{3} \times 0.2511} = 1011A
\]

Therefore:

\[
Total \ Fault \ Current \ (I') = Gen1 \ Fault \ Current \ \times 2 = 2022A
\]

Assumptions made during fault calculations:

- All non-rotating impedance loads neglected
- Synchronous generators armature resistance, saliency and saturation neglected
- Cable impedances to point of fault neglected due to short lengths
- Generators both operating under no load conditions
- Three phase fault calculated
4.4.3. Fault Value
With the fault level calculated at approximately 2000A, it is possible to ensure that the main switchboard equipment is capable of withstanding this prospective fault current. This effectively refers to the main busbar being able to withstand fault conditions for a specified period prior to the circuit breakers acting. In particular, the busbar’s mounts are of major concern with ratings as they undergo large forces during fault conditions. Similarly circuit breakers must be capable of breaking this fault value. Even though the fault current is approximately 2000A, circuit breakers are only available in specified discrete breaking capacity values which include 4.5kA, 6kA, 10kA, 15kA etc. It is these values which are used to determine the withstand rating of the switchboard. The 35M SAR vessel has therefore been constructed with a main switchboard rated at 10kA. Although this is effectively five times the potential fault current, it does ensure a safety buffer is placed on the switchboard to account for potential inferior construction. Additionally, it is known through experience that circuit breakers are readily available at this breaking capacity value which ensures build delays are mitigated.
4.5. Voltage Transient

The DNV rules for classification Pt.4, Ch.8-Electrical Installations, stipulates that the supply voltage variations for transient states must be -15% to 20% of nominal voltage levels. Voltage transients are most affected by the connection and disconnection of loads with the starting of induction motors having greatest effect on the reduction of voltage levels due to their high starting currents.

The reason for investigating transient voltage levels under induction motor starting conditions is to determine the type of motor starting arrangements required for each motor on board the vessel, as the starting currents for the simplest form of motor starting, that being direct on line (DOL), can be 6 to 8 times the full load current it is necessary to determine which motors can be started DOL and which cannot.

In determining the transient level for each motor it is assumed that only one motor at a time is started, this is a reasonable assumption as the majority of the motors onboard the 35M SAR are manually operated. The transient voltage drop is additionally determined under normal operating conditions for the particular motor. For example, such that the fire monitor pump is investigated under fire monitor mode.

The technical specifications data for the alternator and the induction motor in question are required for determining transient levels with each being readily available from their prospective manufacturer. Full data sheets for the UMC274C alternator and motor data sheets for a 25kW motor are located in Appendix C and D respectively.

Figure 12 below shows the locked rotor motor starting curve for the Stamford UCM274C alternator which provides percentage transient voltage dip of the alternator under motor locked rotor conditions.

From the 25kW motor data sheet (Appendix D), the locked rotor current for an induction motor used for the fire monitor pump onboard the 35M SAR is obtained. Using the locked rotor current of 287A and the system voltage of 440V the locked rotor kVA value of the motor can be determined as follows:
In addition to the locked rotor kVA value the load kVA prior to motor starting is also calculated and subsequently added to the locked rotor load as follows:

\[ S_{FLR} = S_{FMLR} + (S_{FMM} - S_{FN}) = 218 + (86 - 31) = 274 \text{kVA} \]

where: \( S_{FLR} \) is full locked rotor kVA; \( S_{FMLR} \) is full monitor locked rotor kVA; \( S_{FMM} \) is full monitor mode operational kVA; \( S_{FN} \) is full monitor pump kVA

As can be seen from figure 12 the intercept of the locked rotor kVA and percent transient voltage dip shows a potential 24% voltage drop when the 25kW motor is operated. As the DNV rules for classification for transient voltages specifies a maximum 15% voltage drop, the starting of this 25kW motor direct on line is not permitted and an alternative starting arrangement is required.

Figure 12: Locked Rotor Starting Curve Stamford UCM274C Alternator – Percent voltage dip for 25kW motor under locked rotor conditions (Stamford UCM274C Technical Data Sheet 2006)
A number of alternative motor starting arrangements are available which will allow the voltage transient value to align with DNV class rules. These include star-delta, autotransformer, primary or secondary resistance and electronic soft starter. The selection of an alternative motor starting arrangement depends on a number of factors, including motor design (squirrel cage or wound rotor), torque requirements of the motor during starting, harmonic injection of starter, costs and complexity. Due to fundamental design considerations of cost, availability, a requirement for minimal harmonic injection and no inherent problems associated with starting any motor on board the 35M SAR with reduced torque, the star-delta arrangement was selected. Note: the direct-online and star-delta type starters are described in section 4.6.

To ensure transient voltage drop is within DNV rules the star-delta motor starting arrangement is similarly investigated under locked rotor starting conditions as previously performed. Using the locked rotor current of 95A and the system voltage of 440V the locked rotor kVA value of the motor can be determined with a star-delta starter. Note the star-delta starter is a reduced voltage starter and consequently reduces starting current and torque to 33% of nominal values such that the new starting current under locked rotor condition is approximately 95A, down from its 287A value.

\[ S_{LR} = \sqrt{3} \times V_{LL} \times I_{LR} = \sqrt{3} \times 440 \times 95 = 72.2kVA \]

where: \( S_{LR} \) is locked rotor apparent power; \( V_{LL} \) is three phase line voltage; \( I_{LR} \) is locked rotor current

Therefore the resultant full locked rotor kVA is:

\[ S_{FRLR} = S_{FMLR} + (S_{FMH} - S_{FM}) = 72.2 + (0G - 31) = 127kVA \]

where: \( S_{FRLR} \) is full locked rotor kVA; \( S_{FMLR} \) is five monitor locked rotor kVA; \( S_{FMH} \) is five monitor mode operational kVA; \( S_{FM} \) is five monitor pump kVA.
From figure 13, it is evident that the inclusion of a reduced voltage starter in the form of a star-delta arrangement limits the transient voltage dip to 13%, which meets DNV classifications of no more than 15%.

Figure 13: Locked Rotor Starting Curve Stamford UCM274C Alternator – Percent voltage dip for 25kW motor under locked rotor conditions (Stamford UCM274C Technical Data Sheet 2006)

The approach of identifying which motors require an alternative starting arrangement other than DOL is performed on all motor sizes. In practice, however, it is a matter of performing this check on the larger capacity motors until a size is found that can operate within DNV rules without an alternative starting arrangement. After that all smaller capacity motors can start DOL.
4.6. **Motor Starters, Circuit Breakers and Contactors**

As was identified in the previous section, the 35M SAR vessel incorporates DOL (direct on line) and star-delta starting arrangements for its motors. This section is an investigation into the operational principle of each starter, with respect to their wiring schematics, and similarly examines the circuit breaker and contactor selection processes.

4.6.1. **DOL (Direct On Line) Starter**

Drawing 870-020 (Appendix E) is a schematic wiring diagram of the starting arrangement for the 0.75kW fuel transfer pump onboard the 35M SAR vessel which incorporates a contactor controlled DOL starter. As can be seen from drawing 870-020, the circuit breaker has thermal overload and over current protection with the contactor being installed to allow remote pushbutton starting and stop capability. The remote start and stop capability in this case is via momentary contact buttons located at the main switch board (MSB) and control station which is mounted local to the pump unit itself.

Operation of the motor begins by pressing of the start button which completes a circuit through the normally closed stop push button to the relay coil. The relay coil closes the main contactor which places the motor online; additionally the auxiliary contact is closed. The purpose of the auxiliary contactor is to provide an electrical interlock or continuous latch across the start button contacts once it has been released. Taking the motor off-line is achieved by pressing the momentary contact stop which de-energies the contactor.

As the fuel transfer pump operates on a three phase supply of 440V it is evident from drawing 870-020 that the control circuit is similarly at 440V due to its connection across the incoming supply lines. The control circuit does not have to be at the supply line voltage and can be operated at reduced voltage with the use of a step-down transformer to provide a lower voltage; the use of a transformer can additionally be used for isolation purposes. The general arrangement of the control circuit operating on the 440V supply value for the 35M SAR is to limit cost and weight issues.
4.6.1.1. Contactor and Circuit Breaker Selection

Contactors are rated on operating voltages and generally sized according to the kW rating of the motor and load conditions. Additionally the contactors are rated with categories which take into account full load and starting currents; these categories are AC-1, AC-2, AC-3, AC-4. The category AC-3, which is of significance in regard to the fuel transfer pump, has the following attributes: “applies to squirrel cage motors with breaking during normal operating running of the motor. On closing, the contactor makes the starting current, which is about 5 to 7 times the rated current of the motor. On opening, it breaks the rated current drawn by the motor” (Schneider 2006)

The fuel transfer pump onboard the 35M SAR vessel is a 0.75kW, 440V three phase motor. As such, Table 6 below is used to select the appropriate contactor.

![Table 6: Contactors (Schneider Electric Catalogue 2006)](image)

From Table 6 above it is shown that the contactor LC1D09N7 is a 3 pole contactor with one integrated N/O (normally open) and one integrated N/C (normally closed) auxiliary contact rated at 4kW and categorised to AC-3 standard that is capable of performing the contactor function for
the DOL starting of the fuel transfer pump. The N/O auxiliary contact is used as the latch for operation after the start button has been released as previously discussed.

Motor protection is in the form of a circuit breaker with thermal overload and short circuit capabilities. The purpose of incorporating both thermal overload and short circuit into a breaker is to allow the thermal action to operate on small overloads thereby offering variations in tripping times. At higher overloads, such as a motor short circuit condition, the magnetic action takes over with a fast response to break the circuit. Referencing Table 7, it is evident that the motor circuit breaker GV2P07 can be selected to perform the circuit breaker function. It should be noted from the table that the breaking capacity of this model is 100kA. This far exceeds the rating of the main switch board withstand current, but as previously mentioned, devices are only supplied at discrete values and therefore options are limited. Of similar importance is the voltage rating, which although specified at 415V, is rated at 690V and therefore is usable on the 35M vessels 440V power system.

<table>
<thead>
<tr>
<th>KW</th>
<th>Current Setting range - A</th>
<th>Breaking capacity Icu</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>415V</td>
<td>0.1-0.16</td>
<td>100kA</td>
<td>GV2P01</td>
</tr>
<tr>
<td></td>
<td>0.16-0.25</td>
<td>100kA</td>
<td>GV2P02</td>
</tr>
<tr>
<td></td>
<td>0.25-0.4</td>
<td>100kA</td>
<td>GV2P03</td>
</tr>
<tr>
<td></td>
<td>0.4-0.63</td>
<td>100kA</td>
<td>GV2P04</td>
</tr>
<tr>
<td></td>
<td>0.63-1.0</td>
<td>100kA</td>
<td>GV2P05</td>
</tr>
<tr>
<td></td>
<td>1.0-1.6</td>
<td>100kA</td>
<td>GV2P06</td>
</tr>
<tr>
<td></td>
<td>1.6-2.5</td>
<td>100kA</td>
<td>GV2P07</td>
</tr>
<tr>
<td></td>
<td>2.5-4.0</td>
<td>100kA</td>
<td>GV2P08</td>
</tr>
<tr>
<td></td>
<td>4.0-6.3</td>
<td>100kA</td>
<td>GV2P10</td>
</tr>
<tr>
<td>4</td>
<td>6-10</td>
<td>100kA</td>
<td>GV2P14</td>
</tr>
<tr>
<td>5.5</td>
<td>9-14</td>
<td>100kA</td>
<td>GV2P16</td>
</tr>
<tr>
<td>7.5</td>
<td>13-18</td>
<td>50kA</td>
<td>GV2P20</td>
</tr>
<tr>
<td>9</td>
<td>17-23</td>
<td>50kA</td>
<td>GV2P21</td>
</tr>
<tr>
<td>11</td>
<td>20-25</td>
<td>50kA</td>
<td>GV2P22</td>
</tr>
<tr>
<td>15</td>
<td>24-32</td>
<td>50kA</td>
<td>GV2P32</td>
</tr>
</tbody>
</table>

Table 7: Circuit Breakers (Schneider Electric Catalogue 2006)
4.6.2. Star-Delta Starter

Drawing 870-024 (Appendix F) is a schematic wiring diagram of the 25kW fire monitor pump incorporating a contactor controlled Star-Delta starter. As can be seen from the drawing, the circuit breaker has thermal overload and over current protection with the main contactor being installed to allow remote pushbutton starting and stop capability. One of the motor requirements for this type of starter is the need to have each end (six ends) of the three phase pole groups of the stator coils available at the motor terminals for connection to be possible to the star-delta starter. Most three phase motors however have all six winding ends brought out to a terminal box which generally comes in one of two arrangements (see Figure 15).
The star-delta starter is a reduced voltage starter, which is achieved by the starter connecting the motor leads in star configuration and placing the motor on-line. When approximately 80%-90% of full load speed is reached the motor leads are connected in delta configuration. With reference to drawing 870-024 (Appendix F) the principle of operation of the star-delta starter is as follows: The action of pressing the start button energises the star contactor ‘S’ due to the normal closed starting position of the timer contact. Additionally on pressing the start button the main contactor ‘M’ is energised concurrently with the timer relay ‘T’ due to the closure of the auxiliary star contactor ‘S’ and the motor is now on-line. On release of the start button power is still maintained to the main contactor and star contactor through the main and star auxiliary contactors. Once the timer has completed its preset time cycle, the timer contactor ‘T’ is switched, de-energising the star contactor and its auxiliary contact while energising the delta contactor and as such connecting the motor in delta configuration. The switch over from star to delta configuration temporarily disconnects the motor from the supply and is referred to as ‘open circuit transition’. As can be seen from the schematic diagram the two normally closed auxiliary contacts of the delta and star contactors are arranged in such a way as to prevent both the star and delta contactors being engaged at the same time; such a condition would cause a short circuit across the supply. Pressing of the stop button interrupts the supply to the main contactor and delta contactor disconnecting the motor supply.
4.6.2.1. Contactor and Circuit Breaker Selection

The selection process of contactors for the 25kW fire monitor pump is similar to that used for the 0.75kW fuel transfer pump as previously discussed. However due to the nature of the star-delta starting arrangement of the fire monitor pump the star contactor is rated to handle 33% of rated power while the delta and main contactors are rated at $1/\sqrt{3}$ of the motors rated power. Rating main and delta contactors at 58% is due to the current across the windings being reduced by delta current relationships.

Table 8: Contactors (Schneider Electric Catalogue 2006)

| Star contactor “S” | Main and Delta contactor “M” & “D” |

From Table 8 it is seen that the contactor LC1D18N7 is suitable for connection as the star contactor. Similarly two LC1D32N7 model contactors are suitable for the main and delta configured contactors. All contactors are 3 pole with one integrated N/O (normally open) and one integrated N/C (normally closed) auxiliary contact and categorised to AC-3 standard, which is capable of performing the contactor function for the star-delta starting of the fire monitor pump.
In addition to the main contactors and the in-built auxiliary contactors, two contact-mounted auxiliary contacts LADN20’s, as shown in Table 9 below, and a time delay relay LADS2 of the form shown in Table 10 below is required for star-delta starting.

**Table 9: LADN20 Auxiliary Contactors (Schneider Electric Catalogue 2006)**

<table>
<thead>
<tr>
<th>Clip-on mounting</th>
<th>Number of contacts per block</th>
<th>To suit contactor</th>
<th>Composition</th>
<th>N/O</th>
<th>N/C</th>
<th>Cont</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front</td>
<td>1</td>
<td>LC1D40 to D95</td>
<td>1</td>
<td>–</td>
<td>–</td>
<td>LADN10</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>–</td>
<td>1</td>
<td>–</td>
<td>–</td>
<td>LADN01</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>LC1D99 to D150</td>
<td>1</td>
<td>1</td>
<td>–</td>
<td>–</td>
<td>LADN11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>–</td>
<td>2</td>
<td>–</td>
<td>–</td>
<td>LADN20</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>LC1D99 to D150</td>
<td>2</td>
<td>–</td>
<td>2</td>
<td>LADY20</td>
<td>LADN02</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>2</td>
<td>–</td>
<td>–</td>
<td>LADS2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>3</td>
<td>–</td>
<td>–</td>
<td>LADN13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>LADN40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>–</td>
<td>4</td>
<td>–</td>
<td>–</td>
<td>LADN04</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>1</td>
<td>–</td>
<td>–</td>
<td>LADC22</td>
</tr>
<tr>
<td>Side</td>
<td>2</td>
<td>LC1D99 to D38 LH side</td>
<td>1</td>
<td>1</td>
<td>–</td>
<td>–</td>
<td>LADN01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LC1D115 &amp; D150 LH side</td>
<td>2</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>LADN20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LC1D40 to D95 Each side (2)</td>
<td>–</td>
<td>2</td>
<td>–</td>
<td>–</td>
<td>LADN02</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>LC1D99 to D38 LH side</td>
<td>2</td>
<td>2</td>
<td>–</td>
<td>–</td>
<td>LADN20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LC1D115 &amp; D150 LH side</td>
<td>2</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>LADN20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LC1D40 to D95 Each side (2)</td>
<td>–</td>
<td>2</td>
<td>–</td>
<td>–</td>
<td>LADN02</td>
</tr>
</tbody>
</table>

**Table 10: LADS2 Star-Delta Timer Contactor (Schneider Electric Catalogue 2006)**

<table>
<thead>
<tr>
<th>Clip-on mounting</th>
<th>Number of contacts</th>
<th>Type</th>
<th>Time delay range</th>
<th>Setting</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front</td>
<td>1 N/O</td>
<td>On</td>
<td>0.1...3 s</td>
<td>LADT0</td>
<td>180.00</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>Off</td>
<td>0.1...3 s</td>
<td>LADT2</td>
<td>180.00</td>
</tr>
<tr>
<td></td>
<td>1 N/C</td>
<td>delay</td>
<td>10...150 s</td>
<td>LADT4</td>
<td>213.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Star-Delta</td>
<td>1...30 s</td>
<td>LADS2</td>
<td>205.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Off</td>
<td>0.1...3 s</td>
<td>LADR0</td>
<td>180.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>delay</td>
<td>0.1...30 s</td>
<td>LADR2</td>
<td>180.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10...180 s</td>
<td>LADR4</td>
<td>213.00</td>
</tr>
</tbody>
</table>
As with the fuel transfer pump all motors including the fire monitor pump have both thermal overload and short circuit protection capabilities. The model GV7RS80 as identified in Table 11 is selected to perform the motor protection of the 25kW fire monitor pump.

<table>
<thead>
<tr>
<th>Thermal Magnetic Circuit Breakers GV7R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control by toggle switch</td>
</tr>
<tr>
<td>Standard power ratings of 3-phase</td>
</tr>
<tr>
<td>motors 50/60 Hz in category AC3</td>
</tr>
<tr>
<td>400/415 V</td>
</tr>
<tr>
<td>kW</td>
</tr>
<tr>
<td>----</td>
</tr>
<tr>
<td>7.5</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>11</td>
</tr>
<tr>
<td>11</td>
</tr>
<tr>
<td>18.5</td>
</tr>
<tr>
<td>22</td>
</tr>
<tr>
<td>22</td>
</tr>
<tr>
<td>37</td>
</tr>
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<td>45</td>
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<td>75</td>
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<td>75</td>
</tr>
<tr>
<td>90</td>
</tr>
<tr>
<td>110</td>
</tr>
<tr>
<td>90</td>
</tr>
<tr>
<td>110</td>
</tr>
</tbody>
</table>

Figure 11: GV7RS80 Circuit Breaker (Schneider Electric Catalogue 2006)
4.7. **Cable Selection**

The pertinent class rules for cable selection within a maritime vessel define the technical requirements for cables along with the cable installation considerations and requirements. Other relevant requirements for cable selection that will not be discussed here include routing of cables within a vessel, the technical requirements for cables as electrical components and cable requirements when used in hazardous areas.

Similar to de-rating factors of cables in land installations, cables in maritime environments use correction factors for the ratings of their cables. These correction factors are applied at various times and are dependent on conditions such as ambient temperature, multi-core cables, periodic loading, intermittent loads and bunching of cables. With respect to the 35M SAR vessel considerations for bunching of cables and ambient temperatures are applied.

The DNV rules for classification, Electrical Installations, Pt4 and Ch8 provide cable ratings at various temperature classes which are all based on the maximum number of cables being bunched together. As per the rules, a correction factor of 0.85 must be applied to cables which have more than six (6) cables bunched together. An alternative to the application of the correction factor is to ensure that the cable installation does not exceed the maximum number of cables. This is the case in the 35M SAR with contractor technical specifications stipulating no more than six cables can be bunched together. The advantage of not applying a correction factor to cables due to bunching relates the reduction of the size of cables required and therefore cost and overall weight; this may not always be possible on all vessels.

The correction factor for cables based on ambient operating temperature relates to operating conditions which differ from the default ambient value of 45°C, as can be seen from Table 12 below. Due to the operational location of the 35M SAR vessel, the default temperature value of 45°C is used and no correction is required.
The selection of an appropriate cable size for the 0.75kW fuel transfer pump is based on the following technical data:

---

Table 12: Correction factors for ambient temperatures (DNV Part4, Chapter 8, 2001)

<table>
<thead>
<tr>
<th>Cable temperature class</th>
<th>Ambient temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>35</td>
</tr>
<tr>
<td>60 2)</td>
<td>1.29</td>
</tr>
<tr>
<td>75</td>
<td>1.15</td>
</tr>
<tr>
<td>85</td>
<td>1.12</td>
</tr>
<tr>
<td>95</td>
<td>1.10</td>
</tr>
</tbody>
</table>

1) Correction factors for ambient temperature below 30°C will normally only be accepted for:
- cables in refrigerated chambers and holds, for circuits which only are used in refrigerated service
- cables on vessel with class notation restricting the service to non-tropical water.

2) 60°C cables shall not be used in engine and boiler rooms.

Table 13: Ratings of cables for temperature class 85°C (DNV Part4, Chapter 8, 2001)

<table>
<thead>
<tr>
<th>Nominal cross-section (mm²)</th>
<th>Current rating (A) (Based on ambient temperature 45°C)</th>
<th>Single-core</th>
<th>2-core</th>
<th>3 or 4-core</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>14</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>20</td>
<td>17</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>28</td>
<td>24</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>38</td>
<td>32</td>
<td>27</td>
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</tr>
<tr>
<td>6</td>
<td>48</td>
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<td></td>
</tr>
<tr>
<td>10</td>
<td>67</td>
<td>57</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>90</td>
<td>77</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>25</td>
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</tr>
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<td>35</td>
<td>145</td>
<td>123</td>
<td>102</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>180</td>
<td>153</td>
<td>126</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>225</td>
<td>191</td>
<td>158</td>
<td></td>
</tr>
<tr>
<td>95</td>
<td>275</td>
<td>234</td>
<td>193</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>320</td>
<td>272</td>
<td>224</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>365</td>
<td>310</td>
<td>256</td>
<td></td>
</tr>
<tr>
<td>185</td>
<td>415</td>
<td>353</td>
<td>291</td>
<td></td>
</tr>
<tr>
<td>240</td>
<td>490</td>
<td>417</td>
<td>343</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>560</td>
<td>476</td>
<td>392</td>
<td></td>
</tr>
</tbody>
</table>

| 400                         | D.C. 650 D.C. 630 D.C. 553 D.C. 536 D.C. 445 D.C. 441 |
| 500                         | A.C. 680 A.C. 629 A.C. 578 A.C. 518 A.C. 476 |
| 630                         | 740 740 714 629 629 588 518 476 |

Cable Selection (0.75kW fuel transfer pump): The selection of an appropriate cable size for the 0.75kW fuel transfer pump is based on the following technical data:

\[ P = 0.75kW, I = 1.66, V = 440V, S = 1.27VA, 3 \text{ Core + Earth} \]
With reference to Table 13 the cable size selected which meets requirements has a nominal cross sectional area of 1.5mm². As can be seen from the fire pumps technical data and Table 13 the selected cable size exceeds full load current rating with a 1mm² cable being capable of performing the duty. The 1.5mm² cable is selected as it is a size which is readily available and reduces the number of different size cables on the 35M SAR making installation easier.

Cable Selection (25kW fire monitor pump): The selection of an appropriate cable size for the 25kW fire monitor pump is based on the following technical data:

\[ P = 25kW; I = 41.6; V = 440; S = 51.7kVA; 3\ Core + Earth \]

With reference to Table 13, the cable size selected which meets requirements has a nominal cross sectional area of 6mm². As the fire monitor pump is started using a star-delta starter two (2) sets of active cables are required.
4.8. **Emergency Power Supply Batteries**

In addition to the batteries used for main propulsion and generating plant starting, DNV class rules, Pt4 Ch8 Sec2 – Emergency Power Supply System, require an emergency power supply system in the form of a generator or an accumulator battery. Due to the size of the 35M SAR vessel, an accumulator battery system is incorporated for emergency purposes. The sizing of an emergency battery system is dependent on class rules and must be sufficient to supply all services essential for safety in an emergency and includes electrical equipment such as emergency lighting and communication equipment. The purpose of the emergency power system in a vessel of this size is to provide emergency power to specified equipment for a dedicated period of time to allow maximum survivability of the crew.

Accumulator or deep cycle batteries are rated by their Ah (amp-hour) capacity, as such the calculation of loads must represent an Ah value. From Table 14, the loads that are required to have emergency power capability, along with their respective Ah loads, are shown.

<table>
<thead>
<tr>
<th>Description</th>
<th>watts</th>
<th>amps</th>
<th>duration(h)</th>
<th>duty cycle %</th>
<th>Amps-hours</th>
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<tr>
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<td>2.08</td>
<td>12</td>
<td>100</td>
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<td>3</td>
<td>100</td>
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<td>12</td>
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<td><strong>TOTAL</strong></td>
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<td></td>
<td><strong>TOTAL</strong></td>
<td><strong>630.14</strong></td>
<td></td>
</tr>
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</table>

Table 14: Emergency DC load schedule 35M SAR vessel (BAE Systems n.d)
Batteries are selected to ensure that the total Ah value exceeds 630Ah. The batteries must additionally be connected as a series/parallel combination in order to maintain a 24V DC design. 24V is a design consideration, initiated in the early design specifications, that is selected based on available equipment voltage requirements i.e. lighting.
Conclusion

The main objective of this report was to investigate the key electrical systems on-board the 35M search and rescue vessel, which could then be used as a basis for future designs of this class of vessel. This effectively meant confirming that the current design complied with build classifications and rules, most notably Det Norske Veritas (DNV). The revalidation itself follows a design process that will give future vessels a design paradigm of the electrical systems, in particular the motor starting arrangements and their required operational equipment such as contactors and circuit breakers, to be correctly selected. Additionally, the report provides an insight into the considerations required under DNV rules regarding cables and emergency power system selection.

Although it is not highlighted within the report, considerable time was required to compare the current system design with DNV rules and standards and then ensure the design process or investigation that is evident within the report meets these rules and standards.

The following important design considerations were addressed in this report.

- Selection of primary power distribution based on a three wire unearthed neutral system.
- Selection of generator sets (the ship’s primary source of power) based on the AC load analysis.
- Selection of batteries (the ship’s emergency source of power) based on the DC load analysis.
- Selection of motor starting arrangements based on anticipated voltage dip at generator.
- Selection on protection devices and their breaking capacities based on short circuit calculations.

A key finding of the project was the difficulty in designing an electrical system that could be transferred to another vessel of similar class as any future vessel, unless identical, would invariably have different requirements and loads. As such only a generic design paradigm that identified areas of design importance could be developed.
Bibliography


APPENDIX A

Det Norske Veritas:

Contents Page
PART 4 CHAPTER 8

ELECTRICAL INSTALLATIONS

JANUARY 2001

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<th>Title</th>
<th>Page</th>
</tr>
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DET NORSKE VERITAS

Veritasveien 1, N-1330 Horten, Norway Tel.: +47 67 57 90 00 Fax: +47 67 57 99 11
APPENDIX B

DWG 101-001 General Arrangement:

35M Search and Rescue Vessel
Omitted due to copyright
APPENDIX C

Stamford UCM274C Alternator:

Data Sheet
STANDARDS

Marine generators may be certified to Lloyd's, DNV, Bureau Veritas, ABB, Germanschel-Lloyd or RNA. Other standards and certifications can be considered on request.

VOLTAGE REGULATORS

**MX341 AVR - STANDARD**

This sophisticated Automatic Voltage Regulator (AVR) is incorporated into the Stamford Permanent Magnet Generator (PMG) control system, and is standard on marine generators of this type.

The PMG provides power via the AVR to the main exciter, giving a source of constant excitation power independent of generator output. The main exciter output is then fed to the main rotor, through a full wave bridge, protected by a surge suppressor. The AVR has in-built protection against sustained over-excitation, caused by internal or external faults. This de-excites the machine after a minimum of 5 seconds.

An engine relief load acceptance feature can enable full load to be applied to the generator in a single step.

If three-phase sensing is required with the PMG system the MX321 AVR must be used.

We recommend three-phase sensing for applications with greatly unbalanced or highly non-linear loads.

**MX321 AVR**

The most sophisticated of all our AVRs combines all the features of the MX341 with, additionally, three-phase rms sensing, for improved regulation and performance.

Over voltage protection is built-in and short circuit current level adjustments is an optional facility.

WINDINGS & ELECTRICAL PERFORMANCE

All generator stators are wound to 2/3 pitch. This eliminates certain (3rd, 9th, 15th...) harmonics on the voltage waveform and is found to be the optimum design for three-phase supply of non-linear loads.

The 2/3 pitch design avoids excessive neutral currents sometimes seen with higher winding pitches, when in parallel with the mains. A fully connected damper winding reduces oscillations during paralleling. This winding, with the 2/3 pitch and carefully selected pole and tooth design, ensures very low waveform distortion.

**TERMINALS & TERMINAL BOX**

Standard generators are 3-phase reconnectable with 12 ends brought out to the terminals, which are mounted on a cover at the non-drive end of the generator. A sheet steel terminal box contains the AVR and provides ample space for the customers' wiring and gland arrangements. It has removable panels for easy access.

SHAFT & KEYS

All generator rotors are dynamically balanced to better than BS6861:Part 1 Grade 2.5 for minimum vibration in operation. Two bearing generators are balanced with a half key.

INSULATION/IMPREGNATION

The insulation system is class H.

All wound components are impregnated with materials and processes designed specifically to provide the high build required for static windings and the high mechanical strength required for rotating components.

QUALITY ASSURANCE

Generators are manufactured using production procedures having a quality assurance level to BS EN ISO 9001.

The stated voltage regulation may not be maintained in the presence of certain radio transmitted signals. Any change in performance will fall within the limits of Criteria 'B' of EN 61000-6-2:2021. At no time will the steady-state voltage regulation exceed 2%.

**NB**: Continuous development of our products entitles us to change specification details without notice, therefore they must not be regarded as binding.

Front cover drawing typical of product range.
### UCM274C

#### WINDING 311

**CONTROL SYSTEM**
- SEPARATELY EXCITED BY P.M.G.

**AVR**
- MD321
- MD341

**VOLTAGE REGULATION**
- ±0.5% ±1.0 % WITH ENGINE GOVERNING

**SUSTAINED SHORT CIRCUIT**
- REFER TO SHORT CIRCUIT DECREEMENT CURVES (PAGE 7)

**INSULATION SYSTEM**
- CLASS H

**PROTECTION**
- IP23

**RATED POWER FACTOR**
- 0.8

**STATOR WINDING**
- DOUBLE LAYER CONCENTRIC

**WINDING RATIO**
- TWO THIRDS

**WINDING LEADS**
- 12

**STATOR WINDING RESISTANCE**
- 2.65 Ohms PER PHASE AT 22°C SERIES STAR CONNECTED

**ROTOR WINDING RESISTANCE**
- 1.12 Ohms at 22°C

**EXCITER STATOR RESISTANCE**
- 20 Ohms at 22°C

**EXCITER ROTOR RESISTANCE**
- 0.291 Ohms PER PHASE AT 22°C

**R.F.I. SUPPRESSION**
- BS EN 61800-5-2 & BS EN 61800-5-4, VDE 0570, VDE 0575, refer to factory for others

**WAVEFORM DISTORTION**
- NO LOAD < 1.5%, NON-DISTORTING BALANCED LINEAR LOAD < 5.0%

**MAXIMUM OVERSPEED**
- 2250 rpm/Min

**BEARING DRIVE END**
- BALL, 6315-2RS (ISO)

**BEARING NON-DRIVE END**
- BALL, 6310-2RS (ISO)

<table>
<thead>
<tr>
<th>Bearing Type</th>
<th>1 Bearing</th>
<th>2 Bearing</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEIGHT COMP. GENERATOR</td>
<td>400 kg</td>
<td>400 kg</td>
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<tr>
<td>WEIGHT WINDING STATOR</td>
<td>131 kg</td>
<td>131 kg</td>
</tr>
<tr>
<td>WEIGHT WINDING ROTOR</td>
<td>122.6 kg</td>
<td>122.6 kg</td>
</tr>
<tr>
<td>WINDING INERTIA</td>
<td>0.0975 kgm²</td>
<td>0.0975 kgm²</td>
</tr>
</tbody>
</table>

**WEIGHTS within a crate**
- 450 kg
- 450 kg

**PACKING CRATE SIZE**
- 106 x 67 x 103 (cm)
- 106 x 67 x 103 (cm)

**50 Hz**
- 90 Hz

**TELEPHONE INTERFERENCE**
- 75% - 25%
- 75% - 25%

**COOLING AIR**
- 0.514 m³/sec 1090 cfm
- 0.817 m³/sec 1900 cfm

**VOLTAGE SERIES STAR**
- 380/240 400/231 415/240 440/240 480/240

**VOLTAGE PARALLEL STAR**

**VOLTAGE SERIES DELTA**

**VIA RATED RATING FOR REACTANCE VALUES**
- 81.8 81.5 81.5 81.5 81.5 81.5 81.5 81.5 81.5 81.5 81.5 81.5

**6-IN-AXIS SYNCHRONOUS**
- 2.60 2.80 1.67 - 2.30 2.20 2.05 2.00

**6-IN-AXIS TRANSIENT**
- 0.10 0.10 0.10 - 0.00 0.00 0.00 0.00

**6-IN-AXIS SUBTRANSIENT**
- 0.10 0.10 0.10 - 0.00 0.00 0.00 0.00

**RCD IA INsert RESISTANCE**
- 1.30 1.30 1.30 - 1.30 1.30 1.30 1.30

**RCD IA INsert RESISTANCE**
- 0.15 0.15 0.15 - 0.15 0.15 0.15 0.15

**ALARM REACTANCE**
- 0.00 0.00 0.00 - 0.00 0.00 0.00 0.00

**INERTIA SEQUENCE**
- 0.10 0.10 0.10 - 0.10 0.10 0.10 0.10

**REACTANCES ARE SATURATED VALUES ARE PER UNIT AT RATING AND VOLTAGE INDICATED**
- 0.025 a
- 0.025 a
- 0.025 a
- 0.025 a
- 0.025 a
- 0.025 a
- 0.025 a
- 0.025 a
- 0.025 a
- 0.025 a

**SHORT CIRCUIT RATIO**
- 1548
UCM274C

Three-phase Short Circuit Decrement Curve. No-load Excitation at Rated Speed Based on star (wye) connection.

50 Hz

60 Hz

Sustained Short Circuit = 430 Amps

Sustained Short Circuit = 560 Amps

Note 1
The following multiplication factors should be used to adjust the values from curve between time 0.001 seconds and the minimum current point in respect of nominal operating voltage:

<table>
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<tr>
<th>Voltage</th>
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<th>Voltage</th>
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<tr>
<td>100V</td>
<td>x 1.00</td>
<td>460V</td>
<td>x 1.00</td>
</tr>
<tr>
<td>415V</td>
<td>x 1.17</td>
<td>460V</td>
<td>x 1.17</td>
</tr>
</tbody>
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The sustained current value is constant irrespective of voltage level.

Note 2
The following multiplication factor should be used to convert the values calculated in accordance with NOTE 1 to those applicable to the various types of short circuit:

<table>
<thead>
<tr>
<th>Type</th>
<th>Factor 3</th>
<th>Factor 4</th>
<th>Factor 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instantaneous</td>
<td>x 1.00</td>
<td>x 1.00</td>
<td>x 1.00</td>
</tr>
<tr>
<td>Minimum</td>
<td>x 1.00</td>
<td>x 1.00</td>
<td>x 1.00</td>
</tr>
<tr>
<td>Sustained</td>
<td>x 1.00</td>
<td>x 1.15</td>
<td>x 2.50</td>
</tr>
</tbody>
</table>

Max. sustained duration 5 min. 5 min. 2 min.

Note 3
Curves are drawn for star (wye) connected machines. For other connection the following multipliers should be applied to current values as shown:
Parallel Star = Curve current value x 2
### UCM274C

**Winding 311 / 0.8 Power Factor**

#### RATINGS

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<tr>
<th></th>
<th></th>
<th></th>
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<tr>
<td><strong>Series Star (V)</strong></td>
<td>380 400 415 440</td>
<td>380 400 415 440</td>
<td>380 400 415 440</td>
<td>380 400 415 440</td>
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<tr>
<td><strong>Parallel Star (V)</strong></td>
<td>190 200 208 220</td>
<td>190 200 208 220</td>
<td>190 200 208 220</td>
<td>190 200 208 220</td>
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<tr>
<td>kVA</td>
<td>65.0 65.0 65.0 N/A</td>
<td>67.5 67.5 67.5 N/A</td>
<td>77.5 77.5 77.5 N/A</td>
<td>81.5 81.5 81.5 N/A</td>
</tr>
<tr>
<td>kW</td>
<td>52.0 52.0 52.0 N/A</td>
<td>54.0 54.0 54.0 N/A</td>
<td>62.0 62.0 62.0 N/A</td>
<td>65.2 65.2 65.2 N/A</td>
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<td>Efficiency (%)</td>
<td>91.6 91.8 92.0 N/A</td>
<td>91.5 91.8 91.9 N/A</td>
<td>91.6 91.4 91.6 N/A</td>
<td>90.8 91.2 91.4 N/A</td>
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<tr>
<td>kW Input</td>
<td>58.8 58.8 58.5 N/A</td>
<td>59.0 58.8 58.8 N/A</td>
<td>68.1 67.6 67.7 N/A</td>
<td>71.8 71.5 71.3 N/A</td>
</tr>
</tbody>
</table>

#### DIMENSIONS

![DIMENSIONS Diagram]

**STAMFORD**

Barnack Road • Stamford • Lincolnshire • PE9 2NB
Tel: 00 44 (0)1780 484000 • Fax: 00 44 (0)1780 484100

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APPENDIX D

WEG 25kW Motor:

Data Sheet
DATA SHEET

Customer: TENIX STANDARD MULTIVOLTAGE
Motor line: 25.0 kW

<table>
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<th>Parameter</th>
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<td>Rated Output</td>
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</tr>
<tr>
<td>Frame</td>
<td>180L</td>
</tr>
<tr>
<td>Poles</td>
<td>4 Poles</td>
</tr>
<tr>
<td>Frequency</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Full load speed</td>
<td>1760 rpm</td>
</tr>
<tr>
<td>Voltage</td>
<td>440 V</td>
</tr>
<tr>
<td>Full load current</td>
<td>41.6 A</td>
</tr>
<tr>
<td>Service factor</td>
<td>1</td>
</tr>
<tr>
<td>Locked rotor amps</td>
<td>287 A</td>
</tr>
<tr>
<td>Locked rot</td>
<td>6.90</td>
</tr>
<tr>
<td>Insulation class</td>
<td>F</td>
</tr>
<tr>
<td>Temperature rise</td>
<td>80 °C</td>
</tr>
<tr>
<td>Full load torque</td>
<td>135.69 Nm</td>
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<tr>
<td>Locked rotor torque</td>
<td>230 %</td>
</tr>
<tr>
<td>Breakdown torque</td>
<td>250 %</td>
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<tr>
<td>Altitude</td>
<td>1000 m.a.s.l</td>
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<tr>
<td>Ambient temperature</td>
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<tr>
<td>Degree of protection</td>
<td>IP55</td>
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<tr>
<td>Slip</td>
<td>2.22 %</td>
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<tr>
<td>No load current</td>
<td>12.0 A</td>
</tr>
<tr>
<td>Locked rotor time</td>
<td>10 s</td>
</tr>
<tr>
<td>Moment of inertia</td>
<td>0.2024 kgm²</td>
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<tr>
<td>Aprox. weight</td>
<td>185.00 kg</td>
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<tr>
<td>Noise level</td>
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Performance under load

<table>
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<tr>
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<th>Efficiency(%)</th>
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<tr>
<td>100 %</td>
<td>0.87</td>
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<tr>
<td>75 %</td>
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</tr>
<tr>
<td>50 %</td>
<td>0.78</td>
<td>88.00</td>
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Bearings Regreasing int. Grease amount

| D.E.     | 6311 C3 | 9500 h | 18 g |
| N.D.E.   | 6211 C3 | 9500 h | 11 g |

NOTE:

FRAME DIMENSIONS

<table>
<thead>
<tr>
<th>Frame</th>
<th>A</th>
<th>AA</th>
<th>AB</th>
<th>AC</th>
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<th>B</th>
<th>BA</th>
<th>BB</th>
<th>C</th>
<th>CA</th>
<th>eD</th>
<th>ES</th>
<th>F</th>
<th>E</th>
<th>C</th>
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<tr>
<td>180L</td>
<td>279</td>
<td>80</td>
<td>350</td>
<td>338</td>
<td>278</td>
<td>279</td>
<td>75</td>
<td>332</td>
<td>131</td>
<td>200</td>
<td>4896</td>
<td>110</td>
<td>80</td>
<td>14</td>
<td>42.3</td>
</tr>
</tbody>
</table>

GD eDA EA TS FA GB GF H HA HC HD K L LC S1 D1 c2

| 9 | 4885 | 110 | 80 | 14 | 42.3 | 9 | 180 | 28 | 317 | 406 | 53 | 763 | 820 | 24MH16-1.5 | DMX16 | DMX16 |

Performed: Checked:

*Note: The values shown are subject to change without prior notice*
APPENDIX E

DWG 870-020:

0.75kW Direct-On-Line Starter Schematic
APPENDIX F

DWG 870-024:

25kW Star-Delta Starter Schematic
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