Project B: Solar Generation of Remote Bore Fields

Team 12: Team Power

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Final Design Report (Individual)

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# Introduction

The project, solar generation of remote bore fields undertaken by Team Power comprises of three designs to power a remote bore field operating in Newman, in the Pilbara region of Western Australia. This bore field supplies water to a mine site located 10km away. The objective is to design a solution that meets all the requirements of the project which are summarised in Appendix A. Throughout the project the team has undertaken a requirements analysis and a design approach both leading to the results included in the final design report. This document includes the Authors contribution to the final design including the design and selection of cables and protection equipment.

## Purpose

This document, the final design report encompasses the decisions and components of the final design. Including how the design decisions were made and how they were designed to meet the design brief and project requirements. The purpose of this report is to concisely outline what the final design is, how it meets the project requirements and the comparison of the proposed designs compared to the base case. In addition, the final design report should make clear to the client how the system will operate and how they will implement it.

This document presents the authors significant contributions to the project. That is from this document it should be clear what aspects of the project she was responsible. It does not cover all that will be completed in the final group submission for the design report.

## Scope

The scope of the final design report includes the final design elements and the justification of the design elements traced to the project requirements. The system integration, stakeholder engagement, safety issues, design outputs and final costs. Additionally, it will provide recommendations for building the design and a manual of operation. The scope of this document however only includes the authors contribution, that is up-to-date requirements, design process, some of the final design elements and justification.

## Structure of this Document

Following the introduction, the document contains the authors summary of contribution in section 2, up-to-date requirements in section 3, the elements of the final design in section 4 which includes system integration, and conclusions in section 5 including the authors most significant contribution and learning.

## Definitions, Acronyms, and Abbreviations

|  |  |
| --- | --- |
| **Abbreviation** | **Definition** |
| AC | Alternating Current |
| DC | Direct Current |
| HV | High-Voltage |
| ICCB | Insulated-case circuit breaker |
| LV | Low-Voltage |
| LVPCB | Low-voltage power circuit breaker |
| MCCB | Moulded-case circuit breaker |
| PF | Power Factor |
| SF6 | Sulphur Hexafluoride |

## References

[1] *AS/NZS 3000:2007 Wiring Rules*, 2007.

[2] Grundfos, "Grundfos Data Booklet MS 6000 Submersible Motors 50/60Hz," 2015, Available: <http://product-selection.grundfos.com/product-detail.product-detail.html?lang=ENU&productnumber=78635520&productrange=gma>.

[3] SMA Solar Technology AG, "Technical Information Short-Circuit Currents," Available: <https://www.researchgate.net/file.PostFileLoader.html?id=57724de040485405d23d51b0&assetKey=AS%3A377895986974721%401467108832347>.

[4] L. G. Hewitson, M. Brown, and R. Balakrishnan, *Practical Power System Protection* (Practical Professional Books From Elsevier). Oxford: Newnes, 2005.

[5] J. L. Blackburn and T. J. Domin, *Protective Relaying*. Baton Rouge, UNITED STATES: CRC Press, 2006.

[6] IEEE Standards Board Corporate IEEE Standards Board, *IEEE recommended practice for applying low-voltage circuit breakers used in industrial and commercial power systems* (Recommended practice for applying low-voltage circuit breakers used in industrial and commercial power systems). Place of publication not identified: Institute of Electrical and Electronics Engineers, 1997.

[7] Schneider Electric, "Schneider Electric Australian Catalogue 2016," ed, 2016.

# Summary of Contribution

Jessica has played a vital role in the completion of this design project and the formation of the report. In addition to her previous contributions in the requirements analysis, design approach and other team activities such as project managing and minute taker, she has made further contributions to both the team and to the project deliverables. Her responsibilities have included chairing team meetings, being minute taker and representing Team Power at the partner meeting held at Jacobs. Her contribution to the final design report includes (but is not limited to) the sizing and selection of cables to be used in the system, including ensuring they meet the standard AS NZ 3000, the selection and sizing of the protection equipment to be used which are covered in this document. Further contributions she will make to the group final design submission include the approvals that must be obtained before the design can be implemented.

# Up-to-Date Requirements

The requirements of the project can be found in Appendix A. These have been updated since the design approach to become more detailed and to avoid confusion.

# Elements of Final Design

In the design approach the team discussed 4 viable solutions to generate power for remote bore fields. The base case consisting of power transmission lines from the mine site to the bore field, hybrid 1 consisting of a photovoltaic array (PV), battery storage system and a back-up diesel generator, hybrid 2 consisting of the same components as hybrid 1 but also including wind turbines. Finally, it discussed a fully renewable system made up of a PV array, wind turbines and a battery storage system. As simulations and calculations were conducted, the team ruled out hybrid 2 and the fully renewable systems as options for the design. This means the focus is on hybrid 1 (now referred to as the hybrid solution) as it has the most design elements. This is compared to a system that runs entirely on a generator and the base case. The block diagram shown in Figure 1 is the configuration for the hybrid solution. This diagram shows the voltage and current characteristics of the cables between elements and the derivation of this is not covered in this report, but will be included in the final group submission.

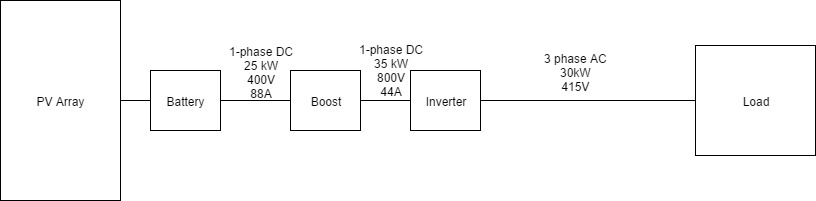


Figure : Block Diagram of hybrid system

## System Integration

The system integration of the power generation system deals with how all the elements of the design will be connected, and how the equipment will be protected. That is the cables that will be used including their lengths, losses and characteristics and the protection equipment that will be used to isolate equipment should a fault occur in the system.

When choosing cables and designing the interconnects of the system, the standard AS NZ 3000 [1] must be consulted as the industry standard and as requested by the client. The most important sections of this standard are in Part 2: installation practices sections 2, 3, 5, 7 and 8.

Section 2 general arrangement, control and protection covers valuable information about the selection and installation of appropriate switchgear and control gear. This includes ensuring automatic disconnection of supply in overload situations accomplished using circuit breakers. It also gives rise to the need for switchboards where switchgear will be placed and states that it must be enclosed against external influences.

Section 3 selection and installation of wiring systems, the important information from this section relevant to the bore field project is outlined briefly here. Important and relevant information was selected based on the details of the project. The external factors deemed relevant are ambient air temperatures, external heat sources, presence of water or high humidity, presence of solid foreign bodies (dust), presence of flora and fauna, and solar radiation. To design the wiring system to meet the standard, the cables will be underground, sheathed, insulated and earthed as required from the standard.

Section 5 the earthing arrangements and earthing conductors, provides information about safely earthing the system. As a result, the design must enable automatic disconnection of supply in the event of a fault through protective earthing arrangement. To enable equipment to function correctly through functional earth arrangements, to mitigate voltage differences between exposed equipment and to provide effective and reliable low impedance fault path capable of carrying fault currents.

Section 7 is special electrical installations, for this project section 7.2, safety equipment, 7.3 electricity generation systems, are the most relevant to the project. The safety equipment must be able to protect the system from both external and internal factors. In addition, it must be able to detect hazards by the use of equipment such as smoke alarms and fire extinguishing systems. Section 7.3 electricity generation covers specific information about the use of battery systems, generators and PV array and states they are covered by further standards, AS 3011, AS/NZS 3010, and AS 4777 respectively. These are the ones relevant to this design project.

Section 8 testing and verification outlines the minimum standard by which the system must be inspected and tested to meet the standard. As stated in the standard, to meet its requirements the system must be inspected as far as is practicable and in accordance with the standard. While access to resources limits this, testing is a very important aspect of the design process.

### Cables

Considering the base case, the hybrid and the generator solutions, cables must be selected in order to satisfy project requirements. Below, the cables that would be supplying the generator are sized. These cables are common to all three designs, that is the cables from the generator to the load (generator and hybrid), the inverter to the load (hybrid) or the transformer to the load (in the base case) all have the same voltage current (V-I) characteristics.

As specified by the client the Grundfos MS 6000 submersible pumps are to be used in the bore field. It is a requirement of team power to supply sufficient power to three 30 kW pumps as seen in appendix A. These pumps require a specific voltage and current as shown in table x [2]. The relevant row is the bottom one referring to the 30 kW pumps. The rated current refers to the maximum current for the pump to continue operating in acceptable conditions. From this information, the voltage and current running to the pumps can be calculated. If the pumps are operating in series, the voltage in the line must be 1245V and must be able to tolerate a current of 63.0A. This can be confirmed using 3 phase power calculations.

Table : Characteristics of Pump 3 x 415V, 50Hz, T40 (voltage code 18, 39) from Grundfos literature [2]

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Power (kW)** | **Rated Current (A)** | **Motor efficiency (%)** | | | **Cos (Power Factor)** | | | **N (min-1)** | **Rated torque (Nm)** | **LRC (%)** | **LRT (%)** | **BT (%)** |
| 100 % | 75 % | 50 % | 100 % | 75 % | 50 % |
| 30 | 63.0 | 84.0 | 84.4 | 82.7 | 0.82 | 0.76 | 0.64 | 2880 | 100 | 530 | 170 | 290 |

The 3 x 415V refers to a line-to-line voltage of 415V, this corresponds to a phase voltage of . Using the power factor and motor efficiency given for when the pump is running at 100% capacity, the power factor (PF), , is 0.82 summarised in Table 1. This can be used to calculate the real and reactive components of the apparent power using the power triangle seen in Figure 2.

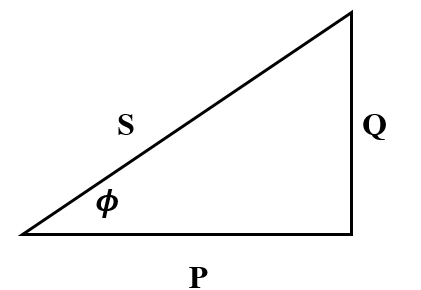


Figure : Power Triangle

From this triangle and using simple trigonometry, , . Using this value for apparent power, the required current can be determined as follows:

This current is below the rated current given in the pump data sheet, this rated current is the maximum current the motor takes and can be calculated using the efficiency of the motor.

This is much closer to the rated current of the motors.

As such the cables will be sized to meet the requirements of the pumps, as well as being capable of higher currents in the case of faults or disturbances in the system.

#### V-I characteristics and selection

As given by the pump data sheet [2] and confirmed by the calculations above, the current required for each motor is a maximum of 63A. The system is connected such that there is one inverter for each pump, meaning that the cables are only required to carry the current necessary for one pump. This is more efficient than one cable since one cable would require a current that is three times higher which would incur more losses. Additionally, since the solar panels from the PV system generate direct current (DC), the cables going to the inverter will be one phase DC cables, while the cables going from the inverter to the load will be three phase alternating current (AC) cables.

The current carrying capacity of the cables is decided from the pump characteristics and possible fault current. That is the cables should be sized to withstand faults without failing. Should cables fail, there are significant safety issues, if the insulation is not sufficient cables can become exposed increasing the risk of fire and harm to people who may have contact with the cable. Since safety is ranked highly as one of the project requirements, this is a very important aspect of the design. To do this, the short circuit current must be calculated, the maximum current is five time the maximum current for the pump. That is the short circuit surge current for these cables is . The surge current only occurs for a very short duration less than 40 s [3], while the symmetrical short-circuit current is . From this the cables will be sized to withstand a current of 310A. A generic cable of this capability has an area of 150mm2 and a voltage drop of 0.27 mV/A m [4].

#### Lengths and losses

From our design, the inverter will be located 8 meters away from the load. Across this distance there will be a small loss in voltage. For an underground cable, capable of carrying the required current, there is a loss of 0.27 mV/A resulting in a loss of 1.36V corresponding to approximately 86W of power. As a result of this, more power must be generated to make up for this loss. The cables between the battery, boost and inverter will be kept as short as possible and as such any losses will be negligible.

### Protection equipment

The protective relaying system of a power system consists of many elements including circuit breakers, current and voltage transformers and relays. The most important aspect that has been considered in the design are circuit breakers. There are four main types of circuit breakers used, oil, air, vacuum and SF6 (Sulphur Hexafluoride). Each of these have their own advantages and disadvantages, oil for example is cheap but prone to fire, air is very loud but is not a fire or health risk, a vacuum is not a health or fire risk, but it is impossible to monitor the medium and SF6 has no fire risk, a low health risk but is a little more complex. These circuit breakers are used in power distribution systems and are for high-voltages (HV) [5]. An important consideration in the selection of a circuit breaker is the voltage level of the system and the locations of the circuit breakers within the system. The circuit breakers must be able to isolate equipment in the case of a fault in the system, as such they must be located between each module shown in the block diagram in Figure 1.

The purpose of a circuit breaker is to switch load currents, break fault currents and to carry a fault current without failing. With the important factors being the speed with which the current is broken when the circuit breaker is tripped, and the current capacity that the circuit breaker is capable of interrupting [4]. When a fault occurs in the system, a large current called a fault current is induced. The fault current will trip the circuit breaker, which interrupts the flow of current from the source to the load, so that it does not reach the equipment protecting it from potential damage. This is an important aspect of the design making it safer and more reliable.

The circuit breakers to be used in the system are designed for the low-voltage (LV) of 415V. The two types of circuit breaker considered for LV systems, they are moulded-case circuit breaker (MCCB), and low-voltage power circuit breaker (LVPCB). Insulated-case circuit breakers (ICCB) are a type of MCCB. MCCBs typically use a quick-break mechanism meaning that the speed the contacts are open and closed is independent of how fast the handle is moved. These circuit breakers can be tripped automatically or manually. LVPCBs use a spring charged mechanism that must be manually closed after the trip unit has opened the circuit breaker [6].

The factors to be considered when selecting the circuit breaker are the system voltage, system grounding, system frequency, load current, ambient temperature and altitude, harmonics and short-circuit current [6]. As a result, a MCCB will be used in the system. This is chosen over ICCB and LVPCB for its current limiting ability, the large number of sizes it is available in and its relatively lower cost. To match the rated current of the pumps, the circuit breaker must have a rated current of at least 63A, and the breaking capacity must be at least 315A (short circuit current). As such a circuit breaker with a rated current of 100A and breaking capacity of 36 kA is more than sufficient. One such circuit breaker is the NSX400/630F: (36kA at 415V) which is used for distribution protection available in a few models from Schneider Electric [7].

# Conclusions

## Most significant contribution

As a member of Team Power Jessica has made significant contributions to the outcomes of the project that was undertaken. Her knowledge and skills in power systems and problem solving have allowed her to design the interconnects and protection of the system to meet the project requirements. In addition to this, she has helped with the decisions and calculations in sizing the system, working through the problem on the whiteboard along with group members Steven and Mark, ensuring that the design is cohesive. Jessica has put in hard work and time into the project, including editing and formatting group documents. Jessica has also been a team player, always attending meetings, initiating and contributing to team discussions about issues the team is facing. She has also taken the time to talk to group members to ensure they understand their role when they were not contributing in group discussions.

## Most significant Learning

This design project has taught Jessica about the design process considerably. She feels that it has been an effective way to learn how projects work in the engineering industry. In particular, taking a design brief given and interpreting what the project requirements are, without being given all the specific details. This makes it different from any other project she has undertaken throughout her university degree. The project dealt with working on a project for a client, this provided the opportunity to interact with members of the industry, teaching Jessica about professionalism and communication. Also, it taught her about putting the client’s requirements first in the design process, excluding ideas that she liked better for ones that the client would prefer was difficult for her. In addition, Jessica has learned a great deal about working in a team, most importantly that not all members of a team have the same motivation to work on and complete the project. She has found it an excellent opportunity to apply what she has learnt throughout her degree, including both technical knowledge and project management skills.

# Appendices

## Appendix A

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Priority | Description of Requirement | Description | Classification | Origin |
| 1 | Operate continuously (24/7) | The power generation system is required to operate for 24 hours a day, 7 days a week, 365 days a year. | EXP, SPO | Design brief |
| 2 | At least 90kW of power available | The mine site requires maintenance of a 3ML storage tank with expected usage of 900 ML per year. This will require 90 kW of power to drive three 30kW pumps. The pumps are maintained by the client and so the team requirement is to supply 90 kW of power. | EXP, SPO | Initial meeting with Jacobs |
| 3 | Operate in desired location. | The power generation system must operate in Newman. This includes tolerating the harsh conditions and remote environment. | EXP, SPO | Design Brief |
| 4 | Safety | The system must run safely. Any safety equipment that requires power must also be supplied. | EXP, SPO, UNS | Standards, code of practice, expectations and ethics |
| 5 | Economy | Maximise the economy of the proposed solution. | EXP, SPO | Design brief and the initial meeting with Jacobs |
| 6 | Telemetry | The system requires telemetry and communications equipment, and these will also require power. | EXP, SPO | Initial meeting with Jacobs |
| 7 | Maintainable | The system must be maintainable. | EXP, UNS | Standards and code of practice |
| 8 | 10-year life | The system must last for at least ten years | EXP, SPO | Initial meeting |
| 9 | Environment | The proposed solution should minimise harm to the environment. | EXP, EXC | Ethics |
| 10 | Time | The proposed solution should take a minimum amount of time to construct. | EXP, EXC | Arises from requirement 5 (economy) |