

L5 – GROUP PROJECT DEVELOPMENT

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ABSTRACT

The aim of this project is to see, “How can a commercial office reduce carbon footprint alongside energy bills in a cost-effective manner?”, This is due to the issue of climate change and how it is being heavily promoted as to make the population more aware about the issue [4]. To achieve our aim the objectives in which we have achieved this are:

- Design a Commercial Power Generation System
- Harness Solar Energy
- Utilise Wind Energy
- Research energy harvesting techniques
- Incorporate Smart Energy Management
- Implement Energy Storage Solutions
- Develop an IoT-Based Monitoring Platform
- Improve Overall Energy Efficiency
- Evaluate System Performance
- Promote Environmental Sustainability

The methods used to achieve this are simulations via ElectricalOM, drawings via AutoCAD and simulations TIA Portal V20. The deliverable of this project is the design and simulation of a commercial energy system, which utilises renewable energy to power the system. Our major findings were that our system would work and could reduce carbon footprint of a commercial building. - JSR

In conclusion, we achieved our aim for the project and have supplied data so that individuals can replicate this to create a renewable energy system for a commercial space. - JSR

We recommend, in the future that this method be used and adapted for domestic use as well, so that carbon footprint and cost effectiveness can be achieved for both private individuals and companies to reduce the effects of climate change for future generations. - JSR

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Below is a Table with the authors names with their initials to reference who is the responsible author of a section of work:

Name	Initials
Joseph Samuel Roan	JSR
Freddie Robert Wilson	FRW
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1. INTRODUCTION

In today's environment we are striding to become more environmentally friendly and sustainable, to preserve the planet for future generations [2] [3]. This is because we are more aware than ever about the issue of climate change [4]. As a result of this, we have decided to try to investigate how a commercial office reduce carbon footprint alongside energy bills in a cost-effective manner? And see how we can implement this. Therefore, we have decided to create a Commercial Power Generation system, as this modernises the commercial industry and can help businesses become more cost-effective in their power usage/management and follow sustainability regulations [5]. - JSR

Based on the information in [12], this project is motivated by the fact that buildings account for approximately 40% of global energy consumption and 30% of global carbon emissions. Therefore, creating more effective and practical power generation and storage solutions for larger commercial buildings can be the first step toward reducing this. - FRW

1.1. Aim

To design and develop an intelligent Commercial Power Generation System that integrates solar panels, wind turbines, thermoelectric energy-harvesting modules, and rainwater micro-turbines to generate sustainable electricity, optimise energy efficiency, and reduce dependence on conventional fossil-fuel-based power sources. This is to answer the question: "How can a commercial office reduce its carbon footprint alongside energy bills in a cost-effective manner?"

1.2. Objectives

- Design a Commercial Power Generation System
- Harness Solar Energy
- Utilise Wind Energy
- Implement Thermoelectric Energy Harvesting
- Incorporate Smart Energy Management
- Implement Energy Storage Solutions
- Develop an IoT-Based Monitoring Platform
- Improve Overall Energy Efficiency
- Evaluate System Performance
- Promote Environmental Sustainability

In the remainder of the report, it will show the design, validation and costing of our final project result. Including research, drawing deliverables and design revisions. – FRW

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LIST OF ACRONYMS AND UNITS

Acronyms	Definition
A	Amperes
AC	Alternating Current
DC	Direct Current
W	Watt
KW	Kilo Watt
V	Volts
kWh	Kilo Watt Hour
MTO	Material take-off
GA	General Arrangement
BLD	Block Diagram
SLD	Single Line Diagram
BMS	Battery Management System
BESS	Battery Energy Storage System
CEMS	Commercial Energy Management System
VAWT	Vertical Axis Wind Turbine
PLC	Programmable Logic Controller
HMI	Human Machine Interface
PIC	Peripheral Interface Controller

2. RESEARCH & LITERATURE REVIEW

2.1 Introduction

The literature review is an 'academic research activity' that collects previous research and uses it to advance knowledge [1]. Additionally, the benefit of this is that it can intergrade different results and points of view from different findings, which a single study cannot encompass [1]. - JSR

Within this section, we have outlined our own personal research, with our own contributions, as well as additional research within this field. The topics covered include Solar and Wind Energy, which covers solar panels and wind turbines. We have also included a comparison with other researchers' findings, which covers the previous studies in this field, additionally explaining their overall conclusions in relation to the topic. We have also included battery storage systems, determining the type of storage system we would use to allow us to storage energy. Furthermore, explaining what commercial energy management systems are and how they can be of a benefit to our project. Finally, exploring Energy Harvesting Technologies, and the different methods used to do this. - JSR

2.2 Research into Solar and Wind Energy

The purpose of the research into Solar and Wind energy was mandatory, for the project, as these are our methods for providing power to the office.

Solar Energy is one of the forms of methods of how we will produce energy, one of the most effective ways to produce solar energy is from solar panels [13]. Solar power can come from solar farms, which are a field full of panels [15] as well as solar panels featured on, near or around properties such as homes, apartments and businesses, most commonly being on roofs [16]. Solar panels are used in domestic, commercial and industrial industries making them suitable for our project. Solar panels also have no harmful effects on the environment as they're sustainable and have no greenhouse gas emissions leading to no negative effects on climate change [18]. We have decided to use Monocrystalline Solar Panels, as it is in a cold climate [19].

Wind Energy is a method of renewable energy, which in most instances is powered by the movement of wind through a giant fan, referred to as a wind turbine [20], which are 'carbon free energy sources [21], due to them producing energy without any greenhouse gas emissions [21]. These structures are more common in industrial uses, rather than in private individuals' ownership [22], so would be useful for our project.

The research into Solar and Wind Power was useful, as this allowed us to see if we could integrate these methods into our design and how we could achieve this, however the research could have included potential miniature wind turbines, as the issue with the energy system is the overall size of the wind turbines, as not all office space will be able to accommodate large wind turbine structures. However, the reason for this is

because, smaller wind turbines are not as efficient as a larger one [14] therefore for our application we would require a larger turbine as shown below in Figure 1.

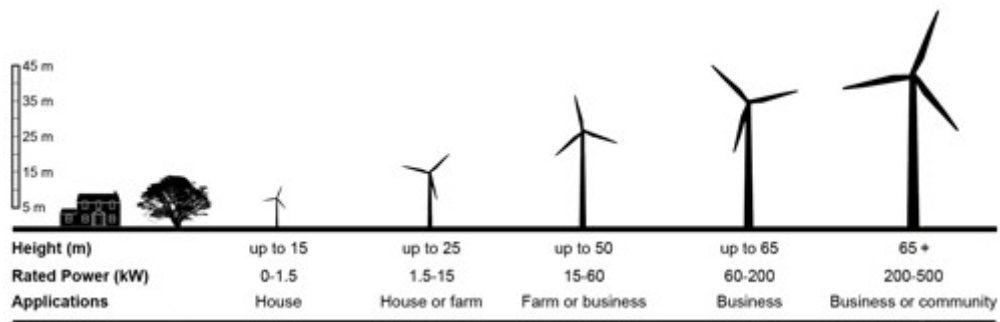


Figure 1: Wind Turbine Dimensions and Rated Power Outputs for various applications [14]

- JSR

2.3 Comparison to another Research

In comparison to other research that has been done on the issue, other researchers have also demonstrated that the implementation of renewable energy systems for commercial space is beneficial to the environment and should be used more widespread [17]. In this several studies on renewable energy technologies have been undertaken, a summary of the previous studies on renewable energy technologies and the field of applications are shown below in Table 1.

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Table 1 - Previous studies on renewable energy technologies and the field of application [17]

Type of hybrid or microgrid system	Configuration of power system	Applications and countries	Software and technique utilized	Performance indicators
Standalone PV/BSS hybrid energy system (HES) [19]	PV/WT/ESS/diesel	A small hotel in Kish Island, Iran	HOMER	NPC, COE and GHG emissions
Standalone HES [20]	WT/PV/BSS	Residential building in Tehran, Iran	HOMER	LCE, NPC, capacity shortage and unmet electric load
Off-grid HES [21]	PV/ESS/diesel/FC	Electrical load of EMERAL, University of Tehran, Iran	HOMER	LCE, NPC, CO2 emission and renewable fraction
Off-grid HES [22]	PV/BSS/WT	Power generation in KhshLU Site, Iran	HOMER	NPC and COE
Standalone HES [23]	PV/ESS/diesel	Primary school, households and small dispensary, Algeria	HOMER	COE, NPC, net renewable fraction fuel consumption, battery autonomy and GHG emissions
Standalone HES [24]	PV/diesel/BSS	Rural electrification of Saharan community, Algeria	HOMER and MATLAB: PSO	COE, unmet load, renewable fraction and CO2 emissions
Standalone system [25]	PV/WT/FC	Vacation homes, Turkey	HOMER	COE, RF and NPC
Standalone power system [26]	WT/PV/BSS	Energy charging stations, Turkey	HOMER	COE, RF, OC, capacity shortage and NPC
Off-grid power system [27]	FC/WT/PV/BSS	Residential electrical load, Ayvalik province, Turkey	HOMER	COE, COH and NPC
Standalone system [28]	WT/PV/ESS/DG/FC/MGT	Electric and thermal loads, Australia	HOMER	COE, NPC and emissions
Standalone system [29]	WT/PV/ESS/boiler	Electric and thermal loads for residential community, Western Australia, Australia	HOMER and MATLAB: GA	COE, NPC and emissions
Off-grid system HES [30]	PV/petrol generator	Residential and small scale enterprises, Dafara, Abuja, Nigeria	Monte-Carlo simulation	LCC and LCE
Off-grid system HES [31]	WT/PV/BESS/diesel	Rural electrification Columbia	MATLAB	LOLP
Off-grid system HES [32]	PV/BESS	GSM BTS, South Africa	MATLAB and HOMER	O&M, LCOE, NPC and GHG emission
Off-grid system HES [33]	PV/WT/BESS	Rural electrification, Auckland, New Zealand	An iterative algorithm and GA	LPSP
Off-grid HES [34]	PV/BESS	Agriculture-Abattoirs, Ibadan, Nigeria	MATLAB	CO, CO2 and cost pumping water
Off-grid system HES [35]	PV/utility/water pump system	Agriculture-irrigation in Pakistan	MATLAB	LCC, payback period and NPV
Off-grid system HES [36]	PV/DEG/BSS	Primary health care, Agbado, Nigeria	MATLAB	LCC
Off-grid system HES [37]	Hydro/PV/diesel/BSS	Rural electrification, Nigeria	HOMER	CO2, TNPC and COE
Off-grid connected HES [38]	PV/WT/diesel/BSS	Remote health care centres in Maiduguri, Enugu and of Isseyin sites, Nigeria	HOMER	COE, LPSP, NPC and GHG emissions
Standalone HES [39]	PV/Diesel/BSS	Community, Pratas Island, Taiwan	HOMER	COE, CO2, NPC, fuel savings, renewable fraction and surplus energy fraction
HES [40]	PV/Diesel/BS/biogas generator	Rural electrification project, Bangladesh	HOMER	NPC, Renewable fraction and COE
Off-grid HES [41]	PV/DG/BSS	Rural healthcare clinics, Fatika village, Nigeria	HOMER	NPC, COE, GHG emissions, fuel consumption and DG operating hours
Off-grid HES [42]	PV/WT/diesel/BSS	Rural area applications, Bangladesh	HOMER	LCE CO2, COE, DF, NPC and
Off-grid HES [43]	PV/WT/DG/BSS	Telecommunication facility, Punjab, India	HOMER	COE and APP
Off-grid HES [44]	PV/diesel/BSS	Fishing community, Sandwip, Bangladesh	GA	CO2 and NPC
Off-grid HES [45]	PV/diesel/BSS	Rural electrification, Khurda district in Odisha, India	MATLAB	Maintenance cost and cost of fuel
Off-grid HES [46]	PV/WT/diesel/BSS	An autonomous hybrid renewable system, Iran	MBA	NPC, COE and ENS
Off-grid [47]	PV/WT/BSS	Remote area of Ras-Shaitan, Egypt	GA, GWO PSO, WHO and HOMER	AC, COE, NPC and LPSP
Off-grid hybrid microgrid system [48]	PV/WT/diesel/BSS	Community, Yanbu, Saudi Arabia	MOSADE	COE and RF
Off-grid [49]	PV/WT/Diesel/BSS	Community, Coastal islands, Sydney, Australia	MILP	COE, LPSP
Off-grid [50]	PV/WT/BSS	A remote island, China	GA and HOMER	COE, LPSP, Unmet load, RF, CO2
Off-grid [51]	PV/WT/pump-hydro	Community, China	MOPSO	COE, LPSP
Off-grid [52]	PV/WT/pump-hydro	Community, Nigeria	GA and HOMER	COE, LLP

- JSR

2.4 Types of Wind Energy

Research conducted by Wilberforce et al. [6] found that the most effective wind turbines for use in areas with poor wind quality are the Savonius and Savonius-Darrieus hybrid turbines. Based on the research, a Vertical Axis Wind Turbine (VAWT) was selected for the project due to lower noise levels and better performance in turbulent wind conditions. Additionally, from a constructability perspective, they can be mounted on roof edges, ventilation shafts, and parapets, making them perfect for an office application.

- FRW

2.5 Battery Energy Storage System (BESS) – FRW

A BESS system was researched as a potential solution to the intermittent nature of the renewable energy sources chosen for this project. Since peak energy production is unlikely to coincide with typical office demand, the BESS can store surplus energy, which is utilised during periods of low production. To ensure the battery system's effectiveness, it is vital to select the correct battery size for the application [7]. In the operational study by McMahon, which used a lead-acid battery system coupled with a low-cost half-bridge converter to provide a mains electricity interface [8], it was found

that small capacities of 3-5 kWh were sufficient for routine applications, such as shifting common domestic loads to off-peak periods. However, more energy-intensive applications such as EV charging, supplying heat pumps, and other typical commercial office uses require significantly larger storage capacities exceeding 10 kWh.

According to the studies referenced in [9], the most common types of batteries in domestic applications are Lithium-Ion (49%) and Lead-Acid (13%). Academic research suggests lithium-ion is the best for the BESS because:

- Best energy storage per kilogram
- Increased longevity
- Less energy waste during charge & discharge
- Prices are reducing each year
- Compact for tight space requirements
- Options ranging from 3.2 V to 700 V and 2 kWh to 159 kWh.

According to [10], thermal runaway is the most significant hazard for lithium-ion batteries, which can result in fires or the release of flammable gases. To ensure safe operation and maintain compliance with IEC 62133, a battery management system (BMS) can be used to monitor and control parameters such as voltage, current and temperature. Additionally, mechanical integrity can be ensured by using rigid enclosures.

The environmental impacts of producing lithium-ion batteries also need to be considered. As shown by Peters et al. [11], producing 1 Wh of lithium-ion battery storage, on average, will generate 110 grams of carbon dioxide (CO₂) and require 328 Wh of energy.

The Research into battery Energy storage system was useful, as we found the best characteristics of an energy storage system, which would allow us to see the type which would be the best fit for our design, as this would solve the issue of the storage of the renewable energy within our system.

2.6 Commercial Energy Management System (CEMS)

The purpose of researching commercial energy management systems also known as CEMS was to investigate how energy monitoring and automated control could improve the efficiency of a commercial power generation system. As commercial buildings contribute to a lot of energy consumption, implementing an effective energy management system can help reduce costs, improve energy efficiency, and support sustainability targets [24].

Commercial energy management system continuously collect data from smart energy meters, sensors and other building systems before processing this information in real

time. This enables facility managers to monitor how much energy is being consumed, where the energy is being consumed, identify insufficient energy usage and optimise the usage of energy in areas like heating, ventilation, air conditioning, lighting, etc [24].

Smart energy meters were also researched due to their importance withing commercial energy management systems (CEMS). Unlike traditional electricity meters, smart meters automatically send accurate energy readings and provide real time information on electricity usage [25]. This allows businesses to understand how much energy they are using throughout the day and identify solutions to reduce energy consumption. For our project, a smart meter will provide the PLC with real time data so it can monitor the buildings energy demand and make decisions on when renewable or battery storage should be used.

Research into energy monitoring also showed that continuously monitoring energy usage allows businesses to identify trends, detects faults and improve the overall performance of the building. Energy monitoring software collects information from connected smart meters and sensors before displaying the data in visual form, reports and real time alerts [26]. This makes it easier to identify to inefficient equipment and unnecessary energy usage, helping to reduce operating costs and improve sustainability.

The research into commercial energy management systems was beneficial to our project because it showed how intelligent monitoring and automated control could improve the efficiency of our commercial power generation system. - ART

2.7 Energy Harvesting Technology

The growing demand for renewable energy is driven by the urgent need to mitigate climate change, reduce dependence on finite fossil fuel resources, and meet increasing global energy needs sustainably [28], [29]. Advancements in renewable energy technologies, energy storage systems, and smart grid infrastructure have considerably improved the efficiency, reliability, and affordability of clean energy solutions [28]. - RD

Energy harvesting is a technique for capturing ambient energy and converting it into electrical energy [30]. By powering small electronic devices without traditional cables or disposable batteries, it enhances system efficiency and enables sustainable, maintenance-free operation in consumer electronics, industrial sensors, and smart buildings [30], [31]. - RD

The Seebeck effect is a thermoelectric reaction where voltage is generated when there is a difference of temperature between two electrical conductors or semi-conductors. - RD

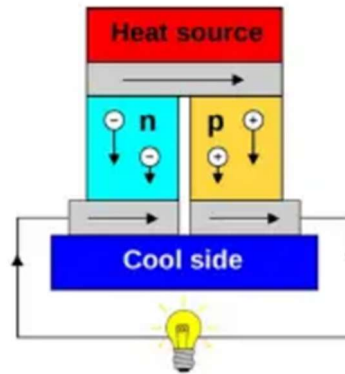


Figure 2: Illustration of a thermoelectric module [32]

These modules can be installed in any heating system to generate small amounts of energy. Further development of these modules is being utilised in solar panels, where the temperature difference between the face and the back sheet of the panel is utilised [34]. - RD

Other types of energy harvesting use kinetic energy; movement, vibrations or mechanical stress can generate electricity. Small-scale turbines can be installed in wastewater downpipes to capture energy generated from flowing or falling liquids, as shown in Figure 2. - RD

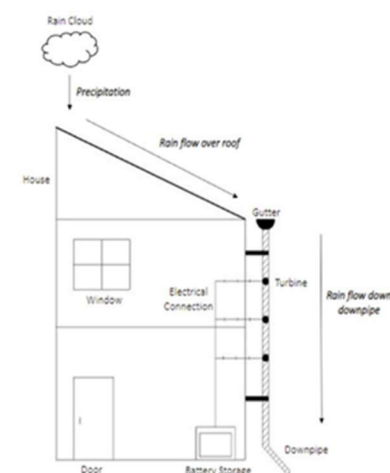


Figure 3: Household downpipe turbine [33]

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New technology has been developed in China, where triboelectric generators are installed on the faces of solar panels and convert movement or friction caused by rainfall [34]. These developments could change how we generate electricity in the future. - RD

3. DEVELOPMENT METHODOLOGY

3.1 Software used

3.1.1 AutoCAD

AutoCAD has been used within this project to illustrate the design of the system. This has been used on the General Arrangement Drawing, Block Diagram and Single line draft. This software was appropriate because the engineers who were creating the drafts were proficient in the use of AutoCAD, additionally, they had access to the software, no particular package was required as the drawings were simple line drawings and didn't have any modelling involved.

- JSR

3.1.2 Modecsoft ElectricalOM

ElectricalOM is a software package for low-voltage electrical design and has been used in this project to ensure the design is valid and compliant with BS 7671. In addition, the software will enable the calculation of the required cable and protective device sizes and types to ensure the entire system operates correctly as a coordinated system and remains safe under fault conditions such as earth faults or short circuits.

- FRW

3.1.3 Microsoft Office

Multiple Microsoft Office applications have been utilised in order to complete this project. Microsoft teams has been fundamental to us communicating in a team as this is where we all add and attach both our individual and group documents, Teams is also where we communicate any problems that we see in our project. Microsoft Word is also used in both group and individual tasks like ethics form, group logbook and our group project coursework. Another Microsoft application that was used is Excel; this is used in our project management section for tasks such as costing, deliverables, Gantt chart and job allocations. Microsoft PowerPoint was also used in our project for our presentations; this is both for our initial project proposal and for group presentation once everything has been completed.

-ART

3.1.4 TIA Portal V20

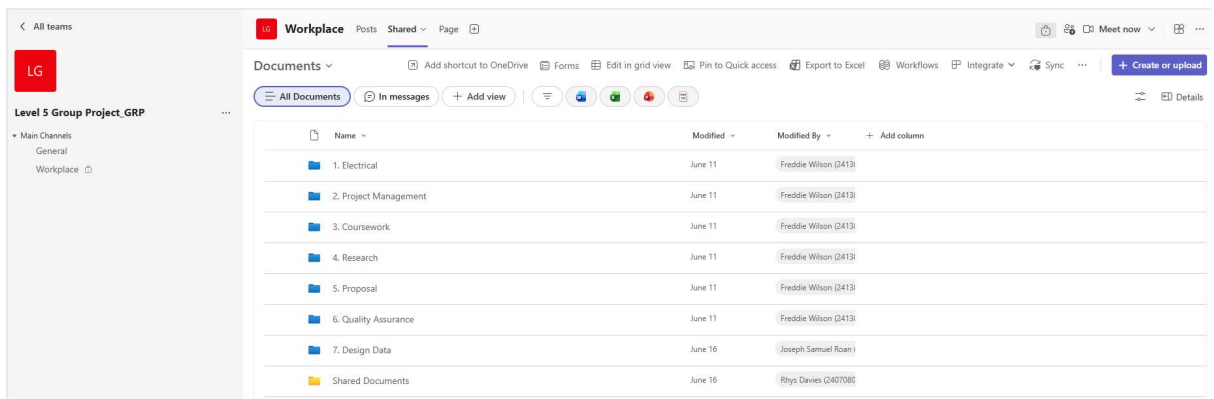
TIA Portal V20 has been used for Programming both our S7-1200 PLC and Siemens Simatic HMI. TIA portal has been used in ladder to develop the PLC control logic for monitoring renewable energy generation, battery storage and building energy usage. It has also been used to design the HMI interface, which acts as the projects smart energy

monitoring system. TIA Portal was selected as it is fully compatible with the Siemens hardware used throughout the project, simplifying communication between the PLC and HMI.

-ART

3.2 Project Management & Quality Assurance

To ensure alignment among group members across the project, a structured MS Teams SharePoint was created, as shown in Figure 4 below. This provided visibility across the team and easy access to documents. Throughout the project lifecycle, drawings and documents were revised from 0.1 to 0.3 as the final version, with 0.2 available if further review was required.



Name	Modified	Modified By
1. Electrical	June 11	Freddie Wilson (2413)
2. Project Management	June 11	Freddie Wilson (2413)
3. Coursework	June 11	Freddie Wilson (2413)
4. Research	June 11	Freddie Wilson (2413)
5. Proposal	June 11	Freddie Wilson (2413)
6. Quality Assurance	June 11	Freddie Wilson (2413)
7. Design Data	June 16	Joseph Samuel Roan
Shared Documents	June 16	Rhys Davies (2407080)

Figure 4: Microsoft Teams SharePoint Structure

Furthermore, important project management deliverables, such as a Gantt chart, deliverables list, risk register, action tracker and critical path analysis, were created at the beginning to assist in identifying potential issues that could be avoided early.

To maintain the highest technical quality of the documents produced throughout this project phase, a document checking and approval notice was created to outline the procedures that have been put in place. It covers the roles and responsibilities, checker and approver requirements, document checking workflows, and modifications to existing documentation. This is to be complied with as a mandatory requirement by every person involved in the project's development.

- FRW

4. DESIGN

4.1 General Arrangement Drawing

The General Arrangement Drawing (GA Drawing) is a drawing of the projects' overall general arrangement of the structural elements and where they can be found [23], but not in extreme detail, like a wiring diagram would have. The lines between the components are showing how everything is connected, however in a simplistic way, so that all audiences can understand and interpret the general system design. Likewise, all components on the GA drawing are labelled for the same reason. The drawing was created using AutoCAD software. The drawing is shown in Figure 5.

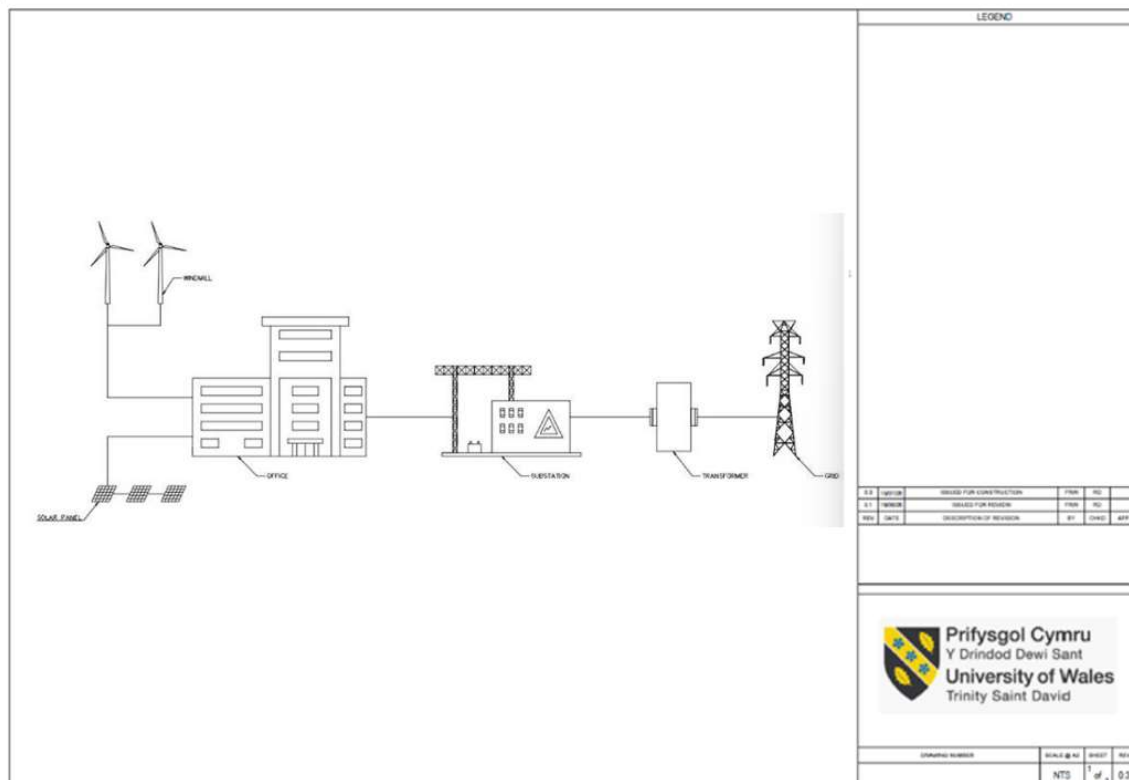


Figure 5: GA Drawing

- JSR

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4.2 Single Line Drawing

The single line drawing (SLD), shown in Figure 6, provides a more detailed view of the system's arrangement. The system is connected to the building's main distribution network to maximise renewable energy use while maintaining safe operation. Additionally, based on the simulation and calculations carried out throughout the project, equipment and protective device ratings were added to the AutoCAD drawing.

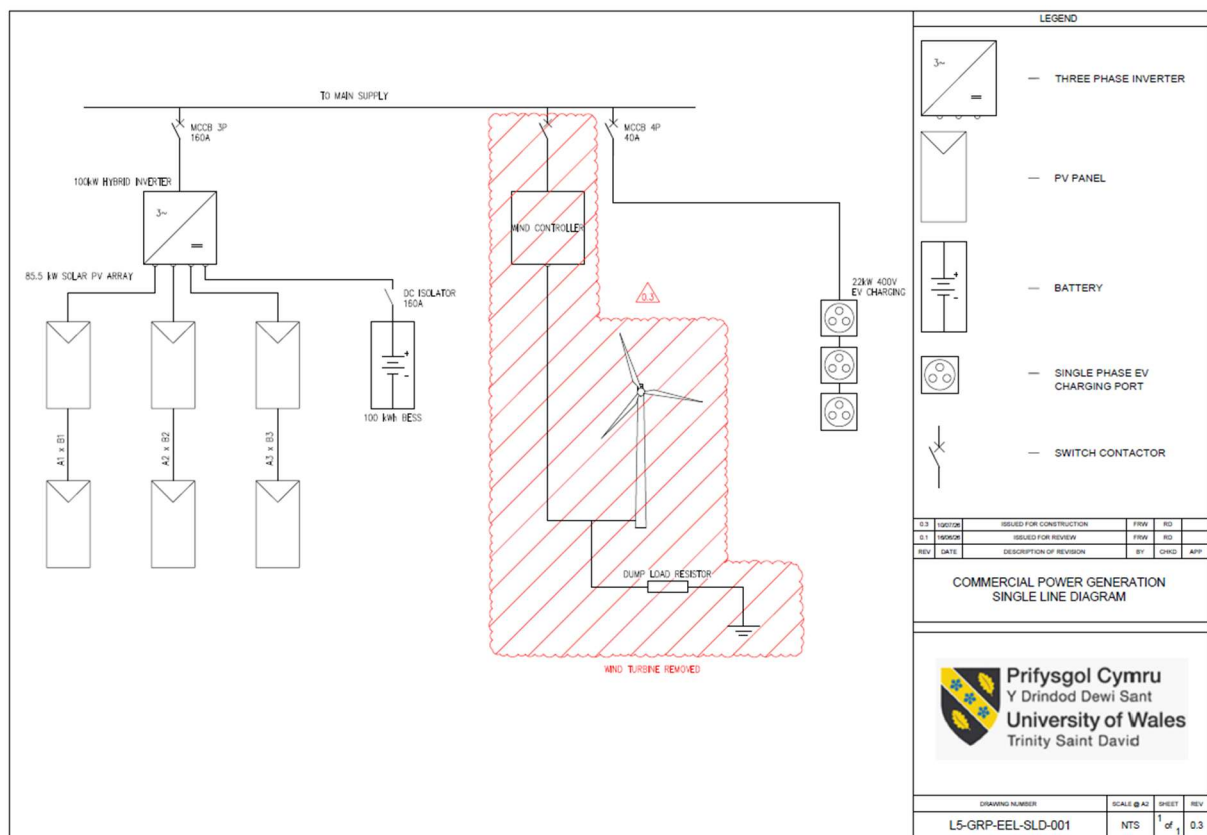


Figure 6: Electrical Single Line Diagram

- FRW

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4.3 Block Diagram

The block diagram in Figure 7, created for the project, provides a high-level overview of how the system operates. It was created as the first drawing in the initial design and was revised throughout the process. This drawing incorporated the major components such as the PV array, hybrid inverter, EV charger and main building distribution board.

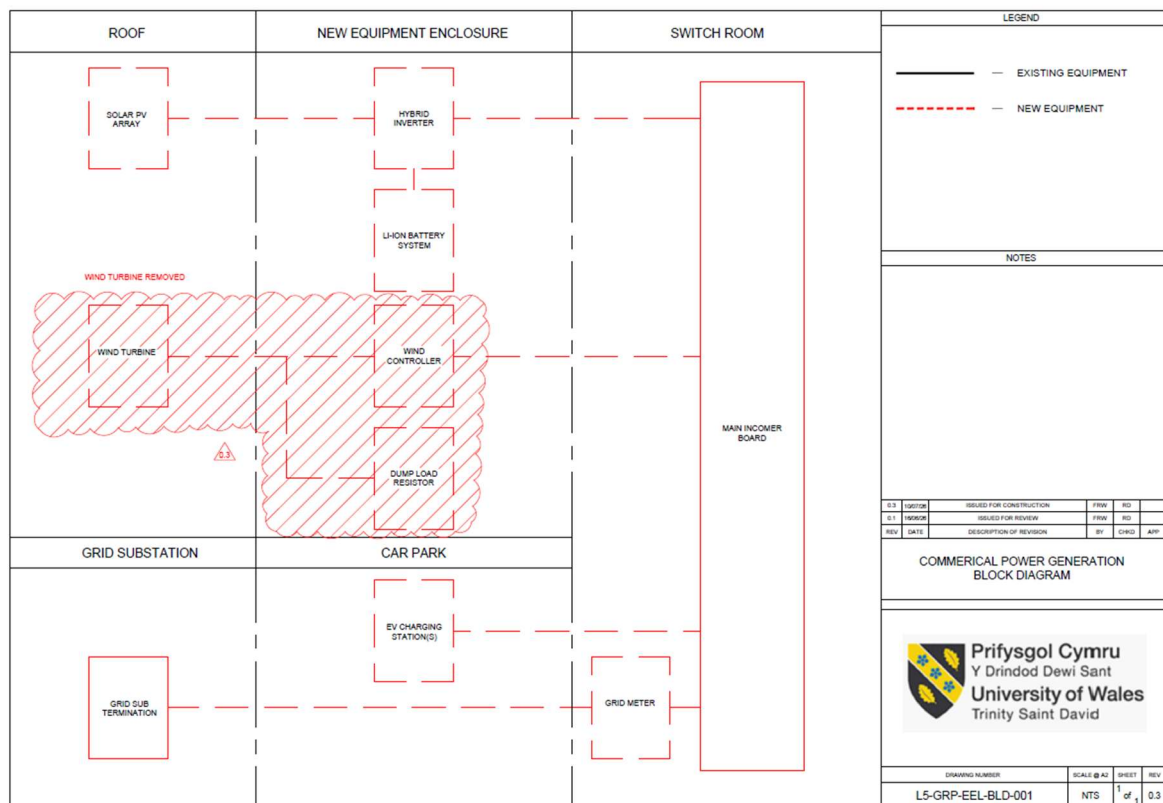


Figure 7: Electrical Block Diagram

- FRW

4.4 Solar Panel Concept Arrangement

To help visualise the design and obtain a more accurate installation cost, a concept design for the PV array was developed using Google Earth and Navisworks Manage to coordinate the layout. This is shown in Figure 8 below.



Figure 8: Solar Panel Layout

- FRW

4.5 Consumption Study

The site that is being considered is a two-story building with an estimated internal floor area of 1400m². The building is used for office space to accommodate over 100 staff members, who require general amenities such as kitchens, toilets and showers. A roof footprint of 700 m² is sufficient to safely install 270 commercial solar panels. Consumption studies reveal an average annual consumption of 80 KWh, as shown in Figure 9. These findings would suggest an 85 KW (80,750 KWh) solar array consisting of 190 (450 Wp) would match the annual consumption profile. – RD

2023	Energy per month		2024	Energy per month	
	Day (kWh)	Night (kWh)		Day (kWh)	Night (kWh)
January	6078.90	1540.20	January	6030.90	1610.40
February	5319.50	1345.70	February	5393.70	1344.80
March			March	5780.70	1378.40
April	5212.40	1302.10	April	5815.40	1273.20
May	5197.30	1224.90	May	5601.60	1212.80
June	5254.10	1290.60	June	4713.10	999.70
July	5151.30	1344.00	July	5642.30	1114.00
August	6267.20	1482.00	August	6064.80	1325.60
September	6424.80	1531.80	September	5001.30	1178.70
October	7052.70	1688.70	October	5171.50	1223.40
November	6748.70	1797.40	November	4970.10	1162.50
December	5281.20	1497.90	December	5097.80	1283.50
Column sum	63988.10	16045.30	Column sum	65283.20	15107.00
Total	80033.40		Total	80390.20	

Figure 9: Consumption studies for 2023 & 2024

4.6 Components and Equipment

4.6.1 Solar Inverters

A solar inverter converts direct current (DC) electricity generated by solar panels into alternating current (AC) [35]. This allows the harvested solar energy to safely power your household appliances or be exported back into the grid. - RD

4.6.2 Hybrid Inverters

A hybrid inverter combines a traditional solar inverter and a battery charge controller into one system [35]. It converts DC power from solar panels into usable AC electricity while managing

battery charging, allowing you to store excess solar energy for later use and reduce reliance on the grid [36]. - RD

4.6.3 Wind Controllers

A wind turbine controller continuously monitors environmental conditions and the turbine's mechanical and electrical operating parameters to maximise power generation while protecting the system from damage caused by excessive wind speeds, overspeed conditions, or electrical faults [37], [38]. Unlike a solar inverter, a wind turbine controller must accommodate the highly variable and intermittent nature of wind energy. In stand-alone and battery-based wind energy systems, a dump resistor (or dump-load resistor) is commonly used to dissipate excess electrical energy as heat when the electrical load is insufficient. This prevents turbine overspeed and maintains a safe electrical load on the generator [37], [39]. – RD

4.7 PLC Design

A siemens S7-1200 PLC was selected to act as the main controller for the commercial energy management system (CEMS). The PLC continuously monitors key system values, including solar generation, battery level, building energy consumption and grid export. This information is processed in real time, allowing the system to respond to changing operating conditions. The PLC was chosen due to its reliability, flexibility and compatibility with siemens software, making it suitable for commercial energy management applications. Although a simpler controller could have been used, the siemens S7-1200 PLC provides greater opportunity for future expansion and the addition of further automation functions. - ART

4.7.1 HMI Design

A siemens Simatic HMI was developed using TIA Portal V20 to provide a user-friendly interface for monitoring the system. The HMI displays live information such as battery charge level, solar generation, annual energy consumption, exported energy and daily performance statistics. A simple dashboard layout was chosen to ensure important information can be viewed quickly by the facility manager or maintenance team without necessary complexity. Navigation buttons were also included to allow access to additional pages such as historical data, alarms and system settings. – ART

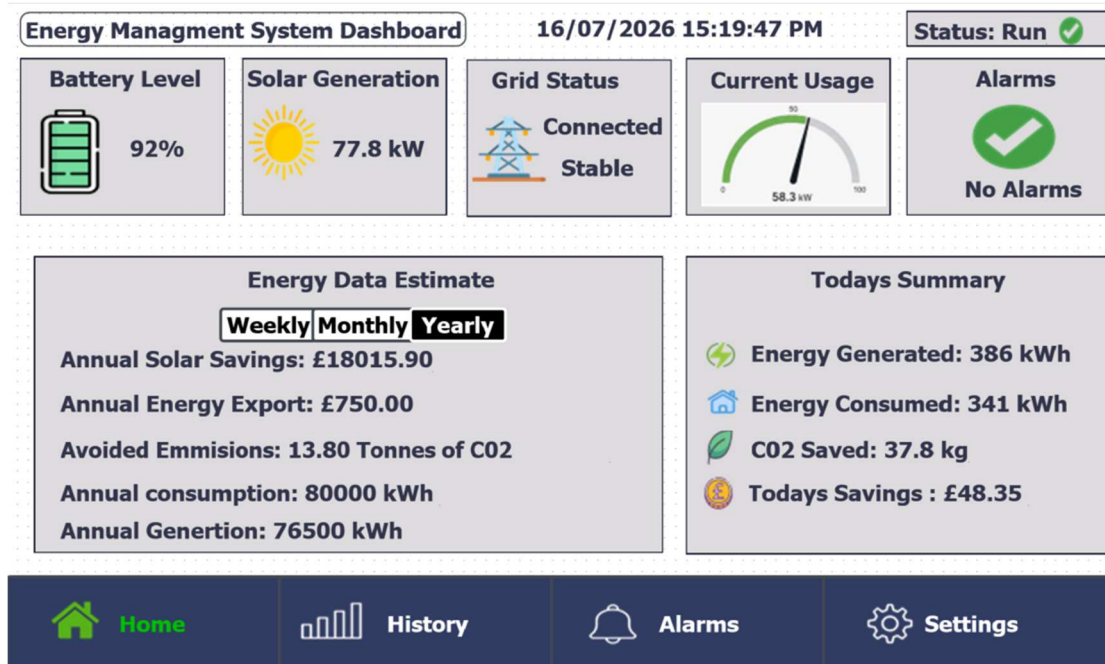


Figure 10: HMI CEMS Design

4.7.2 PLC and HMI communication

The PLC and HMI communicate through tags configured within TIA portal V20. These tags allow live values from the PLC to be displayed on the HMI and updated automatically as conditions change. This provides the facility manager with accurate real-time information regarding the performance of the renewable energy system. Using Siemens hardware and software throughout the project also simplified integration between the PLC and HMI making development and testing more straightforward. - ART

5. IMPLEMENTATION

5.1 System Simulation & Calculation

To validate the design, the system was built as shown in Figure 10 and simulated using ElectricalOM v.2025.12.30.23 to verify compliance with the BS 7671 wiring regulations [27] and the system's overall safe operation. As seen in Figures 11, 12, and 13, the circuits for the solar PV hybrid inverter, EV charger, and each of the 10 PV strings met the pass requirements with the chosen cable sizing, equipment rating, and protective device selections. However, the BESS cable sizing and specifications are indicative only and are subject to final manufacturer and vendor requirements that are not available at this stage of engineering.

From this, a report was generated from the software detailing cable types and sizing, voltage drop, earth fault calculations, protective devices, and cable operating temperatures. This allowed a final MTO to be produced, finalising the procurement scope and costing of the project.

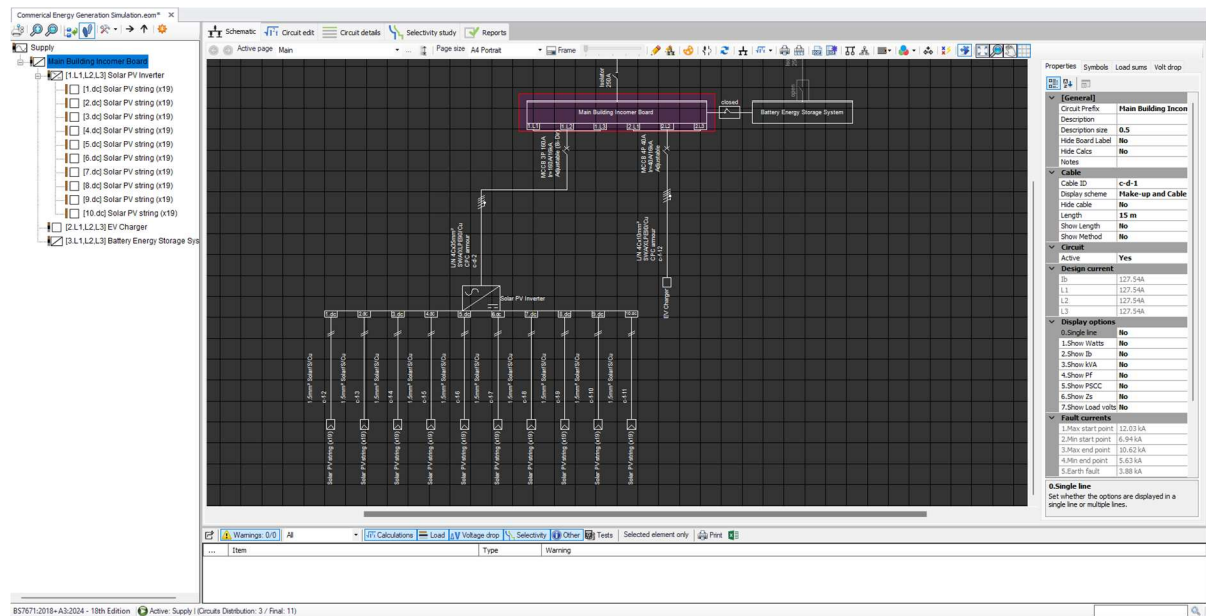


Figure 11: ElectricalOM Circuit

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Commercial Power Generation
Client: UWTSO

Analytical calculations report																
Company		University of Wales Trinity Saint David - IQ Campus University of Wales Swansea Waterfront SA1 8EW									 Prifysgol Cymru Y Drindod Dewi Sant University of Wales Trinity Saint David					
Designer		Freddie Wilson														
Circuit Description		Solar PV Inverter				Voltage / Phase		Three phase+N (400V And 230V E@230V) / L1,L2,L3 => DC 1140V DC - Load end volts = 396.99V								
Supply from		Main Building Incomer Board > 1.L1,L2,L3				Circuit type		Solar PV Inverter @ 80 kW AC								
Remarks						Cable ID Classification		c-d-2								
Status: Pass - Calculated using ElectricalOM v.2025.12.30.23 - BS 7671:2018 + A3:2024																
Circuit design data																
Conductor type		Multicore 90°C thermosetting insulated armoured, SWA/XLPE90/Cu					Conductors		4Cx35mm² + E(armour)		Length (m) 15 (Max for VD:51)					
		Element		Copper (Cu)		Armour	Steel	Temp (°C)		Full loaded:90 / Actual:67.2		Reference	BS/4E4			
Installation method		On a perforated cable tray - Reference method E					Correction factors		Ct:1 Cg:1 Ca:1 Ct:0.93 Cf:1 Ch:1							
		Settings		Ambient temperature (°C): 30. Trays: 1. Cables/Tray: N/A. Arrangement: Horizontal Touching												
Protective conductor		Installation settings		Cable armour												
CPC		Separate conductor (mm²)		0		Armour (mm²)		78		Total equivalent to phase conductor (mm²)		25.09				
Protective devices		Overcurrent		Generic, MCCBs Electronic Adjustable MCCB 16kA - Bidirectional					Rating (A)		160 (Set to 160)		Icu / Ics	16kA / 16kA		
		RCD/Earth fault device		No							mA		-			
Circuit calculations																
Currents (A)						Impedances at full loaded temperature (Ω)										
Design current Ib	Device setting Ir		Minimum effective conductor capacity - min Iz		Tabulated conductor capacity It		Phase conductor Z1		CPC Z2		Earth external		Phase external			
127.54	160 (Set to 160)		160		162		0.01003		0.03909		0.0566		0.0325			
Load factors	L1	L2	L3	Total Load		L1	L2	L3	N/Totals		Voltage Rise		L1 %	L2 %	L3 %	VD@400V
Power factor	1	1	1	Current (A)		127.52	127.52	127.52	0		Solar Inverter Connection Point to Grid		0.24%	0.24%	0.24%	0.97V
3rd Harmonics (%)	0	0	0	Load (kVA)		29.33	29.33	29.33	87.99		Solar Inverter circuit		0.51%	0.51%	0.51%	2.04V
Diversity factor	1	1	1	Resistive (kW)		29.33	29.33	29.33	87.99		Total		0.75%	0.75%	0.75%	3.01V
Spare (%)	0			Reactive (kVAr)		0	0	0	0		Limit		Solar Inverter to Grid Volt Rise Limit: 2%			8V
Earth Fault Calculations		Earth fault current (kA)		Zs (Ω)		Max Zs (Ω)		Max Disconnection Time (s)		Device Disconnection Time (s)		Min CPC (mm²)				
		2.1536		0.1019		0.7587		5		0.05		3.37				
Phase Fault		Max/Min at starting point (kA)		Max at end point (kA)		Min at end point (kA)		Disconnection time of MCCB (s)		Conductors withstand duration (s)						

MODECSOFT ElectricalOM 2025.12.30.23 (PROFESSIONAL) - BS 7671:2018 + A3:2024 (www.electricalom.com). The Licensee: InSite Technical Services Limited

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Figure 12: Hybrid Inverter Circuit



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Commercial Power Generation
Client: UWTSO

Analytical calculations report											
Company	University of Wales Trinity Saint David - IQ Campus University of Wales Swansea Waterfront SA1 8EW									Prifysgol Cymru Y Dreioedd Ddeall Sarn University of Wales Trinity Saint David	
Designer	Freddie Wilson										
Circuit Description	EV Charger				Voltage / Phase		Three phase+N (400V And 230V E@230V) / L1,L2,L3 - Load end volts = 397.36V				
Supply from	Main Building Incomer Board - 2 L1,L2,L3				Circuit type		Other circuit 3Ph and N				
Remarks					Cable ID Classification		c-4-12				
Status: Pass - Calculated using ElectricalOM v.2025.12.30.23 - BS 7671:2018 + A3:2024											
Circuit design data											
Conductor type	Multicore 90°C thermosetting insulated armoured, SWA/XLPE90/Cu				Conductors		4Cx10mm ² + E(armour)		Length (m)		15 (Max for 10:170)
	Element	Copper (Cu)		Armour	Steel	Temp (°C)	Full loaded 90 / Actual 48.7		Reference	BS/IE4	
Installation method	In underground ducts - Reference method D				Correction factors		Cc:0.9 Cd:1 Cs:1 Cg:1 Ct:0.88 Cf:1 Ch:1				
	Settings	In Plastic Conduit/Duct Ø50 Light 1 Bends. Ground temperature (°C): 20. Underground settings: Depth 0.7m. Soil thermal resistivity 2.5K.m/W.									
Protective conductor CPC	Installation settings				Cable armour						
	Separate conductor (mm ²)	0		Armour (mm ²)		42		Total equivalent to phase conductor (mm ²)		13.51	
Protective devices	Overcurrent				Generic, MCCBs Electronic Adjustable MCCB 16kA			Rating (A)	40 (Set to 40)		Icu / Ics 16kA / 16kA
	RCD/Earth fault device				No						mA -
Circuit calculations											
Currents (A)						Impedances at full loaded temperature (Ω)					
Design current Ib	Device setting In	Minimum effective conductor capacity - min Iz		Tabulated conductor capacity It		Phase conductor Z1	CPC Z2	Earth external		Phase external	
33.43	40 (Set to 40)	44.44		58		0.03464	0.07226	0.0566		0.0338	
Load factors	L1	L2	L3	Design load		L1	L2	L3	N/Totals	Voltage Drop (VD)	L1 % L2 % L3 % VD@400V
Power factor	0.95	0.95	0.95	Current (A)		33.43	33.43	33.43	0	Source	0.24% 0.24% 0.24% 0.98V
3rd Harmonics (%)	0	0	0	Load (kVA)		7.72	7.72	7.72	23.16	Circuit	0.42% 0.42% 0.42% 1.67V
Diversity factor	1	1	1	Resistive (kW)		7.33	7.33	7.33	22	Total	0.66% 0.66% 0.66% 2.64V
Spare (%)	-			Reactive (kVAR)		2.41	2.41	2.41	7.23	Limit	Public supply other uses 5% 20V
Earth Fault Calculations	Earth fault current (kA)			Zs (Ω)	Max Zs (Ω)		Max Disconnection Time (s)		Device Disconnection Time (s)		Min CPC (mm ²)
	1.4016			0.1565	3.0347		5		0.05		2.19
Phase Fault Calculations	Max/Min at starting point (kA)			Max at end point (kA)		Min at end point (kA)		Disconnection time of MCCB (s)		Conductors withstand duration (s)	
	Max:10.6177 Min:5.6259			5.547		2.2861		0.05		0.39 (k ² S ² = 2.05x10 ⁶)	

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Figure 13: EV Charger Circuit

Commercial Power Generation
Client: UWTSO

Analytical calculations report										 Prifysgol Cymru Yr Undeb Ddeur University of Wales Trinity Saint David	
Company		University of Wales Trinity Saint David - IQ Campus University of Wales Swansea Waterfront SA1 8EW									
Designer		Freddie Wilson									
Circuit Description		Solar PV string			Voltage / Phase		798V/DC - Load end volts = 790.14V / UoC_MAX: 1140V				
Supply from		Solar PV Inverter > 1.dc			Circuit type		Solar PV Panel x19 - Class II Equipment				
Remarks					Cable ID Classification		c-4-2				
Status: Pass - Calculated using ElectricalOM v.2025.12.30.23 - BS 7671:2018 + A3:2024											
Circuit design data											
Conductor type		Solar Energy Cable BS EN 50618, Solar/SCu				Conductors		2x1Cx1.5mm²		Length (m)	
		Element	Copper (Cu)		Armour	No	Temp (°C)	Full loaded 90 / Actual 61.9		Reference	BS/Solar
Installation method		Clipped direct flat touching - Reference method C				Correction factors		Ct:1 Cg:1 Ca:1 Ct:0.85 Cf:1 Ch:1			
		Settings	Ambient temperature (°C): 30.								
Protective conductor CPC		Installation settings									
		Separate conductor (mm²)		-	Other CPC (mm²)		-		Total equivalent to phase conductor (mm²)		-
Protective devices		Overcurrent						Rating (A)		10=2.88@1140V	Icu / Ics
		RCD/Earth fault device									mA
Circuit calculations											
Currents (A)						Impedances at full loaded temperature (Ω)					
Isc_MAX (A)	Device rating In	Minimum effective conductor capacity - min Iz		Tabulated conductor capacity It		Phase conductor Z1		CPC Z2		Earth external	
17.5	-	17.5		24		0.4315		-		-	
Load factors	L+			Design load		L+	L-Totals		Voltage Drop (VD)		L+ %
Power factor	1	-		Isc_MAX (A)		17.5	-		PV Array to Inverter		0%
3rd Harmonics (%)	0	-		Load (kVA)		0.45	-		Solar PV String		0.98%
Diversity factor	1	-		Resistive (kW)		0.45	-		Total		0.98%
Spare (%)	-	-		Reactive (kVAR)		0	-		Limit		Volt Drop to Solar Inverter: 3%
Earth Fault Calculations		Earth fault current (kA)		Zs (Ω)		Max Zs (Ω)		Max Disconnection Time (s)		Device Disconnection Time (s)	
Phase Fault Calculations		Max/Min at starting point (kA)		Max at end point (kA)		Min at end point (kA)		Disconnection time of Fuse (s)		Conductors withstand duration (s)	

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Figure 14: PV String Circuit

5.2 Restrictions and Limitations

A solar and wind system totalling 90 KW renewable energy, connected to the UK electricity distribution network must meet several legal, technical, and safety requirements to ensure safe operation, grid stability, and regulatory compliance. - RD

5.2.1 G99

The primary requirement is compliance with ENA Engineering Recommendation G99, which governs the connection of generating equipment. The proposed installation falls under 'Type A' of the G99 recommendations: 0.8 KW–1 MW (connection voltage < 110 KV). An "Apply to Connect" application must be submitted to the local Distribution Network Operator (DNO) before installation begins [40]. The DNO will assess the network's ability to accommodate the proposed generation and may specify export limits (G100) or network reinforcement works before granting approval [40]. - RD

5.2.2 G100

ENA Engineering Recommendation G100 specifies the requirements for export-limiting schemes used on generation systems connected to the UK distribution network. Its purpose is to ensure that the amount of electricity exported to the grid never exceeds the agreed export capacity set by the Distribution Network Operator (DNO) [43]. - RD

For example, although the system can generate 90 KW, a G100-compliant export-limitation system continuously monitors power flow and automatically reduces inverter output or diverts excess energy to ensure that no more than the agreed export limit is exported [43]. There are several reasons G100 compliance may be required;

- The existing network cannot accommodate the full export capacity [40].
- Network reinforcement would be expensive or impractical [40].
- A larger generation system is required for on-site consumption than the network can accept [43]. - RD

-

Limitation methods;

- Reduce the output of PV or wind inverters [43].
- Increase battery charging to absorb excess generation [43].
- Divert surplus energy to controllable loads (e.g., water heating or industrial processes) [43].
- Use an Energy Management System (EMS) to coordinate generation, storage, and site loads [43]. - RD

5.2.3 Planning and Regulatory Considerations

A 90 KW renewable energy installation must satisfy relevant planning and statutory requirements. Under the Town and Country Planning Act 1990, planning permission may be required depending on the technology, scale, and location of the development. -RD

The proposed installation has been designed to include a roof-mounted solar array, which may qualify as permitted development and may not require formal planning permission, provided it meets criteria set out in planning legislation [42]. - RD

Where building-mounted wind turbines are proposed, planning permission is always required regardless of orientation (vertical/horizontal axis). Local authorities will consider;

- Visual impact [42].
- Noise and vibration [42].
- Structural integrity [42].
- Ecology impacts [42]. - RD
-

5.2.4 Regulations and Legislation

Other regulations and standards that must be adhered to;

- Electricity Safety, Quality and Continuity Regulations 2002 (ESQCR).
- Electrical installation standards BS 7671:2018+A2:2022 (IET Wiring Regulations).
- Photovoltaic array design and installation BS EN IEC 62548.
- Health and Safety at Work etc. Act 1974.
- Electricity at Work Regulations 1989.
- Construction (Design and Management) Regulations 2015 (CDM). - RD

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5.3 Cost

A total of £86595.46 (ex VAT) will be required to complete the project, materials and labour cost are presented in Figures 14 and 15. A 10% contingency will be added to the total budget, which equals £95255.00 (ex VAT).

COMMERCIAL POWER GENERATION							
VENDOR	PART NO.	DESCRIPTION	RATING	QUANTITY	UNITS	COST (£)	COMMENTS
EQUIPMENT							
		Solar Panel Unit	450 Wp	190	Total	16,530.00	JA Solar 450W All Black Solar Panel N-Type Mono PV Module including brackets
		Solar DC/AC Hybrid Inverter & batteries	100kW / 1500V	1	Each	19,999.00	Sigenenergy M1 100kWh Three Phase Hybrid Inverter with SigenStack 48kWh Storage Package
		EV Charger	22 kW 400V	1	Each	439.81	ROLEC EVO 22KW - ROLEC5013
CABLES							
		4c 35mm² SWA/XLPE/Cu	-	15	Metres	324.15	EXISTING DISTRIBUTION BOARD - INVERTER
		4c 10mm² SWA/XLPE/Cu	-	15	Metres	98.40	EV CHARGER
		1c 4mm² BS EN 50618 Solar Energy Cable	-	500	Metres	385.00	DC LINK CABLE (SOLAR ARRAY)
		1c 70mm² DC Cable	-	30	Metres	381.30	BATTERY - INVERTER
CIRCUIT BREAKERS							
		MCCB 3P 160A 32kA	-	1	Each	425.82	Eaton 160A Three Pole 32kA MCCB
		MCCB 4P 40A 16kA	-	1	Each	267.37	Eaton 40A Four Pole 25kA MCCB
		160A DC Isolator	-	1	Each	395.91	Proteus 160A 4 Pole Rotary Isolator Switch IP65
				COMMERCIAL POWER GENERATION MATERIAL TAKE-OFF		 Prifysgol Cymru Y Drindod Dewi Sant University of Wales Trinity Saint David	
						L5-GRP-EEL-MTO-001	
						Sheet 1 of 1	
						Revision 0.3	
0.3	Issued For Construction	FRWRD	10/07/28				
Rev.	Description	Drawn	Date				

Figure 15: Required Materials – FRW / RD

Figure 16: Labour Requirements – FRW / RD

6. RESULTS & ANALYSIS

Table 2. Estimated performance of the solar array.

Description	Assumptions
Annual Consumption	80000 KWh
System Size	85 KW (Peak)
Estimated Annual Generation	76500 KWh
Battery Storage	40 KWh
Annual Self Use	69000 KWh
Annual Export	7500 KWh
Grid Electricity Price Import (KWh)	26.11p [44]
Grid Electricity Price Export (KWh)	10.00p [45]
UK Grid CO2 Factor	0.20 Kg/KWh [46]

6.1 Integrated Cost & Carbon Reductions

Savings from using generated solar;

$$69000 \text{ KWh} \times 26.11\text{p} = \text{£18,015.90}$$

Income from estimated exported solar;

$$7500 \text{ KWh} \times 0.10\text{p} = \text{£750.00}$$

Total annual benefit;

$$\text{£18,015.90} + \text{£750.00} = \text{£18,765.90}$$

Avoided CO2 emissions (Annual self use);

$$69000 \text{ KWh} \times 0.20\text{Kg/KWh} = 13,800\text{Kg} = \textbf{13.80 Tonnes of CO2}$$

These estimated calculations would indicate the projected capital payback period for a £95,552.00 budget would be just over 5 years.

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Table 3. Estimated saving over a 25 year period (solar panel life).

Savings	25-year estimate
Financial	£400,000 + (Excluding inflation)
CO2	345 Tonnes

RD

7. EVALUATION

7.1 Overall Project Evaluation

Overall, the project successfully met its aim of designing a commercial Power Generation system capable of reducing operating costs and carbon emissions through the use of renewable energy generation and intelligent energy management. The proposed system successfully integrates monocrystalline solar panels, battery energy storage, and a commercial energy management system (CEMS) controlled by a Siemens S7-1200 PLC. The research undertaken throughout the project directly supported the final design decisions, with the selected technologies proving to be the most practical and suitable solution for our climate and for a commercial office environment. - ART

7.2 Design Changes During Project

Throughout the project, several changes were made as further research was carried out, and ideas were discussed as a group. The original concept was to design a renewable energy system for domestic properties using a PIC microcontroller. However, after researching current commercial energy management systems and renewable technologies, it became clear that a commercial office building would benefit more from the proposed system due to its higher energy demand and opportunity to reduce electricity costs and reduce carbon emissions. As a result, the decision was made to use a Siemens S7-1200 PLC and HMI instead of a PIC microcontroller. Although the project's focus changed from domestic to commercial, the original idea has not been abandoned and is planned to be developed further in the future as a domestic residential version.

As we did more research, we also discovered that collecting rainwater to use as an energy generation source was not justifiable. We discovered that rainwater was not going to generate sufficient energy to justify adding to our commercial power generation system. As a result, we have decided not to use this idea in our project.

Originally wind power was one of the sources of energy that we were going to use, after doing more research we discovered that wind turbines would be a bigger problem than we originally thought as we discovered all wind turbines need planning permission, Wind turbines also need maintenance to keep them running and can cause noise pollution, vibration, structural integrity and can cause a visual impact to the area [42].

Another energy source that was considered during the design process was thermoelectric energy harvesting. Although it is a proven technology, it's not worth implementing existing renewable technologies.

- ART

7.3 Improvements For Future

Although the proposed system met the overall project aim, there are several improvements that could be considered in the future. One improvement would be to develop the commercial into a domestic power generation system, allowing the same renewable energy principles to be applied to residential properties. Wind energy will also be considered if planning permission and site conditions are suitable, as this would further increase renewable energy generation.

- ART

8. CONCLUSIONS & RECOMMENDATIONS

8.1 Conclusion

Within the report, we have discussed our research findings into specialist topics linking to the Commercial Energy System we are designing. Additionally, we have included our system design, utilizing technical drawings to show our plan. We have worked out overall costing for the project, to ensure that we have energy savings, so that we achieve our aim, ensuring we also include the components and equipment required to complete the project. We have carried out simulations to prove that the system would work, including our results to show this. Overall, we met our project aim, by following the objectives to the best of our ability - JSR

8.2 Suggestions For Further Work

For further avenues of research following this report, we could adapt our model from commercial office space to domestic buildings, for instance a house. This could have the same aim in trying to be as cost effective as possible. A potential recommendation could be utilizing a system that uses more wind energy, as energy production could be higher. However, consideration of this is the associated costs of having any wind turbine, with the planning permission, maintenance costs, etc. - JSR

8.3 Benefits From The Project

From the project, certain benefits have been achieved, for instance; the cost savings for a business, as this would make businesses more likely to transition to renewable energy systems, which would reduce carbon footprint, which is a part of our aim. Additionally, from this there could be further research, and our work could be expanded to create a more environmentally friendly world, not just commercially, but also domestically, for the potential further avenues, refer to section 9.2. – JSR

9. REFLECTION

9.1 Reflection - JSR

While completing the report, I have learned and developed some skills. From the research, I have developed better referencing skills, as I ensured only use sources which are reliable, relevant, impactful, and scholarly, when applicable. I will carry this forward in all referencing I undertake; therefore, this has improved my skillset. Additionally, I have improved my drafting skills and my personal ability using the AutoCAD software, from the drafting I have undertaken. This will help me develop professionally, as my current occupation is an Electrical Design Engineer and as I use AutoCAD within my job role, this project has been beneficial for my continued career development and proficiency in CAD software. Additionally, as this was a group project, this is good for both personal and career development, as working within a team on a project is mandatory for most projects in a real working environment, this has taught me how to communicate effectively within a team, as well as methods in which we can all collaborate effectively together to achieve a common goal. This has changed me as a person as I feel more confident with compiling research and references for projects both academic and real-world. Additionally, using drawing software to complete drafts, I feel that this has helped me with professional development, for my future career.

9.2 Reflection - ART

During the group project module, I have developed many skills that I can implement in both my career and university learning. Firstly, expanding on my ability to work efficiently and effectively within a team. This has been done by using different methods and tools like Microsoft teams which makes communication easy within the team and team organisation simple. Throughout the project, I also improved my technical knowledge by learning how to use Siemens TIA Portal V20 to develop a PLC program and design a CEMS HMI screen. Although I have some previous knowledge of PLCs, this project helped me gain a better understanding of how industrial automation systems can be used to monitor and manage renewable energy systems. In addition, I developed my research, report writing and referencing skills by gathering information from reliable sources and using it to justify the decisions throughout the project. These skills will be valuable in future university assignments and in my career.

9.3 Reflection - FRW

Throughout this group project, I have gained applicable professional skills that will be beneficial to the workplace and future university modules. To begin with, my technical knowledge has improved as I have developed skills using ElectricalOM software to create the system and perform cable and protective device sizing to comply with BS 7671 and verify project safety. Additionally, my AutoCAD and drawing skills has improved as a part of this project via the creation of the SLD and BLD, which is a widely used and applicable software in the engineering industry. Next, I developed several key

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soft skills. Firstly, communication skills improved through communicating ideas clearly and providing constructive feedback. Moreover, I became more confident in taking initiative by coordinating tasks and supporting the team. Finally, I strengthened my problem-solving skills by being adaptable and responding to different challenges swiftly, which helped us remain on track and progressing with minimal delays.

9.4 Reflection - RD

The group project module has helped me improve as a student and an Electrical Technician. At the beginning, I was tentative and unsure of what I could bring to the group; this, over time, diminished as I realised my technical knowledge and skills were useful in the sections of the project I undertook. Freddie and I worked together on the schematic and layout drawings; his skills with AutoCAD overshadowed my hand drawings, a gap in my skill set that I will look to improve. I struggled working within a team on the report writing; I felt I was not contributing equally in some sections, but more so in others. Communicating this to my peers made me realise that within any project, everyone has their recognised field of contribution, and instead of seeing it negatively, there is a learning opportunity. I have strengthened many skills and believe completing this group project will prepare me for my final dissertation.

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11. APPENDICES

APPENDIX A:

CABLE PRICING

https://www.electriccable.co.uk/armoured-cable.php?gad_source=1&gad_campaignid=20575782662&gbraid=0AAAAAD_TrDvO_hlLmiCFNJzge93fzO7vR&gclid=EA1aIQobChMI-qTD8_jRIQMVC5SDBx1ZeqnfEAAYASAAEgKy_PD_BwE

APPENDIX B:

Components

<https://www.cef.co.uk/>