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Electrical Power Engineering

Simulating Converter System with Energy Storage for Offshore Applications

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Summary:

This thesis focuses on simulating a power converter with an energy storage system for peak loads shaving in offshore oil and gas processes and operations. Oil and gas industry operations often encounter peak power demands that strain the existing power system, leading to inefficiencies in power and increasing costs. To mitigate these concerns this peak shaving system is proposed and simulated a model to observe how system reacts.

The simulation framework is a collection of subsystems of ESS, power converter system, grid, an induction motor and an auxiliary load. By modelling these systems together and without the peak shaving system, the behavior of the power system due to peak loads can be replicated and analyzed. Integration of offshore renewables and regenerative energy in offshore platforms are discussed to facilitate charging options for the onboard energy storage.

The simulation model elaborates the economic benefits considering factors of fuel consumption and capital cost and through the comprehensive studies, this thesis contributes to development of sustainable energy solutions in offshore oil and gas field.

Preface

Completing this master thesis traces my enrichment of academic journey that has been both challenging and gratifying as I offered countless hours for literature reviewing, analyzing, simulating, and writing the report to keep the work on track. I feel an extreme sense of gratitude and attainment.

This thesis focusses on integrating a converter system together with an energy storage for peak load shaving in offshore industries. I am happy that I was able to simulate a model of a peak shaving system which is the main aim of this thesis. Through a comprehensive study of literature review, electrification of offshore industry is addressed here.

I owe a dept of appreciation to Professor Kjetil Svendsen whose steady support and guidance have been invaluable throughout this semester. His expertise and encouragement enriched the quality of this thesis. In addition, I would like to extend my gratitude to Ole Petter Bjørnstad from Tinfos for his contribution through provoking discussions, resource sharing and total involvement for navigating this thesis topic in a perfect manner.

It is my faithful hope that this thesis provides a meaningful contribution to offshore oil and gas industry and inspires future research on electrification.

The computer tools used in this thesis are:

- MATLAB Simulink R2023b for simulating the model.
- Microsoft Word for thesis writing

Porsgrunn, 15.05.2024

Lasintha Piyatissa

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Nomenclature

AHC	-	Active Heave Compensation
CAES	-	Compressed Air Energy Storage
ES	-	Energy Storage
ESS	-	Energy Storage System
FBES	-	Flow Battery Energy Storage
SPWM	-	Sinusoidal Pulse Width Modulation
FES	-	Flywheel Energy Storage
GHG	-	Green House Gases
IGBT	-	Insulated-Gate Bipolar Transistor
Li-ion	-	Lithium-Ion
NaNiCl2	-	Sodium Nickel Chloride
Na-S	-	Sodium-Sulphur
Ni-Cd	-	Nickel-Cadmium
Pb-A	-	Lead-Acid
PHS	-	Pumped Hydro Storage
qZSI	-	quasi–Z Source Inverter
SCES	-	Super capacitor Energy Storage
SMES	-	Superconducting Magnetic Energy Storage
V_c	-	Carrier Voltage
V_r	-	Reference Voltage
VSI	-	Voltage Source Inverter

1 Introduction

1.1 Background

Powering an offshore platform for operations and utility consumption is not so cheap. Diesel powered generators and gas turbines are the most conventional method of supplying electricity for oil rigs today which contribute to adverse consequences in every aspect. An increasing fraction of world's energy consumption is conveyed through electricity by transferring to renewable energy sources and environmentally friendly solutions. It is becoming more vital to use energy storage systems as a sustainable energy solution and maximize operational efficiency by reducing fuel consumption. Among the different challenges faced in offshore industry, dealing with peak loads while providing uninterrupted supply remains a critical concern.

This report explores a novel approach to address this challenge by simulating a model for peak load shaving in oil and gas fields utilizing a power converter and energy storage system. Moreover, this presents a comprehensive study of integrating offshore renewable energy sources and regenerative energy to recharge the storage system, thereby encouraging a more sustainable ecosystem.

Power stability in the presence of variable demands in the field is a major point when it comes to deciding the capacity of power sources. In Oil and Gas field where literally uses diesel generators as their main power source consumes much fuel during periods of high demand and it subjects to overload. Therefore, installing an ESS for levelling peak loads contributes to the generator system in oil rigs more efficiently. Power converters in this peak shaving system play a significant role as it controls voltage and frequency according to the load requirements in addition to the power conversion. A thorough examination of power converter topologies is outlined here in this report. At the end, this provides economic and environmental concerns of integrating an ESS for peak load smoothening.

1.2 Motivation

The motivation for this research is the growing deviation for sustainability and energy optimization within the offshore oil and gas industry. As global regulations regarding environmental concerns are tightened, there is a vital need of innovative solutions that can enable a transition offshore platform towards cleaner energy. In the other hand, the unpredictability of oil prices and never-ending demand encourage for cost-effective operation of offshore projects.

1.3 Objectives

The main objective of this thesis is to support the generator set installed in offshore platforms by using an energy storage together with power converter system to reduce the installed capacity of generators. The aim is to supply power from ESS when peak loads occur in the system. It is simulated a model to see how it behaves when connecting all systems together. The other objective of this thesis is to study integration of energy storage system with power electronic converter to connect with main supply. It is explored existing research and developments regarding the integration of energy storage systems with power electronic converters to facilitate connection with the main power supply on offshore platforms. The next is to examine regenerating power methods and renewable sources available in offshore fields to capture energy, with a focus on efficiency and feasibility. This objective set up with the purpose of connecting this energy to the ESS to charge it up using green energy. So, the charging of ESS using renewable energy can be combined together with the system modelled in this thesis in future.

Identifying peak load scenarios in offshore applications is one of other objectives of this thesis. This is done considering factors such as equipment usage patterns and operational fluctuations. As the last objective, it is performed a comprehensive analysis of the cost implications and environmental impacts associated with implementing energy storage systems and peak shaving strategies in offshore platforms.

By achieving these objectives, the report aims to provide valuable insights and optimization for energy management strategies and promoting sustainability in the offshore oil and gas industry.

1.4 Structure of the report

The structure of this report is summarized below.

Chapter 1 :

The background, motivation and objectives of this thesis topic which is “simulating converter system with energy storage for offshore applications” are introduced in this chapter. The arrangement of this report is summarized at the end.

Chapter 2 :

Requirement of having energy Storage and technologies is presented in this chapter. Structures of power converters and related control strategies for low voltage peak shaving systems are discussed.

Chapter 3 :

Peak load scenarios and the necessity of shaving peak loads in offshore rigs are discussed here.

Chapter 4 :

Possible renewable and regenerating energy sources which can be used to charge onboard energy storages in offshore platforms are explored.

Chapter 5:

A description of the simulation model and presentation of Simulink results for the system are summarized.

Chapter 6:

This chapter analyses economic and environmental impacts on integrating an ESS to offshore oil and gas industry.

Chapter 7:

There is a discussion based on ESS integrations for peak load levelling in oil and gas fields and offshore renewable sources allocation for recharging storages.

Chapter 8:

This chapter concludes with the results found in the simulation model and literature reviews and also provides recommendations for future work to continue this topic further.

2 Integration Of Energy Storage System with Power Converter System

The integration of ESS exhibits a great advancement of modern engineering which allows a high range of applications. This chapter explores the current research and developments, challenges and gaps between existing power converter systems and improvements for potential applications by applying ESSs in Offshore oil and gas industry.

2.1 Energy Storage System

ESS is one of best options to increase efficiency in electrical grids and reduce costs by energy shifting, load levelling and peak shaving. This can be used to improve stability and reliability by frequency regulation, voltage control and spinning reserve. The other important feature of ESSs is the enhancement of power quality from handling interruptions, mitigating harmonics of voltages and currents for sensitive industries [1].

2.1.1 ESS Requirements in Offshore applications

Offshore oil and gas industry was contributed for 26.7% of complete GHG emission of Norway in 2020 [2] . It is necessary and beneficial to introduce energy efficient options for a transition of sustainable world. ESSs can be utilized therefore to store energy produced by renewables and use for offshore fields' consumption reducing carbonized power sources. This is not only for decarbonization but also to reduce oversizing of diesel or gas powered generators due to peak demands. Peak loads can be levelled from an ESS and controlled generators not to overload. It is also important that offshore assets to have blackout start and continuous, regulated voltage and frequency support.

2.1.2 Energy Storage Technologies

There are different ESTs for storing energy consisting mechanical, electrical, thermal, chemical and electrochemical processes. A classification of ESTs is shown in Table 2.1. When comparing the energy density of ESTs, electrochemical ESs have higher values and when it comes to power density, FES, SMES, and SCES have the best performances [3]. One major technical characteristic of ESTs is discharging duration which shows the suitability of power and energy applications. Li-ion batteries can be widely used in power applications due to long duration discharge and round-trip efficiency. Economic considerations are the main concern when deciding an adaptation of ESs. Recent findings have shown that a steady decrement in capital costs of battery technologies where increments happen in competitiveness and attractiveness of ESs for various applications [6].

The most common way of categorizing ESTs is using their form of storage which is shown in Table 2.1.

Table 2.1: Types of ESTs available today [3].

Mechanical	**Electrical**	**Electrochemical**	**Thermal**	**Thermo -chemical**	**Chemical**
Pumped Hydro - PHS Compressed Air – CAES Flywheel - FES	Capacitor Super capacitor – SCES Superconducting magnetic - SMES	Secondary battery Pb-A, Ni-Cd, Na-S, NaNiCl, Li-ion Flow battery	Sensible/Latent Heat storage	Solar fuels Heat storage	Hydrogen fuel cell

2.2 Power Converter System

When connecting an ESS to main supply, a power electronic converter system plays a key role in managing electric energy parameters in accordance with all requirements. The power converter system's primary function here is to convert electrical power stored in the ESS into appropriate form to connect the main supply and it serves here as an interface between the ESS and power loads.

The main power supply outputs alternating current (AC) to power up oil field equipment while an ES stores direct current (DC). A power inverter should be implemented in this case for the power conversion from DC to three phase AC. And it adjusts output voltage and frequency to maintain within acceptable limits as per regulations. Since both generators set and the ESS supply power to the loads, power converter system should be able to manage the load balancing process and demand fluctuations to optimize overall system efficiency ensuring consistence power to the loads. The power converter system is completely responsible for controlling voltage and frequency of the system and switching power supply from main supply to the ESS when the peak loads occur and switching back to main supply during normal conditions in this peak shaving system.

2.2.1 Power converter topologies

A power converter is designed with different structures and one or more intermediate conversion stages. This sub tittle presents the introduction of converter topologies used in low voltage systems when integrating into main AC power supply.

1. Isolated Single Stage Bidirectional Converter

   The single stage converter topology does not include intermediate DC-link storage element and possible to decrease number of semiconductor devices use due to only one conversion stage which effect to increase efficiency and decrease complexity, cost and weight. Many topologies, including single-stage and two-stage designs, utilize electrolytic capacitors to absorb 120/100Hz power [8], impacting system reliability due to limited capacitor lifespan. In some cases, this power ripple may affect batteries, shortening their lifespan. It's also crucial to ensure power factor and total harmonic distortion (THD) remain within acceptable limits.

   However, bidirectional isolated single-stage converters are not widely used as multistage due to complex control requirement and complicated procedure of optimization and calculations despite the reduced number of semiconductor devices are used.

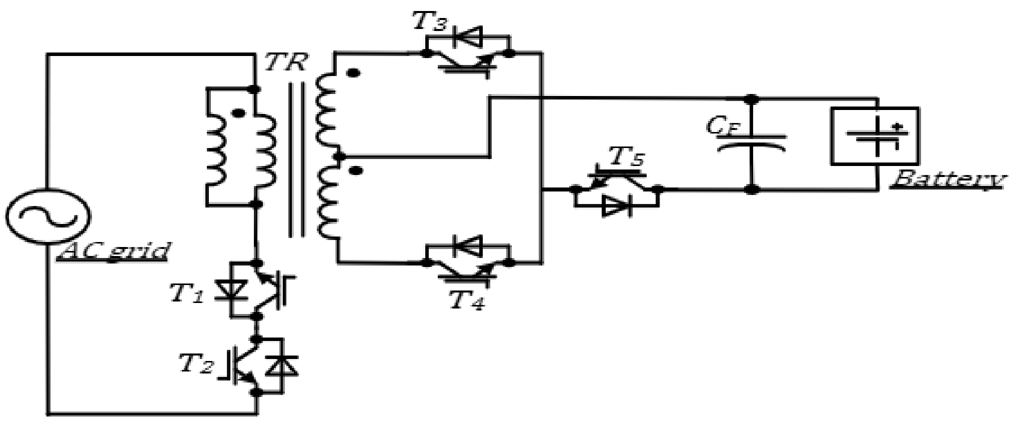

Figure 2.1: Single stage bidirectional (a flyback converter) [8].

2. Isolated Multistage Bidirectional Converter

   Multistage DC to AC converter can be consisted with two stages or more. Typically, two stage AC to DC bidirectional converter topology combines DC to DC voltage regulation stage and DC to AC inverter stage which can directly connect to AC grid or loads. The AC to DC converter contributes to rectify AC into DC voltage and controls power quality of the grid. An inductor or a capacitor is connected as DC link storage in the DC side of the converter. DC storage is used as a separation between AC to DC stage and DC to DC conversion and therefore both systems can be optimized accurately [8]. Figure 2.2 is an example of bidirectional isolated multistage converter which consists of low voltage and high voltage side and where both converters and inverters are exist.

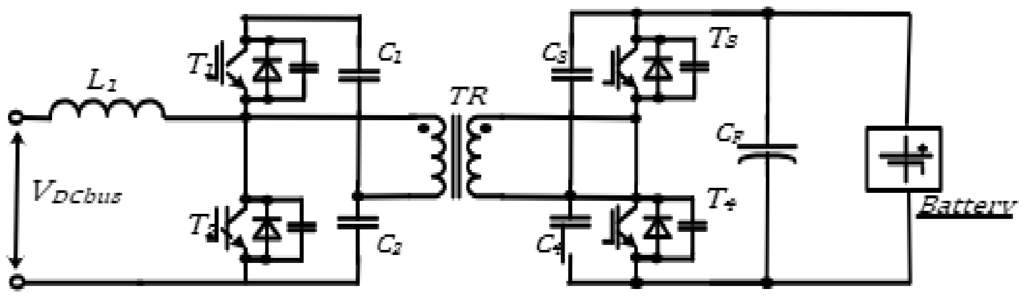

Figure 2.2: Current fed half bridge converter [8].

3. Non-Isolated High Step-Up Converter

   It is also possible to use non isolated converters with high voltage step up and down functionality when integrating low voltage energy storages to grid. There are some drawbacks of this topologies such as complexity, low efficiency and mostly they have unidirectional power flow [8]. The combination of a non- isolated DC-DC converter and bidirectional inverter also good for low voltage energy storage integration to AC grid.

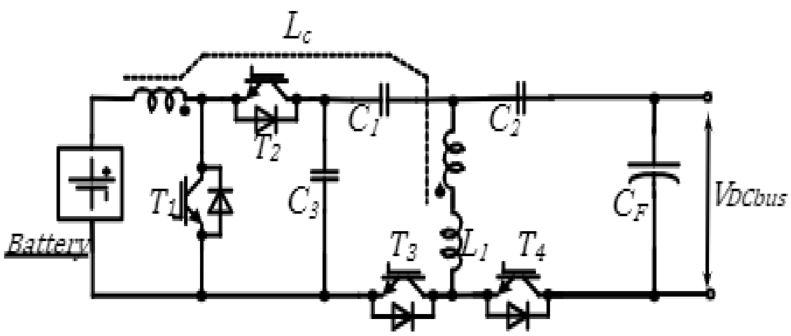

Figure 2.3: Step-up/step-down bidirectional DC-DC converter for high power applications [8].

4. Multiport Storage System with Renewable Energy Integration

   Renewable energy integration for recharging energy storages is one of main objectives in this thesis. Here, a multiport single stage inverter is shown in Figure 2.4 which is possible for placing ESS near renewable energy source [8]. These topologies mainly connected in a stand-alone power system. Figure 2.4 is a proposal for soft started inverter for controlling power of a solar system, battery and an AC load which is capable of turned-on switches under zero voltage and less active switches can be used.

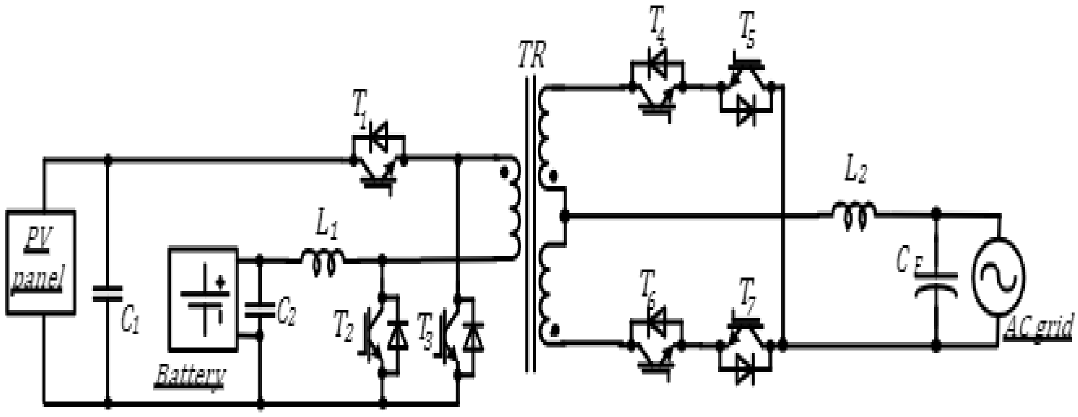

Figure 2.4: Three port single stage converter topology for renewable sources integration [8].

5. Topology for Renewable Energies and Low Voltage BESS Integration to AC Grid

   This is a promising approach to store extra energy during low consumption and supply without a shortage in power source. Figure 2.5 presents Z-source inverter with integrated ES where the storage is connected in parallel to quasi-Z-source capacitor. This has capability of controlling output power and state of change (SOC) of the ES by duty ratio and modulation index. [8]. It is possible to use SPWM based modulation signal for qZSI. This bidirectional converter is possible to use in grid connected applications where two types of storages can be used.

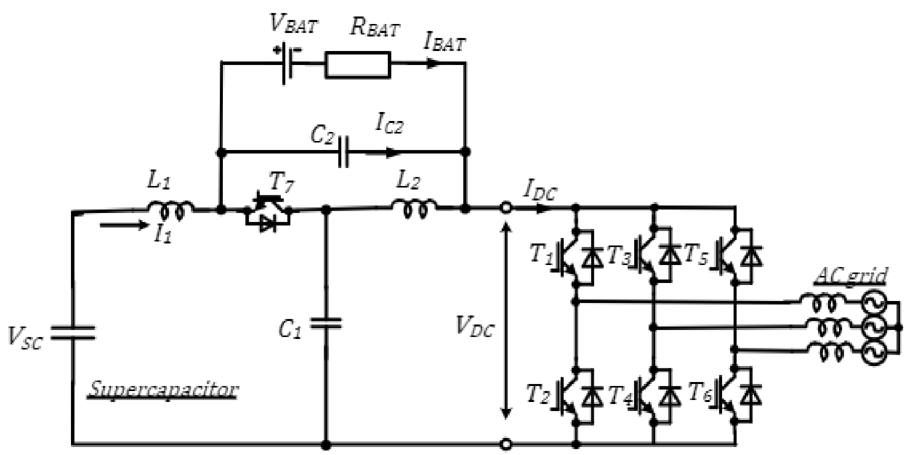

Figure 2.5: Bidirectional two energy stored qZSI [8].

2.3 Control Strategies for Power Converter System Integration

2.3.1 Hysteresis Current Controller

There are many types of controllers available in power electronic engineering, but this controller can be a preferable option when it comes to controlling current with fast response. This is also referred as tolerance band control for current regulators. This is a way of controlling voltage source inverter and a reference current wave form is followed by the output current. The hysteresis control method for an Active Power Filter (APF) operates by establishing upper and lower tolerance thresholds for which the error signal is compared. The maximum allowable error is encountered by the difference between these thresholds. When the error signal remains within this tolerance band, no switching occurs within the filter but as soon as the error, switching pulses are initiated, prompting the APF to generate signals for injection into the supply line [4].

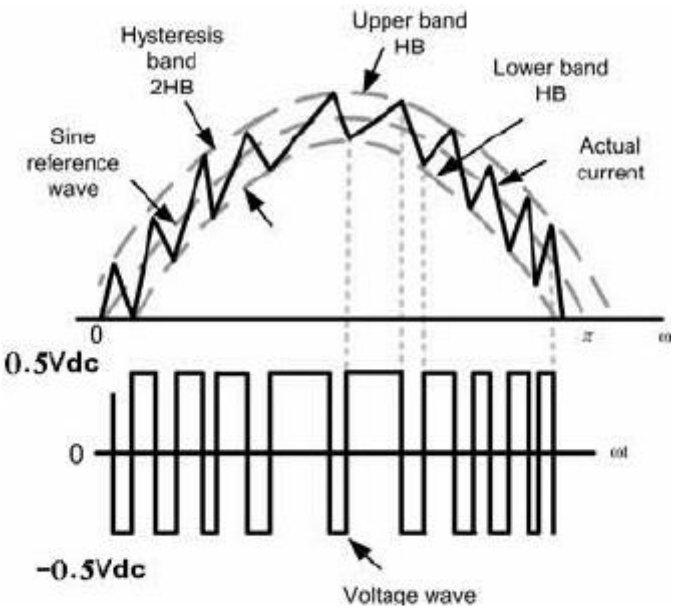

Figure 2.6: Hysteresis current controller [4] .

2.3.2 Proportional Integral (PI) Controller

PI controller which is a feedback control system is widely used one for industrial automation. This controller adjusts the output based on error between the set value and actual value of a process variable. The proportional action in PI controller reduces steady state error and provides quick response to the error signal but it might exist some offset error. The integral control action helps eliminate steady-state errors caused by factors such as system bias or disturbances that persist over time. Combining these two parts together makes improved stability and robustness to the controller [13].

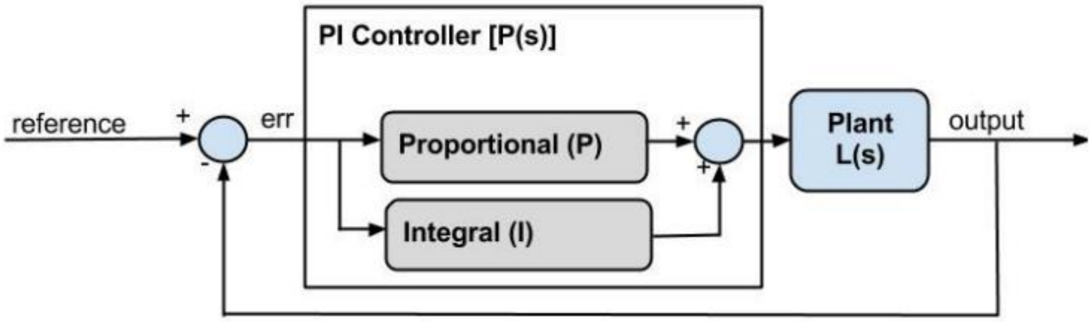

Figure 2.7: General structure of a PI controller [13].

2.3.3 Model Predictive Control (MPC)

A method that proves highly effective in enhancing tracking performance is Model Predictive Control (MPC), categorized among the nonlinear control techniques currently utilized in DC/DC converters. This strategy has attracted substantial interest around power converters and motor drive systems [5]. This control strategy is maximizing the transient behavior with constraints, dealing multiple goals with rapid dynamics. And estimation-dependent methods are used to achieve accurate tracking.

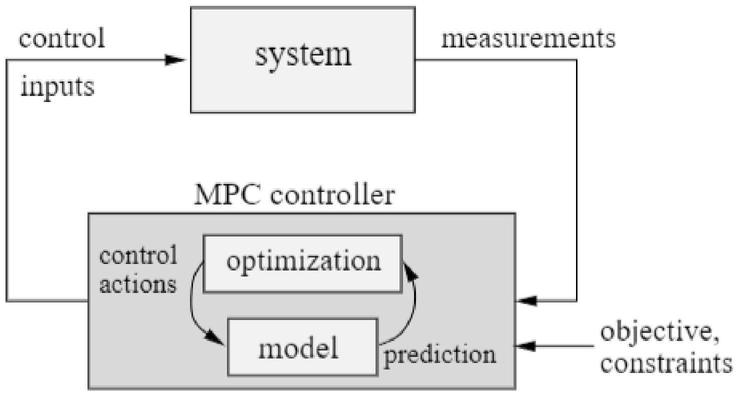

Figure 2.8: A basic illustration of Model Predictive Control [9].

2.4 Reference Frame in Controlling

The same way of methodology is implemented for grid connected converter control and motor drive control because of their same likeliness [14]. In here, three reference frames of control structure are described from previous studies and were used for controlling the first simulation models I created. They are natural or *abc* reference frame, stationary or *αβ* reference frame and synchronous or *dq* reference frame. These reference frames can be used to represent basic three phase voltage and current throughout the control process.

2.4.1 Natural or *abc* Reference Frame

This is the general three phase system where no transformation is applied and the control structure in here needs one controller for each phase. This reference frame has no time-consuming and laborious transformation involved so that the dynamic response of controllers is accurate [14].

2.4.2 Stationary or *αβ* Reference Frame

The reference frame referred to here converts three-phase *abc* signals into a two-phase orthogonal system where both the α and β axes are fixed in position through Clark's transformation. In grid-tied inverter control, essential parameters such as line currents and grid voltages which are originally existing in three-phase form, can be converted into two-phase sinusoidal quantities that vary over time. This transformation with fewer variables simplifies the control structure by reducing one control loop compared to the control implemented in the *abc* reference frame. These transformations can be achieved using Equation (2.1), Equation(2.2) and Equation (2.3) [14] .

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos 0° & -\cos 60° & -\cos 60° \\ 0 & \sin 60° & -\sin 60° \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{2.1}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & 2/\sqrt{3} & -2/\sqrt{3} \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{2.2}$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \frac{3}{2}\begin{bmatrix} {}^{2}/{}_{3} & 0 \\ -{}^{1}/{}_{3} & {}^{1}/{}_{\sqrt{3}} \\ -{}^{1}/{}_{3} & {}^{2}/{}_{\sqrt{3}} \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{2.3}$$

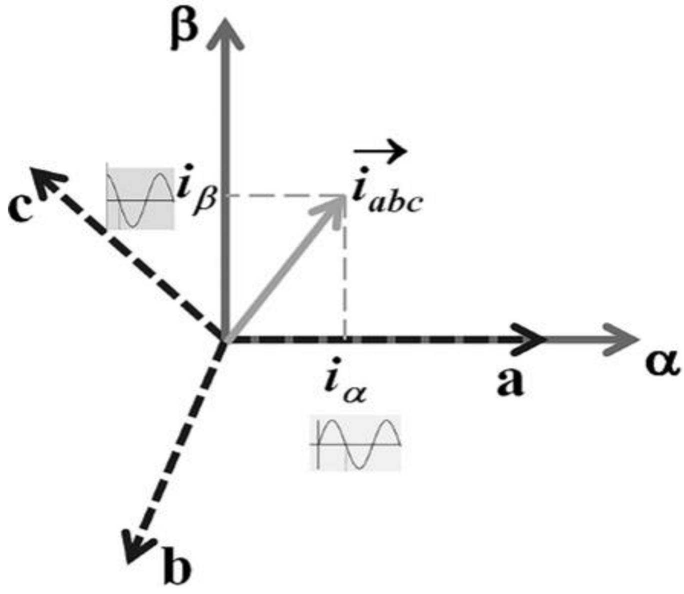

Figure 2.9: Stationary reference frame current vector with its α and β components [14].

2.4.3 Synchronous or *dq* Reference Frame

In the stationary reference frame, three-phase signals show time-changing behavior due to the fixed nature of the reference frame. Some current controllers in grid-connected Voltage Source Inverters (VSI) operate using DC control loops, requiring the use of equivalent DC quantities to represent AC currents. To achieve time-invariant or DC-transformed quantities, the reference frame must rotate along with the space vector representing the three-phase quantity. This transformation can be done in two steps. A three-phase signal is transformed into two phase signals using $\alpha\beta$ transformation first and then to obtain the dq component signal, the matrix equation can be used as in Equation (2.4) [14].

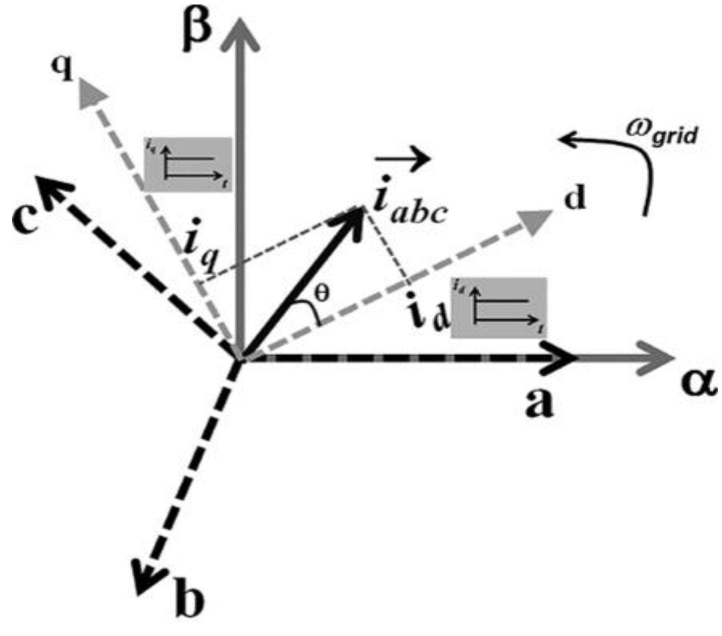

Figure 2.10: Stationary reference frame current vector with its q and d components [14].

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta - {}^{2\pi}/_{3}) & \cos(\theta + {}^{2\pi}/_{3}) \\ -\sin\theta & -\sin(\theta - {}^{2\pi}/_{3}) & -\sin(\theta + {}^{2\pi}/_{3}) \\ {}^{1}/_{2} & {}^{1}/_{2} & {}^{1}/_{2} \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{2.4}$$

3 Peak Shaving using an Energy Storage System in Offshore Applications

Offshore rigs are typically run with variable power consumables like drilling, motor pumps and dynamic positioning. And peak loads can be occurred at any time during the process. Integration of an energy storage system by reducing operation hours of the diesel-powered generators may lead to optimize energy and the ESS can be used to peak load shaving which enables the generators to operate at optimal load. This is a step forward to improve cost effectiveness and sustainability of oil and gas industry.

3.1 Peak Load Scenarios in Oil and Gas Industry

Equipment such as large electric motors, pumps, cranes are more commonly used for drilling and operation in oil suction systems. Furthermore, oil rigs are like a small city where the staff is living for lengthy period during operation, and it is a huge task to provide total electricity requirement. The chill water skid, HVAC unit, waste processing and sea water desalination unit consume high energy, and it needs to fulfil energy demand in a cost-effective way. The electricity consumption and supply balance and lower and upper limits of power supply are most important concerns for energy optimization [10]. Figure 3.1 is an example for load variation of a grilling rig where power peaks occur during the operation.

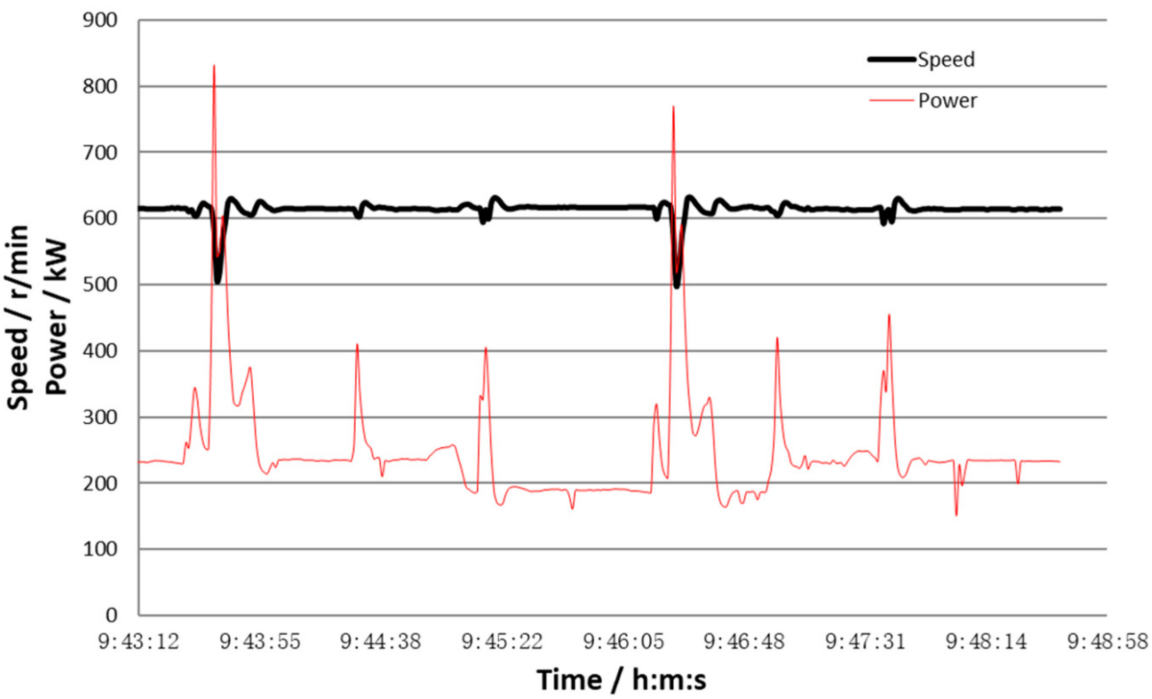

Figure 3.1: Load fluctuation in a drilling rig [28].

Table 3.1 shows a summary of electricity consumption within a month in an oilfield in the year of 2012 which is taken from [27]. It categorizes minimum, average and peak power demands separately for wells, injection pumps and production pumps.

Table 3.1: Electrical power consumption in an Oilfield [27].

Well	Status	Monthly Average Power Consumption 2012 [kW]		
		Minimum	Average	Peak
Wells	Operating	54	-	678
Injection Pumps	Operating	4,485	4,489	4,494
Production Facilities	Operating	1,664	1,664	1,664

The wells have a power consumption range from minimum 54kW to 678kW at peak. This clearly elaborates the power consumption variation during a month where exists a huge gap between minimum and peak demands. There is a need for at least 678kW of power supply to match this peak demand without interruptions thereby it must have connected a capable diesel generator set to the system. Even though these peak power requirements exist in few minutes or few seconds it is must to have a capability of the power supply to bear this.

3.1.1 Electric motors

Electric motors are the one of most essential components in the oil and gas field. They are crucial in numerous operations, such as providing the requisite pressure for gas transportation and processing through compressors. Additionally, electric motors drive gas pumps, facilitating the efficient extraction and transfer of oil and gas. They also power winches, which play a crucial role in lifting heavy objects and aiding in various rigging tasks. Electric winches provide a means for the precise manipulation of anchor lines and mooring ropes, allowing vessels to anchor securely or attach to piers without being solely reliant on manual labour.

Moreover, offshore cranes rely on electric motors to handle equipment and materials for precision and safety. These diverse applications of electric motors contribute significantly to ensuring smooth operations, enhancing productivity, and upholding safety standards in the ever-evolving oil and gas industry.

Starting a large motor results considerable disturbances to the connected power system and main busbar which is away from motor starting point. In power systems equipped with one or two generators, the impedance of the power source is notable. Consequently, initiating motor startups can lead to a reduction in the speed of the generator [15]. For off-grid power systems like oil rigs, the surge or startup consumption of motors inside the flatform must be always accommodated in the internal system to deal with additional peak loads. The peak demand usually differs notably from the average load demand.

3.2 Peak Load Shaving

The peak load shaving signifies that leveling peaks in the electricity demand by industrial and commercial power consumers. Supplying necessary peak power requirement is important in terms of grid stability, but it also affects power procurement costs. The oil rigs usually have an uneven load curve during the day. And the load profile is not predictable or repeating either. It is therefore important to identify, detect and optimize power supply governance inside offshore platforms. The diesel generators' capacity for supplying energy needs to be dimensioned for those peak loads even though the other time of the day it has an underutilization. So, the extra cost for keeping up the power supply for the peak demands can be deducted by utilizing an ESS to the field. This leads to minimize the installation capacity of the generators which occupies for the peak demands [11]. As illustrated in Figure 3.2 power peaks can be leveled down by using an ESS and only the power requirement under red graph is providing by the generator set.

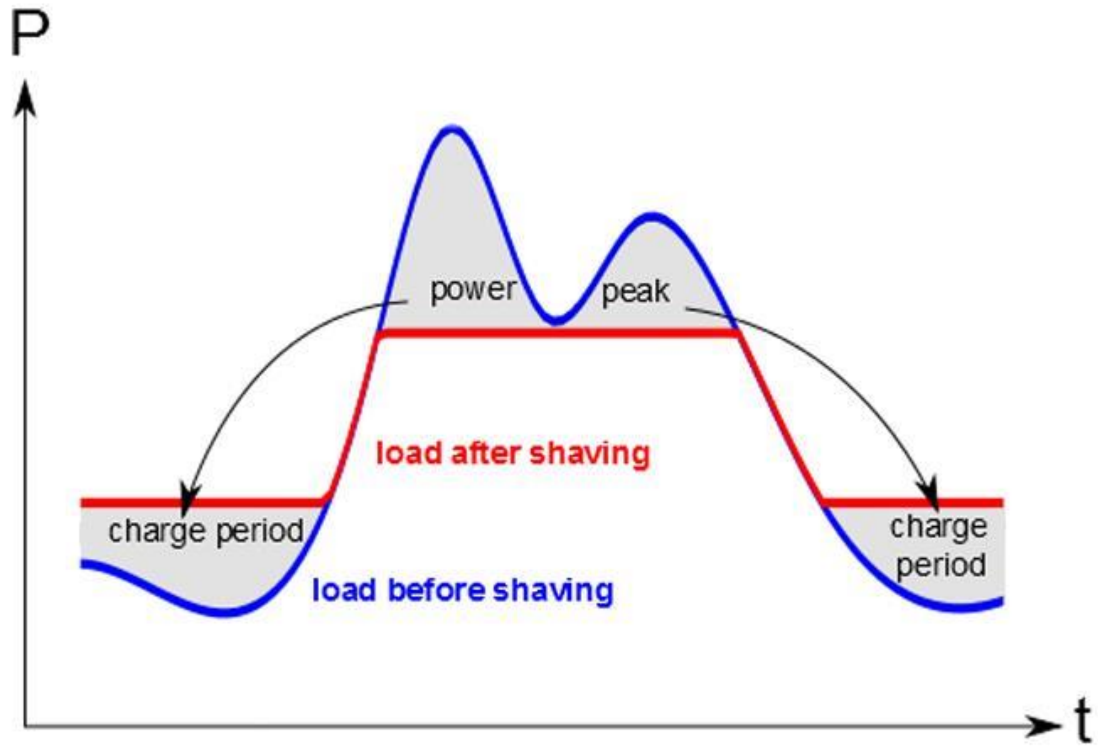

Figure 3.2: Illustration of peak shaving [11].

As the generators are only operated at full capacity during the peak times, it is a waste as well as inefficient energy allocation with high operational and maintenance costs. In addition to that, using an ESS at least for peak shaving decreases use of fuel resulting in a way forward to the cold energy.

3.2.1 Benefits of Peak Load Shaving Systems

There are several potential benefits for using peak shaving systems in various categories. Technical, economic and environmental benefits are major among them. Economic and environmental benefits will be analyzed in section 6. This subsection explores main factors from a technical point of view [7].

1. Power quality improvement
   The mismatch of generation-demand has been significantly approaching by various peak shaving methods which leads to regulated power quality.
2. Utilization of efficient energy
   The load factor (F_{load}) as implies in Equation (3.1) can be significantly increased by minimizing the peak load (P_{peak}) which shows how efficient the installed capacity of generator system is being used.

$$F_{load} = \frac{P_{average}}{P_{peak}} \tag{3.1}$$

3. Integration of renewable energy
   As thoroughly explores in section 4 , renewable and regenerative energy can be integrated to ESSs while introducing a solution to store renewable energy produced.
4. Supporting reactive power
   Peak shaving by ESSs can help to absorb or inject reactive power to keep grid or main supply voltage stable.

4 Renewable and Regenerating Energy to Charge ESs

Electrification, which means mitigating fossil power sources by using renewable or regenerating energy is an effective way of reducing emission of greenhouse gases (GHG). Offshore installation and processing are the main sources of GHG emission which need immediate solutions. The future will be functioned on oil and gas for a considerable period therefore it is necessary to focus on low carbon solutions as much as possible.

4.1 Offshore Renewable Energy Sources

4.1.1 Offshore Wind

Offshore wind farms are the large installations of wind turbines situated in bodies of water, typically oceans or large lakes, specifically designed to harness wind energy for electricity generation. They offer several advantages over onshore wind farms, such as stronger and more consistent wind speeds, larger available areas for installation, and reduced visual and noise impacts on populated areas. Harnessing offshore wind energy can provide a clean and renewable alternative to traditional fossil fuel-based power generation methods [16].

There is an estimated value of 15 TWh of electricity is needed for the active fields in Norwegian continental shelf in the year 2008 [17]. Offshore wind farms offer an exceptional chance to decrease the reliance on oil and gas for generating electricity of offshore rigs in the Norwegian Continental Shelf. A durable energy storage device and a specialized power electronic converter system are essential for storing excess energy from strong winds, to be utilized during the periods of low wind. A basic arrangement of a wind farm integration into the offshore rigs is depicted in Figure 4.1

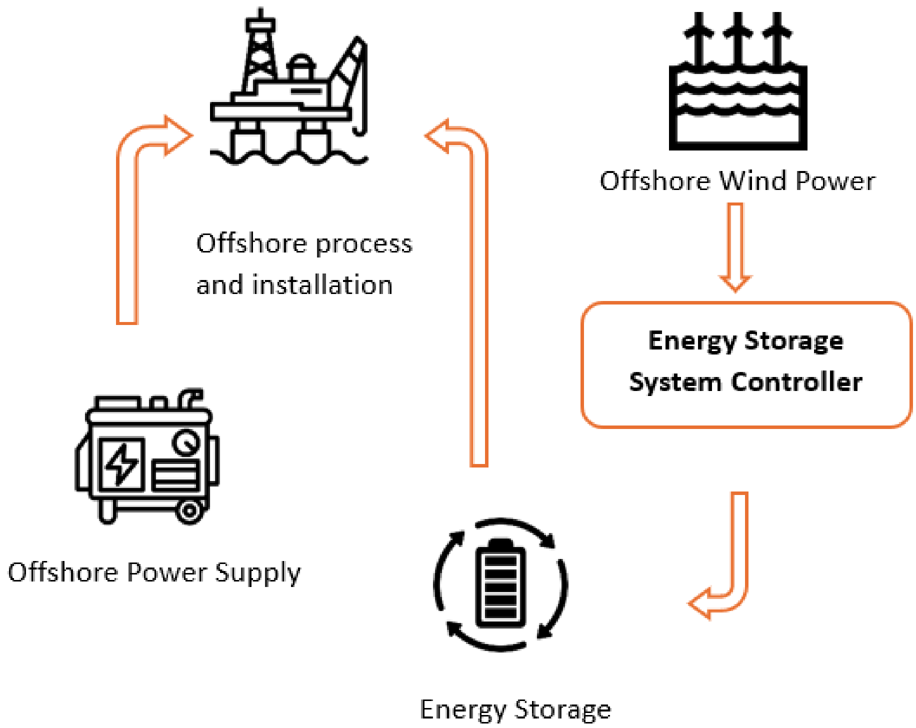

Figure 4.1 : An illustration of an offshore wind farm integration to an oil and gas platform.

EU strategy on offshore renewable energy initiated a strong proposals in 2020 and set targets of offshore wind with installed capacity of 60GW and ocean energy of 1 GW by 2030, and in 2050 it will be increased to 300GW and 40GW respectively [18].

4.1.2 Ocean Renewable Energy (ORE)

Investing in offshore renewables is becoming the wisest way forward to energy crisis and for the clean energy concept which is continued by European nationals. Energy generating using natural waves and tidal can be included under ocean renewables which are capable of supplying continues and steady power contribution to offshore platforms. European countries as well as the private sector have already emerged on this over four billion euros within last ten years for pilot projects and research and they have targets on cost cutting using ocean technologies for coming years [18].

4.1.3 Floating Solar Systems

Floating solar panels installed on water surface close to offshore platforms is a good transition of generating energy which can be utilized to charge onboard ESs. Once taking necessary assessments and research for efficiency and productivity, solar panel systems can be installed as it comes with minimal operational cost and low maintenance. It also provides cleaner air and reduces water evaporation which is beneficial for marine life and the whole globe.

Figure 4.2: A floating solar system from Ocean sun SA [26] .

4.2 Regenerative Energy

4.2.1 Active Heave Compensation

Heave compensation is necessary for hoisting and lowering heavy loads in frequent, repetitive motions, which is placing considerable strain on power systems. These repetitive movements lead to significant and sudden variations in energy demand. The lifting equipment, such as winches, both consume and release energy to raise loads and to lower them respectively. This regenerated energy has previously been taken as a challenge to the operations without getting any advantage out of it.

When looking at this from an innovative point of view, this regenerated energy can be stored instead of dissipating it by boiling water or using braking resistors thereby optimizing energy allocation in offshore rigs and improving low carbon footprint. The Figure 4.3 illustrates a basic idea how does this works. There are sufficient results of having this system such as it reduces power consumption on a rig by as much as 80% compared to conventional designs [21].We can have any suitable payload here in Figure 4.3 as the ROV.

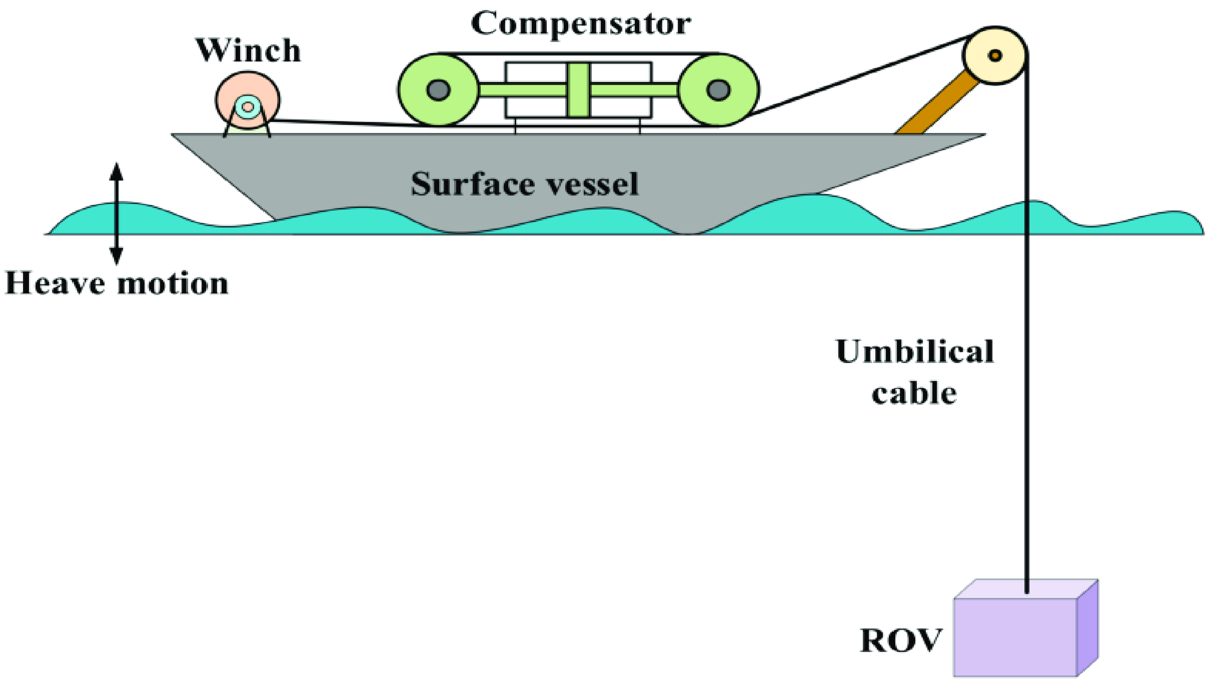

Figure 4.3: Illustration of Active Heave Compensation (AHC) [22].

As an example demonstrated in Figure 4.4, the braking energy generated in the winch motor can be connected to a battery or any other energy storage through power converter systems and thereby feed through the DC link to the main power line on offshore rigs. This system adds more reliability and safety to the rig electricity system and stops the waste of energy.

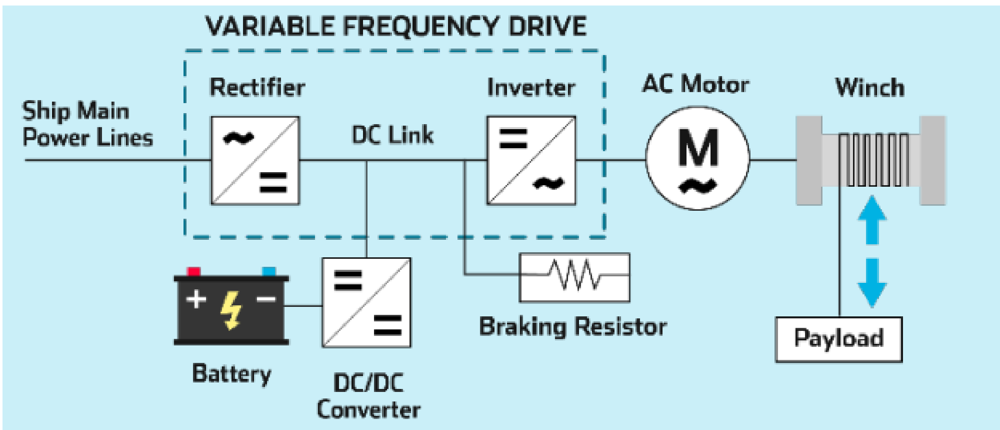

Figure 4.4: Energy storage for AHC system [23].

In the Figure 4.5 illustrates an another example for integrating a flywheel energy storage to store kinetic energy from the movements of drilling rod connected to a winch motor. This machine works as both motor for discharging and generator for charging which is driven in bi-directionally using a power converter interface which controls the flow of the energy [28].

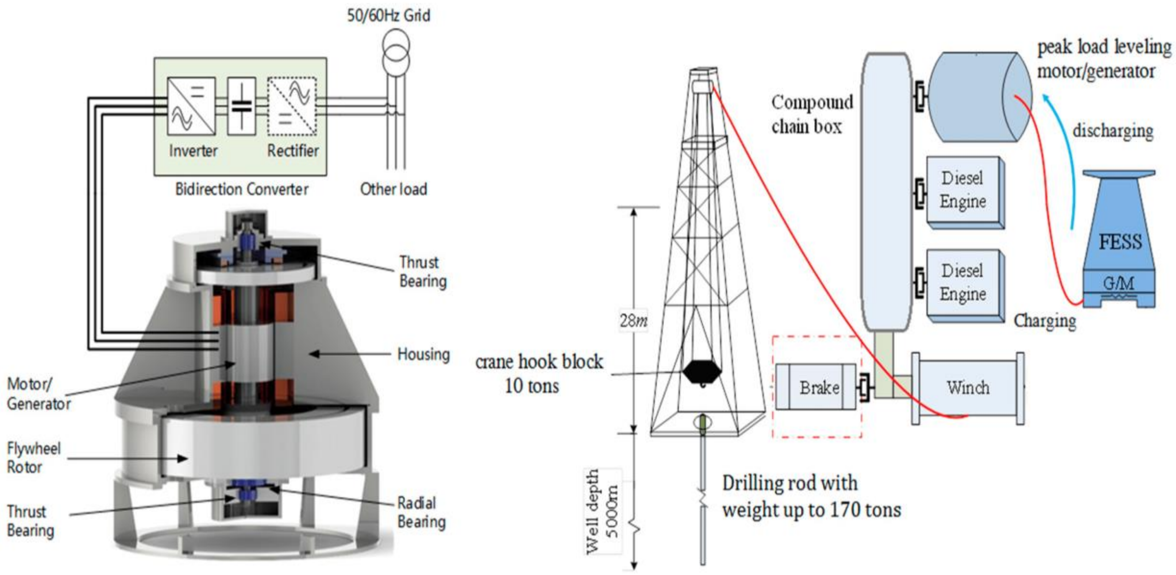

Figure 4.5: Peak load leveling and braking recovery through FES [28].

If we are able to emerge these renewable energy sources and regenerating energy into the ESs for recharging, this topic which is peak load shaving by energy storage systems becomes more interesting in every aspect. The goal of supplying green energy to oil and gas fields, which is the largest and most essential industry in the world is almost done.

5 Simulation Model of the System

This section elaborates the simulated model of the peak load shaving system in an offshore rig using energy storage combined with power converter system. For simulating this system, MATLAB Simulink software was used as it equipped with plenty of related libraries and customizable parameters inside each block.

5.1 Block Diagram of the System

The complete peak shaving model is built with subsystems of an energy storage, which is a battery in this model, high power motor as a winch motor which consumes high inrush current while starting, a modelled grid as the rig power supply, a power electronic inverter system and auxiliary loads as shown in Figure 5.1.

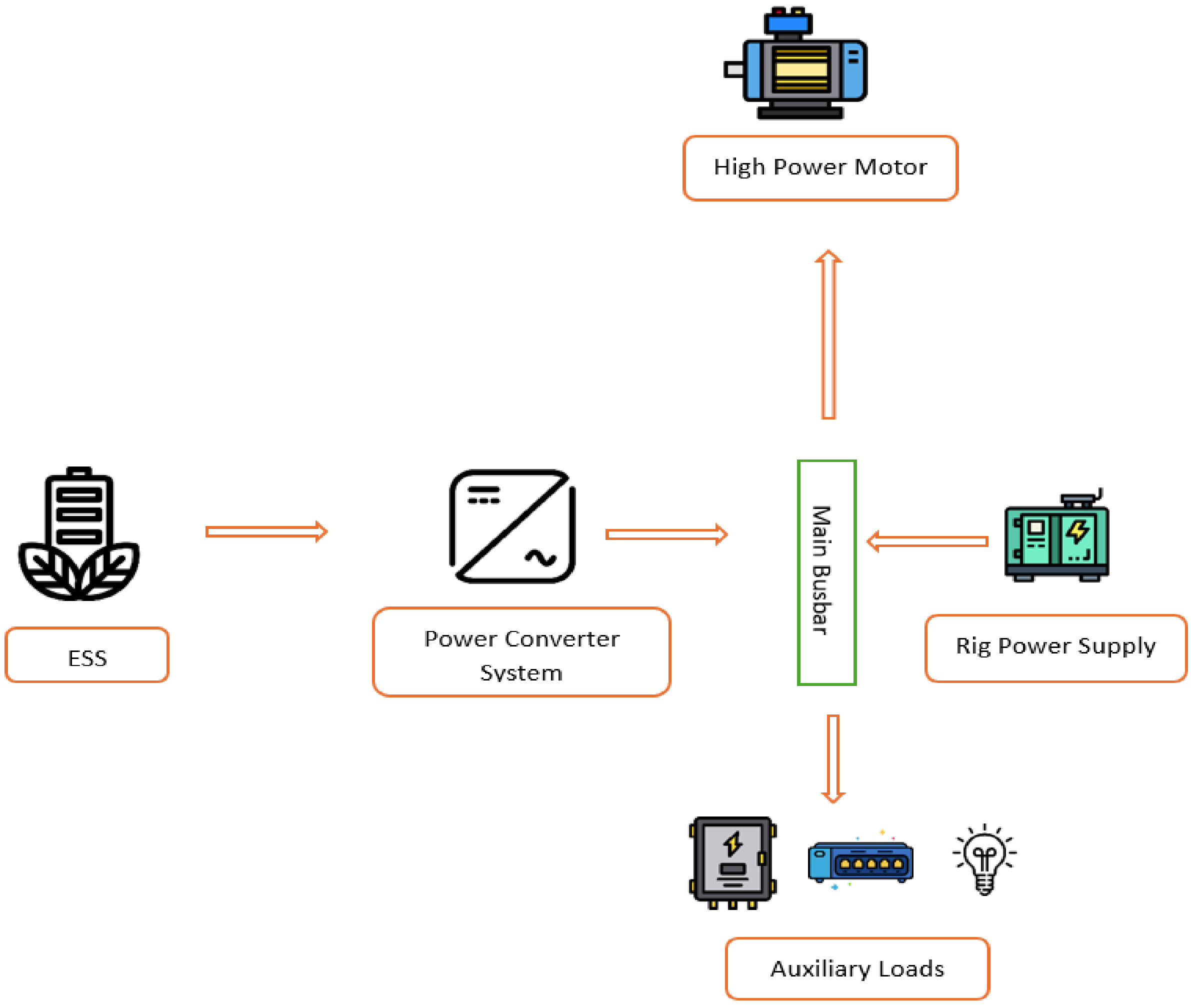

Figure 5.1: Block diagram of complete peak shaving system for offshore loads.

5.2 Power Converter System

5.2.1 Voltage Source Inverter

In this system, AC power is required to feed through the three-phase supply to the connected AC loads. A DC-AC converter or an inverter is used for the conversion of DC power in the battery into AC power at desired output voltage and frequency.

A voltage source inverter (VSI) is used here because the battery has small or negligible internal impedance and the voltage at the input terminal is fixed. A constant DC link voltage is maintained using a filter capacitor across the input of the inverter and this therefore behaves as an adjustable frequency, voltage source. VSI in this model is built with six IGBTs as the switching devices which control their on and off status by self-commutation using gate signals. The modelled simulink inverter system is shown in Figure 5.2, in which the control of AC output voltage is done since the AC loads like induction motors in this model is required to adjust voltages in their operational period [19]. That is the reason why it was selected as a VSI in the system so that it fulfills the requirement of the loads by controlling its output voltage. In this peak shaving system, voltage of the grid or the main supply to the offshore platform drops once the induction motor is connected to the power system.

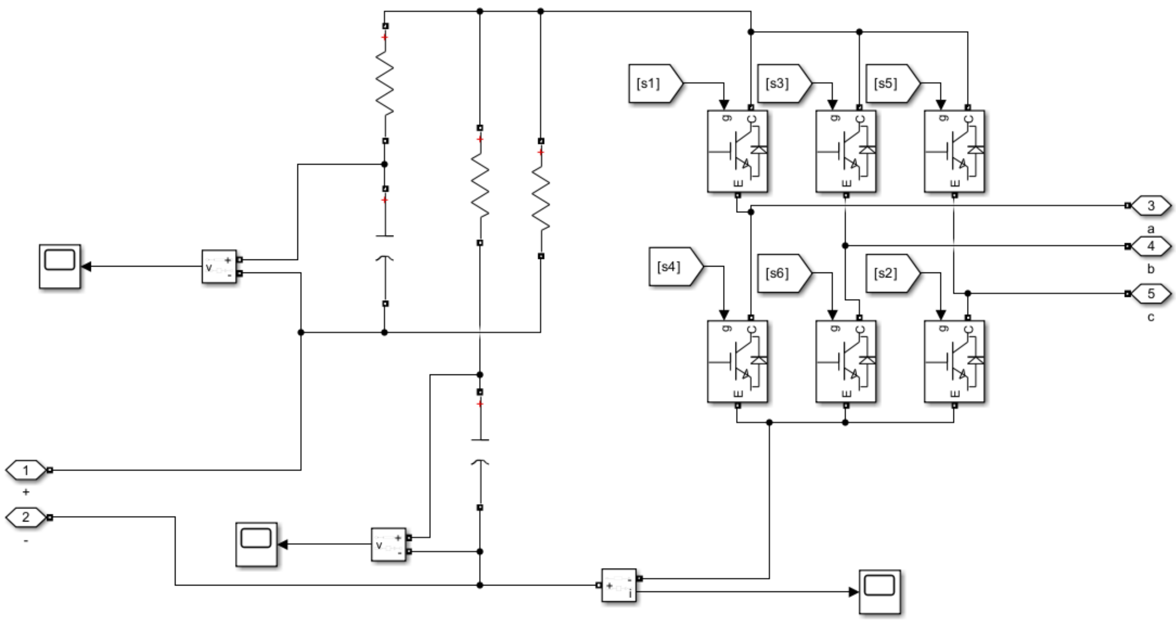

Figure 5.2: Simulink model of the power converter system.

5.2.2 Pulse Width Modulation Generation

VSI is triggered by PWM generator which is supported to internal control of the inverter. PWM controls the inverter output by keeping magnitude of inverter voltage constant. As represented in Figure 5.3, IGBTs' gate switches S1, S2, S3, S4, S5 and S6 are triggered through sine wave generators and repeating sequence together with relational operators and NOT logical operators. It is important here that controlling of output voltage can be achieved without any additional controlling technique and components [19]. On the other hand, PWM mitigates lower harmonics, but filters also can be used to reduce higher order harmonics.

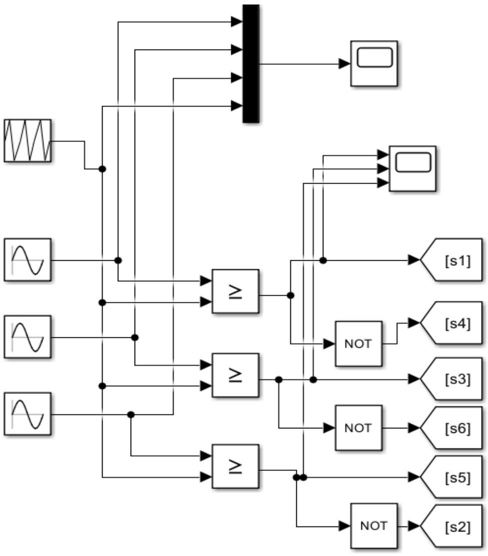

Figure 5.3: Simulink model of Sine wave PWM generator.

A sinusoidal pulse width modulation (SPWM) which is illustrated in Figure 5.4 compares a high frequency triangular wave v_c generated from repeating sequence with the sinusoidal reference wave v_r with required frequency.

$$v_r > v_c \text{ respective switches on, } Voltage_{output}\,(V_o) = \frac{Voltage_{battery}\,(V_d)}{2}$$

and

$$v_r < v_c \text{ respective switches off, } Voltage_{output}\,(V_o) = \frac{Voltage_{battery}\,(V_d)}{2}$$

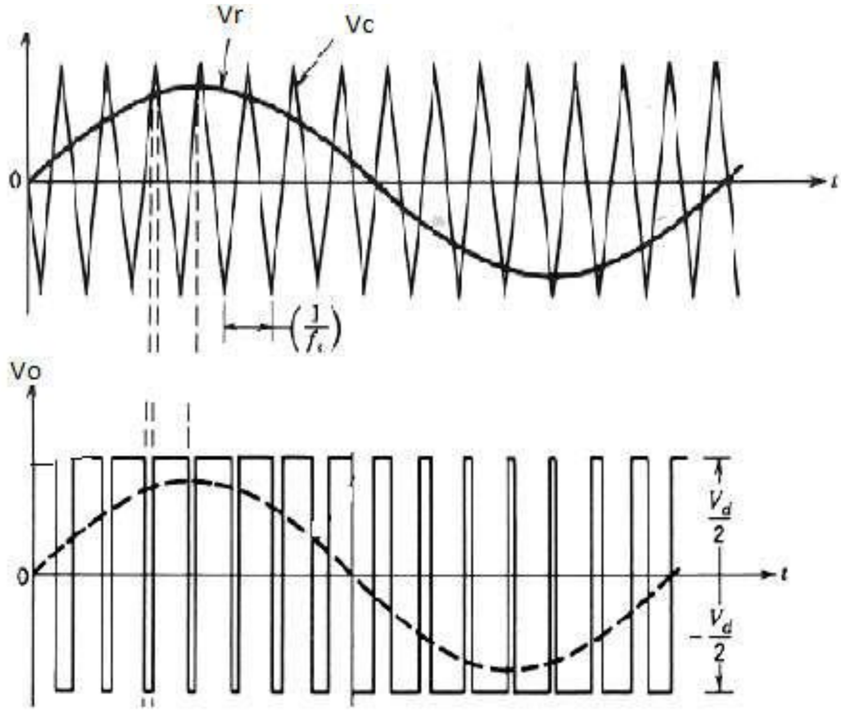

Figure 5.4: Sinusoidal Pulse Width Modulation [20]

Figure 5.5 shows how switching pulses output from the simulink PWM generator for the peak shaving system.

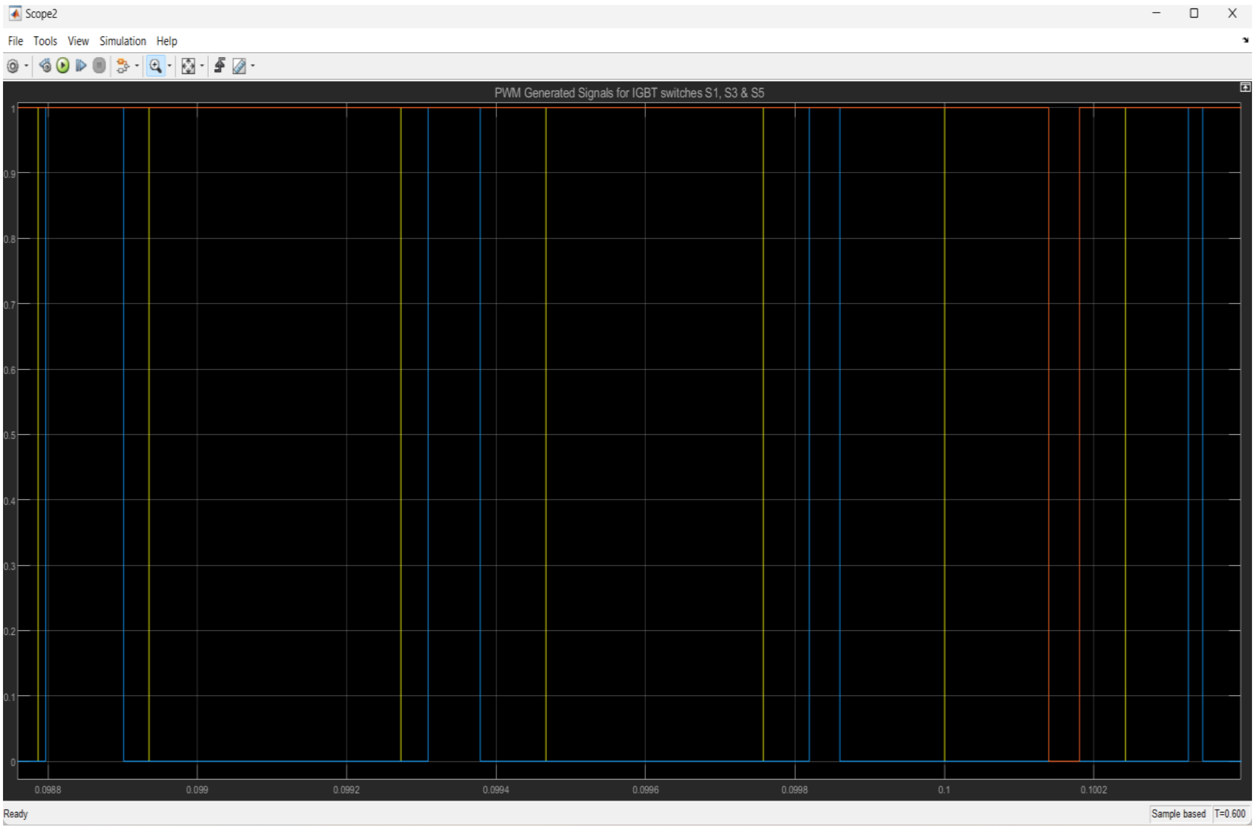

Figure 5.5 : MATLAB simulink output from PWM generator.

5.2.3 Harmonic Filter

When we convert DC input to AC output, AC contains distortion due to switching devices such as IGBTs here. Noice and unwanted signal are generated in the converter which make unsuitable current and voltage magnitudes. So, these harmonics or ripples should be reduced or filtered out to achieve suitable values. Inductors and capacitors with different combinations are mainly used in power electronic converters as active and passive harmonic filters. In this model a RC filter is used to mitigate distortion generated from switching IGBTs and enhance the output power quality [25].

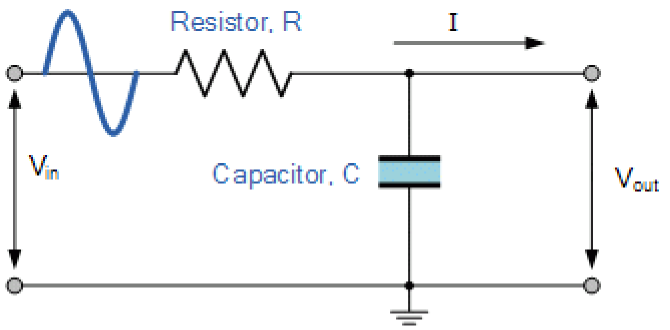

Figure 5.6: A circuit diagram of a passive RC low pass filter [24].

5.3 Battery

A Lithium-Ion battery is used as the energy storage in this model with following parameters mentioned in Table 5.1. In practical applications, any type of energy storage can be used as the ES according to the requirement and suitability as discussed in section 2.1.2.

Table 5.1: Parameters assigned in the battery.

Parameter of the Battery	Value
Nominal Voltage	507V
Rated Capacity	3000Ah
Initial State-of-charge	95%
Full Charged Voltage	590V
Nominal Discharge Current	1304A
Internal Resistance	0.00169Ohms

5.4 Grid or Rig Power Supply

The grid implemented here in the model is to be used as the main power supply in the offshore platforms. Most of the time, it is a set of diesel generators. It is a three-phase power source which provides 460Vrms phase to phase voltage at 60Hz frequency and it has small resistive internal impedance.

5.5 Induction Motor Load

The Induction motor connected here is a dominant component since it uses as the dynamic load where peak current occurs. The motor load consumes high power and pulls high current within a small period once it powers up. This is called motor inrush current, and the modelled system is working to level up these peaks from the grid once they occur by switching power supply from grid to the ESS leaving the main supply for that particular period. A squirrel-cage 5HP 460V 60Hz 1750 RPM asynchronous machine is set up in the model as the motor load. Figure 5.7 illustrates how the motor load behaves when it connects to the electricity system after 0.1s.

In the second graph of Figure 5.7, peak current spikes can be seen when the motor starts at 0.1s, and they continue for a few seconds. The voltage in the first graph drops until peak current occurs and comes back to the nominal value once the peak current ends. It consumes more than 6 times of rated current value when the motor starts.

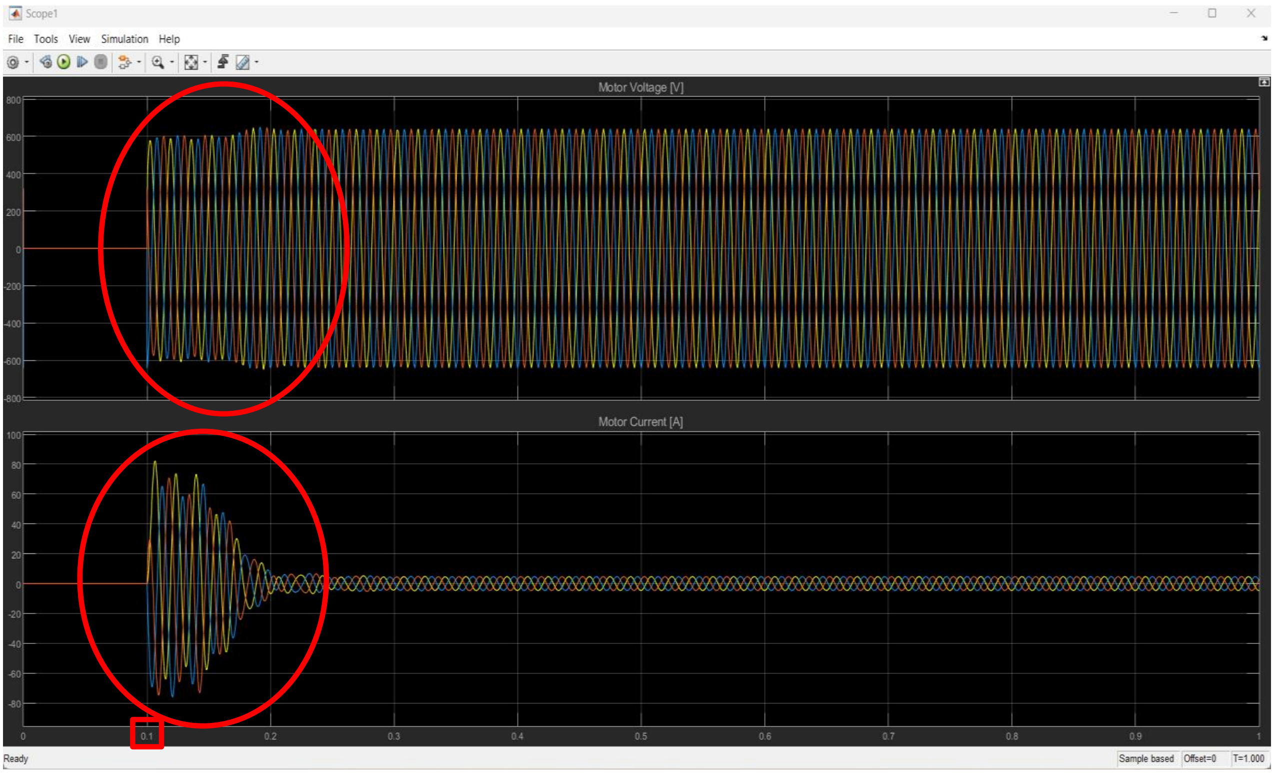

Figure 5.7: Simulink results of input voltage and current of the induction motor load.

5.6 Complete system

Firstly, an observation is done on how the grid reacts when it is not connected the ESS and the converter system to the system and allow motor to consume power from the grid by closing the switch after 0.1s. The grid voltage and current can be noticed in Figure 5.8 and consumption of active and reactive power can be observed from Figure 5.9. It clearly shows the peak current flow from the second graph of Figure 5.8 as the motor load is connected after 0.1s and it continues for a few milli seconds. The current flow after 0.25s is stabilizing again but at a higher current than the previous amount. The voltage drop is another significant concern which is noticed in the voltage graph of Figure 5.8, this is something that should be controlled to keep voltage within the regulated limits and for the power quality.

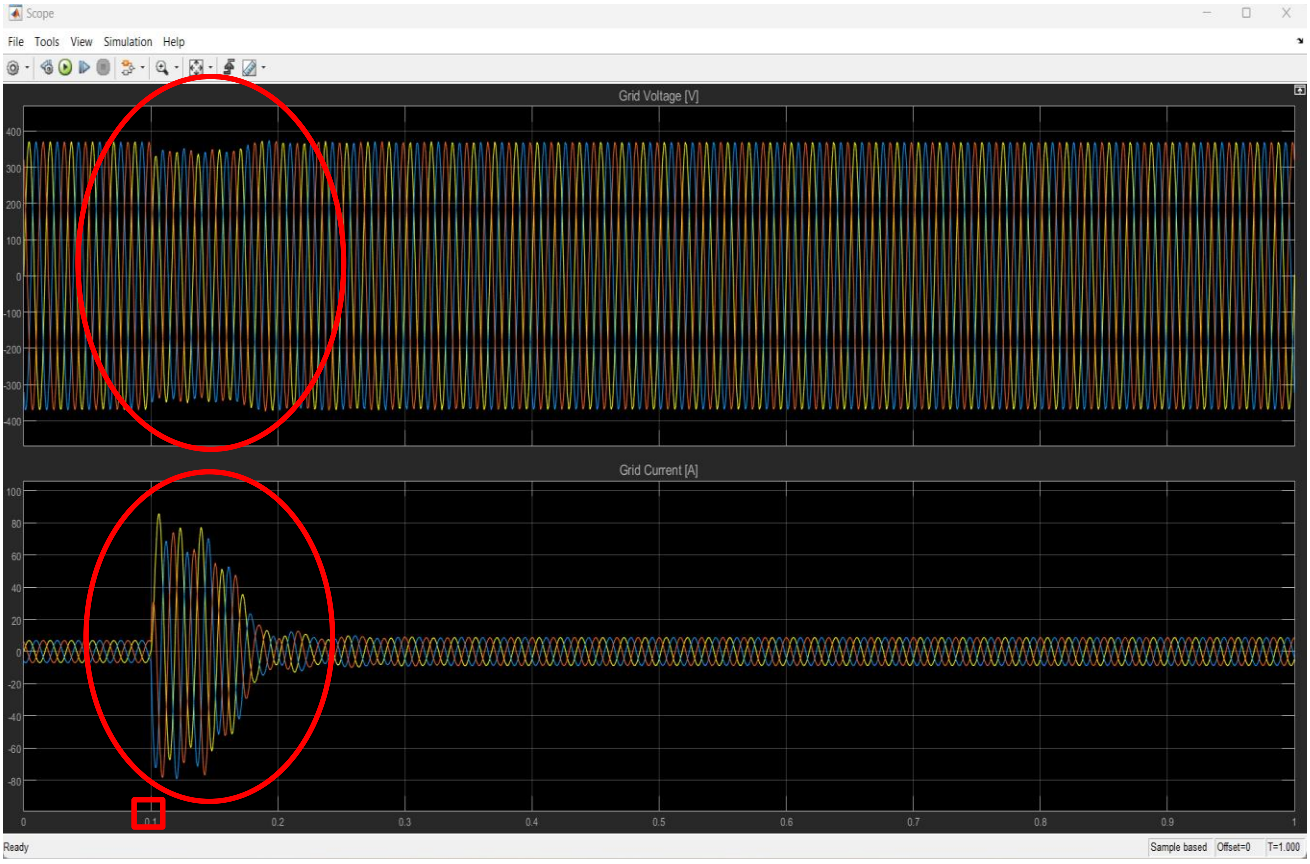

Figure 5.8: Simulink results of grid voltage and current before peak shaving.

A notable amount of active and reactive power increment is detected after 0.1s in Figure 5.9 when the motor connects to the grid. These high-power peaks should not be supplied directly from the grid as it requires the grid to have large capacity and that is why it needs to consider a peak loads shaving system.

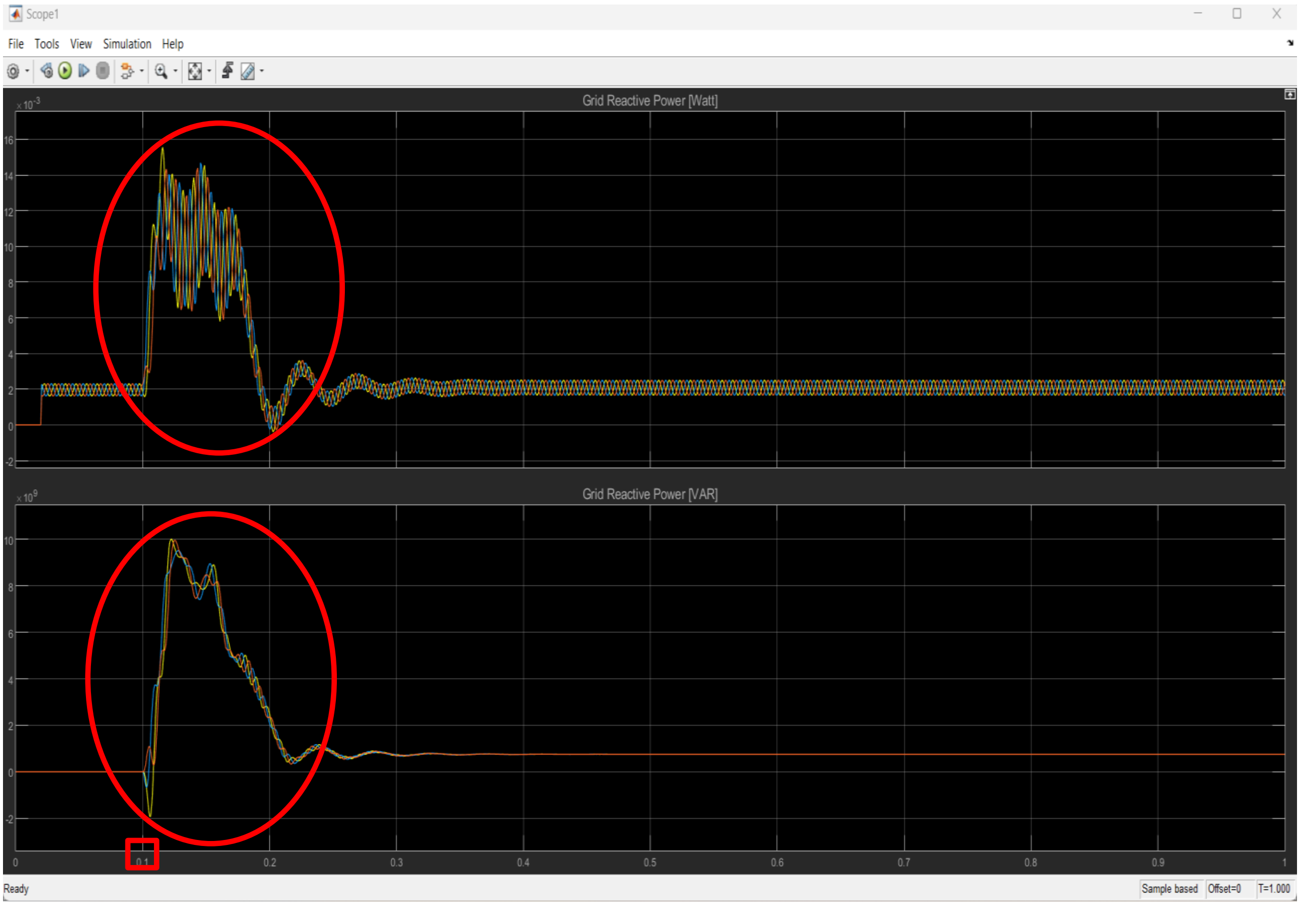

Figure 5.9: Simulink results of grid active and reactive power before peak shaving.

Here, it discusses how the peak shaving system is implemented and the ES and converter system integration as a solution for above mentioned concern.

Now, the ESS together with converter system is connected to the main power line as shown in Figure 5.10 to observe how the complete peak shaving model works. An enlarged snip image is attached in Appendix B. This complete system supplies electricity to the rig loads as stated in Table 5.2 .

Table 5.2: Logic of the peak shaving model

Demand Type	ESS State	Main Supply/Grid status	Output
Peak Load	Discharge	Keep supplying base demand	The ESS supplies power for the peak demands
Off -Peak	Idle/Charge	Supply total power requirement of the rig	Supply from the Grid to the loads

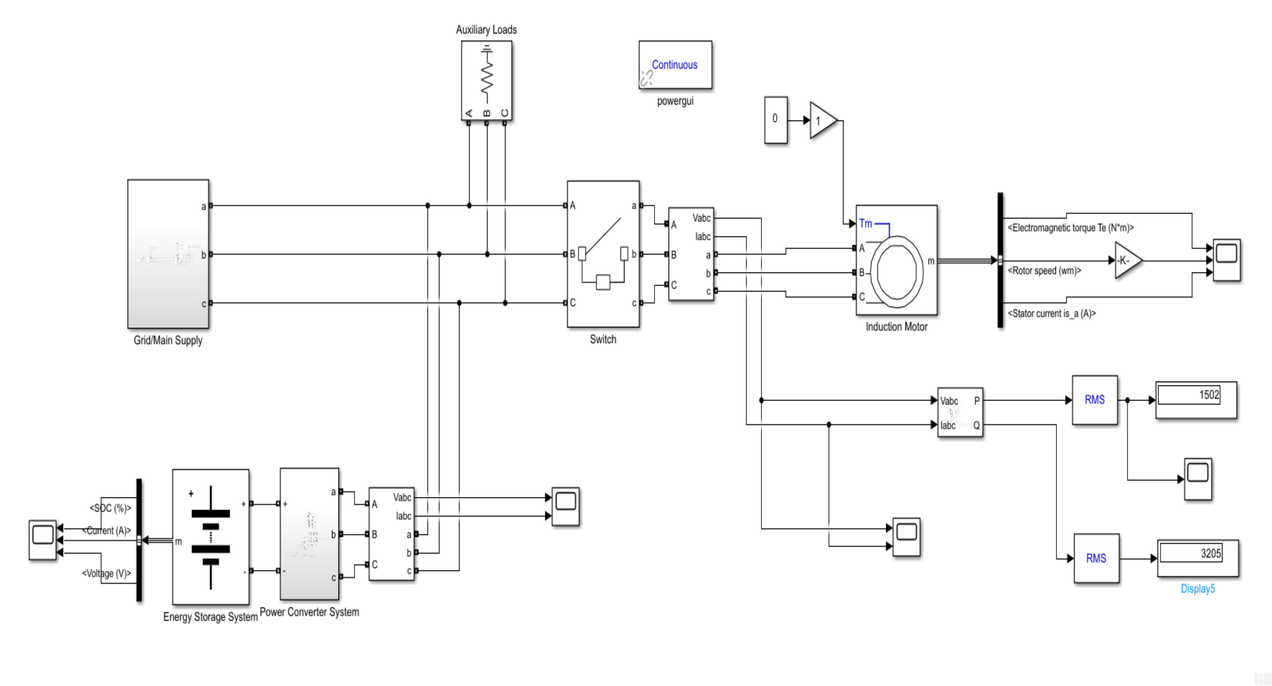

Figure 5.10: The complete MATLAB simulink model of the peak load shaving using an ESS.

It is shown in Figure 5.11 and Figure 5.13 below how the grid reacts when the ESS is connected to the system. The enlarged graphs of Figure 5.11 and Figure 5.13 are shown right after them which reveal the zoomed-out waveforms of voltage, current, and power close to the time 0.1s when the motor load is connected.

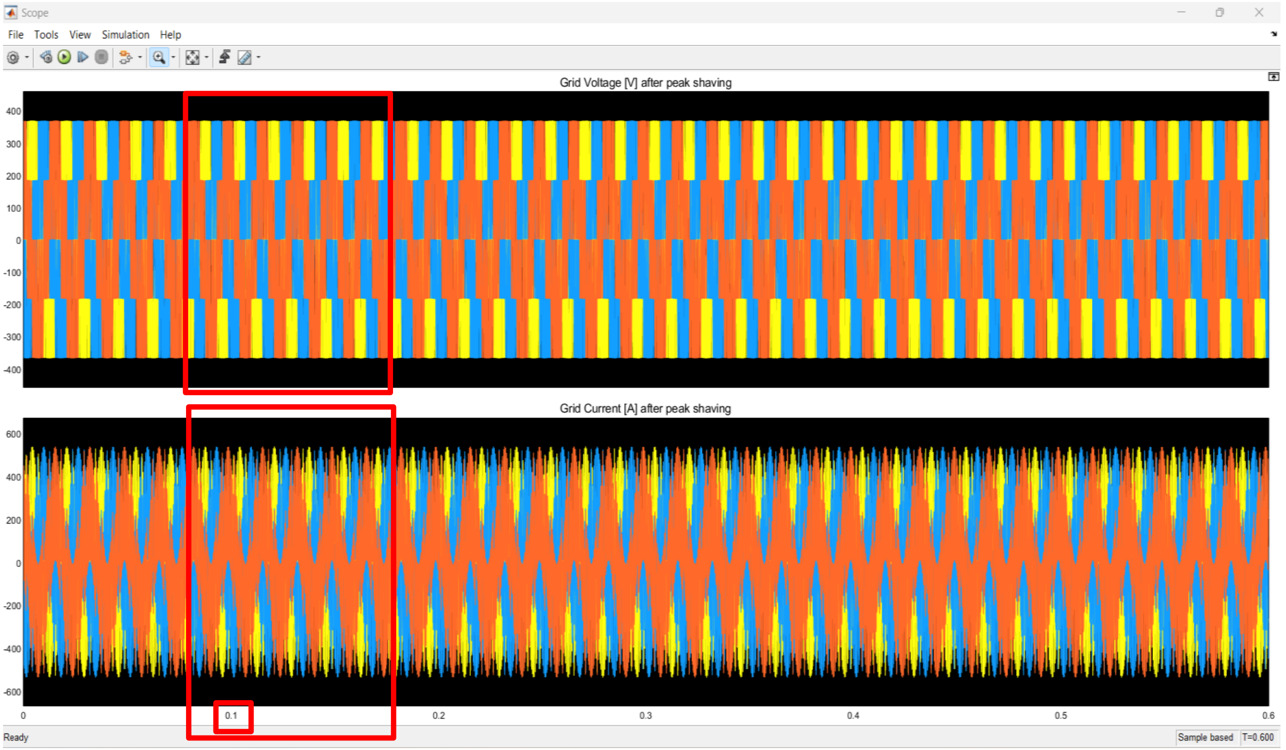

Figure 5.11 : Simulink results of grid voltage and current after peak shaving.

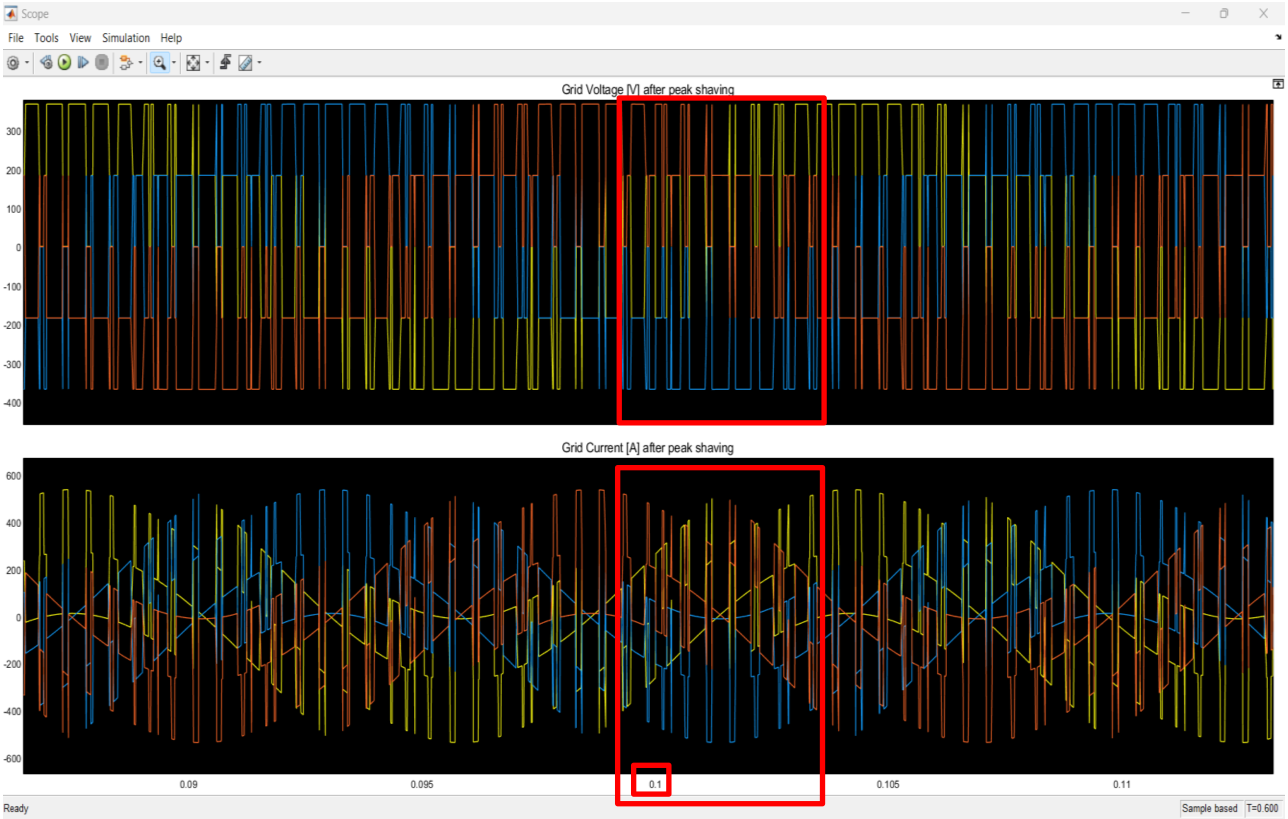

Figure 5.12: Enlarged plot of Figure 5.11

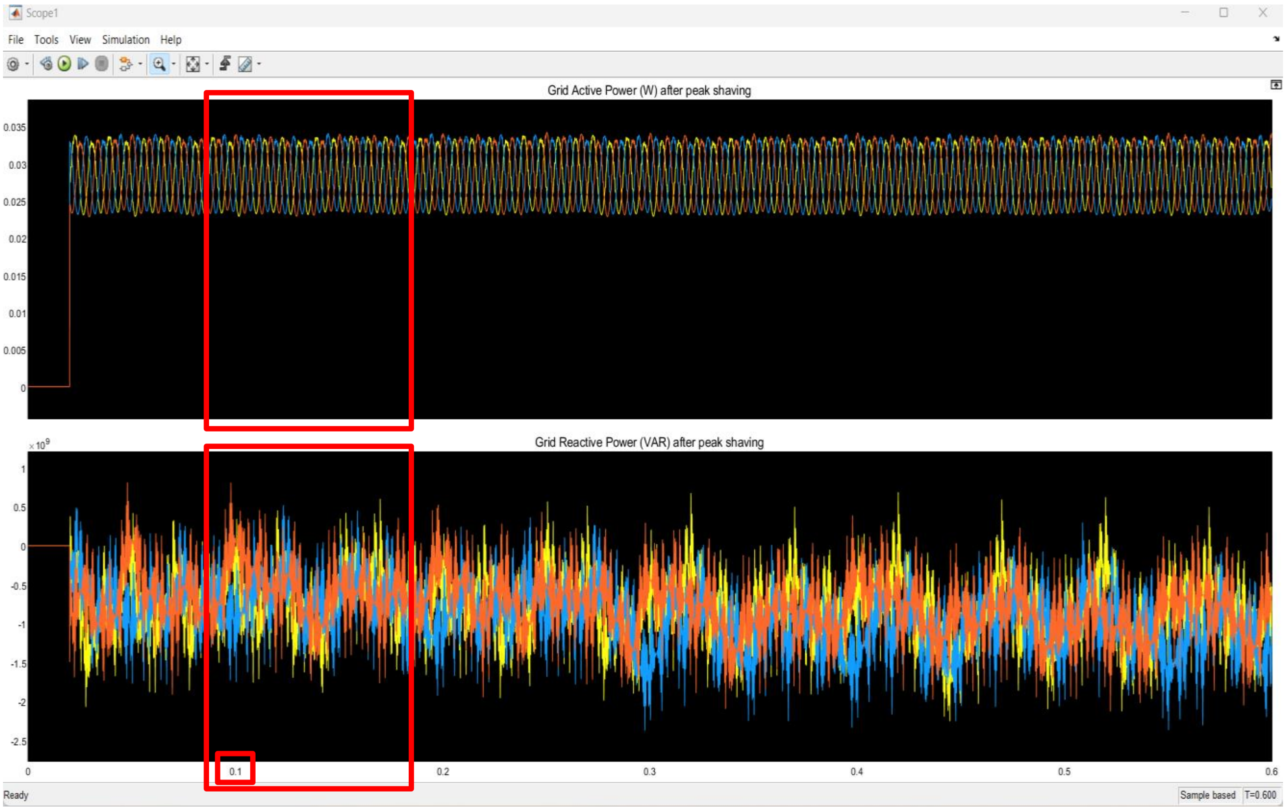

Figure 5.13: Simulink results of grid active and reactive power after peak shaving.

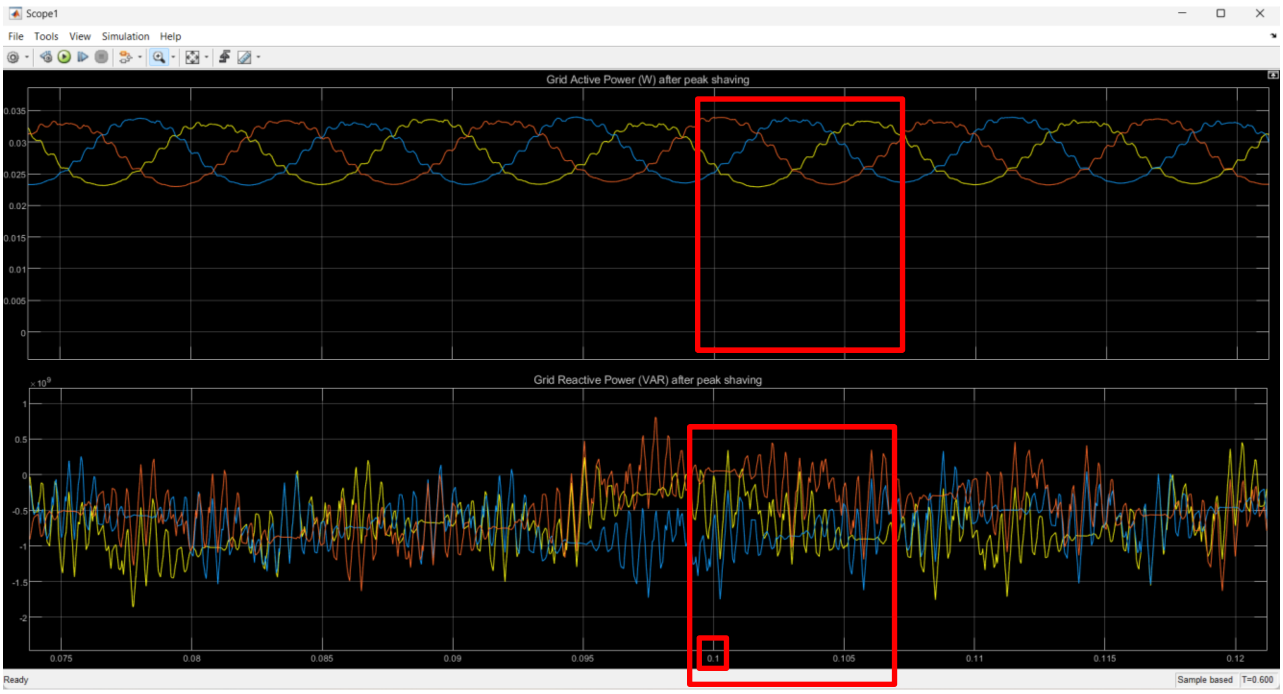

Figure 5.14: Enlarged plot of Figure 5.13

It clearly appears that the peak current demand is not presented in the grid current graph anymore, and also the voltage drop cannot be seen in the grid voltage graph in Figure 5.11. In the power graphs, power peaks were removed after 0.1s and the grid operates in nominal conditions as in Figure 5.14. This reflects that connecting converter system and the ESS smoothen the power peaks in the electricity system by shaving peaks.

6 Cost – Environment Analysis

It is always wise to think about economic and environmental impacts on a new implementation. This chapter highlights how the ESS for peak load shaving effects on economic and environmental edges. A peak load shaving by ESSs is indeed beneficial in economically. Followings are the main factors why it is good to go for a peak shaving system by integrating a storage in offshore industry.

6.1 Economic Benefits

1. Increased lifespan of generators.
   The expenses for wear and tear can be reduced as the system operates by the ESS during peak electricity demand and generators will not be subjected to overload.
2. Cut additional cost for fuel consumption.
   There is a notable amount of fuel saving due to the usage of energy storage which is supposed to recharge by renewable or regenerative energy.
3. Reduced capital investment of generators.
   This contributes to considerable downsizing the generator capacity of offshore rigs and therefore reduces CAPEX and OPEX due to less operational and maintenance costs.

6.2 Environmental Benefits

1. Reduces GHG emissions.
   The ESS marks for zero CO_2 emission compared to the tons of CO_2 emitted annually by diesel generators. This is thereby a huge turning point to decarbonization.

7 Discussion

The integration of converter system with energy storage in offshore oil and gas industry marks a step forward to sustainability and electrification. This thesis basically focuses on simulating a model for peak demand shaving in offshore loads which reflects in section 5. The simulation results show that this model can be used to flatten power peaks in the grid. The converter system plays a crucial role in this system as it facilitates total control over electricity demand changes without any external controlling system. So, the voltage and current fluctuations due to variable loads in the grid are stabilized by the voltage source inverter used here. The combination of six IGBTs provides variable frequency and voltage control to the motor load by arranging triggering pulses for switching time. The sinusoidal PWM technique is used for controlling the inverter AC output voltage. Voltage of output terminals of the VSI keeps constant thereby when the offshore loads are varying. As shown in Figure 5.11 and Figure 5.13, the results after connecting the converter system with energy storage smoothen the waveform during the presence of power peaks. This VSI drive contributes to efficient operation for peak shaving system. There are harmonics occur while switching of IGBTs which is mitigated through a passive RC filter.

The grid modelled in the simulation assumes the diesel generator system in offshore rigs which provides total electricity demand basically. The motor load is worked as a dynamic load which consumes peak power during the starting. So, this performs a peak load scenario to the peak shaving system.

Offshore renewable energy sources and regenerating energy integration to recharge energy storages fulfils two requirements here. The electricity generated in offshore by renewables should be transported to the land for the usage. So, the generated electricity closer to the offshore oil and gas fields can be consumed for offshore operations instead of transporting a long distance with losses. As discussed earlier, we can use those power to recharge our onboard energy storages when it needs charging, and it is indeed a best option to store high amount of energy generated in some months of the year. There are new energy storage technologies that can store and release energy more efficiently while recharging it by renewable energy sources and regenerating energy.

8 Conclusion and Future Work

8.1 Conclusion

Energy storage system integration for peak loads shaving enables the offshore oil and gas industry's shift of sustainability and operational efficiency. Through the simulation of peak load shaving by utilizing such a power converter system and energy storage presents potential benefits and innovative solution to offshore oil rigs.

On an offshore platform, there are heavy burdens on power supply as discussed in the report when it subjected to broad variations due to power peaks. It is averagely around 10 large generators occupy for total power demand on the rig. As reflected from the simulation results, the converter system together with ESS smooths the load profile, levels voltage and current variations and allows main power supply to have a uniform demand. It improves generator lifespan by easing wear and tear, saves fuel consumption and thereby eliminates GHG emission drastically. Operating fewer generators at higher loads can result in greater fuel savings compared to running multiple generators simultaneously to achieve the same power output.

Harnessing the energy storage and renewable sources into offshore fields, not only levels power peaks but also enhances power system stability, reduces emissions of pollutants and dependency on traditional fossil fuels.

8.2 Future Work

This thesis presents a simulation model for the peak shaving system using an ESS and it outputs expected results. It is more valuable to build a lab scale model for this system in the future. And the current ESS simulated in MATLAB simulink is for peak load shaving in offshore rigs but there is no specific charging method integrated and simulated for the energy storage. The possible methods of renewable and regenerating electricity in offshore are explored in section 4. The integration of these renewable and regenerative energy sources to charge onboard energy storages can be thoroughly investigated and continued in future. This will lead to environmentally friendly and economical oil and gas processes and operations.

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Appendices

Appendix A: Task description of the Master Thesis

Appendix B: Simulation model of peak load shaving for specific peak hours using breakers

Appendix C: A simulation model of the peak load shaving for specific peak times using breakers

Appendix A: Task description of the Master Thesis

University of
South-Eastern Norway

Faculty of Technology, Natural Sciences and Maritime Sciences, Campus Porsgrunn

FMH606 Master's Thesis

Title: Simulating Converter System with Energy Storage for Offshore Applications

USN supervisor: Kjetil Svendsen

External partner: Tinfos

Task background:
We are currently in a transitional period where an increasing fraction of the world energy consumption is conveyed through electricity. This is done to decrease CO2 and greenhouse gas emissions. Energy from renewable sources like wind and solar are making a up a substantial fraction of the produced power and reduce the emission of the CO2. There is a special concern for generating power using Diesel generators in industrial applications.

It is becoming more vital to use energy storage systems for environmentally friendly and as sustainable energy solutions to replace Diesel generators. New energy storage systems can store and release energy efficiently while using renewable energy sources and regenerating energy to recharge.

The electrical power stability for variable loads in industry is a major concern when it comes to decide the capacity of power sources. In Oil and Gas field where mainly uses Diesel generators as their main power source consume much fuel during periods of high demand and undergo overloading. Onboard energy storage systems can be used to implement peak shaving strategies and optimize power consumption during the processes.

This change demonstrates a commitment to mitigate environmental impact, enhance energy resilience and optimise resource utilization.

Task description:

-Literature review

- Study the integration of energy storage system with power electronic converter to connect with main supply.
- Explore regenerating power methods in Oil and gas field.
- Identify peak load scenarios.
- Investigate different power electronic topologies suitable for peak shaving.

-Simulate the model of power electronic converter system.
- Simulate the onboard energy storage system
-Evaluate different configurations for storage system and peak shaving
-Cost-environment impact analysis

Student category: EPE (EET, EPE, IIA or PT students)

Is the task suitable for online students (not present at the campus)? Yes

Practical arrangements:

Supervision:
As a general rule, the student is entitled to 15-20 hours of supervision. This includes necessary time for the supervisor to prepare for supervision meetings (reading material to be discussed, etc).

Signatures:

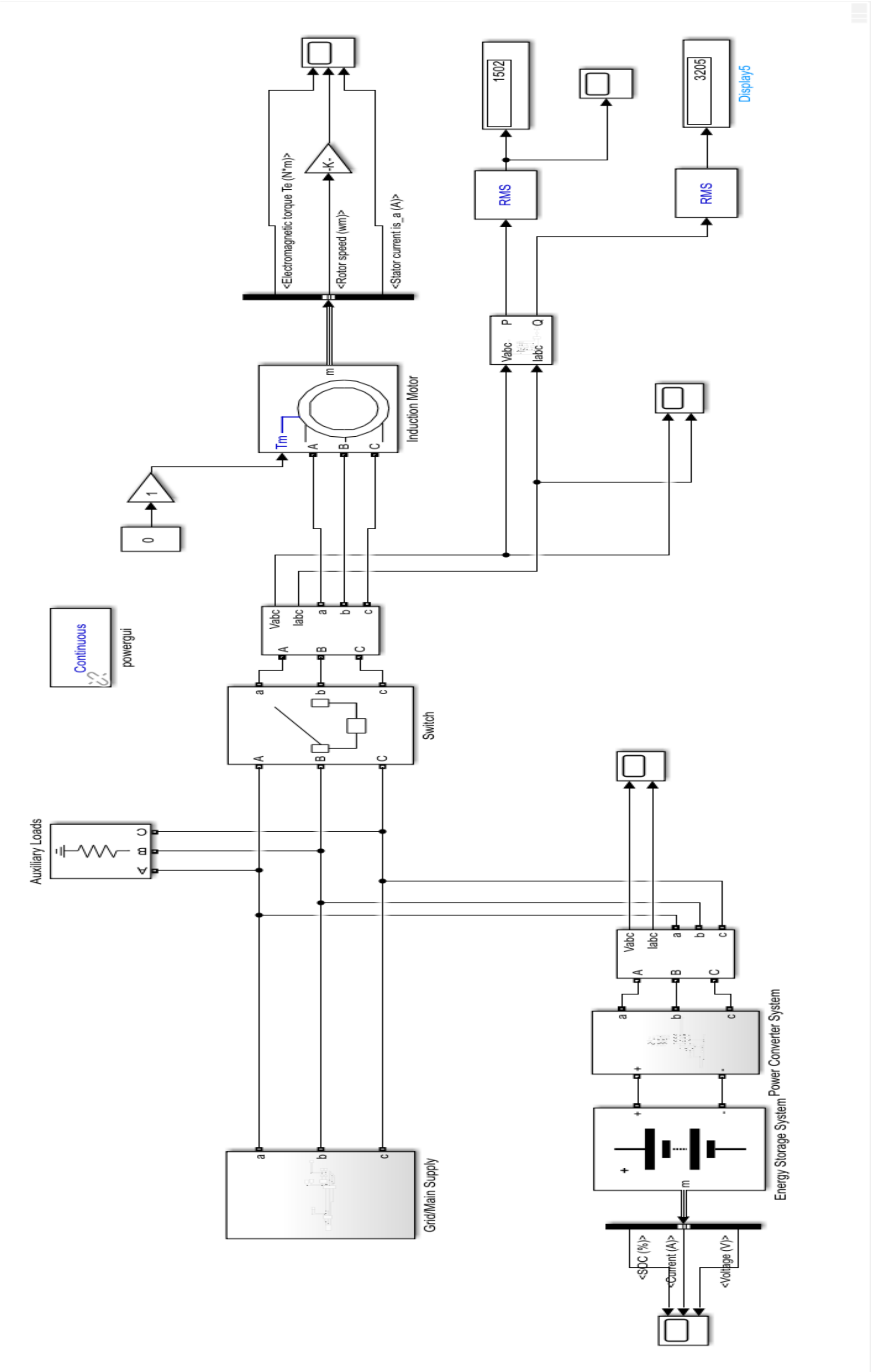
Supervisor (date and signature): 1/2 24

Student (write clearly in all capitalized letters): PAHALA GEDARA LASINTHA S. PIYATISSA

Student (date and signature):

02.08.2024

Appendix B: Simulation model of peak load shaving using the converter system and the ESS.



Appendix C: A simulation model of the peak load shaving for specific peak times using breakers.