# DEVELOPMENT OF ENERGY STORAGE SYSTEM FOR STORING REGENERATIVE BRAKING ENERGY FROM TRAIN

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**A project report submitted in partial fulfilment of the requirements for the award of Master of Engineering (Electrical)**

**Lee Kong Chian Faculty of Engineering and Science**
**Universiti Tunku Abdul Rahman**

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# DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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## APPROVAL FOR SUBMISSION

I certify that this project report entitled **"DEVELOPMENT OF ENERGY STORAGE SYSTEM FOR STORING REGENERATIVE BRAKING ENERGY FROM TRAIN"** was prepared by **FAIZAL ZAMANI BIN DOLLAH** has met the required standard for submission in partial fulfilment of the requirements for the award of Master of Electrical at Universiti Tunku Abdul Rahman.

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# ABSTRACT

This research aims to explore the development of energy storage systems in railway projects. Investigate the characteristics of energy generated and/or energy used by the electric train, design an energy storage system to recover the energy from the energy used and evaluate the performance of the system developed.Recent research in railways and studies in newspapers and conference papers have highlighted the importance of different technology and operative strategies to optimise the railway system's efficiency, but due to a broad range of interdependent factors, more dedicated studies are required to tackle energy costs and the need for optimised and reliable strategies. Energy from a moving train from static stop to movement has produced significantly excessive energy which can be harvested and reused for train operations or used by the local system, e.g., traction substations, stations, convenience stores and residential townships. In certain scenarios, the non-regenerative braking will be considered since the worst-case scenario is in the design parameter.In this study, and the train operating data are collected to ascertain the current perceptions of energy conservation to railway applications. The information is then used as the parameters for modeling the Mass Rapid Transit System. ETrax software is used for dynamic load flow simulations to obtain an accurate estimation of the energy recovery captured in the system in each operation mode by incorporating train headway interval variations, algorithm and the effects of train schedules on the operating mode.

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| | |
|---|---|
| PV | Photovoltaic |
| COE | Cost of electricity |
| ESS | Energy storage system |
| VRB | Vanadium redox flow |
| Li-ion | Lithium-ion |
| ZnBr | Zinc Bromide |
| EMS | Energy Management Strategy |
| DOD | Depth of discharge |
| RESP | Rural Electricity Supply Programmes |
| LF | Load flow |
| CC | Cycle charging |
| SOC | State of charge |
| SDS | Safety Data Sheet |
| SEDA | Sustainable Energy Development Authority |
| PV | Photovoltaic |
| PQ | Power Quality |
| HSR | High-Speed Rail |
| JR | Japan Rail |
| RES | Renewable Energy Sources |
| CO2 | Carbon Dioxide |
| DC | Direct Current |
| VVVF | Variable Voltage/Variable Frequency |
| RPC | Rail Static Power Conversion |

| | |
|---|---|
| NREP | National Renewable Energy Policy 2010 |
| IEA | International Energy Agency |
| APAD | Agensi Pengangkutan Awam Darat |
| GTMP | Green Technology Master Plan 2017-2030 |
| PVMS | PV Monitoring System |
| FiT | Fit In Tariff |

# CHAPTER 1

# INTRODUCTION

## 1.1 **Introduction**

In most developing countries, the transportation system is important either to transport the goods or to keep the smooth transition of people moving from one area to another area. This is the main factor to facilitate and continuous growing of the transportation mode i.e., air, road, water.

In the case of railway application in the transportation mode, the development of the technology and recent advanced studies by the researchers by the university and service provider, the railway system had been developed toward a new perspective and this had changed it into new thinking to the development of the new enhancement of using the new energy from this transportation mode. One of the key solutions toward this is the development of the Energy Storage System (ESS). This had been widely used in most modern railway systems and this helps the asset owner and operator to provide the transportation service. It is a national contribution toward supporting the new green energy assessment.

## 1.2 Problem Statements

Modern transportation had provided a large number of opportunities for the use of back-recovery and storage of energy. The huge of amount kinetic energy from the railway infrastructure introduces significant sources for reuse excessive energy to better new sources of energy as mentioned earlier (Lakshminarasimhan and Athani, 2013).

The rolling stock also known as trains is a complex system that covers traction. The system is a dynamic system where the operation is generating high impact energy consumption during the system accelerates and decelerates. The dynamic of the system provides the transient behaviour of the train and produces instantaneous energy to the rail system (Wang and Rakha, 2017). Initiative to reduce energy consumption and toward to green technology, the DC traction system had provided a significant harnessing regenerative energy and sources of energy that generates a substantial amount of electrical energy (Saleh et al., 2017)

For purpose of multi-train simulation, the dynamic train movement is derived for the evaluation of energy recovery to the system. The effect of the DC traction system variables impacting the amount of energy magnitude by the regenerative brake. Modelling of simulation traction between the station should evaluate the system been developed (Saleh et al., 2017).

Recently, there has been a lot of interest in the literature on using energy storage systems to improve the operation of electrified light transportation systems. The major objectives in this area are to improve energy efficiency and reduce pantograph voltage dips. As a result, determining the best storage device to meet these goals, both stationary and onboard, can be highly intriguing (Iannuzzi, Lauria and Tricoli, 2012). It is indicated that the Energy Storage System (ESS) has brought an idea to reduce energy consumption and toward green energy. According to the author, (Iannuzzi, Lauria and Tricoli, 2012), their low investment costs and high-quality service in terms of pollution and energy efficiency point to their rapid growth in the future. Furthermore, automotive technology is always developing, allowing for lighter and more cost-effective alternatives, and additional advancement may be reasonably predicted.

### 1.3 Aim and Objective

The goal of this study is to design an Energy Storage System (ESS) for use in railway systems. To accomplish this, the author has identified the major goals that must be met and established to achieve the goal. As follows is the objective: -

a) To investigate the characteristics of energy generated from the regenerative braking
b) To design an energy storage system to recover the energy from the regenerative braking
c) To evaluate the performance of the system developed

### 1.4 Scope of Study

The scope of this study is to produce a design development on the Energy Storage System (ESS). The existing data will be used from the operation railway This research will focus on the MRT Line Project relevant stakeholders and support to contribute to the study. They are the stakeholders that involve in MRT projects and also the potential respondent that will contribute toward to study scope. This study limits only to the energy storage system and the limitation of the study configuration of the infrastructure and design of the Energy Storage System depend on the result from the simulation.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Literature review

This chapter sets out the context of the research important to the nature of the field of study. The research history offers general knowledge on the impact of the adoption of the energy storage system in the urban transit system in Malaysia, with a cross-reference to other advanced rail systems, and on the large implementation of energy storage systems capable of potential, benefits and challenges i.e., reducing the burning of fossil fuels, as well as the impact of Greenhouse. The details of the significance of the study and the design of the research structure shall be explained further.

## 2.2 Implementation Energy Storage System

The railway was built with a modern concept in mind, and the system that had been used had been mobilized to great success. The use of a combined solution has been widely used to develop a new power generation solution that can be used independently or as part of a grid system. In the context of the railway system, one option that has been widely used in the railway application as a solution to minimize the trade-off from the utility company and to resolve the power quality concern in the system is the energy storage system (Ovalle et al., 2018). According to the author (Ovalle et al., 2018), energy storage systems are becoming increasingly important in transportation and electrical systems due to their contribution to efficient performance and potential reduction of environmental impacts. The railways had their capacity limitation by the power that can be supplied through the electrification system i.e., catenaries, third rail system and fourth rail system. The standard voltage is tabulated in Table 1.1**.** (Ovalle et al., 2018).

**Table 1.1 Standard voltage for DC railway**

Standard voltage limits for DC railway lines.

| Transient minimal tension (V) | Nominal tension (V) | Transient maximal tension (V) |
|---|---|---|
| 400 | 600 | 800 |
| 500 | 750 | 1000 |
| 1000 | 1500 | 1950 |
| 2000 | 3000 | 3900 |

The new railway networks should develop an efficient train substation system with a variety of designs and more robust electronic equipment that does not obstruct traffic or energy efficiency. Additionally, rail operators are examining technical and economic options for modernizing the energy sector to meet anticipated increases in electrical demand. One possibility is for railway power systems to incorporate alternative energy sources and storage devices. Through the use of storage devices, this approach achieves partial energy independence and increases power-energy efficiency. According to the International Energy Agency (IEA), rail is one of the most energy-efficient modes of transportation, accounting for 9% of global passenger traffic and 7% of freight traffic. Rail consumes only 3% of the total energy consumed (IEA, 2020).

## 2.3 Research Background

As previously said, railway transit is an efficient and environmentally favourable mode of transportation. Electric energy consumption is substantial (Hayashiya et al., 2014), and energy storage system deployment could reduce energy consumption by optimizing the energy storage system. According to the author (Hayashiya et al., 2014), the use of the energy storage systems in railway's substations had contributed more than 5 per cent reduction of total traction power supply and Japan's is plan to have more energy storage systems in the system. Japan's railway has the example implementation in the system as illustrated in Figure 2.1 (Hayashiya et al., 2014).

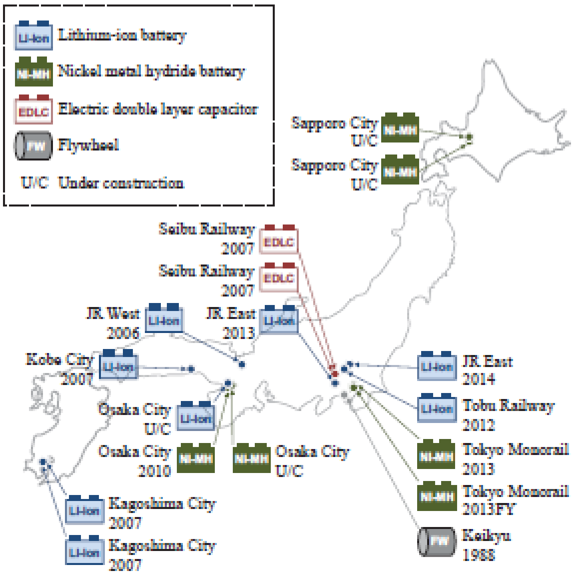



**Figure 2.1 Energy Storage System in Japan's Railway**

From Figure 2.1 Energy Storage System in Japan's Railway considered that the implementation of the energy storage system must investigate an adequate site to use a high regenerative brake performance. The installation of this system must go through an assessment to determine the conditions that must be considered to ensure the energy storage system's effectiveness, which include the length of the fleet, moderate operation frequency, station condition and location i.e., slope and the long interval between substations. (Hayashiya et al., 2014). Base on the study case by the author (Wu et al., 2021), the scenario base track condition, speed criteria, condition of the location and infrastructure contributed to the final result of energy storage systems. The result of the case study shows that the Li-ion battery system contributed more benefit to the project event the energy-saving rates at the lowest return.

Since its commissioning, the energy storage system has required ongoing monitoring to 20 optimize its operation and performance. The energy storage system must be fine-tuned by the designer before being placed into service after a year. The amount of regenerative brake received at the station/substation is based on the number of trains in service. (Hayashiya et al., 2014).

Modern efficient railway substation control systems with different designs and stronger electronic equipment must be developed without interfering with railway lines' traffic or energy efficiency. Furthermore, railway operators are keen to look at technological and economic options to address a rise in future energy demand with the modernization of the electricity market. The integration into railway electricity grids of renewable energy sources and energy storage units is one solution. This solution would lead to partial independence from power suppliers and boost the quality of power through storage units (Pankovits et al., 2013). According to the author (González-Gil, Palacin and Batty, 2013) the most viable Energy Storage System is achieved by combining two systems: Wayside ESS and Onboard ESS. It contributes varying percentages of energy savings to the railway system ranging from 15 per cent to 3 per cent. The statement also supports by the author (González-Gil et al., 2014), energy storage could be increased by 25 to 35 per cent by implementing energy-optimized timetables, energy-driving strategies, improved control of comfort functions in vehicles, and wayside energy storage systems.

The traction energy flow illustrated in Figure 2.2 Typical traction energy flow is a typical traction energy flow chart for an urban system. As mentioned by the author (González-Gil et al., 2014), the energy flow chart is the illustration of energy that could be used for the energy storage system. (González-Gil et al., 2014)

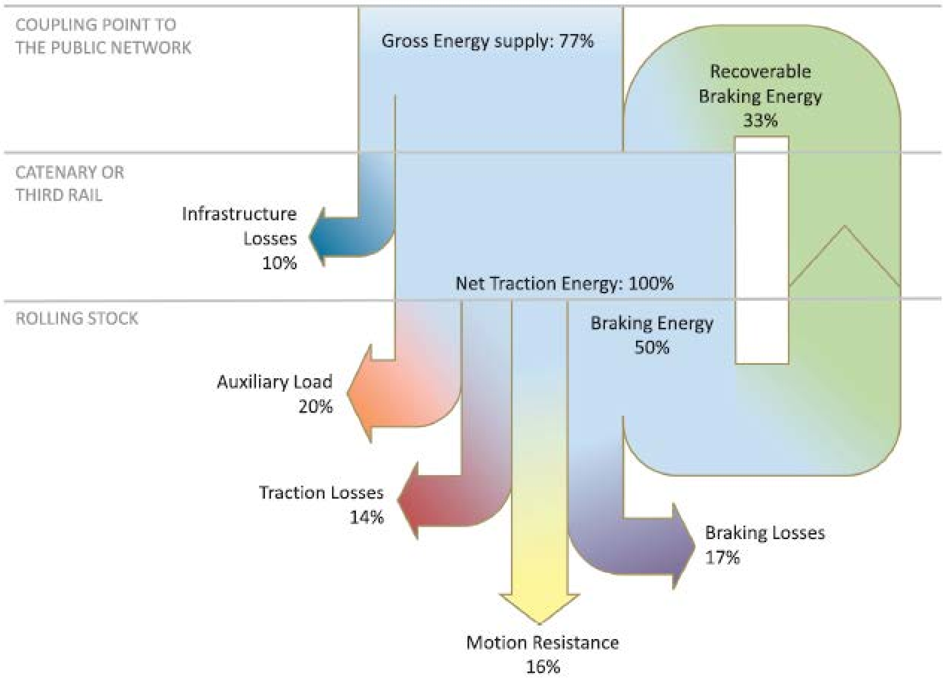



**Figure 2.2 Typical traction energy flow**

The Urban rail system is typically grouped in energy proportion, infrastructure losses and percentages value. A report in Metro Oslo, the heating system contributed 28% of total traction energy and all auxiliary supply contributed 10% of total vehicle consumption in London underground (González-Gil et al., 2014). Regenerative braking: Ideally, vehicle acceleration would use excessive braking energy in the same electric portion, but at the same time vehicle acceleration and de-speculation are unlikely and energy-wasting in brake resistance. To optimize the utilization, these are the option to be adopted which are Wayside energy storage system, On-board energy storage system, Optimizing the operation service table, inverter and traction energy recovery system. The energy storage system can save up to 30 per cent of energy (González-Gil et al., 2014). The optimization of the energy storage system is illustrated in Figure 2.3 Proposed action to save energy. (González-Gil et al., 2014)

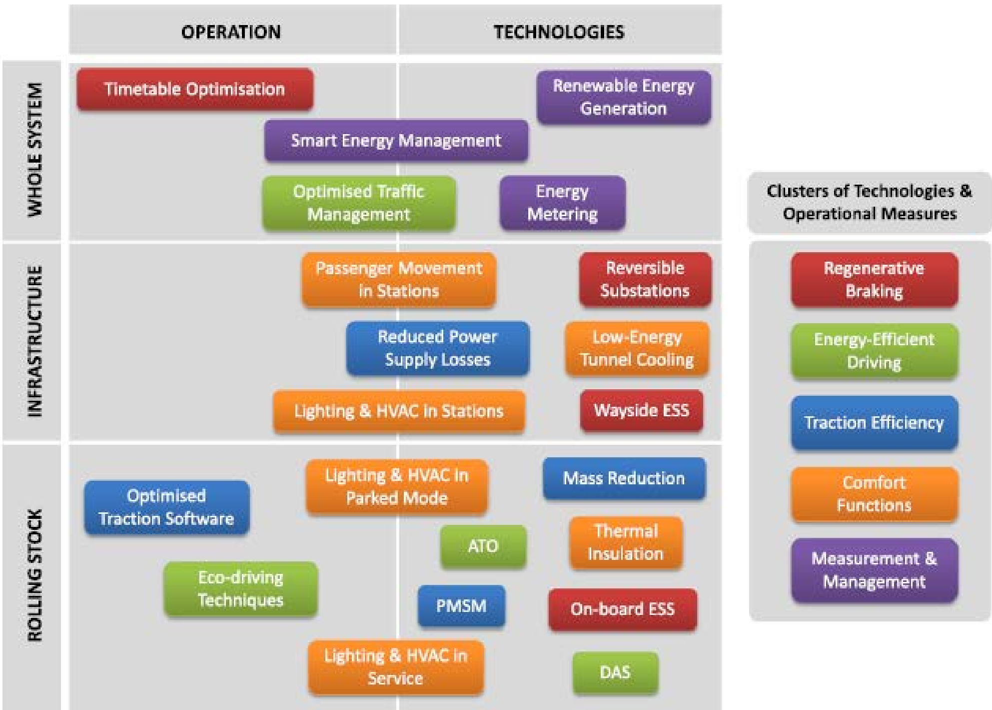



**Figure 2.3 Proposed action to save energy**

The main focus from the figures is the illustration strategy implementation for the energy storage system, reversible substation i.e., traction energy recovery system, On-board energy storage system in the options to optimise the regenerative brake from the departure trains. This optimization shall also support with operation and strategy were governed the whole system implementation. The requirement of these features shall be captured by other studies and to overview the overall performance in the integration studies. The optimal algorithm, optimal eco-driving and driving strategy provide a base behaviour of the energy storage system where it is corresponding to the train speed, State of Energy and the power of energy storage energy obtain (Wu et al., 2021) and Figure 2.4 illustrates the model for the energy storage system. (Wu et al., 2021)

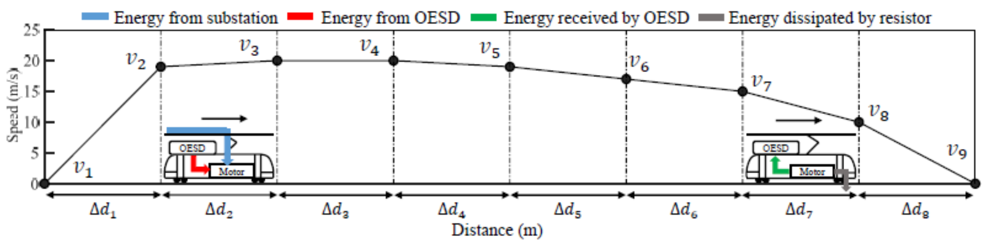



**Figure 2.4 A schematic for speed profile and energy flow for ESS**

The energy storage system also contributes significantly to the fleet wheel and this shall be considered before the final design is captured. According to the author (Wu et al., 2021), supercapacitor contributes a high ratio of 0.85 compared to Li-ion battery at 0.08. Table 2.2 The maximum power, capacity and weight shown in the compilation of summary and support the statement. (Wu et al., 2021)

**Table 2.2 The maximum power, capacity and weight**

| OESD type | Maximum power (kW) | Capacity (kWh) | Mass (t) |
|---|---|---|---|
| Supercapaitor | 750 | 1.87 | 0.85 |
| Flywheel | 500 | 3.50 | 0.50 |
| Li-ion battery | 80 | 13.88 | 0.08 |

Over the last decade, the rail system has developed rapidly, both in cities and between cities, and has laid the groundwork for fast, emissions-efficient transport. With unprecedented growth, China is leading the way in the high-speed rail where their passenger traffic has increased by about 13 per cent in 2019, which is more than twice of their domestic aviation. More rail investment in India and Southeast Asia will help the transport sector step forward with Sustainable Development Scenario, replacing more emission-intensive modes such as cars, trucks and aircraft (IEA, 2020). The energy conservation of railway systems is a critical topic for lowering operational costs as well as lowering carbon emissions as a step toward sustainable development. Due to the inherently dynamic nature of traction loads, determining the optimal operating mode for the transformers requires a thorough simulation that incorporates train dynamics and schedules. As a result, a comprehensive electrical model is required that incorporates both the low voltage traction and high voltage supply networks. Massive installations and their easy maintenance are not necessary to preserve (Morita et al., 2012).

With the advanced development of the metro system such as Japan and China, the development using Renewable Energy had been increased rapidly and ideas of using nature as the main component for the energy production had been the mainstream in a modern design system. Because of its high capacity, safety, reliability, and superior environmental performance, urban rail is seen as an ideal solution for reducing the impact of urban travel (González-Gil et al., 2014) (Hayashiya et al., 2012a).

Energy-saving and conservation are the issues facing the consumer or the user. The key consumers of energy resources reported by the Energy Commission Malaysia are transport recorded at 4 per cent comprising the aviation, residential and commercial at 11 per cent and industrial at 28 per cent sectors (ST, 2016). This showed that the transportation sectors in general and specific to railways application, where could contribute major roles in the adoption of the energy storage systems. As mentioned by the author (Nakashydze, Hilorme and Nakashydze, 2020), the poor dynamic of decrease in energy in power consumption volumes indicates a low level of production in modernization.

Unresolved problems remain in the formation of power supply systems in many countries of the world due to the inadequate formation of scientific principles for the design and the selection of energy-efficient climate control systems. Fragmentation in the selection of project solutions for complex climate control systems for residential, industrial buildings and power supply contributed to the impact of the insufficient effect of energy saving. To ensure the significant impact, scientific and practical to be developed and establish a foundation for building energy-efficient systems that provide climatic conditions for use of energy from the solar and the environment energy. For the growth of the global power sector, it is an important scientific and practical issue, which needs further development and solution (Nakashydze, Hilorme and Nakashydze, 2020).

The development of the railway's system had been improved and receiving advanced technology in line with the railway technology development. The application of the railways had been improved and the energy developed from the electric train had been implemented in a variety of applications either the traction substation, railways station, electric train etc. This development showed the market is required a compatible design and development to implement green energy and the necessity to reuse the energy either in the railway's system or stationary system at the stations. As mentioned in Figure 2.3 Proposed action to save energy 2 main characters influence the performance of the railway's system which is given by operation and technology. These two characters are supported by the rolling stock, infrastructure and whole system. According to the author, the optimum recognition of the system is also supported by an option of the technology i.e. inverter, Energy Assurance Resistivity Unit, Energy Storage System, and algorithm to conformance to the ultimate configuration. This design development requires more study and research to ensure the selection of the design is reliable and maintainable by the railway's operation. This is the key of the selection to the design in the project implementation and specification.

According to the author (Ates, Acikbas and Soylemez, 2019), the timetables is pre-scheduled and prepared to meet the demands and capacity following the needs of the people and stakeholders. The author also covered the minimum cost for the operation, maintenance, investment, personal and equipment are the key subject to be addressed to meet the objective of the railway transport needs. The expression of the effective timetable in Table 2.3 Character on Effective timetable. (Ates, Acikbas and Soylemez, 2019)

**Table 2.3 Character on Effective timetable**

| No | Characteristic Indicator |
|---|---|
| 1. | Number of trains, passengers and load in period |
| 2. | Amount of passenger/km and ton-km/period |
| 3. | Headways and buffer times |
| 4. | Schedules dwell times |
| 5. | Time and effort for modification and updating |
| 6. | Frequency |
| 7. | Regularity |
| 8. | Precise and realistic run-time |
| 9. | Sufficient and acceptable recovery time |
| 10. | Exact minimal headway time |

The train braking from an operational speed contributed and generated energy to be used attraction to the substation, stationary equipment and stations. The most important is the accessive energy from the braking action to be stored in Energy

Storage System is effective to safeguard the equipment from the power quality issue and reduce the energy usage from the grid. According to the author (Qu and Yuan, 2021), there are difficulties to recover the energy from the stopping train either in supercapacitor or high-density energy batteries. It is also written in the research that the energy recovery during the train braking either could be fully recycled or not is subject to the performance of the systems and its operational algorithm (Ates, Acikbas and Soylemez, 2019).

Production of the regenerative brake had been in modern railways system in high-speed railways, electric vehicles and urban metro. Based on the current research, the demand for using the battery with sufficient capacity is in consideration due to the energy storage system not sufficiently catering for the accessive energy (Qu and Yuan, 2021). The research focuses on the stationary energy storage system for the urban metro. The installation and capacity correlated to the different studies of traffic conditions (Qu and Yuan, 2021) (Ates, Acikbas and Soylemez, 2019), where contribute the optimum of railways operation and recycling of the energy from the regenerative braking. The illustration of the Hybrid Energy Storage System in Figure 2.5 The Hybrid Energy Storage System (Qu and Yuan, 2021).

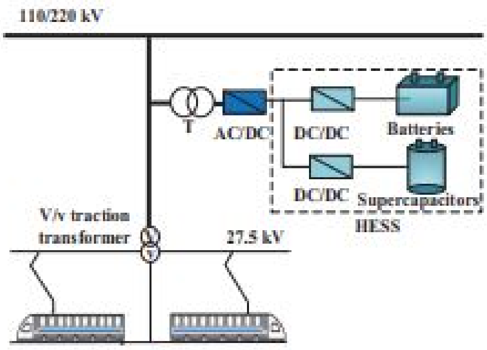



**Figure 2.5 The Hybrid Energy Storage System**

The configuration considered the connection of the AC/DC converter and the system connected to the supercapacitor bank and battery bank system. The converter is a bidirectional converter where the recycle energy system from the grid and release the supply to the traction system of the railways.

The increased power required because of the increase in the number of vehicles circulating simultaneously, even if the future appears to be especially bright, requires finding new solutions to optimize the energy consumption and improve the overall performance, as far as possible, also explore the possibilities of the new technologies brand (Iannuzzi, Lauria and Tricoli, 2012). According to another, the energy storage systems (ESS), which can be on board or stationary and installed at substations or along the track, are possible options for increasing efficiency, lowering pantograph voltage dips, and lowering substation current peaks in this context.

In addition to the benefit of the ESS, a design combination with adequately managed power converters, storage devices can considerably enhance the dynamic response of the entire light transport system. These advantages also indicate an upgrade to current systems, since the cost of capital is greatly decreased. In the previous years, several storage technologies have been studied and some have successfully been launched with extremely acceptable dependability criteria.

The use of energy storage devices to improve the performance of electrified light transit systems has received significant attention. The major objectives in this area are to improve energy efficiency and reduce pantograph voltage dips. As a result, determining the ideal properties of a storage device for achieving these goals, both fixed and onboard, can be quite interesting. The studies demonstrate that the best design of a stationary storage device may be treated as a classical isoperimetric problem, whose solution is extremely appealing in determining also the optimal storage device allocation. For more complex transit system configurations, the methodology described can be expanded by solving a restricted optimization problem, which can match all of the specified technical requirements in a very broad manner. The simulations that have been reported back up the validity of the proposed design strategy. Although the future seems to be particularly bright, due to the growing number of vehicles circulating at the same time, the increase in energy consumption and the improvement of the entire performance of the transport network also imposes finding new solutions to optimise the energy use and explore the potential of the new technologies market (Sirmelis, Zakis and Grigans, 2015)

**2.4 Energy Storage System Awareness and Improvement**

For the transport systems, the choice of the most appropriate storage technology must also be achieved with acceptable power density and high cycle numbers. Supercapacitors, flying wheels (FW), and supranational magnetic storage systems seem to be some of the most qualified systems for light transport systems among the many storage technologies.

Energy storage systems (ESS), which can be on board or stationary at substations or along the track, are viable options for increasing efficiency, lowering pantograph voltage drops, and lowering substation current peaks. In other words, ESS can play a key part in the saving of energy in light-freight systems, which can no longer be postponed. Furthermore, storage systems are also suitable for greatly boosting the dynamic response of the complete light transit system in conjunction with properly managed power converters. These benefits imply an upgrading of existing systems as well, as capital investments have extremely short payback periods (Sirmelis, Zakis and Grigans, 2015).

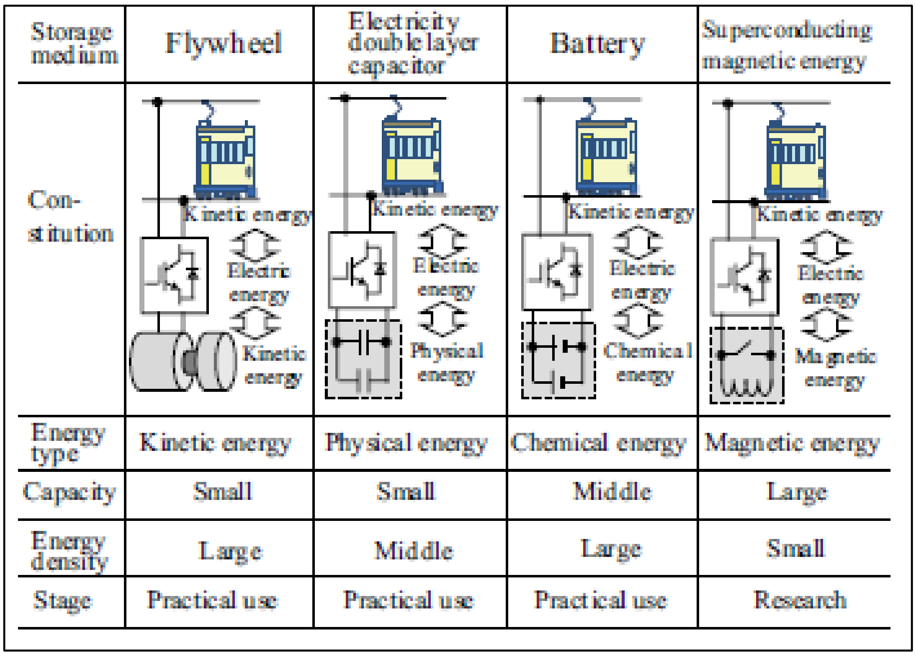
**2.5 The factor of selection Energy Storage System**

In the previous years, several storage technologies have been studied and some have successfully been launched with extremely acceptable dependability criteria. For the transport systems, the choice of the most appropriate storage technology must also be achieved with acceptable power density and high cycle numbers. Supercapacitors, flying wheels (FW), and superconducting magnetic storage systems (SMES) seem to be some of the most qualified systems for light transport systems among the many storage technologies (Iannuzzi, Lauria and Tricoli, 2012).

Numerous storage systems have been studied in recent years, and several have been successfully sold with extremely high-reliability standards. In terms of transportation systems, the selection of the most appropriate storage technology must take into account both high power density and cycle count. According to the author(Sirmelis, Zakis and Grigans, 2015), the selection of the suitable storage technology shall have effective benefits by satisfying good power density and the high number of cycles. It also noted that the opportunity adoption of these approaches i.e., Supercapacitors, flying wheels (FW), and superconducting magnetic storage systems (SMES) to optimise the energy consumption and to reduce line voltage drop. Additionally, energy storage devices have been employed to mitigate power surges generated by electrical substations during train acceleration and braking. Further to that, numerous modelling issues arise when designing transportation networks, especially when the time-varying nature of electrical circuits must be considered. The author (Sirmelis, Zakis and Grigans, 2015), stated that It is needed to mention that this last point has a significant impact on the architecture of the storage system.

In comparison to other forms of energy, electrical energy is easily controllable. Furthermore, electrical energy is beneficial to the environment. Electrical energy is also used as the driving energy of railway rolling stock. On the other side, to offer stable electric energy, the power supply system must have sufficient supply capacity for demand. The electric power utilized in electric trains has the advantage of having a high peak power and a low average power. This is a result of the rising cost of electricity.

With the introduction of the vehicle where the transmission of high-power is required, and the power storage facility is expected remedies against such a problem, the effective use of resurrection energy and the necessity of voltage descent measures rise (Okui et al., 2010). Concerning information in Figure 2.6 Japan railway Energy Storage System (Okui et al., 2010) showed the voltage drop between DC substations has been notable as the electric load has increased. As a result, the use of battery installation was suggested to help mitigate the voltage drop. It is beneficial to battery installation that does not necessitate a substantial investment, such as power lines supplied by generators and substation equipment (Okui et al., 2010).



| Storage medium | Flywheel | Electricity double layer capacitor | Battery | Superconducting magnetic energy |
|---|---|---|---|---|
| Con-stitution | Kinetic energy<br>Electric energy<br>Kinetic energy | Kinetic energy<br>Electric energy<br>Physical energy | Kinetic energy<br>Electric energy<br>Chemical energy | Kinetic energy<br>Electric energy<br>Magnetic energy |
| Energy type | Kinetic energy | Physical energy | Chemical energy | Magnetic energy |
| Capacity | Small | Small | Middle | Large |
| Energy density | Large | Middle | Large | Small |
| Stage | Practical use | Practical use | Practical use | Research |

**Figure 2.6 Japan railway Energy Storage System**

In many circumstances, an energy storage system requires a power converter i.e., an inverter, a converter, or chopper equipment. The standard design for an energy storage system for electrification purposes incorporates a step-up/down chopper i.e., DC chopper. The Figure 2.7 DC chopper for Japan Railway illustrated the primary circuit for an energy storage system (Okui et al., 2010).

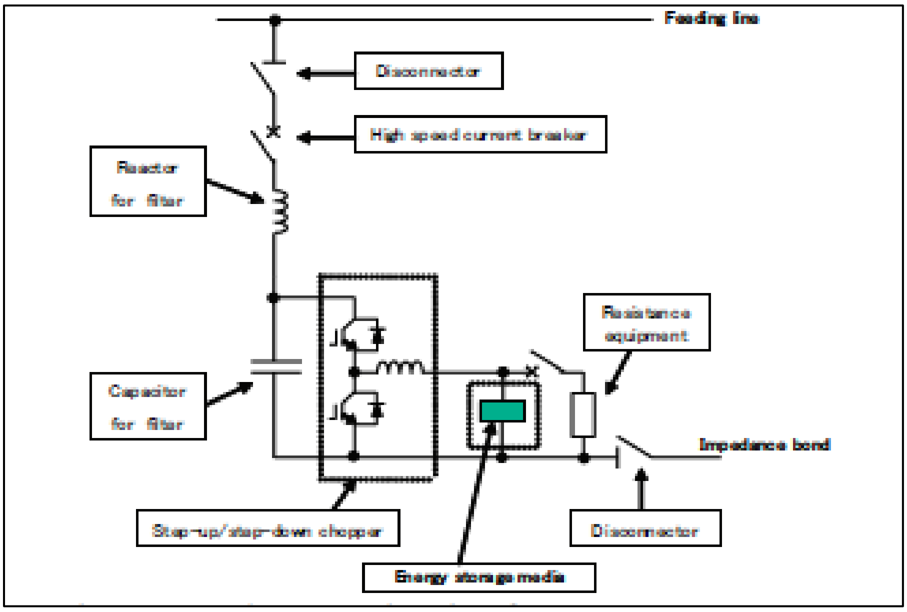



**Figure 2.7 DC chopper for Japan Railway**

## 2.6 Adoption Energy Storage System

The utilization of electric railways for vehicle resurrection energy is becoming more effective, as is the need for voltage decline precautions. Furthermore, an electric railway must make excellent use of regenerating energy from rolling stock for energy conservation and as a safeguard against voltage drops. Using an energy storage system on electrified railways is one solution to these challenges. The development and application of energy storage systems for the railway had been increasing rapidly (Chen et al., 2021). According to the author (Okui et al., 2010), the "Law about the rational use of energy" is provided in Japan since the oil crises, several techniques have been taken. Furthermore, after 1973, the co-efficiency of performance was improved by more than 30 per cent. The rationalization toward to green energy environment had been enforced by the Kyoto protocol and Malaysia had pledged a commitment to reduce its carbon emission intensity by 35 per cent in the year 2030 or 40 per cent with the support from developed countries which was held at the 21st Conference of Parties (Nations, 2015) in 2015. This national commitment has been ratified by the 2015 Paris Agreement, which was adopted by the Member States of the United Nations to counter tackle adverse effects on climate change (ST, 2019).

The adoption of a clean energy vehicle, as well as a modal shift to public transportation with minimal environmental impact, are mandated by this rule. In such a situation, the automobile industry is progressing in the development of an electric vehicle, a fuel-cell vehicle, and so on, with particular emphasis on the creation of an electric power storage medium. On the other hand, the electricity storage capacity of the vehicle and the power storage facility for supplementing the substation is being used in the railway sector in practice (Okui et al., 2010). In 1912, the ESS erected the Maruyama and Yagasaki substations in the Usui pass, which is located on the Shinetsu line. Due to the power supply conditions being poor at the time, the load was provided for a brief period by the battery, and the load factor improvement was established by driving the battery and rotary converter in parallel during commute time (Okui et al., 2010).

In 1980, a three-year case study was done in Japan at Kabe Line to monitor the voltage feed to the substation. The battery banks of 792 cells are discharged and recharged using the threshold setting; the maximum voltage is 1585V. The post had performed admirably in terms of voltage drop correction. A thyristor was utilized to switch between the feeding line and the lead-acid batteries in the post (Okui et al., 2010). Examples of energy storage systems in operation on Japan's railway categories and a case study before actual implementation tabulated in Table 2.4 Japan ESS implemented after 1988 (Okui et al., 2010) and Table 2.5 Japan ESS for Case Study after 1988Table 2.5 Japan ESS for Case Study after 1988 (Okui et al., 2010).

**Table 2.4 Japan ESS implemented after 1988**

| Rated capacity of energy storage system for practical use | | | | |
|---|---|---|---|---|
| Company | Installation year | Storage medium | Rated power (kW) | Rated energy (kWh) |
| Keihin Electric Express Railway | 1988 | Flywheel | 2,000 | 25 |
| West Japan Railway Company | 2006 | Lithium ion battery | 1,050 | 140 |
| Kagoshima City Transport Bureau | 2007 | Lithium ion battery | 250 | 18.1 |
| Kobe Municipal Transportation Bureau | 2007 | Lithium ion battery | 1,000 | 37.4 |
| Seibu Railway Co., Ltd. | 2007 | EDLC | 2,560 | 6.875 |

**Table 2.5 Japan ESS for Case Study after 1988**

| Rated capacity of energy storage system for examination | | | |
|---|---|---|---|
| Company | Storage medium | Rated power (kW) | Rated energy (kWh) |
| Nagoya Railroad Co., Ltd. | Lithium ion battery | 500 | 18.7 |
| Osaka Municipal Transportation Bureau | nickel-metal hydride battery | 5,600 | 576 |

### 2.6.1 Energy Storage System toward Renewable Energy Policy

According to (Hashim and Ho, 2011), the government had measures in place to investigate and promote stringent action in promoting Renewable Energy as a means of energy production and environmental protection. These include the Fifth Fuel Policy of 2000, the National Biofuel Policy of 2006, the National Green Energy Policy of 2009, and the National Renewable Energy Policy of 2010. Malaysia's government unveiled a new renewable energy strategy in 2018.

In 2000, the 4 Fuel policy was transformed into the 5th Fuel Policy, which declares it the 5th fuel in the Mix for Renewable Energy Supply (The Eighth Malaysia Plan 2001-2005). Electricity was also encouraged to prevent Malaysia from being a net importer of energy that would influence economic growth (Jalal and Bodger, 2009).

The 9th Plan has strengthened Malaysia's 8th Sustainable Energy Efficiency Plan activities in the expansion of energy use. Further attempts at the incorporation of alternative fuels further emphasize reducing dependence on petroleum. Several exemptions for energy conservation implementers and renewable energy generators have been implemented. The 10th Malaysian Plan (2011-2015) examines the development of stronger renewable energy incentives. Malaysia has many RE resources, including biogas, mini-hydraulic energy, biogas and solar, used to make energy provision sustainable and secure, as stated in its 10th Malaysian plan (Yusoff and Kardooni, 2012).

It was stressed by the new policy that 20 per cent renewable energy is available in its 2025 generation mix, while the national COP21 contribution was supported. In 2016-2020, the 11th Malaysia Plan set further guidelines for green growth in Malaysia. The GTMP has established a new energy source for sustainable power generation and energy efficiency (ST, 2019). The GTMP as mentioned in Figure 2.8 GTMP direction for the energy sector (ST, 2019)

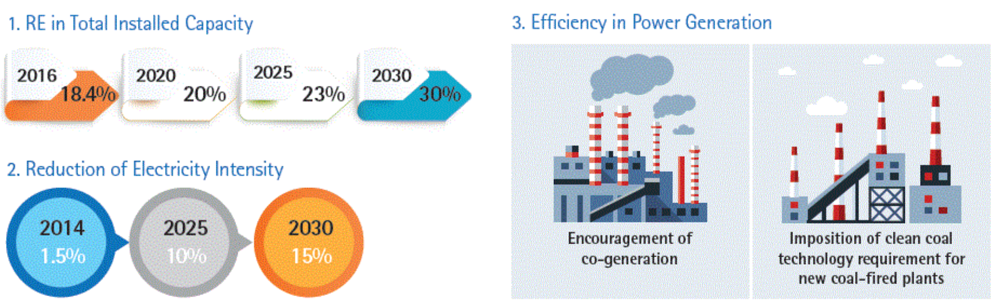



**Figure 2.8 GTMP direction for the energy sector**

In Peninsular Malaysia, energy storage systems in not include renewable energy production include solid waste, hydro-small waste, biomass, biogas, solar, and geothermal waste. Large hydropower plants with more than 100 MW are not listed as RE. By 2025, the 20 per cent renewable energy target will improve the generation of solar energy and provide large companies, microenterprises and households with new market opportunities. The 20 per cent renewable energy target at 6,371 MW is reached (ST, 2019). In the future development, the application of the energy storage systems may also be contributed for Malaysia especially for railway application usage.

The Construction Industry Development Board was established by the Act 1994 (Act 520) to control, improve and foster the construction industry to attain global competitiveness. The board shall advise the federal and state governments and other parties concerned about or related to the construction industry The guidelines on construction in Malaysia are provided in Table 2.6 CIDB strategic plan for Malaysia construction industry (CIDB, 2016) and (Cream, 2021).

**Table 2.6 CIDB strategic plan for Malaysia construction industry**

| No | Planning and direction information | Remarks |
|---|---|---|
| 1. | Construction Industry Transformation Programme (2016-2020) Driving Construction Excellence Together | 2016-2020 |
| 2. | Construction 4.0 Strategic Plan (2021-2025) Next Revolution of the Malaysian Construction Industry | 2021-2025 |

The transitional strategy of Malaysia was strong and demanded more representatives from the main contributor. Table 1 provided recommendations and standards for enhancing integrity and advanced building industry applications technologies. The environmental sustainability strategy for integrated technology in a common life cycle project is an important aspect of these proposals. The Board of the CIDB shall provide information on issues related or related to the construction industry to the government, government and other stakeholders.

The Canada Green Building Council has noted that the council aims at achieving a 30 per cent emission reduction by 2050, where large buildings which covered more than 200.00 $ft^2$ and between 25.000 $ft^2$ and 200.00 $ft^2$ are to be restored and buildings older than 35 years of age retrofitted and renewable energy installed on-site in buildings (Rounis, Athienitis and Stathopoulos, 2021). The approach could be implemented in the existing railway's system especially in Malaysia since the energy storage system could also contribute as recommended by the Canada Green Building Council.

According to a UKM-MTDC survey (Alam et al., 2016), there is a planning development to build a sustainable environment, conversely, while presenting clean renewable energy sources, it concentrates on learning about how individuals feel. Therefore, it is vital to examine users' interest in the effort on sustainable energy, problems and solutions to sustainable energy growth in Malaysia.

A survey of respondents' by UKM’s researcher aims for environmental protection and the level of their interest in renewable energies. It was discovered that 20 per cent of those polled preferred not to be fined for environmental contamination. Similarly, 2 per cent said they will research the action before investing in renewable energy resources (Alam et al., 2016). The statistic could be increased if more programs implement to promote this.

For this reason, strategic planning is needed to make an impact on the implementation of renewable energy in major companies, micro-companies and households, in particular in the construction project of the railways. The best way to use a sustainable energy policy for green energy is by implementing an energy storage system.

The wide area to be explored and studied in Malaysia's rail project was proved by Japanese railways where the photovoltaic, Energy Storage System (ESS) application returned investment in the development of alternative action toward to energy sources and the adoption of an energy-efficient system and reduce energy consumption usage on the railway system application.

### 2.6.2 Railways System

This part will focus on the investigation and review of the research on-going or developed to improve renewable energy application in terms of controllable elements such as available legislation, impact implementation, and challenges. The uncontrollable elements, such as cost and the environment, will be considered as a supplement to this research.

The East Japan Railway Company operates around 1,700 stations in Japan, and solar electricity generated by photovoltaic systems can be installed on platform roofs. The potential of a few selected and examined stations, as well as the potential of other stations, is approximated based on the potential of the stations sampled (Hayashiya et al., 2012b). The author recommendation in Japan railway is supported by the other author (Rounis, Athienitis and Stathopoulos, 2021), where to explore the potential building for the energy storage system.

According to a 2007 assessment by the Japanese Minister of Property, Housing, Transport, and Tourism, railways are one of the most environmentally sustainable modes of transportation in terms of CO2 emissions per passenger-kilometres. Railway emissions of CO2 are just one-sixth those of an aero plane and one-tenth that of a plane. (Hayashiya et al., 2012b).

According to the report's statistics, railways contributed 28 per cent of the transportation mode significant altering the railway as a centralized/decentralized power generation business. The statistics demonstrated significant modifications that may be implemented to improve the environment and green technology (Hayashiya et al., 2012b).

Traditional lines accounted for 47 per cent of total energy use. Implementing energy-efficient rail cars that can convert kinetic energy into electric energy during deceleration, as well as variable voltage/variable frequency (VVVF) inverters that use power motors without wasting electricity. Between 1991 and 2010, renewable energy implementation declined by 12 per cent (Hayashiya et al., 2012b). The essential topics had been addressed in the planning, and the plan's execution contributed to the policy's goal. It has taken approximately 9 years to examine the effectiveness of renewable energy and its contribution to the impact of energy storage energy, i.e., potential, benefits, and problems in Table 2.7 Potential energy implantation in railway (Hayashiya et al., 2012b).

**Table 2.7 Potential energy implantation in railway**

| No | The potential energy generated by Urban Transit System | Type Renewable Energy adoption in application |
|---|---|---|
| 1 | Utilizing regenerative energy from the train braking | PWM converter, Regenerative Energy, Energy Storage Energy, RPC |
| 2 | Usage of loads from available service in the stations | Regenerative Energy, Energy Storage Energy, PV System |

In Japan, in addition to silicon rectifiers for the DC traction power supply system, the regenerative inverter was introduced over 20 years ago (Hayashiya et al., 2012a). The traction power generating system will transform excess electricity in the AC and DC systems from the train into 3 modes, one of which is to: convert the power to the stations/inject loads or to inject the electricity into the traction system; 2) save the electricity in the energy-saving systems i.e., battery; and 3). This approach was consistent with the other journal, where renewables might be regenerated and used for different purposes (Robyns et al., 2016). Renewable brake energy recovery in Oslo Subway System 4 is reached up to 30 per cent (Vorobiev and Vorobiev, 2011).

Figure 2.9 Concept of regenerative inverter and Storage Battery and RPC System (Hayashiya et al., 2012a) indicated and demonstrate the design concept to harvest the excessive from the trains in the mainline. The design concept applies to the Japan railway that accommodates the Alternative Current and Direct Current system. This design is beneficial to other railways project that could be implemented and toward the green energy concept.

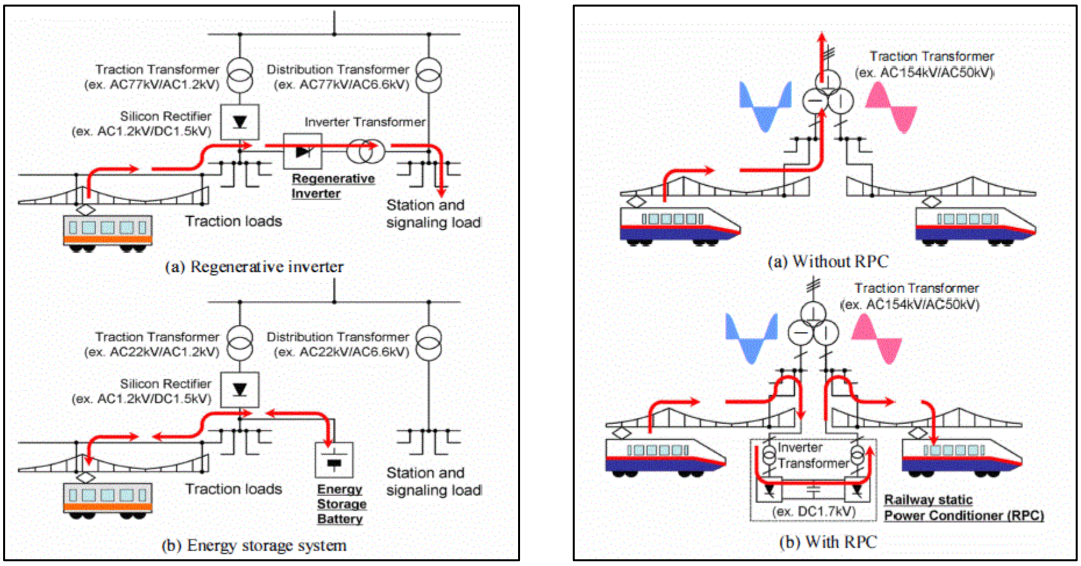



**Figure 2.9 Concept of regenerative inverter and Storage Battery and RPC System**

A prototype experiment was carried out with the possibilities of recharging the traction energy supply in the light tram (Kameya et al., 2014), a battery bank with two storage batteries of 17.5VC, primary and 15 VDC as secondary. The experiments involved proofing energy and regenerative energy. There are 2 viable sources in the journal approach, i.e., wind and solar sources, but solar is used by the renewable energy source in this prototype. The prototype electric train with a 40W DC engine is connected to a 4-wheel drive. The electric train was utilised for three times the straight train i.e., up and down of 9m with a length of 15minutes to demonstrate the weight of 65kg and the experiment was concluded if the electric train was unable to complete three times the whole train. The system can accomplish 236 round trips from 8 am to 5 pm with 9 hours of operation (Vorobiev and Vorobiev, 2011). The concept is to be examined and may serve as an option for the urban transit system railway application in Malaysia, but also subject to feasibility research throughout the project development phase.

According to the case study and data collection in the Istanbul Metro network (Demirci and Celikoglu, 2018), Infra and system contribute the same energy consumption, studies to optimise the Regenerative Brake and use by the acceleration train from the train departure. Infra and system contribute the same energy consumption, studies to optimise the Regenerative Brake and use by the acceleration train from the train departure. The train consumes 50 per cent of the total energy consumed by the rail system, and the author believes that the increase in energy consumption necessitates more research into energy efficiency.

Traditional studies have been carried out to increase energy efficiency in railways, such as designing intelligent stations, optimizing power systems, reducing vehicle masses, energy-efficient driving strategies, etc. Due to their high costs and some restriction, storage systems were not applied significantly.

### 2.6.3 Energy Storage System in Railways System

In many current electrical systems, intermittent non-dispatchable renewable energy supplies and energy storage systems are being implemented widely in railway applications. The energy storage system could help enhance the penetration of the renewable energy source by providing and implementing these services. Appropriate battery technology had been growing rapidly and this future technology had been chosen as one of the options to reduce energy consumption by reducing the use of peak energy in the metro system in a wide approach. The battery technology had been used widely in the Japanese railway and the enhancement of the local technology keeps the technology mature and gives a good impact on the railway system and train services will not rapidly be interrupted by heavy use of the headway (Kawasaki, 2018). The demand to adopt alternative energy sources is greater than ever before, with global oil output projects to peak around 2020(Leadbetter and Swan, 2012). According to the author, the Solar Photovoltaic showed a drastic increase in installed capacity up to 39.8 MW by the year 2010. A project implemented in European country i.e. Turkey, Asia Country i.e. Korea and Japan support this statistic where the system had been implemented in the railway application. The energy storage system is also a big opportunity for this implementation and continuous research and collaboration with the industry could bring this technology as realistic and implement widely in the railway application. The application is illustrated in Figure 2.10 Profile of battery bank for energy storage system and shows the statistic of the implementation of the Energy Storage System (ESS) and the group of the system rating chosen by the railway embedded system (Leadbetter and Swan, 2012)

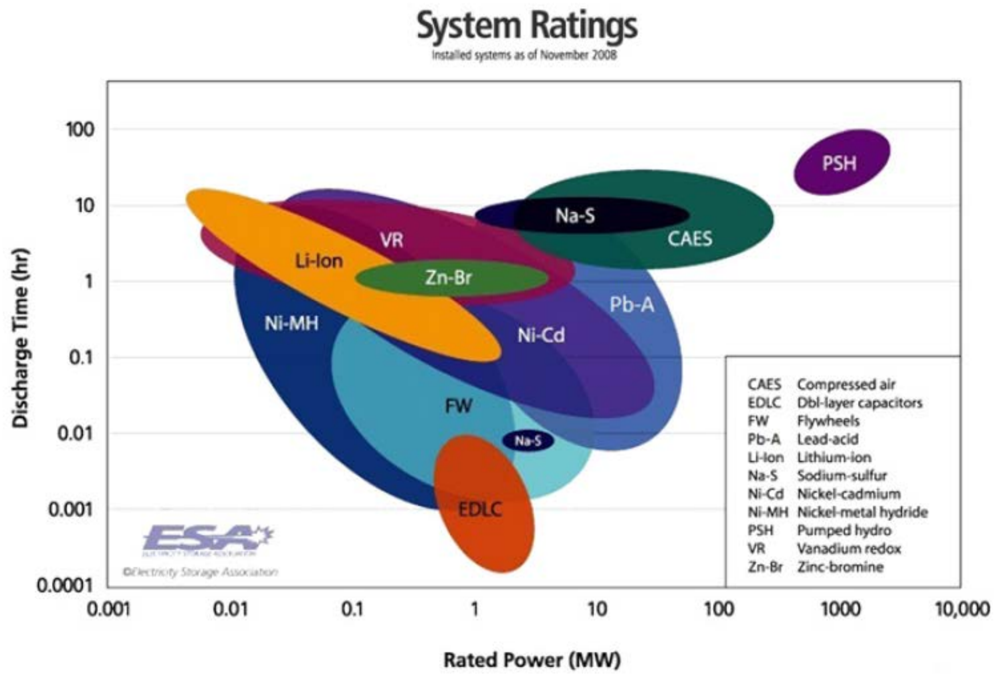



**Figure 2.10 Profile of battery bank for energy storage system**

From the above Figure 2.10 Profile of battery bank for energy storage system, various of installed energy storage system, which included various battery products and the final energy record of 80MW. According to the author's table (Leadbetter and Swan, 2012), the supercapacitor system (ELDC) is lightly chosen due to current technology limitations, and the cost of implementation is significantly higher when compared to the battery system. The critical analysis by the author (Leadbetter and Swan, 2012) stated that the energy storage system contributed 2.5 per cent to 15per cents to the grid system. The summary of the energy storage system is tabulated in Figure 2.11 The Battery characteristic (Based source from the author) shows the battery characteristic by a different type of supplier  (Leadbetter and Swan, 2012).

| Battery type | Pb–A | | Li-ion | | Na–S | VRB |
|---|---|---|---|---|---|---|
| | Power cell | Energy cell | Power cell | Energy cell | | |
| Cycle life (cycles @ % SOC variation) | 50 to 200 @ 80% [30], 1000's for shallow cycles [31] | 200 to 1800 @ 80% [13,30] | 3000 @ 80% [13] | 3000+ @ 80% [13] | 4500 @ 80%, 2500 @ 100% [74] | 10,000 to 12,000+ @ 100% [86] >270,000 @ few % [89] |
| Specific energy (Wh $kg^{-1}$) | 30 to 50 [30] | 30 to 50 [30] | 75 to 200 [10,13] | 75 to 200 [13] | 150 to 250 | 10 to 30 [86] |
| Specific power (W $kg^{-1}$) | 300[a] | 75[a] | 2400 [103] | 75 to 300[a] | 150 to 230 possible, commercial ~30 [74] | N/A |
| Energy density (Wh $L^{-1}$) | 50 to 80 | 50 to 80 | 200 to 500 [103] | 200 to 500 | 150 to 250 | 16 to 33 |
| Power density (W $L^{-1}$) | 300 to 400 | 10 to 100 | 4500 [103] | 1500 | N/A | N/A |
| *E/P* ratio (kWh $kW^{-1}$) | **0.13** | **0.5** | **0.025 to 0.075**[a] | **0.27 to 0.6**[a] | **6** [74] | **1.5 to 6+** [89] |
| Self-discharge per day | <0.5% [13] | <0.5% [13,30] | 0.1–0.3% | 0.1–0.3% | 20%[b] | Negligible |
| Cycle efficiency | 63 to 90% [13,104] | 63 to 90% [13,104] | 80 to 98%[a] [13] | 80 to 98%[a] [13] | 75 to 90% [13,104] | 75 to 80% |
| Format | Cylindrical | Prismatic | Cylindrical | Prismatic | Tall cylindrical | Separate tanks |
| Active material phase | Solid | Solid | Solid | Solid | Liquid | Liquid |
| System level cost (US$ $kWh^{-1}$) | 200 to 600 | 200 to 600 | 600 to 1200 [13] | 600 to 1200 [13] | 350 | 150 to 1000 |
| Maturity level | Mature | Mature | Commercial | Commercializing | Commercializing | Developed |
| Notable characteristic | Modular | Modular | Sealed, modular | Sealed, modular | High temperature | Flowing liquids |

[a] Based on the authors' laboratory results from testing several different power and energy cells.
[b] Although heat input requirement is ~20% of battery capacity, thermal losses are mostly or entirely counteracted by internal $I^2R$ losses and therefore little to no actual parasitic discharge is observed.

**Figure 2.11 The Battery characteristic (Based source from the author)**

In other views, the Figure 2.12 Energy Storage System in Japan's Railway is supported by the author (Okui et al., 2010) in which the Japanese Railway system used a large number of Energy Storage Systems, and the system was also implemented in the New Metro (Kawasaki, 2018) The following is the information typical type about the Japanese Railway's Energy Storage System (Okui et al., 2010).

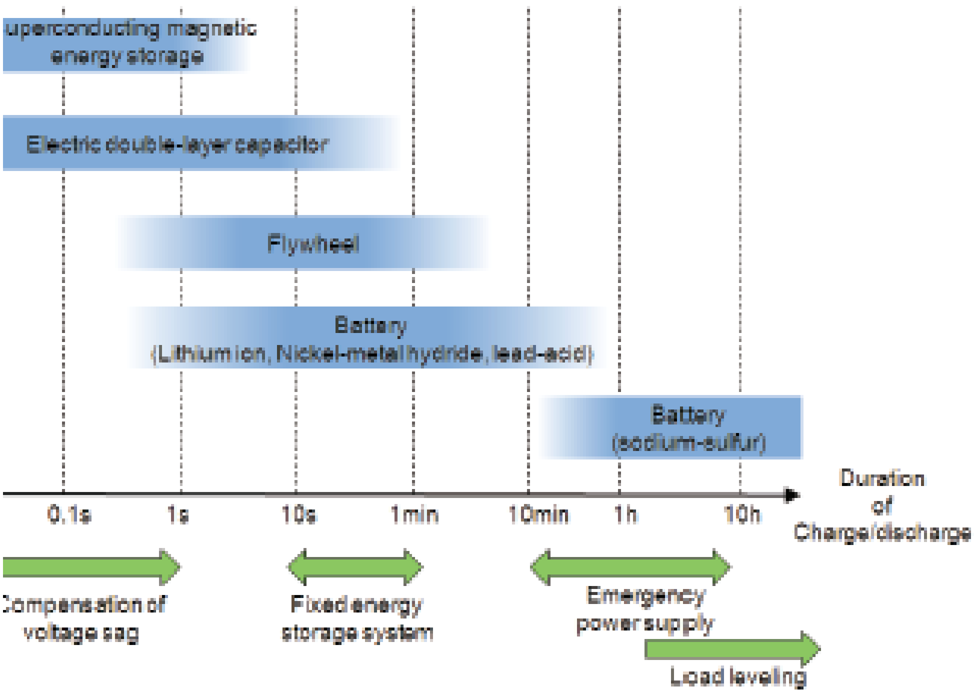



**Figure 2.12 Energy Storage System in Japan's Railway**

In Japan's railway system, four storage mediums have been implemented or are in the process of being implemented and are currently in research.

# CHAPTER 3

# RESEARCH METHODOLOGY

## 3.1 Introduction

This chapter sets out the context of the research important to the nature of the field of study. The research history offers general knowledge on the impact of the adoption of renewable energy in the urban transit system in Malaysia, with a cross-reference to other advanced rail systems, and on the large implementation of renewable energy capable of potential, benefits and challenges. The nature of the analysis, the significance of the study and the design of the research structure.

## 3.2 Research Methodology

All required facts and graphs, such as statistics, diagrams and flow charts, are to be presented to allow the author to get a clearer understanding of how the study is carried out. In the beginning, this study will begin with the author describing the current problems of the author's interest subject. The models are then categorized, filtered, and clustered to determine the study gap that can be addressed.

The topic of interest would then be sorted, filtered and classified so that the study gap currently being studied is established. The author's deficiency will search the journal, article and news, read the relevant supporting books on the compilation of the concept of the energy storage system (ESS) in the use of railways in Malaysia. The author shall then define the appropriate problem statements to the gap referred to by the other researcher, either in Malaysia or from international sources, to resolve the research topic, component, purpose and objective related to the case study of the possible effect of the energy storage system (ESS) in the urban transit system in Malaysia.

With the aim and context of past studies, the author shall carry out a case study on the effect of the introduction of the energy storage system (ESS) on the urban transit system in the rail sector, i.e., the MRT Project to define the pros and cons of the new project. The data set would then be evaluated using a brief new argument based on the outcome achieved and collected from the simulation and reading from the article/literature review. In conclusion, the author shall consolidate and suggest a recommendation based on the findings of the study to endorse the goal and the substantial effect of possible advantages and obstacles on this concept. List of research activities implemented in flow below:

a) Data collection and local analysis
b) Aim and Objective Research
c) Literature review of the research
d) Quantitative and Qualitative
    1. Interview (where applicable)
    2. The data collected from the publication and database
e) Performance evaluation on simulation and analysis of the data
f) Conclusion and Feedback

The research flow charts will explain the process involved and provide a clear idea of how the study initiates.

### 3.2.1 Research Workflow

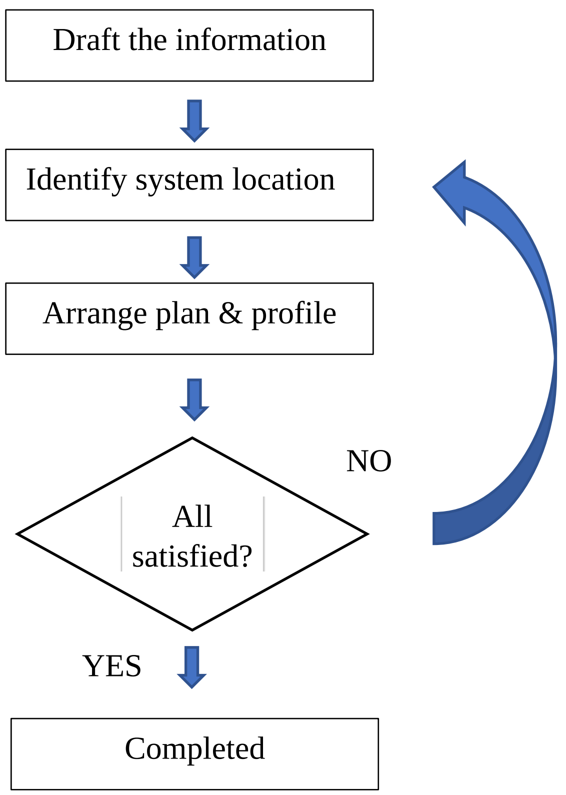


**Figure 3.1 Methodology approach**

Source: (AGENCY, 2019)

### 3.2.2 Research Sequence

The railway system schematic shall be used to illustrate the system capabilities and the system characteristic is developed and suitable characteristic is gathered from the simulation studies. The information of the database then will be evaluated and used to facilitate the requirement of the energy storage system. The energy storage system is simulated from the schematic based on the actual parameter and infrastructure.

The operation scenario shall be demonstrated in the studies and the actual operation headway shall be used to facilitate the capabilities of the energy storage system. According to the author (Ates, Acikbas and Soylemez, 2019), the characteristic of the railway depending on the parameter need to be considered in the operation strategy. In this case, the requirement of the parameter will allocate a portion on the recommended since there is a limitation of the simulation study capabilities and assumptions. The strategy of the study is considering the railway headway where its system capabilities i.e., traction transformer, the rectifier will be used to simulate the requirement of the energy generated by the electric train.

The electric train then shall consider the condition during the operation in 2 modes of application which in without and with the regenerative braking. The simulation database then will be analysed and used to define the energy storage system refining the data characteristics from the simulation result.

## 3.3 Data and Information

### 3.3.1 Raw Data and literature review

The raw data from the railway project shall be used to simulate the system characteristic. The database is then populated in the ETAP and a power system circuit shall be built to simulate the system characteristic.

The literature review from the previous research and study will explain and elaborate on the detailed requirement of the energy storage system. The system characteristic simulated from the ETAP shall help to reiterate the fundamental of the characteristic and help the studies on the energy storage system.

### 3.3.2 Simulation Study

Simulation Study is essential for this research to gather the system characteristics and the characteristic is depending on the railway infrastructure and system design specification. The result from the simulation will be not the same as another railway due to the different specifications on the infrastructure and system design.

For the research studies, the Mass Rapid Transit data specification is used to simulate the system characteristic and the information shall be analysed and refined the energy storage system requirement based on the information available in the previous research and current railway project implementation.

## 3.4 Analysis information

As mentioned in section 3.3, the simulated system characteristic shall be evaluated and analysed. The analysis shall be referred to the relevant research and studies by other researchers or system implementation based on the literature paper. The analysis shall advise the scenario that has been simulated and the system characteristic shall be advised and referred to the operation scenario in the railway operation and application.

### 3.4.1 Modelling of railway power supply and distribution system

The energy from the train dynamic movement required a huge amount of energy and the energy is similar for both directions of the train movement. This show that the regenerative braking from the dynamic system contributed a large amount of energy if the energy generated by the train dynamic movement could be harvested and reused for other application i.e., train movement to the arrival stations, stationary load at the station, ancillary building and traction power supply.

The scenario operation is the same but it is different once the application of the regenerative braking is implemented in the traction by the dynamic movement of the train. There is a case where the existing railway system is not resistive and capable to sustain the huge amount of energy and impacting the other equipment to failure and causing a flashover component i.e., surge arrester. In this case, the train regenerative braking needs to be reduced and the application of the mechanical brakes is much dominant for the train operation application which does not utilise the electric train capability and the saving of the operation and maintenance cost on the braking mechanism. The design consideration shall be considered all factor covering the existing railway network is sustainable and capable to accommodate the new modern electric train. In most cases, a stationary energy storage system is considered to be implemented to the railway network especially in the exiting railway network due to the major factor i.e., extra weight to the train loading, space constraints, traction capabilities.

In the simulation, the assignment of the train movement shall be assigned to simulate the ultimate headway. This is to ensure that the system is capable to meet the demand by the operation if the railway's owner is required to expand the fleet. It is important and necessary to consider the worst-case scenario of the maximum fleet to be operated in the railway network. There is also another factor that contributes to the reliable railway system which is the dependency on signalling system, backbone communication, infrastructure and Supervisory Control Acquisition Data System. These are the major system that ensures the optimum railway operation and the optimum contribution to the optimum energy storage system. This subject is still debated by the system designer and researcher. There are no specific requirements to design requirements and depend on the best practice by the design consultant but an international standard covered this requirement that had been placed to ensure that all stakeholders meet the minimum of design requirement which has been applied widely. One of the typical drawings for an energy recovery system in. On Figure 3.2, It is shown the Typical Traction Single Line Diagram (GK, 2018) and it is illustrated the typical power traction circuit Mass Rapid Transit System and the energy storage system that could be introduced to the system and implementation to suit the stationary load, stations load and local traction load within the power traction loop.

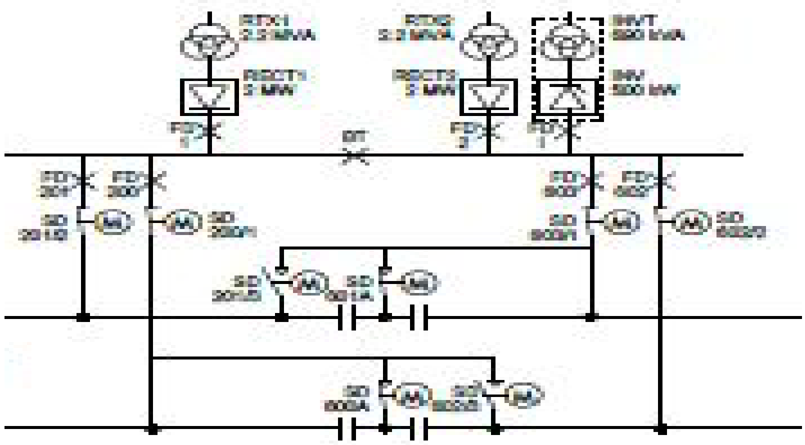


**Figure 3.2 Typical Traction Single Line Diagram for Mass Rapid Transit System**

Figure 3.3 Typical simulations of the train in ETAP software indicates the typical circuit on the simulation study for the energy storage system to come out with characteristic results. The simulation running is regulated on the timetables and headway and a summary of the result will be discussed in the next chapter.

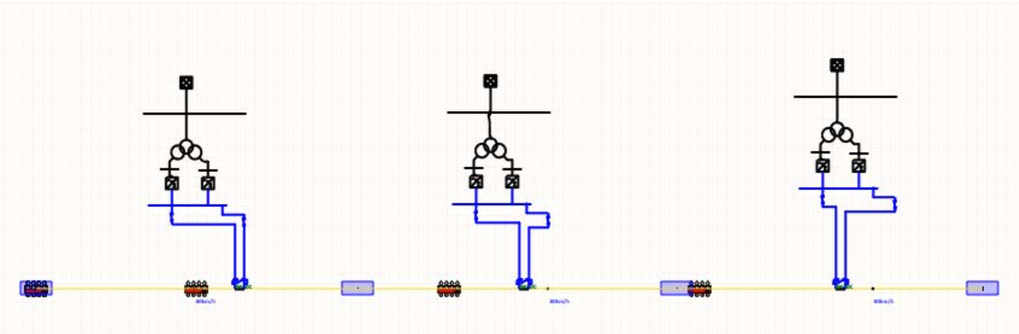


**Figure 3.3 Typical simulations of the train in ETAP software**

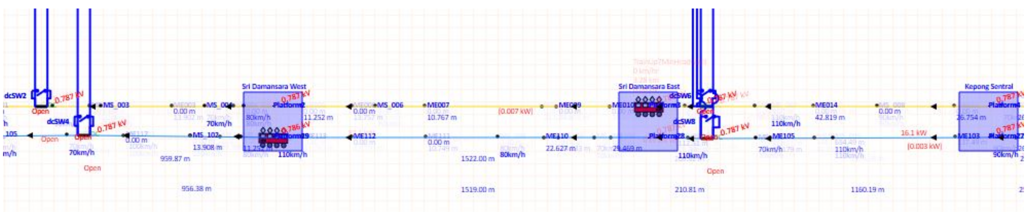


**Figure 3.4 The actual simulation circuit for the trains**

From the simulation study, the characteristic of the energy during the operation based on the timetable and headway had been simulated. The data gathered from the simulation shall be explained and assigned to a suitable energy storage system. Figure 3.4 The actual simulation circuit for the trains  is illustrated the modelling circuit as mentioned earlier.

### 3.4.2 Alternative Current (AC) and Direct Current (DC) Network

The main power supply distribution is illustrated in Figure 3.5

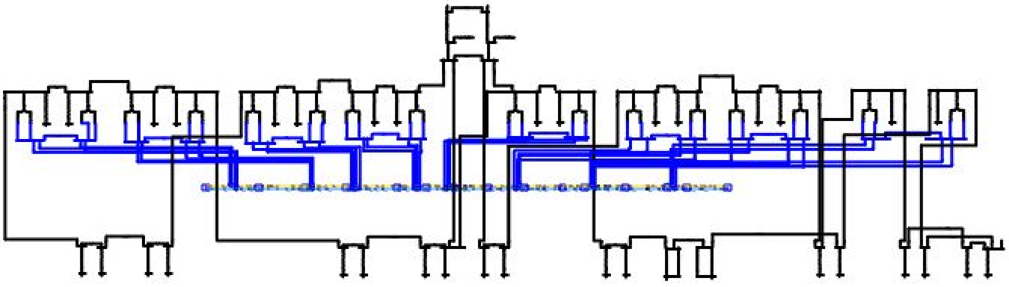


**Figure 3.5 The power supply and distribution system modelling**

The DC traction (etrax) is illustrated in Figure 3.6

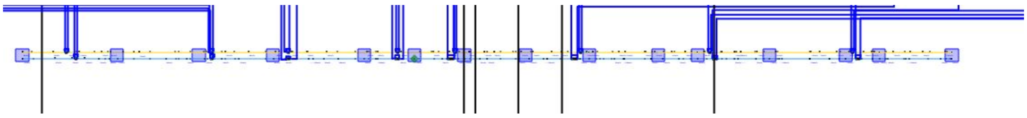


**Figure 3.6 The etrax modelling for trains running**

### 3.4.3 E-Trax information and parameter

The parameter of the etrax is simulated by adding the required information in Figure 3.7.

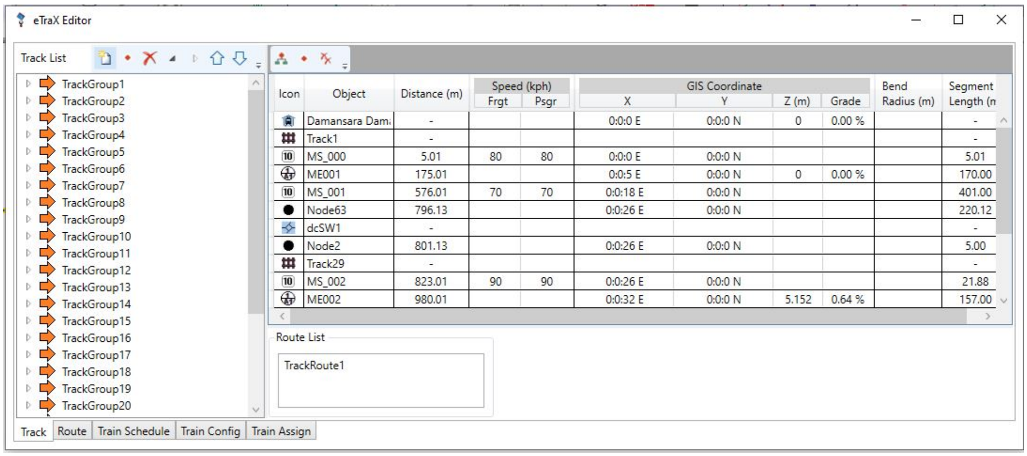


**Figure 3.7 etrax data information for the modelling**

The train parameter is illustrated in Figure 3.8

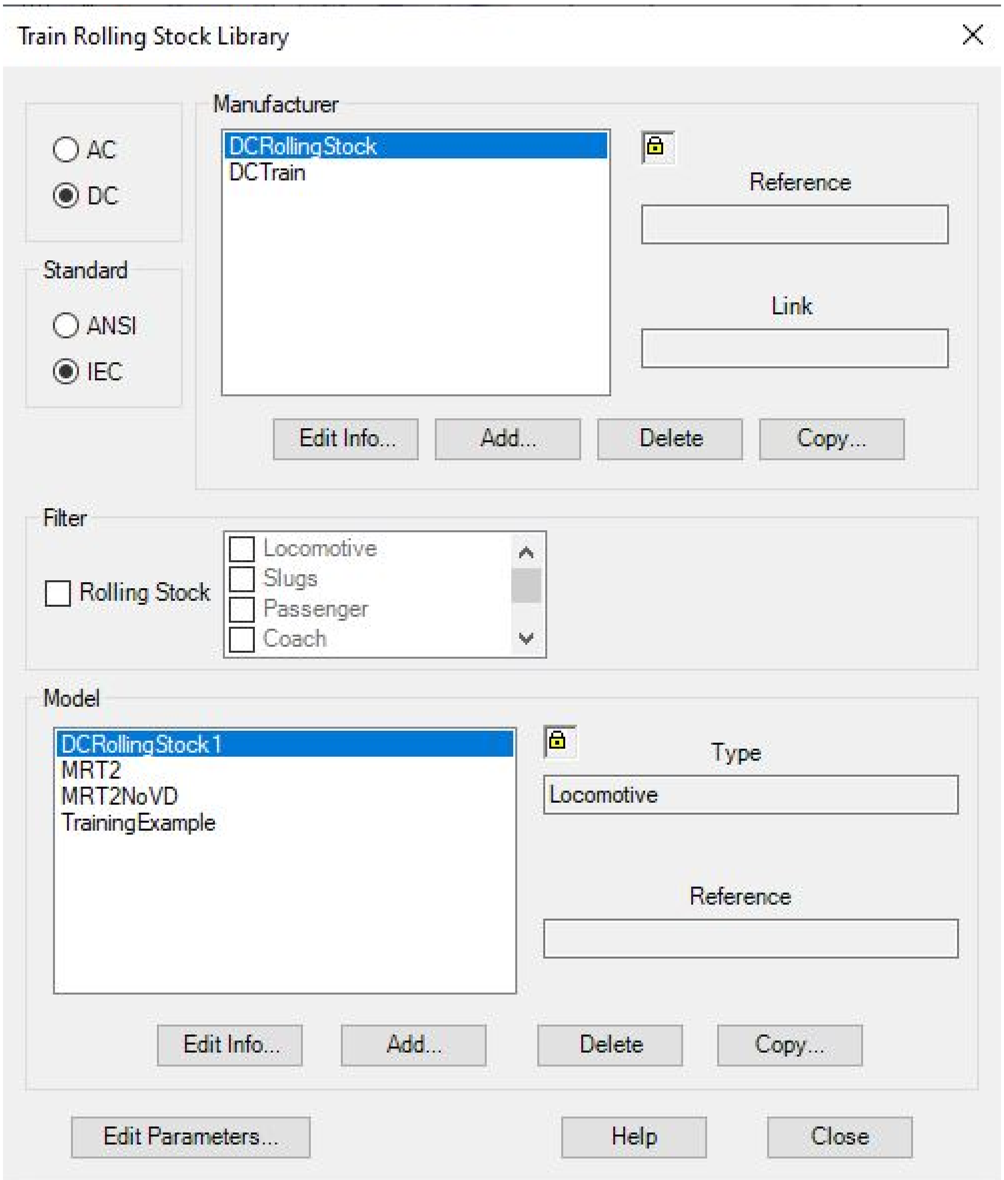



**Figure 3.8 Train data configuration**

# CHAPTER 4

# RESULT AND DISCUSSION

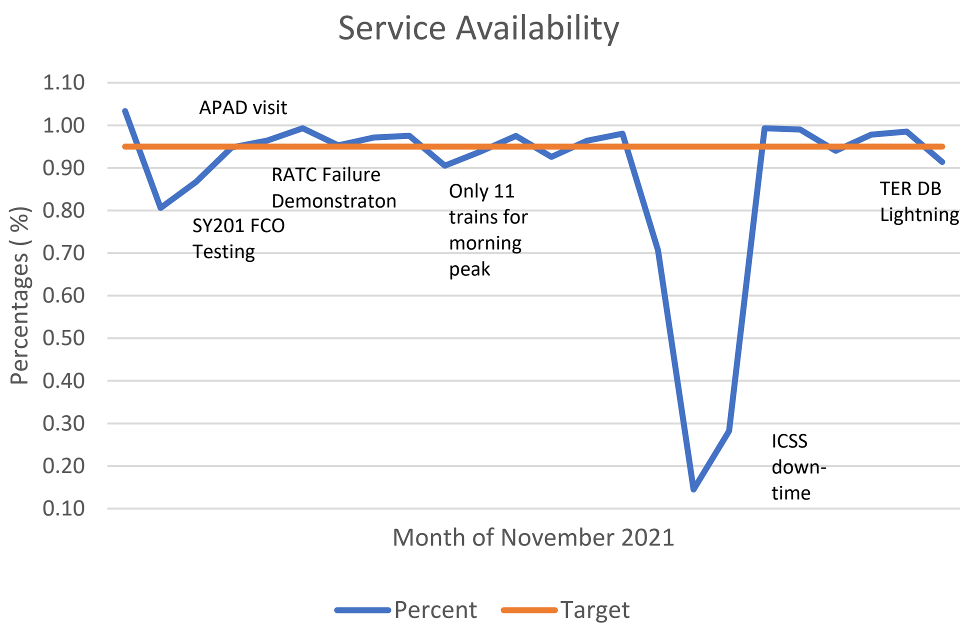
## 4.1 Introduction

This chapter sets out the result of the research and the important part of the field study. The result from the research could have an impact in implementing the system in the urban transit system especially in Malaysia where the studies are modelled from the larger and modern railway system and its characteristic in refining the system specification i.e., energy storage system. The nature of the analysis, the significance of the study and the analysis design of the research will be explained.

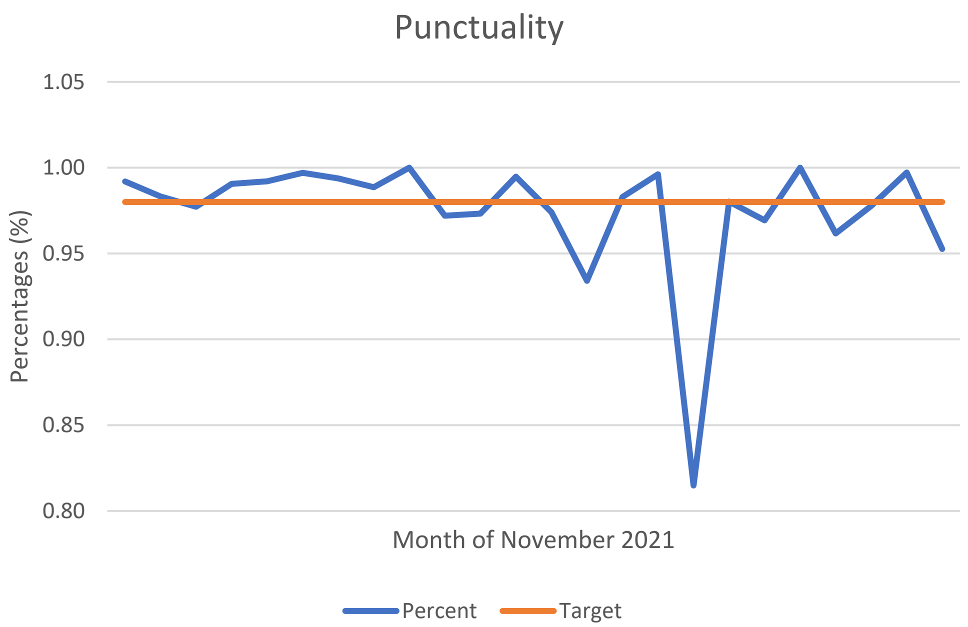
## 4.2 Information and simulation data

The simulation study is to estimate the energy generated by the dynamic movement of the train on the track alignment. The alignment of the track is different from the other. The information and alignment characteristics are influent the outcome of the result and estimate the information required based on the data entered in the modelling. The operation outcome shall be varied due to the performance of the system availability and punctuality.

The ultimate configuration shall be defined to ensure that the requirement of the overall system is met as required by the specification. The ultimate configuration is assigned on the rigid configuration where the system is dependent on the timetable and headway. The continuous study on the optimum performance of the operation is progressively initiated by the other researcher and the outcome of the research is focusing on the locality of the railway. The fundamental of the assignment should be the same but adjustment and modification shall be conducted to eliminate the unnecessary circumstances contributed by the other factors i.e., load demand by the train performance, stationary load at the stations, ancillary building and another applicable load to be attached in the system. It is crucial and critical to define this information to have an optimum study and estimate the required demand by the systems. Figure 4.1 System performance for (a) punctuality and (b) availability (Bouchard, 2021) showed the example of the system performance that contribute to the regenerative braking to the traction power supply system and its dependence on the optimum system performance. It can be observed that the average punctuality is 98 per cent, which satisfies the minimum requirements of the train operator. The average service availability is 95 per cent, which satisfies the minimum requirement for service availability.




(a)




(b)

**Figure 4.1 System performance for (a) punctuality and (b) availability**

The energy generated by the train dynamic movement is much dependent on the overall system performance and this is not covered by this research study. The actual energy generated shall be measured and recorded to tabulate the actual energy is being received and stored on the energy storage system. This is also aligned with authority requirements in line with the energy performance in large scale of energy usage by the end-user i.e., railways operator, shopping complex etc. The train data performance is illustrated in Table 4.1 Dynamic Performance (Sam Ng, 2020).

**Table 4.1 Dynamic Performance**

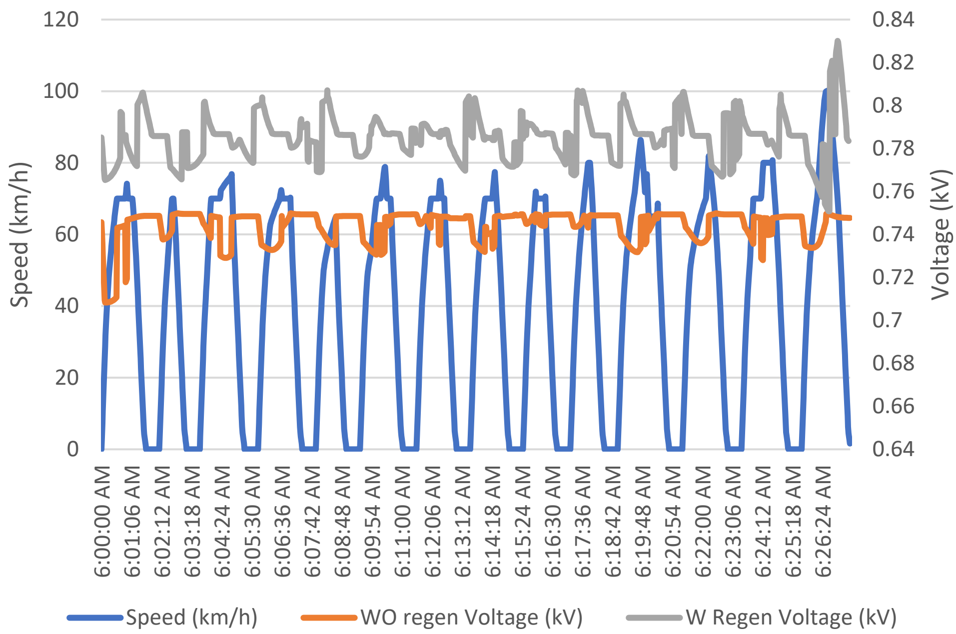
| No | Train Characteristic and Performance | Value |
|---|---|---|
| 1. | Maximum Operating Speed | 100km/h |
| 2. | Maximum Voltage | 900 VDC |
| 3. | Minimum Voltage | 500 VDC |
| 4. | Auxiliary Load | 216kW/270kVA |
| 5. | Maximum Voltage for regenerative braking | 950 VDC |
| 6. | Train configuration | 4 Cars |

## 4.3 Results

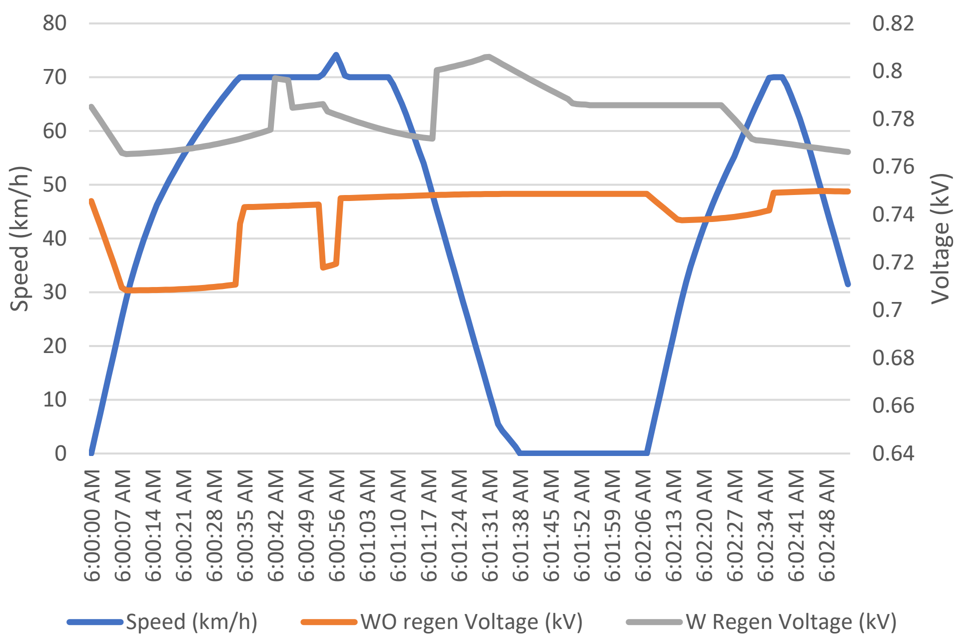
The result from the studies will be explained and the result of the simulation shall explain the amount of energy generated by the electric train with its capability to produce the energy to the power supply traction network. The timetable and headway of the train operation contribute a power demand to the power supply traction network and the load from the moving train contribute ¼ of the load demand distribution. It’s it showed that an optimum algorithm of operation with supplementary of another design fundamental (Ates, Acikbas and Soylemez, 2019). This is a subjective and argument to be discussed and the requirement of the algorithm is also depending on the operation strategy and network demand of the railway alignment.

The demand for the railways will gradually increase in line with the development along with the alignment of the railway operation. The simulation result of the research is based on the 18km of PY line alignment for Sungai Buloh-Putrajaya which covered 80 per cent of elevated alignment and the remaining 20 per cent is covering the underground.

Figure 4.2 shows the train speed and the track voltageduring the operation with and without the regenerative braking. The operation without regenerative braking indicates that the voltage is fluctuating between 750 VDC and 900 VDC. However, the voltage fluctuation for the case with regenerative braking is in between 750 VDC to 830 VDC. This is due to the injection of regenerative braking energy into the DC network that causes the rise of voltage level. In the modern train system, most of the new railways had implemented the demand to use the regenerative braking from the train dynamic movement to convert it and use energy as mentioned by other railways and researchers in the previous section.



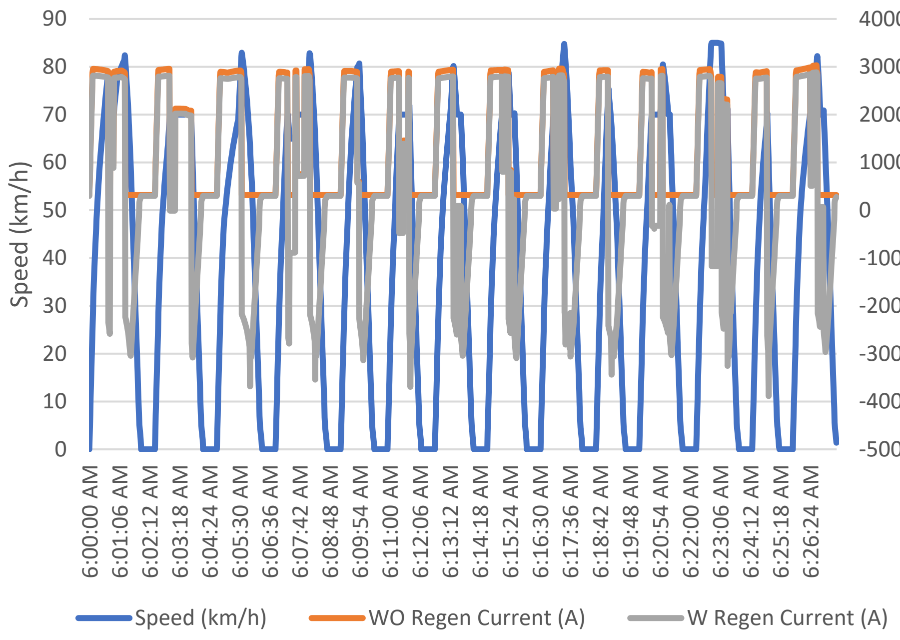

(a)



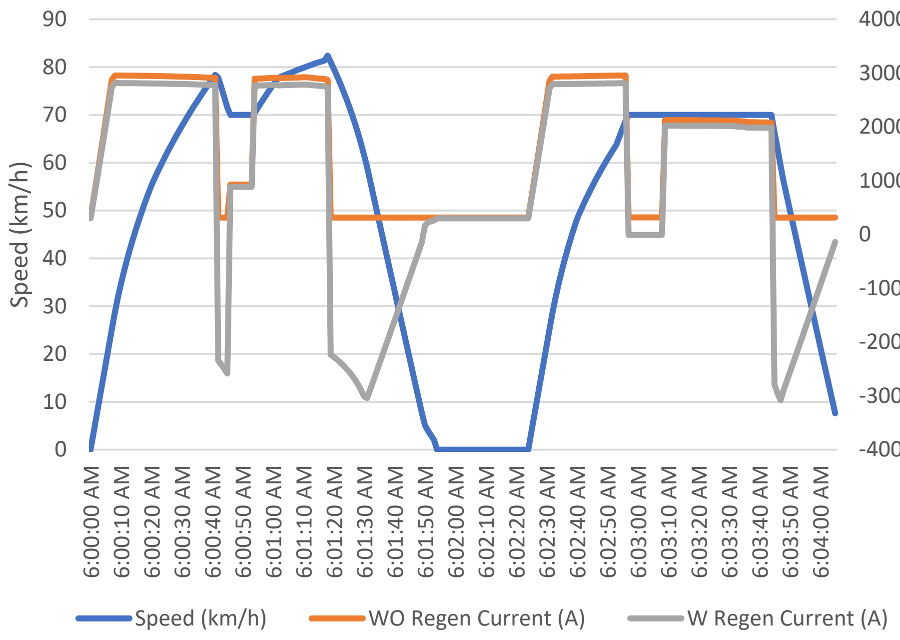

(b)

**Figure 4.2 The characteristic of Voltage Vs Speed for 26 minutes (a) Single trip (b) 3 minutes voltage fluctuation**

The current during both modes shows a large amount of current to the system. The characteristic of these scenarios illustrated in Figure 4.3 shows the current fluctuation during the regenerative braking and contributing the energy to the system. It is much different from the result of applying regenerative braking to the traction power supply. The changes in the voltage and current contributions to the amount of energy to be retrieved or harvested in a storage system. It is observed that the maximum regenerative braking was recorded at approximately 4000A. The relationship between the voltage, current and energy illustration of the case study captured in chapter 4.4 and these parameters will be illustrated in informative character based on the case study.




(a)



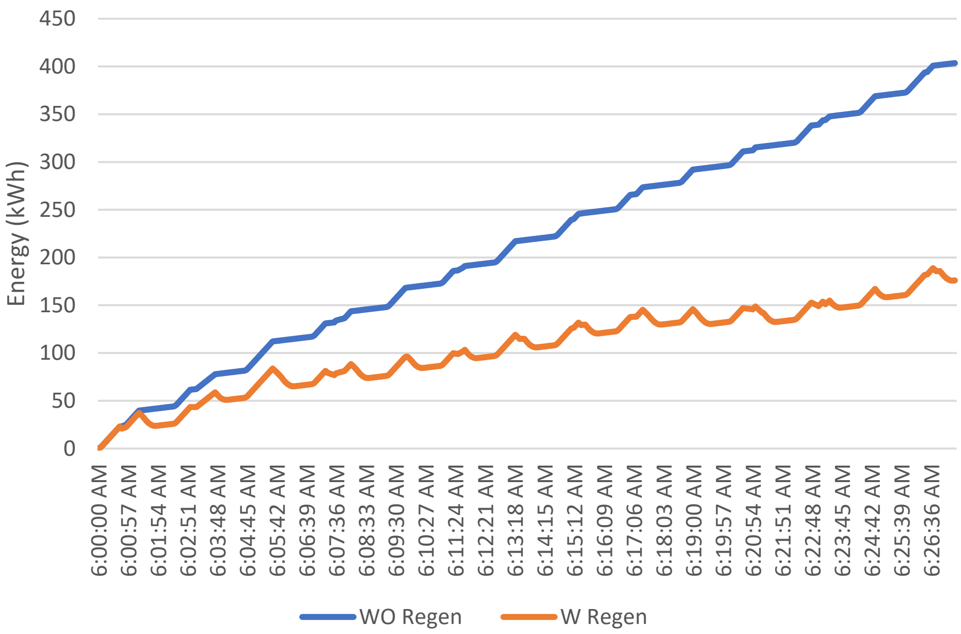

(b)

**Figure 4.3 The characteristic of the Current Vs Speed (a) Single trip for 26 minutes (b) 4 minutes current fluctuation**

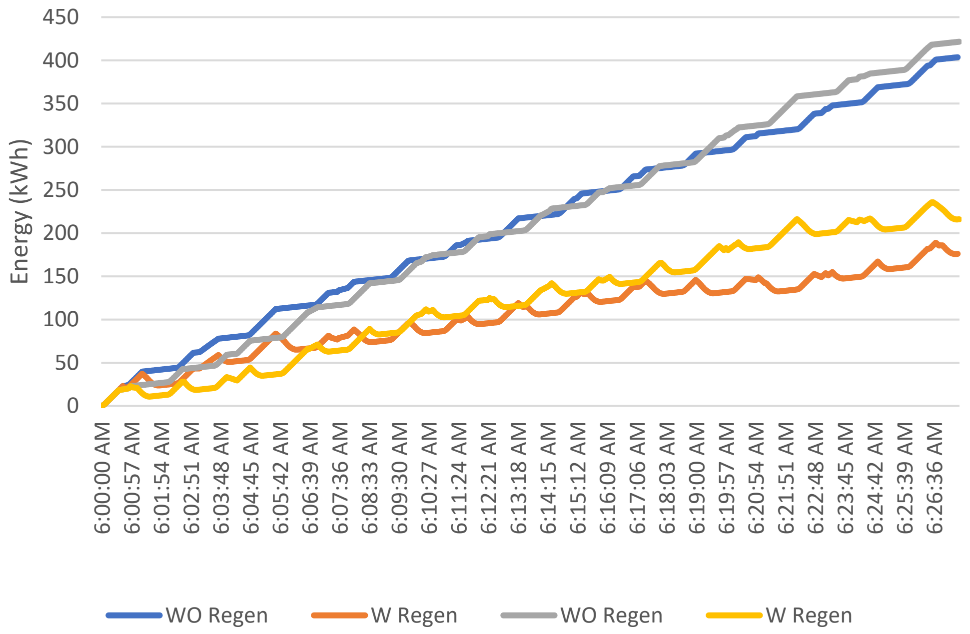
### 4.4 Case study: Energy profiles for the trains

The modelling of the railway has estimated the energy produced and could be used back to the system. The characteristic of the energy shall be explained and briefed on the energy storage system (ESS) requirement. The studies case is explained in 3 scenarios. From Figure 4.4, it is observed the energy that can be retrieved are illustrated on (a) and (b). The characteristics of section 4.4.1 shall be evaluated with other cases.

#### 4.4.1 Single train with and without regenerative braking




(a)

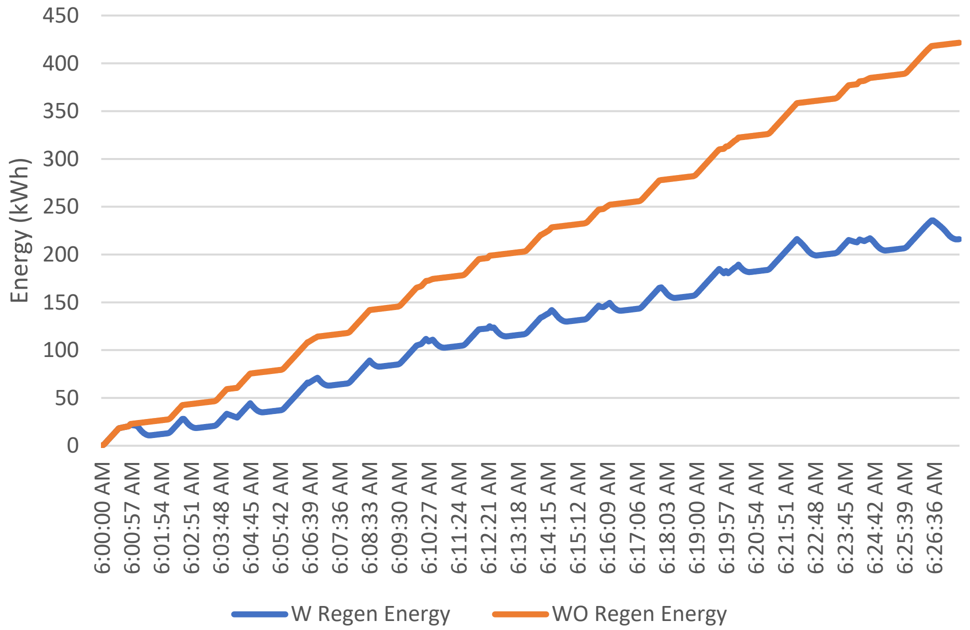



(b)

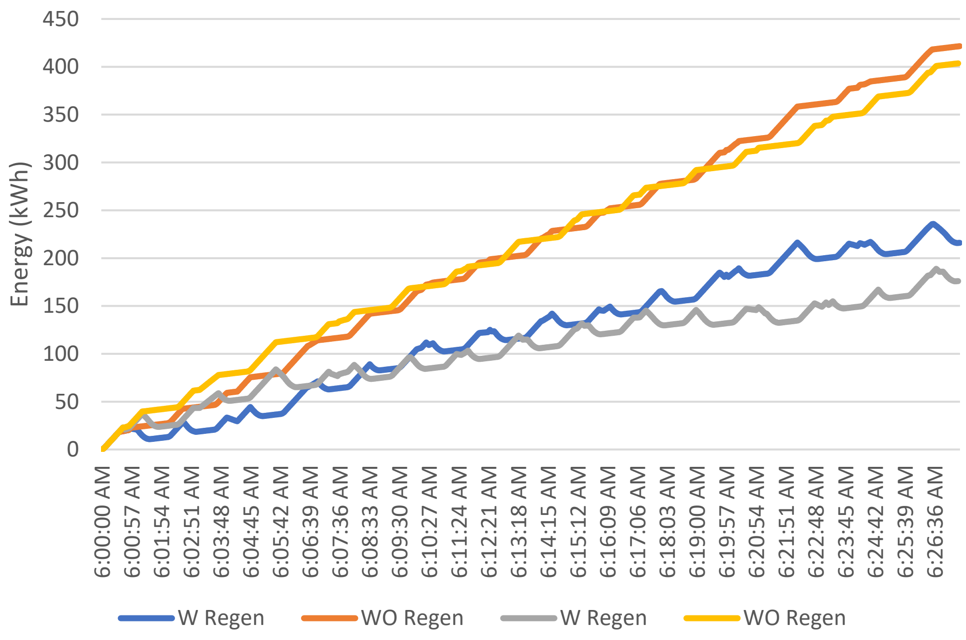
**Figure 4.4 The characteristic of the energy (a) single train (b) 2 trains operation**

### 4.4.2 15 trains with and without regenerative braking

From Figure 4.5, it is observed the energy that can be retrieved are illustrated on (a) and (b). The characteristics of section 4.4.2 shall be evaluated with other cases.




(a)

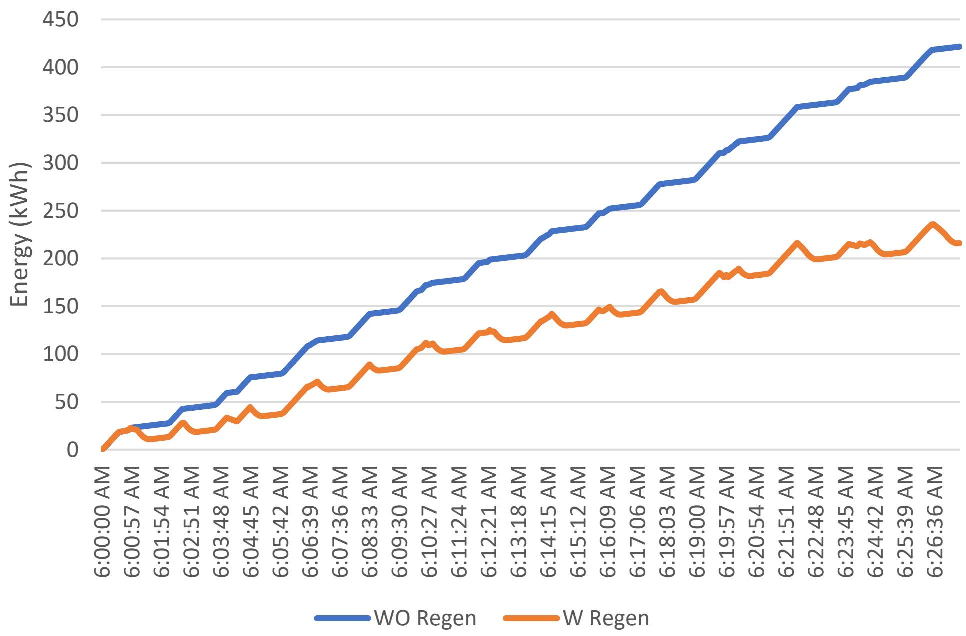



(b)

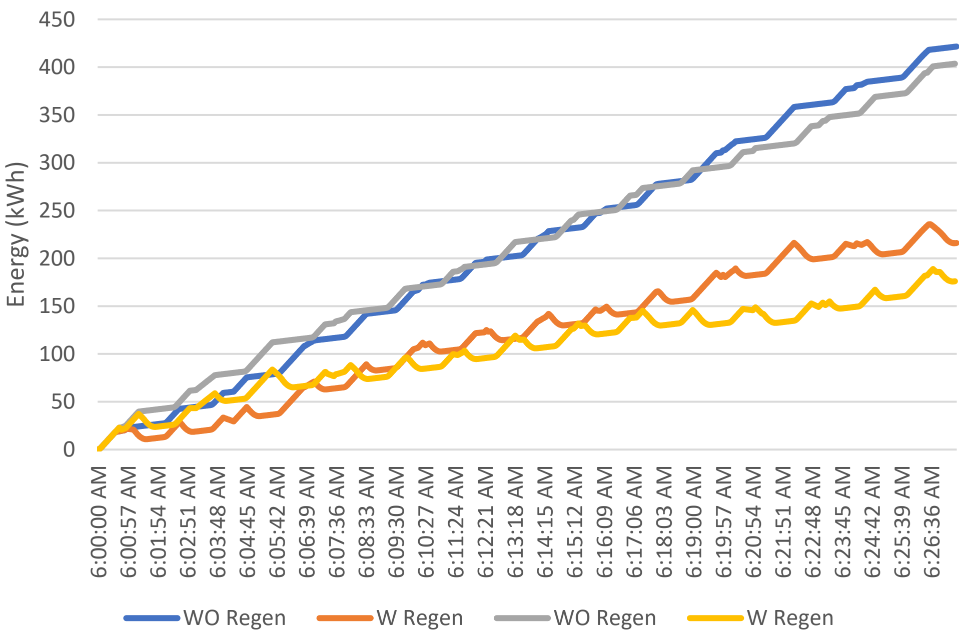
**Figure 4.5 The characteristic of the energy (a) single train (b) 15 trains operation**

### 4.4.3 20 trains with and without regenerative braking

From Figure 4.6, it is observed the energy that can be retrieved are illustrated on (a) and (b). The characteristics of section 4.4.3 shall be evaluated with other cases.



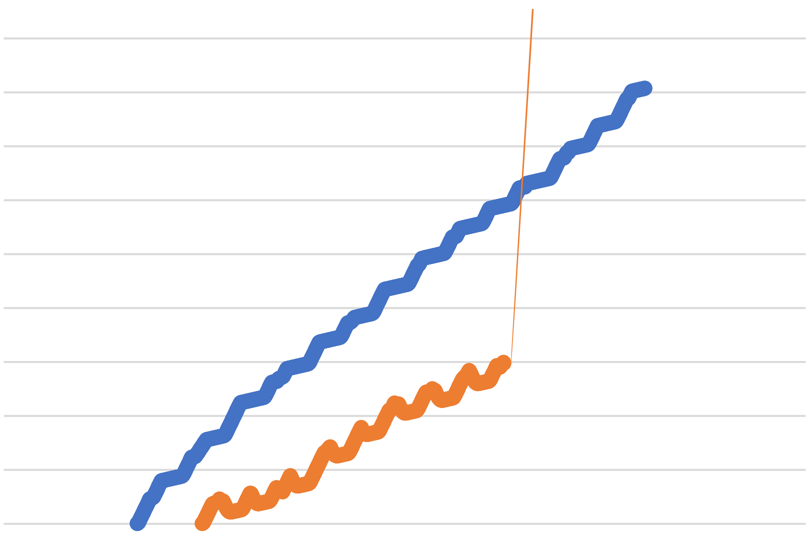
(a)




(b)

**Figure 4.6 The characteristic of the energy (a) single train (b) 20 trains operation**

In Figures 4.4, 4.5 and 4.6, it is observed that the regenerative same characteristics of the energy which is shall be used to determine the energy to be recovered from the train operation headway and timetable.The specific energy is illustrated in Figure 4.7 to show and illustrate the characters as briefly explained in the above section.



(a)

(b)

**Figure 4.7 The Energy characteristic (a) with and without regenerative braking (b) various headway energy characteristic**

It is observed that regenerative braking has a significant change in the energy which is correlated with the voltage and current which contributed to the amount of energy used by the train. The voltage and current captured toward the direction of the arrival station which is reflected in the train acceleration during departure. The energy consumed by the train dynamic movement as shown in Figure 4.7 (a) and (b), demonstrated the illustration of the energy generated by the trains and the amount of energy that could be harvested is subject to the operation strategy of the rail system. It is observed that the energy changes in event of trains injected in a different headway in the simulation study. The above graph also 4.7 illustrated the characteristic of headway and the curve characteristic have a differently projected.

The train running based on the timetable and headway shall be explained in this chapter and the result from the simulation shall determine the required energy that generates from the train operation based pre-determined time frame that has been assigned by the system. The headway simulation is to demonstrate the train running throughout the alignment and additionally to demonstrate the power system requirement for the traction system.

From the traction result running through the train electric performance, it will generate the trains requirement on generating the energy in the traction power system in 2 conditions either in non-regenerative braking and regenerative braking. The train generative performance will be revalidated in each case on the train running and analysis of the cases will justify the energy storage system for the railway system.

The observation on the simulation study showed that the energy from the train produced a large amount of energy. The amount of the energy is the study based on the multiple cases of headway and information shall be used to examine the requirement of the energy storage system.
It is observed that the amount of the energy produced is approximately average at 400 kWh and the amount of the energy shall be compared with the cases simulated in the regenerative braking mode and a suggestion of the energy storage system will be recommended according to the applicable international standard.

The regenerative braking energy from the trains is depending on the specification and the manufacture of the train. The different manufacturers have their internal development design standard specification and it is also noted the other railways' projects may have a different energy curve but most important is to have an analysis and studies for each on the characteristic and any recommendation and proposal shall be referred to the project specification requirement on the system and their infrastructure

There is a different characteristic that had been generated by the system shall be explained and illustrated in the graphical information to brief the different characters of the energy that could be harvested from the regenerative braking. From the simulation case that was conducted, there is much difference between the condition brief above. The amount of the energy from the train dynamic movement is the important component to be used and design the optimum solution for the energy storage system. From the observation, it is noted that there is no difference for the energy with the regenerative condition from the trains. The amount of energy consumed is larger and could be considered to be used in the energy storage system

Figure 4.8 and 4.9 demonstrates the amount of energy according to the mainline profile, the regenerative braking showed the energy been produced during the train movement. From the graph, it is observed that the curve profile is showing the energy had been reduced through the travelling to the end of the journey. The length and infrastructure profile also contributed to the energy being produced and the ultimate usage of the energy is used by the moving trains but it also depends on the strategy on the railways' operation which had been highlighted by other researchers and authors.

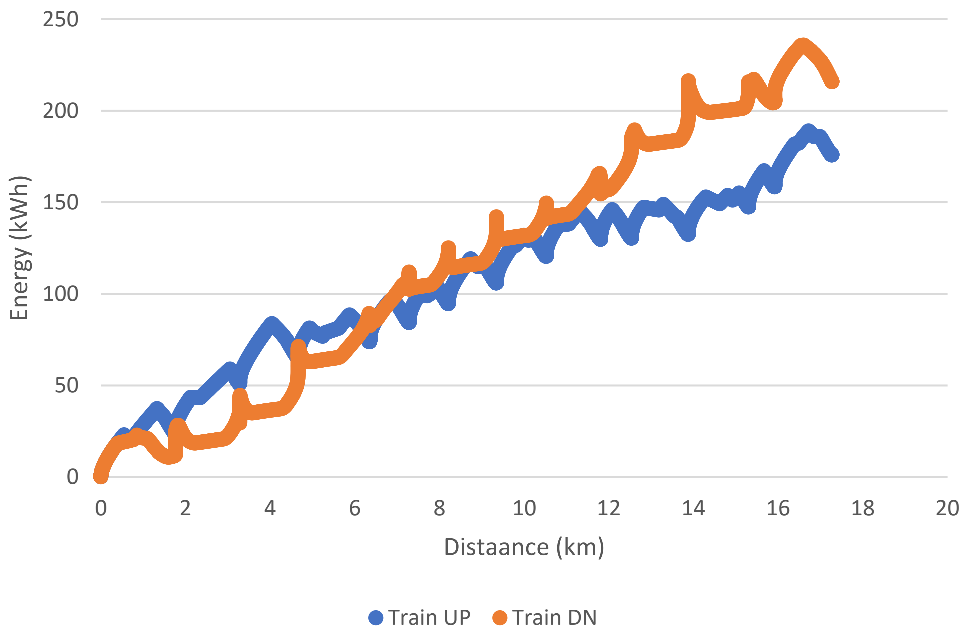



**Figure 4.8 The regenerative braking throughout the infrastructure profile for Southbound and Northbound**

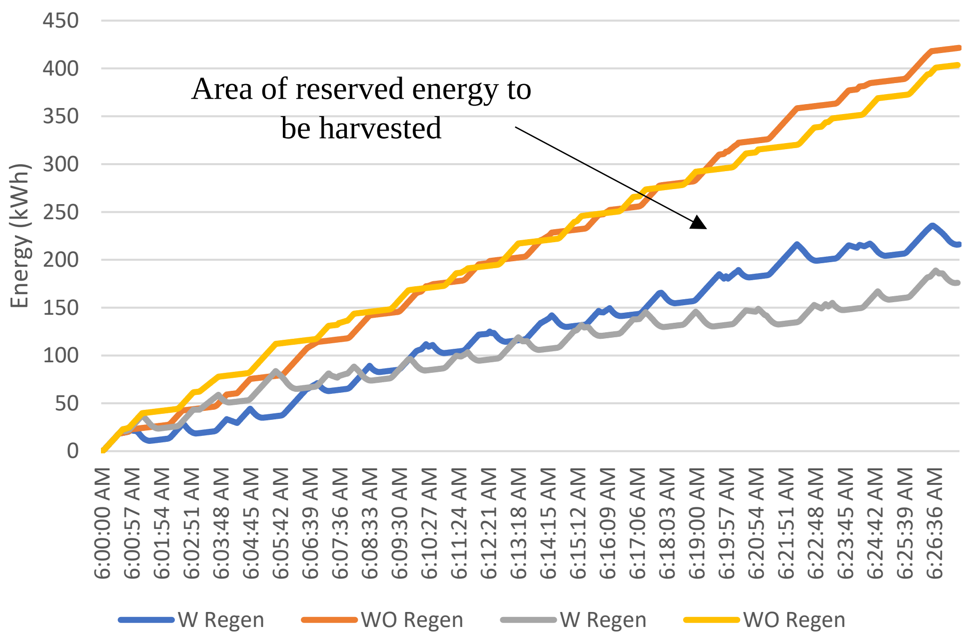



**Figure 4.9 Area of energy to be harvested from trains movement**

From the Figures 4.9 captured above and cross-refer to Figure 4.4, 4.5 and 4.6, it is observed the amount of energy that could be harvested is estimated at the formula below:

$$Energy\ (kWh) = \int_{t0}^{tx} Amount\ of\ energy\ produced\ (kWh_e) \qquad (1)$$

The legend is as follows:

- kWh is the amount of energy generated from the system
- $t_0$ and $t_x$ are referring to the duration time of the cycle
- kWh-e is the energy generated by the system

**4.5 Finding of the results**

From Figure 4.9, it is observed that the energy can be recovered for the energy storage system from the formula (1). From the energy curve in the simulation, the rectangular type will be evaluated and validated the amount of energy that has been produced and could be harvested from the railway network. The mathematical function shall be representative as formula below:

$$Energy\ (kWh) = \int_{t0}^{tx} \frac{1}{2}\ Foot\ print\ (time\ duration) x\ Height(energy\ produce),\ (kWh_e)$$

(4.1)

The legend is as follows:

- $t_0$ and $t_x$ are referring to the duration time of the cycle which ***t0=0s and $t_x$=1586s / 0.45 hrs***
- The energy produced referring to the ***$E_1$= 404kWh and $E_2$=216kWh***

The energy produced during the no regenerative and regenerative braking is illustrated as follows,

**<u>Nonregenerative braking:</u>**

$Energy\ (kWh) = \frac{1}{2}$ (0.45) x (404) = 90.9 kWh (4.2)

**<u>Regenerative braking:</u>**

$Energy\ (kWh) = \frac{1}{2}$ (0.45) x (216) = 48.8 kWh (4.3)

Note: Energy that able to be retrieved from the system amount at 42.1kWh

From the information given in (3) and (4), it is observed that the amount of energy that can be retrieved and harvested from the system is approximately 42.1 kWh. Based on a website by Sunwatts (SunWatts, 2021), 100kW is sufficient to cover approximately 6500 square feet. It is also noted that the amount of 12,000 kWh is estimated to be produced for alternating current for a month. From the statement and observation in the simulation, the amount produced by the trains could be able to generate the energy required by the area i.e. stationary equipment, stations and traction auxiliary supply system. The scenario of the study is notable different where the Traction Power Supply System is located far away in some of the cases.

This also noted that the result from the simulation is an indicator for the energy storage system to be implemented at the location where the traction power system is located. In certain locations, the Traction Power Supply system is isolated from the stations where the station load of the system is much larger. In this case, the scenario considers at the location of Traction Power Supply System location either the location is located near to stations or far away from the stations.

### 4.5.1 Design of Energy storage system

It is observed that in the modelling of the railway power supply and distribution system, the energy produced during the operation on non-regenerative and regenerative braking observed that the energy that able to be retrieved from the system amount at 42.1 kWh. The required capacity of the Energy Storage System (ESS) is calculated as the formula :

$$P = E/t \tag{4.4}$$

where
$P$ = power, kW
$E$ = energy, kWh
$t$ = time, s

From the modelling of the railway and graphical in figure 3.5, the maximum duration time for the regenerative braking is up to 30 seconds. Based on the literature review, current implementation of the Energy Storage System (ESS) and the outcome from the result, the supercar technology is chosen to store the regen. The supercapacitors are chosen based on this benefit (a) Capability of charging and discharging time with balancing energy storage, (b) its capability to charge in a short duration of time and (c) wide-ranging in operating temperature (-40F to 150F). From the equation at 3.3, the capacity of the Energy Storage System is

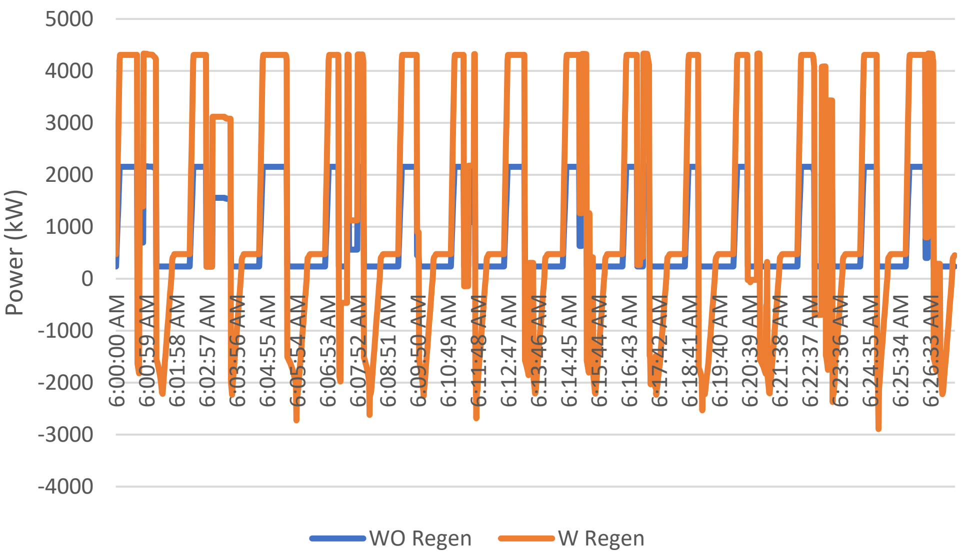
$$P = E/t \Rightarrow P = 42.1\ kW(3600)/30 = 5{,}052\ kW.$$

With the safety factor to be considered in the design, 1.25 safety factor shall be considered to govern the worst condition scenario. The final capacity of the Energy Storage System is

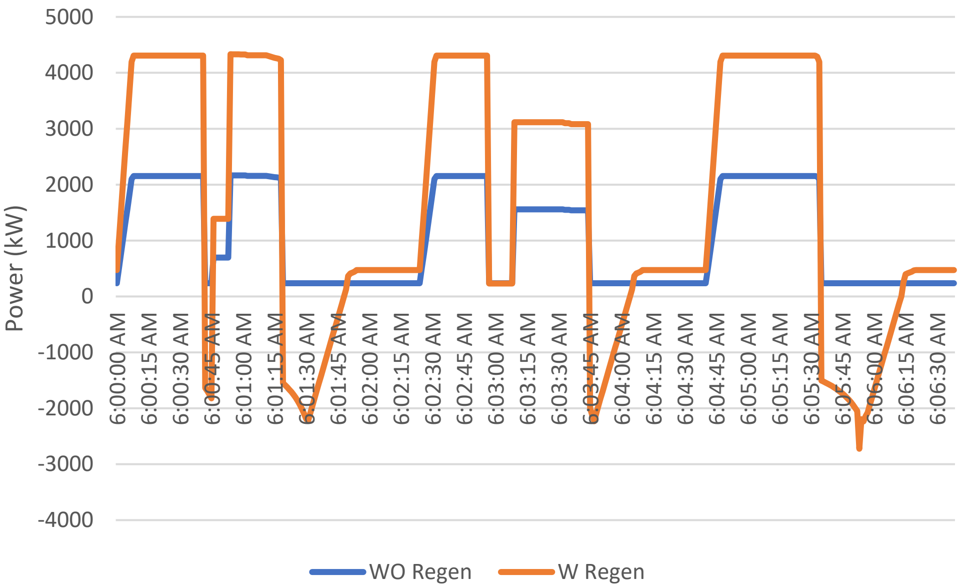
$$P = E/t \Rightarrow P = 42.1\ kW(3600)/30 = 5{,}052\ kW \times 1.25 = 6{,}315\ kW$$

In consideration of the capacity, it is noted that the capacity of the Energy Storage System is estimated at 6,315 kW. The power conditioning for the system shall be designed to accommodate the size of the Energy Storage System. With the current design, a redundancy power supply system in the train and consideration in the train power system design shall consider this requirement. Other factors also shall be considered in the design i.e. temperature, power losses due to cable resistance, power conditioning losses. The design of the power conditioning is as per the modelling graph in Figure 4.10. It is observed that the cumulative power during regenerative braking contributes a large amount of energy compared to non-regenerative braking. From Figure 4.10 (b), the maximum power captured during the regenerative braking is 2960 kW. The requirement of the power conditioning shall be rated at modelling capacity. It is also noted that the safety factor shall be considered to accommodate the fluctuation in the electronic component and other factors i.e., power losses, harmonic loss. The final capacity of the power conditioning is

$$P = E/t \Rightarrow P = 2960\ kW = 2960\ kW \times 1.25 = 3700\ kW$$




(a)




(b)

**Figure 4.10 Commutative power by trains during operation (a) all trains (b) 6 minutes duration by the trains**

From the result above, the Energy Storage System and Power Conditioning design as Table 4.2

| No | Energy Storage System | Capacity |
|---|---|---|
| 1. | Supercapacitors Bank | 6315 kW |
| 2. | Power Conditioning (Inverter/Converter) | 3700kW |

**Table 4.2 Summary of the Energy Storage System**

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

This chapter sets out the outcome from the studies and the information shall be concluded and explained according to the result achieved from the exercise. The outcome context of the research is important to the nature of the field of study. The nature of the analysis, the significance of the study and the design of the research structure will be concluded and future exploring the information which incorporated the other factor recommended by other researchers and authors.

The focus of the studies to overview the 3 objectives is as follow

a. To investigate the characteristics of energy generated from the regenerative braking

The characters of the system had been evaluated based on the simulation and the result from the simulation had been recorded and captured in section 4. The energy produced and could be harvested from the system has been estimated at approximately 42.1 kWh. The amount of the energy had been explained based on the finding by the author for future reference and studies.

b. To design an energy storage system to recover the energy from the regenerative braking

From the studies, the energy from the regenerative braking was observed to be estimated at 42.1 kWh. The amount of the energy is been explained in Figure 25.1 which had shown the amount of energy that could be harvested and reused by the local supply requirement i.e., stations, ancillary building and traction power supply system. The energy harvested from the train operation is considerable large and able to feed to the vital equipment in event of any power failure in the railway system. It is noted that the design is also covered by the Uninterruptable Power Supply (UPS) were to cover the essential and critical components in the system. The result from the studies shows that the energy generated by the train operation is a valueadded to the design implementation and recommendations on the energy storage system shall be widely integrated into the power system design study.

c. To evaluate the performance of the system developed

The energy produced by the model is largely able to power up the essential and critical supply without relying on exporting the energy from the grid power supply. It is also noted that the grid power supply is important to initialize the power for the railway operation but the renewable energy implementation i.e., the energy storage system is one of the options to reduce the current focus by all countries to reduce global warming and toward the green environment. As mentioned in previous chapters, it is supplementary to using the battery type for two (2) main purposes either Compensation Voltage Sagging or Fixed Energy Storage System.

The aim of the studies is covered by the achieved 3 objectives and could be addressed other detail requirement by recommended by other authors i.e., operation strategy. The commitment to reusing renewable energy is part of the world commitment to preserving nature and renewable energy could also reduce the dependency on fossil raw materials.

## 5.2 Recommendations

From the studies, the energy storage system is a way forward to have a better energy storage system. The energy produced by regenerative braking is widely been used by the railway system to provide an action toward green energy. There is a lack of databased to be referred on the journal to supplement the characteristic of the trains. It is because the open market has several train manufacturers that a different train performance and characteristics. The information of these databased, in future, shall help the researchers to have a better implementation of the renewable energy i.e., energy storage system where it could be largely used in modern railways systems.

Further to that, the information also could be used by the renewable energy system to implement the system with some modifications to suit the operation strategy and algorithm requirement (Ates, Acikbas and Soylemez, 2019). It is noted that future studies in the various characteristic of trains could help the researcher to have an overview of the specific requirement based on the train performance.

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# APPENDIXES

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