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Energy Management System Design for Hybrid and Intelligent Light Train

***Abstract**. Electric trains are mass transportation that is developing very rapidly along with technological developments and in line with the need for mobility from modern society. Currently, electric energy-based vehicles are a solution to reduce emissions to the environment. Electric trains generally use a source of electrical energy coming from the electrical grid which is then channeled along the railroad tracks through a system called a catenary. Limited infrastructure and the electric rail network is a problem in the electric train system in Indonesia. Therefore, it is necessary to have a hybrid traction system coupled with energy storage to accommodate the needs of electric trains on non-electrified railways. The hybrid traction system has the concept of combining more than one source of electrical energy as a source of traction energy from the driving motor on the electric train to be operated. The research will be carried out on the design and simulation of electric trains with a traction system hybrid generator in diesel, fuel cells, and batteries as a source of electrical energy. With the use of several energy sources, there will be differences in the characteristics of each type of electrical energy generation component in the system, this system requires an energy management system (EMS). Based on the results of the analysis, it can be concluded that EMS can regulate power division by making duty cycle changes to the EMS control. By using EMS it can be possible to regulate the output power based on the need for the load borne. EMS control can also regulate the process of charging and delivering power on the battery by controlling the bidirectional converter on the battery source..*

Streszczenie**. Pociągi elektryczne to transport masowy, który rozwija się bardzo szybko wraz z rozwojem technologicznym i zgodnie z potrzebą mobilności ze strony nowoczesnego społeczeństwa. Obecnie pojazdy napędzane energią elektryczną są rozwiązaniem ograniczającym emisje do środowiska. Pociągi elektryczne na ogół wykorzystują źródło energii elektrycznej pochodzącej z sieci elektrycznej, która jest następnie kierowana wzdłuż torów kolejowych przez system zwany siecią trakcyjną. Ograniczona infrastruktura i elektryczna sieć kolejowa stanowią problem w systemie kolei elektrycznych w Indonezji. Dlatego konieczne jest posiadanie hybrydowego systemu trakcyjnego sprzężonego z magazynowaniem energii, aby zaspokoić potrzeby pociągów elektrycznych na niezelektryfikowanych liniach kolejowych. Hybrydowy system trakcji ma koncepcję łączenia więcej niż jednego źródła energii elektrycznej jako źródła energii trakcyjnej z silnika napędowego pociągu elektrycznego, który ma być eksploatowany. Prowadzone będą badania nad projektowaniem i symulacją pociągów elektrycznych z generatorem hybrydowym układu trakcyjnego w oleju napędowym, ogniwami paliwowymi i bateriami jako źródłem energii elektrycznej. Przy zastosowaniu kilku źródeł energii wystąpią różnice w charakterystyce każdego rodzaju elementu wytwarzającego energię elektryczną w systemie, system ten wymaga systemu zarządzania energią (EMS). Na podstawie wyników analizy można stwierdzić, że EMS może regulować rozdział mocy, dokonując zmian w cyklu pracy układu sterowania EMS. Za pomocą EMS można regulować moc wyjściową w oparciu o zapotrzebowanie na przenoszone obciążenie. Sterowanie EMS może również regulować proces ładowania i dostarczania energii do akumulatora poprzez sterowanie dwukierunkową przetwornicą na źródle akumulatora.* (Projekt systemu zarządzania energią dla hybrydowego i inteligentnego pociągu lekkiego***)

Keywords: EMS, Electric train, Hybrid traction
Słowa kluczowe: pociąg elektryczny hybrydowt, zarządzanie energią

Introduction

Train is one of the mass transportation modes that is developing very rapidly. Currently, train transportation in Indonesia is still dominated by the type of train powered by conventional diesel engines which still use petroleum as the main fuel to drive engines Diesel. The use of a diesel engine-powered railway system produces emissions and causes unfavorable environmental impacts that pollute the surrounding environment, as well as conventional vehicles. Petroleum-based is very difficult to meet evolving environmental regulations [1]. However, along with the development of the times technological advances had a major impact on the railway industry, where electric trains began to appear with an electric power base as an energy source mainly. Currently, in Indonesia there are already electric rail trains (KRL) where this system uses train lines that are electrified on it (overhead lines) as an energy supply electricity on KRL electric trains. However, the limited infrastructure of this electric railroad can only operate on electrified railroads, so the reach of the train is only limited to rails that are electrified by electricity (Electrified Railway) only.

In the operational application of electric railroads (KRL) in Indonesia, this system relies heavily on the electrified rail network. Thus, several problems arise when the catenary system does not work as it should, such as interference or blackouts in the electric rail network which results in operations electric railroads (KRL) became stalled. In addition, the limitations of the electrified rail network infrastructure also make these electric trains limit the operating range of electric rail units (KRL).

The development of a hybrid traction system refers to the idea of the concept of applying electric traction technology by combining electrical energy storage (energy storage). The power source of the hybrid traction system on electric trains is obtained from various kinds of energy sources such as electric generators, fuel cells, and also the batteries themselves. Therefore, it is necessary to have an Energy Management System (EMS) in a hybrid traction system on electric trains to optimize the performance of each energy source used.

Energy Management System (EMS) is a system used to regulate the use of each energy source used to monitor, control, and optimize energy use in a system. To ensure proper operation of such hybrid systems and identify energy needs in the system, energy management techniques need to be used [2]. In its application, some of these energy sources have different characteristics in distributing power to the traction needs of electric trains. Thus, EMS is needed to regulate the use of this power. The use of EMS in electric train traction systems can maximize all the energy potential available in the electric traction system of the train.

Basic theory

A. Battery

Batteries are one of the important components for storing the energy needed in electric train traction systems that operate on tracks that do not distribute electrical energy. Batteries here will act as a provider of electrical energy as well as as an energy supply for the traction needs of electric train motors as well as additional energy needs for auxiliary power purposes on trains.

Battery Electric Multiple Unit Trains are electric trains in which there is battery storage (on-board) with the aim of operating electric trains on non-electrified rail lines. This system is used to benefit from electric trains without having to provide electrical energy along the railroad tracks. The performance of the battery used in this electric train depends on the chemical factor of the battery, which will have an impact on the battery capacity, the output power produced, and also the lifecycle of the battery, where each type of battery will have differences in terms of energy and power which also affects the weight and capacity of the battery. Therefore, the BEMU system must meet the needs of the power profile of the electric train as measured in the c-rate calculation to determine the battery power output to the battery capacity [3].

Batteries used in electric-based vehicle systems generally use a li-ion battery type.

1) Battery Capacity

The capacity of the battery to be used is measured in the form of ampere-hour (Ah) where the capacity of the battery shows the amount of energy stored when the battery is in a full state until the battery is discharged or discharged (Fully discharged). The most important character of the battery is that the higher the current released from the battery, the smaller the capacity value of the battery used. Therefore, the capacity of the battery is calculated by reference to the distribution of battery current in every one hour [1].

2) State of Charge

State of Charge or commonly known as battery SOC is a percentage of the battery capacity that is charged from the predetermined battery capacity value. The SOC value of a battery is generally difficult to measure with certainty, several methods are used to estimate the amount of the SOC percentage value of a battery. In addition, referring to the battery capacity that decreases with the age of the battery, an accurate calculation of the battery SOC is needed which refers to the battery rating capacity used [1].

(1) $$SOC = \frac{Available\ Capacity\ (Ah)}{Rated\ Capacity\ (Ah)} \times 100\%$$

B. Proton Exchange Membrane Fuel Cell (PEM FC)

Fuel Cell is an equipment that can convert chemical energy from a fuel into electrical energy through a chemical reaction to oxygen or other oxidizing agents. Unlike batteries, fuel cells require a constant source of fuel and oxygen or air to maintain the chemical reaction that takes place.

Proton exchange membrane fuel cell (PEMFC) is the most widely used technology in Fuel Cell Vehicles. In technical terms, PEM Fuel Cell has a high energy density, is needed to meet the energy needs of the vehicle, and the working temperature of about 70 °C allows for a fast start-up. The efficiency of the fuel cell is usually 40-60% and the output power can be changed to meet the requested load quickly. Another characteristic of the PEMFC system is compactness and lightness. As a result of these characteristics, PEMFC is considered the best candidate for vehicle applications. The disadvantage of this technology is that it is sensitive to fuel CO contamination and the catalyst is quite expensive, higher CO levels result in loss of fuel cell performance. In transport applications, this technology is used in hybrid configurations with electrical energy storage devices, such as batteries or supercapaccitors. [4]

C. Diesel Generator (DC)

A diesel generator or in this system called a generator is a combination device between a generator and a diesel-fueled drive engine (diesel engine) to produce electric power. The working principle of the generator uses the faraday principle where when the coil is moved in a magnetic plane or vice versa, there will be a change in magnetic flux in the coil, so that there is a potential difference between the ends of the coil (generating electrical energy) [5].

In a dc generator with separate excitation is a dc generator where the field current is supplied from a separate dc voltage source. Here's the Equation on a dc generator with separate excitation.

(2) $$V_T = E_A - I_A R_A$$

The voltage V_T represents the measured voltage at the terminals of the dc generator, and the I_L current represents the electric current flowing on the line connected to the terminals of the dc generator. Then, the current flowing on the anchor coil is represented with I_A. In dc generators with separate excitation the value of I_A is equal to the value of I_L.

When the load on the dc generator increases, the current in the anchor coil will also increase, then the value of $I_A R_A$ also increases. This will cause the voltage at the generator terminals to drop or decrease. Thus, to maintain the terminal voltage, it is necessary to increase the flying voltage of E_A [5].

(3) $$E_A = K\phi\omega$$

D. Converter DC-DC

1) Buck Converter

A buck converter is a converter in which there are input voltage components, controlled switches, diodes, inductor filters, capacitor filters, and resistor loads. The buck converter is capable of producing an average output voltage lower than its input voltage.

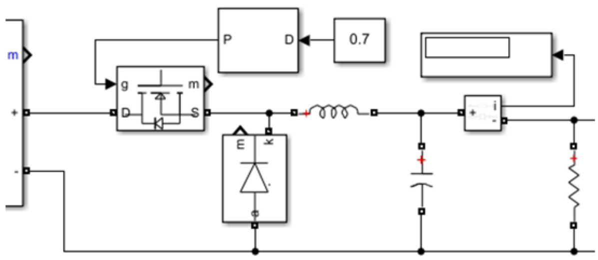

Fig 1. Buck Converter Modelling

Determination of duty cycle value:

(4) $$V_R = DV_s$$

Determination of capacitor value:

(5) $$C = \frac{D}{R(\Delta V_o/V_o)f}$$

Determination of the value of the inductor :

(6) $$L = \frac{V_o(1-D)}{\Delta i_L f}$$

2) Boost Converter

Boost converter is a dc dc converter circuit that is able to produce an average output voltage that is greater than the source voltage or input voltage. Just like other dc dc converters in the boost converter circuit there are components of the source voltage (Vs), inductor (L), switch (S), rectifier diode (D), capacitor filter (C), and resistor load (R).

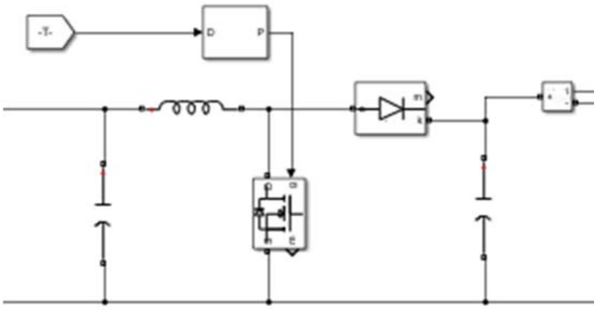

Fig 2. Boost Converter Modelling

Determination of duty cycle value:

(7) $1 - D = \frac{V_i}{V_o}$

Determination of capacitor value:

(8) $C = \frac{D}{R(\Delta V_o / V_o) f}$

Determination of the value of the inductor :

(9) $L = \frac{V_o(1-D)}{\Delta i_L f}$

3) DC-DC Bidirectional Converter

In the dc-dc bidirectional converter it can be possible to drain power in two different directions. This can be used to drain power from the battery to the motor load (discharge) and can also be used to drain power from the DC link bus to the battery for the battery charging process if needed.

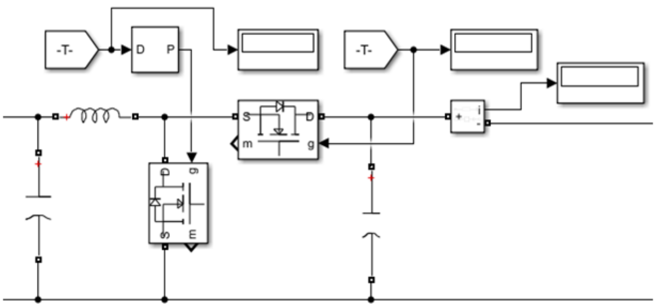

Fig. 3. Bidirectional DC-DC Converter

Determination of duty cycle (boost) value:

(10) $1 - D = \frac{V_i}{V_o}$

Determination of capacitor value:

(11) $C = \frac{D}{R(\Delta V_o / V_o) f}$

Determination of the value of the inductor :

(12) $L = \frac{V_o(1-D)}{\Delta i_L f}$

E. 3 Phase Inverter

In the use and control of induction motors, especially in electric vehicles which have a variety of different parameters and are not linear, a power conditioning device is needed that is able to regulate the power requirements of the induction motor. A 3-phase inverter is used in the system to convert the energy flow that was originally a DC voltage into a 3-phase AC voltage to supply a 3-phase induction motor [6].

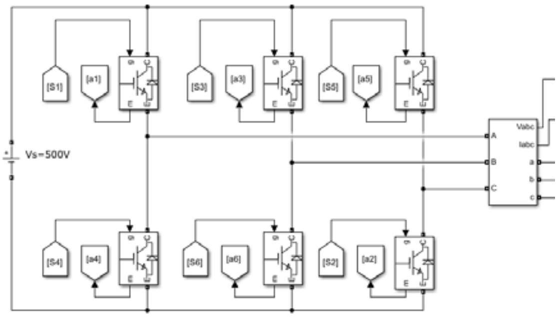

Fig 4. 3 Phase Inverter Modelling

F. 3 Phase Induction Motor

Induction motors are electric machines that have physical similarities in stators with synchronous machines. The stator used in the induction motor machine is the same as the stator in the synchronous machine. Then in the rotor the induction motor is divided into two types of rotors that can be placed inside the stator of the induction motor. The first type of rotor is the type of cage rotor, then the other type is the winding type of rotor.

A rotor induction cage motor consists of a series of conductor rods placed in the cut slots of the rotor surface and short circuits at each end of the rings. This design is called a cage rotor because the existing conductor, if observed, will resemble a squirrel cage [5].

The induction voltage applied to the rotor of the motor is shown as follows:

(13) $e_{ind} = (v \times B) \times l$

G. Electric Train Hybrid System

Hybrid traction systems work by combining several energy sources used in the same system to drive traction motors in electric vehicles. The hybrid traction system on electric trains with lithium-ion batteries with energy sources derived from diesel engines and fuel cells is one of the effective ways to reduce emissions from rail transportation, especially those that utilize regular line electric trains without electricity (non-electrified lines). Hybrid traction systems on non-electrified lines are divided into several types based on traction systems that use electrical energy from diesel engines and fuel cells [8]. In its application, the hybrid system of electric train traction uses new and renewable energy (EBT), where generally the use of this NRE is off-grid so that it does not depend on the installed electricity network [2].

Simulation

A. Simulation Diagram Schematic

In figure 1. It can be known that energy sources are connected to DC-DC controlled converters which can regulate the power output of each existing source. Then. After the nominal DC voltage has been set on the DC link bus, the power current is flowed to a controlled inverter using the sinusoidal pulse width modulation method or commonly known as the SPWM inverter. Furthermore, the outgoing power flow becomes a 3-phase AC power flow that can rotate the induction motor that handles the load for electric train traction.

In the energy management system control system, an input signal from the induction motor is used to find out the power required by the induction motor load as traction for the electric train. Then, an SOC input signal from battery is also used to find out the condition of the power stored from the battery so that the control of the energy management system can regulate charging and discharging on the energy source of the battery

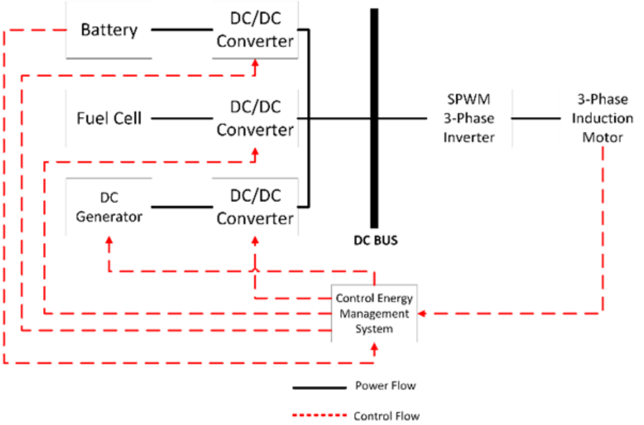

Fig 5. Design Diagram Flow

B. Battery

The type of battery used as a source of energy and energy storage is a li-ion battery type battery. The type of li-ion battery was chosen because of the greater energy density value when compared to the type of lead-acid battery or nickel-candium battery. The following is battery modeling in the matlab simulink simulation used.

Table I. Battery Specification

Battery Type	Lithium-Ion
Nominal Voltage (V)	250 Volts
Capacity Rating (Ah)	100 Ah
Initial State-of-charge (%)	90%
Battery Response Time	30 s

Table II. Battery Discharge Specification

Maximum Capacity	100Ah
Voltage Cut-off (V)	187.5 Volts
Voltage when SOC condition is 100% (V)	290.9 V
Nominal discharge current (I)	43,478 A
Inner obstacles (Ohms)	0.025 Ohms
Capacity when nominal voltage (Ah)	90.43 Ah

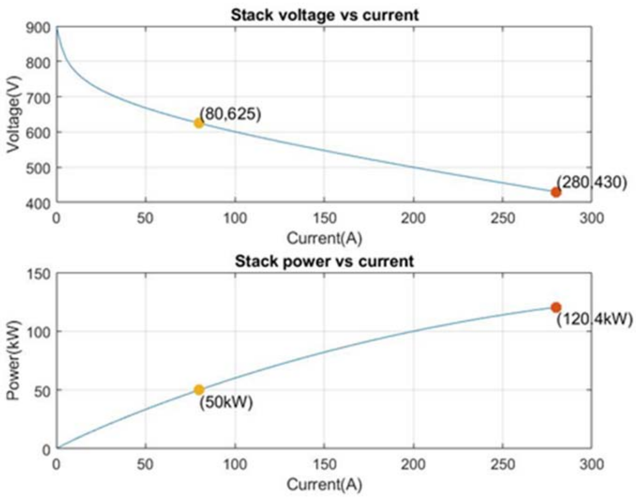

Fig 6. Matlab-Simulink Fuel Cell Characteristic Curve

C. Fuel Cell

The type of fuel cell used in this simulation is the Proton Exchange Membrane Fuel Cell (PEM) fuel cell type. The PEM type of fuel cell was chosen because in this type of fuel cell can produce enough power to drive the load of the traction motor from the electric train used. In addition, pem type fuel cells also only need oxygen or external air which functions as combustion oxidants from the hydrogen fuel used. Pem type fuel cells also have a lower operating tempertaure compared to other types of fuel cells, namely up to 80o Celsius and also the efficiency of PEM type fuel cells is considered good in the efficiency range of 40-60% electrification efficiency.

Table III. Fuel Cell Specification

Fuel cell type (Nominal)	PEM Fuel Cell – 50kW- 625 Vdc
Voltage at currents of 0A and 1A	900 V and 895 V
Nominal Operating Point	80 A and 625 Vdc
Maximum Operating Point	280A and 430 Vdc
Number of cells	900
Nominal efficiency on the FC stack	55%
Working temperature FC	65° Celsius
Nominal flow rate	2100 lpm
Nominal fuel and air pressure	1.5 bars and 1 bar
Nominal composition of hydrogen, oxygen and air	99.95% H_2, 21% O_2, 1%H_2O

D. DC Generator

In the energy management system research on electric trains this time, a DC engine is used which will work as a DC generator on the electric train system used. The DC generator will function as a DC voltage generator that will be transmitted to the induction motor load. The DC generator here functions as a power plant when the power from the battery and fuel cell cannot meet the power needs of the induction motor load.

TABLE IV. DC GENERATOR SPECIFICATION

Dc Engine specification type (Nominal)	100 HP, 500 V, 1750 RPM, F:300V
Mechanical Inputs	Rotor speed (RPM)
Rotor Type	Rotor roll (Wound)
Anchor coil resistance(Ra)	0.2828 Ohms
Anchor coil inductance (La)	0.004453 H
Terrain Coil Resistance (Rf)	69.77 Ohms
Medan Coil Inductance (Lf)	9,413 H
Reverse inductance (Laf)	0.59 H

E. 3-Phase Induction Motor

In this study, an asynchronous machine simulink block was used which was operated as a 3-phase induction motor. A 3-phase induction motor is assumed to be an electric train drive on EMS simulations. In the simulation carried out, the induction motor works as a load that works on the variableized value of the mechanical torque input (N.m). The type of induction motor used is the cage rotor induction motor type

Table V. Induction Motor Specification

Rotor Type	Cage Rotor
Specifications (Nominal)	100 HP ; 460 V ; 60 Hz ; 1780 RPM
Mechanical Inputs	Torque (N.m)
Nominal Power	74.6 kW
Stator Resistance (Rs)	0.03957 ohms
Rotor Resistance (Rr)	0.02215 ohms
Inductance Stator (Ls)	0.000389 H
Rotor Inductance (Lr)	0.000389 H
Reverse Inductance (Lm)	0.01664 H

F. Bidirectional DC-DC

In the dc-dc bidirectional converter it can be possible to drain power in two different directions. This can be used to drain power from the battery to the motor load (discharge) and can also be used to drain power from the DC link bus to the battery for the battery charging process if needed.

Table VI. Bidirectional DC-DC Specification

Parameters	Value
Input Voltage (V_i)	250 Volts
Output Voltage (V_o)	500 Volts
Switching Frequency	100 kHz
Minimal Inductor value	$208{,}3\ \mu H$
Minimal Capacitor value	$250\ \mu F$
Duty Cycle	0,5
Ripple (Ripple)	10%

G. Buck Converter

In this study, a buck converter type converter was used to adjust the voltage on the energy source derived from the fuel cell. The fuel cell voltage output is adjusted to the dc link bus voltage so that the use of power sources from the fuel cell can be utilized properly. The working characteristics of the fuel cell in this study tend to emit constant power at certain nominal voltage (V) and current (I) value points. Thus, the buck converter here functions as a voltage lowering from the input voltage Vi from the fuelcell to the nominal voltage of the output Vo.

Table VII. Buck Converter Specification

Parameters	Value
Input Voltage (V_i)	625 Volts
Output Voltage (V_o)	500 Volts
Switching Frequency	100 kHz
Minimal Inductor value	$200\ \mu H$
Minimal Capacitor value	$400\ \mu F$
Duty Cycle	0,8
Ripple (Ripple)	10%

H. Boost Converter

In this study, a boost converter type converter was used to adjust the voltage on the energy source derived from the diesel generator. The generator voltage output is adjusted to the dc link bus voltage so that the use of power sources from the fuel cell can be utilized properly. The working characteristics of the DC generator in this study tend to emit constant power at mechanical revolutions in a certain RPM value. Thus, the boost converter here functions as a voltage adjuster from the input voltage Vi from the generator to the nominal voltage output Vo.

Table VIII. Boost Converter Specification

Parameters	Value
Input Voltage (V_i)	+- 400 Volts
Output Voltage (V_o)	500 Volts
Switching Frequency	100 kHz
Minimal Inductor value	$334{,}3\ \mu H$
Minimal Capacitor value	$250\ \mu F$
Duty Cycle	0,2
Ripple (Ripple)	10%

I. EMS Algorithm Design

In designing the energy management system algorithm, there are several variables that need to be considered. To design, the amount of energy produced by each source must be considered. In the battery energy storage system, it is also necessary to pay attention to the SOC value of the battery that works to store and distribute power. The value of the load produced by the induction motor must also be considered so that each source can handle the power requirements of the induction motor load. In this research simulation, the role of the function of the energy management system is as a control of the amount of power that will be flowed to the motor load. In addition, the control energy management system also allows to regulate control discharge and charging on the battery used.

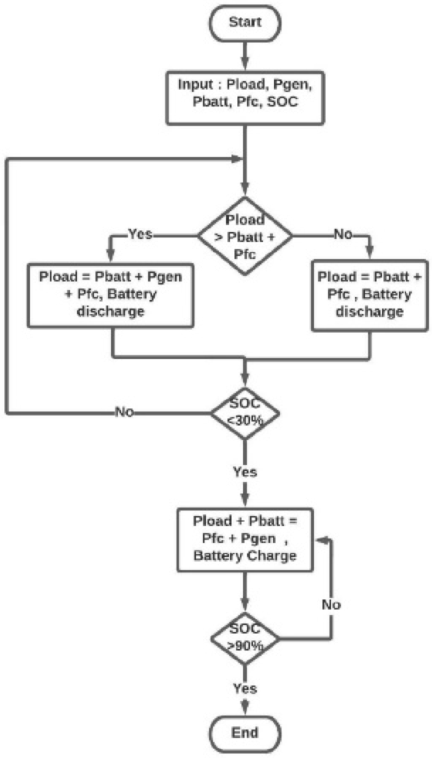

Fig 7. EMS Algorithm Flowchart

[1] The condition of the load power needs can be met by the battery source and fuel cell
- Pload = Pbatt + Pfc

[2] The condition of the load power needs cannot be met by the battery source and fuel cell
- Pload = Pbatt + Pfc + Pgen

[3] Battery SOC condition below 30%
- Pload + Pbatt = Pfc + Pgen, charging battery

Results and Discussion

A. First Low Torque Input Testing

In this test scenario, an EMS simulation was carried out at a torque below 200 N.m, in this scenario an electric train was operated in a low torque requirement. In low torque conditions, electric trains utilize power supply from batteries and fuel cells so that they are more environmentally friendly. In the first test scenario the fuel cell power is greater than the battery power.

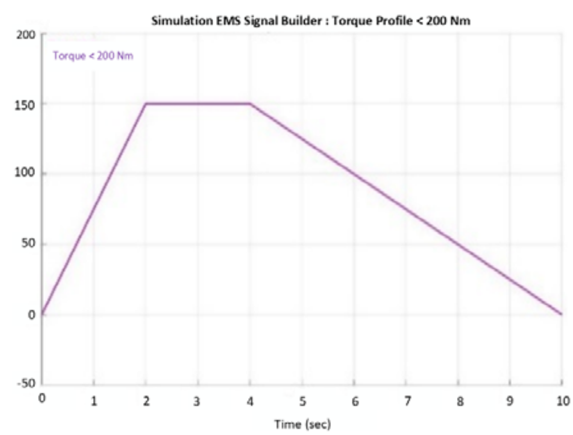

Fig 8. Low Torque Input Profile

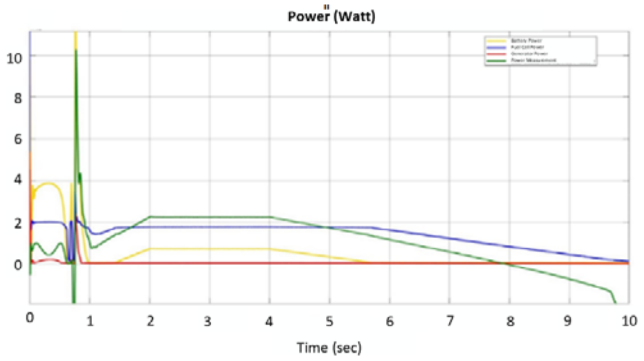

Fig 9. Power Balance Test 1

The initial condition between t = 0 to t = 1 is the starting process of the induction motor so that at that time the current is of high value and in this study data analysis is limited only when the motor has passed the starting phase, namely t = 1 to t = 10.

Based on the data obtained, it can be seen that the fuel cell works to provide the largest portion of power supply at a low torque input. The fuel cell power provided reaches a value of 17.88 kW at an input torque of 150 N.m when t=4 s. Whereas in the battery, the power given in this scenario reaches a value of 7,165 kW at a torque input of 150 N.m when t=3 s. The power requirement of the induction motor depends on the torque input given the higher the torque input value, the greater the power required. At the time of t=4s with a torque input of 150 N.m the required power reaches 22.5 kW at an induction motor rotational speed of 1500 RPM.

B. Battery Charging and Discharging Analysis

In this study, simulations were carried out to apply EMS to electric trains, a storage system was used by utilizing lithium-ion type batteries. To maximize the work of the battery and extend the life-time of the battery, a minimum SOC is set on the battery, which is 30% with a maximum SOC at 90%. Thus, the battery used does not discharge excessively and does not overcharge occur when charging the battery.

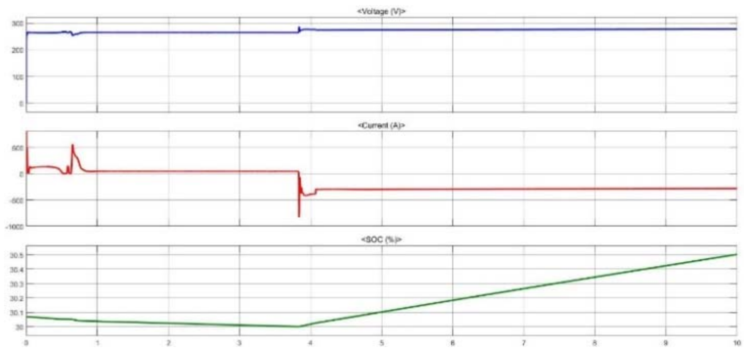

Fig 10. Battery Condition Analysis

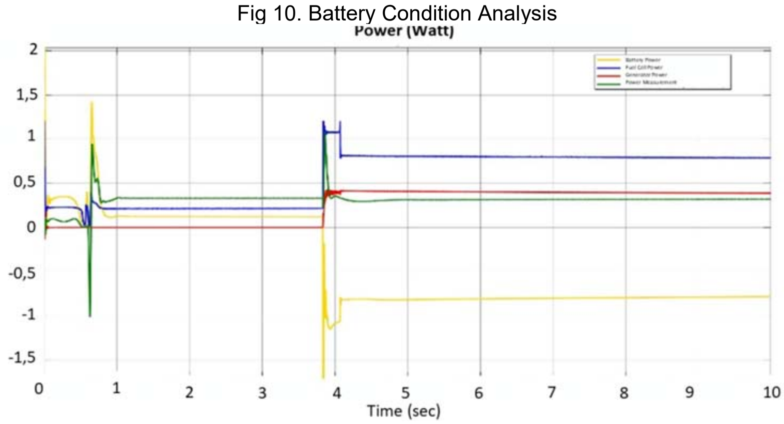

Fig 11. Power Balance When Charging and Discharging

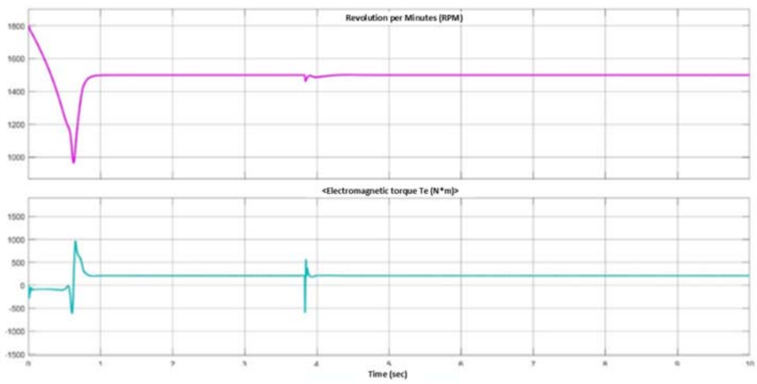

Fig 12. Motor Stability When Charging Battery Condition

In the analysis of the condition of the charging battery, a constant torque input is used to facilitate the analysis of power division in the simulation. The torque input used in the simulated discharge and charging of the battery is 200 N.m at a motor rotational speed of 1500 RPM.

Based on figure 10, it can be seen that the battery is in a charging state when the battery SOC touches 30%. At the time of discharge the battery voltage is stable at 264.8 volts and the discharge current is 46.01 amperes. Then, when the battery enters the charging state, the battery voltage rises to 274.9 volts with a charging current of 297 amperes. It can be seen that when t=3.82 s the battery undergoes a transition from discharging to a charging condition, in that transition condition there is a momentary surge in voltage and current with a very long time briefly.

It is known based on the data obtained when simulating the SOC increase occurred as much as 0.08% every second. So, calculations can be made to reach the capacity of 90% SOC from the charging value of 30% it takes 750 seconds. Assuming that each source runs with a constant load of induction motor at a torque input of 200 N.m and a motor rotational speed of 1500 RPM.

C. Power Balance When Charging and Discharging

In the battery charge discharge scenario, EMS will regulate the power input coming from each source by providing a duty cycle input value on the power converter of each energy source. When the battery is in the charging condition the diesel generator works as a provider of power that is missing from the battery and also helps in the process of charging the battery. In the fuel cell, the power released is the maximum power of the fuel cell which helps to balance the power for battery charging and also to meet the needs of induction motor loads.

D. Motor Stability

In figure 12. it can be noticed that the speed of the motor is running constantly at 1500 RPM and also the electromagnetic torque flying by 209 N.m. However, at the time of the transition between the discharge and charging conditions of the battery, the induction motor undergoes a momentary change in rotor speed i.e. at t=3.83 s decreases to 1472 RPM then after adjusting the rotor speed back to normal at t=4.29 s. Similarly, the electromagnetic torque that flies has a momentary increase and decrease at that time and then the normal value returns at the time of t=4 s

Conclusion

From the results of this research, the following conclusions can be drawn:

1. Energy Management System (EMS) can act as a power control of the energy sources used in the hybrid traction system of electric trains.
2. The different working characteristics of battery sources, fuel cells, and diesel generators can be optimized using EMS control.
3. The voltage stability on the dc link bus has an effect on the performance of the induction motor load and the power delivery of the energy source.
4. Taking into account the high and low loading profiles EMS can maximize the work of batteries and fuel cells to maximize the use of environmentally friendly renewable energy.
5. EMS can limit battery performance to SOC values of 30%-90% and regulate the charging and discharging process.

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