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SYSTEM INTERGRATION OF ELECTRIC TROLLEY

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***Abstract*— Development of environmentally friendly vehicles increasingly attracted the attention of almost all countries in the world, including Indonesia. There are various types of environmentally friendly vehicles, such as electric vehicles, hybrid, and fuel gas. The Electric vehicle has been developed in Indonesia, a private or public vehicle. But many electric vehicles had been developed using the battery as a power source, while the battery technology for electric vehicles still constraints in capacity, dimensions of the battery itself and charging system. The Trolley bus is one of the electric buses with the main power source of the network centenary/overhead line with trolley pole as the point of contact. This paper will discuss the design and manufacture electrical system and overhead line (OHL) test track in Trolleybus.**

Keywords- Trolley Bus; Electric Propulsion System; Design; Overhead line; Electric Vehicle

I. INTRODUCTION(*HEADING1*)

Mass transportation facilities to cope with congestion and environmentally friendly, match and the potential to be applied is a low mass transportation carbon emissions or category of Low Carbon Emission Car (LCEC). Trolley buses are included in the category of LCEC, because it is driven by an electric motor that does not emitexhaustemissions. Trolley buses get a supply of electrical energy from the centenary system by using telescopic pantograph installed on the bus.

Trolleybuses are environmentally and energy friendlier transport means than buses, having in mind the general tendencies of environmental protection and energy savings. Trolleybuses may be said to be the most favorable electrical transport means in public urban transport of passengers, if the introduction of some rail system for the transport of passengers is not economically justified. (J. Zavada 2010) [1]

There is still a lot that can be developed within the trolley bus, researchers from various countries to until now develop a trolley bus to be applied in a more optimal performances. (AT. de Almeida, 2009) [2] Developing a trolley bus system that is supplied from renewable energy in order to further reduce emissions from fossil fuel use. (S. Hamacek 2014) [3] increasing the extent of regenerative braking energy utilization in trolley bus by made accumulation in the super capacitors or a change in the topology of the power supply system in order to facilitate energy flow.

The purpose of this study was to develop mass transportation vehicle to reduce the use of fuel oil has been increase. We expect by using this electric-based vehicle, can save the use of fuel oil in Indonesia and exhaust emissions from the combustion engine.

For the use of telescopic pantograph and centenary system on Trolleybus aims to address the various problems related to the battery unit for traction power supply during Trolley bus operation. This differs from the Bus Power that require battery units in large quantities so that the bus becomes heavy, expensive and long battery charging time will reduce the hours of operation. Given these advantages, trolley buses need to be studied further to see the possibility of its application in Indonesia to provide alternative solutions to increase the amount of mass transportation that is environmentally friendly and can reduce the number of private vehicles.

Compared to fossil fuels (12,000Wh/kg, gasoline fuel), the energy density of today's batteries (100150Wh/kg, Li-Ion battery) is significantly lower. To achieve reasonable electric ranges, large battery packs have to be installed which negatively affects the net weight and production costs of today's Battery Electric Vehicles. For a range of 100kmonly 7.3kg of gasoline fuel needs to be stored in the vehicle, but 188kg for a Nickel-Metal-Hydride (NiMH) battery and 136kg for a Lithium-Ion (Li-Ion) battery. (Frieske Benjaminet. Al 2013) [4].

This paper will explain electric propulsion system and overhead line test track design and manufacture that was developed. The electric propulsion system has been successfully manufactured, while the OHL test track has just reached the design process. The novelty of this research is a trolleybus has the same capability as the electric bus with a large enough battery capacity, so the bus is able to walk when out of the OHL and the bus mechanical designs designed with high floor due to the condition of several flooded city areas, an average urban area using high shelter. Figure 1 shows the block diagram of the trolley bus propulsion system.

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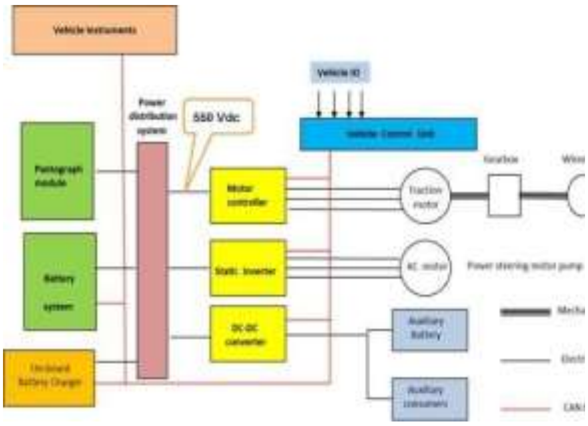

Figure1.BlockDiagramoftheTrolleybus.

II. TRACTIONSYSTEMDESIGN

A. MainTractionSystem

Main traction system on the rolling chassis components such as: Overhead line (OHL), batteries, traction inverter, AC servo motorsand mainconnectorpanel.Specificationsvoltage on these components are:

battery:+/-550VDC/132Ah

motor:+/-335VAC/90kW

Hereisablockdiagramofthe maintractionsystems.

In the process of installation of wiring, line from thebattery before it is connected to the motor controller will go through a safety fuse panel box 200A, MCB, main contactor, and disconnecting switch as the switch, which all components are assembled in the main panel contactor. Wiring diagram of the traction system and the main contactor panel as shown in figure 2.

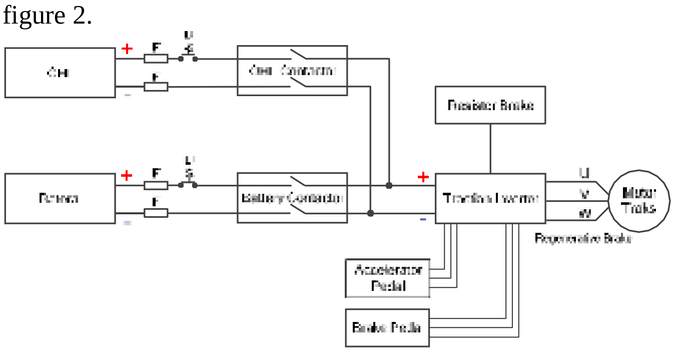

Figure2.WiringdiagramMainTractionSystems

B. MotorControllerandRelaySystem

ControlandRelaysytemusing24VDCasavoltage.

- Motorcontroller

MotorcontrollerhaslowDCvoltage,amongother things

- 24VDCpowersupply,
- Inputacceleratorpedalandbrakepedal5VDC,
- Inputtemperaturesensorandspeedsensor
- ThemotorcontrollerportconnectionX1
- I/O systemPLC

Pin connection on the motor controllerisshowninfigure 3.

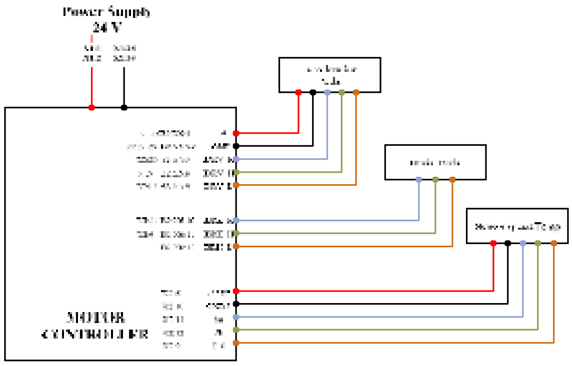

Figure3.Wiringlowvoltage motor controller

- RelaySystem

24VDC low voltage in the traction system is also used to distribute the panel contactors, relays and a batterypowersupplyfan.Ateachbatterytherearefour fans, fans specification are 24V / 0.15A, 3.6W power required, bringing the total six pack batteries required total power 86.4W.

The resources obtained from the auxiliary battery / battery capacity of 2x (12V / 35A).

Connectionofthepanelandbatteryfanisdescribed as figure 4.

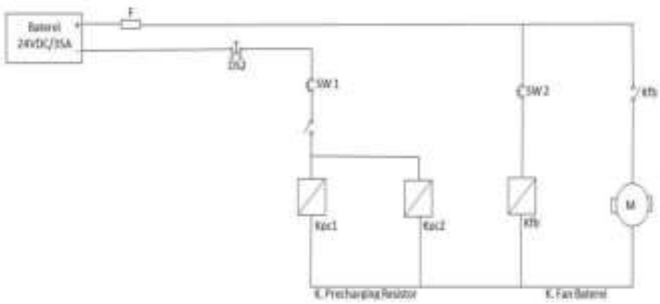

Figure4.RelayandBatteriesfanWiringPanel

III. AUXILIARIESSYSTEMDESIGN

A. ACVoltageSystem

Auxiliaries system using AC voltage 220 VAC, the system used to drive the power steering motors, compressor motors, and some supporting components such as contactors and relays. Power on the system is obtained from the auxiliary power source battery with capacity 2x (12VDC / 200Ah). The output voltage of the battery voltage 24VDC to 220VAC electrical conversion using auxiliary inverter. 200A fusepanels are installed as an extra protection.

Infigure5 shownthe wiringdiagramofthesupportsystem voltage of 220VAC.

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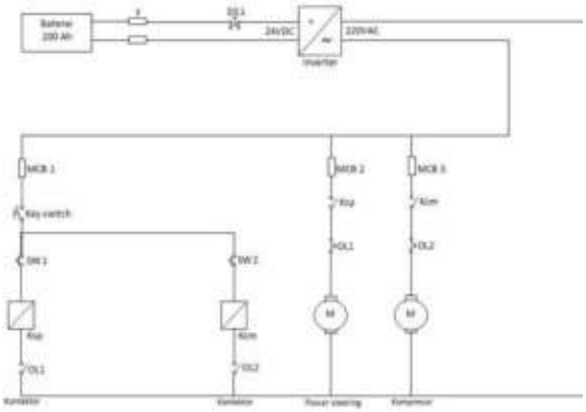

Figure5.ACAuxiliariesSystemVoltage

B. DCVoltageSystem

DC voltage auxiliaries system using 24VDC supply istaken from the static converter. This system connectsupporting components such as relays, and is also used for the dashboard instruments, horn, and lighting. Figure 6 shows DC voltage auxiliaries system.

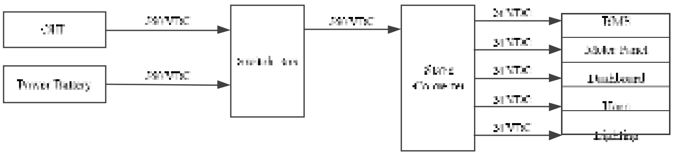

Figure6.DCVoltageAuxiliariesSystemEquations

IV. INSULATIONSYSTEM

Insulation on the trolley bus system must comply with the applicable standards ofreference, so that the trolleybuses safe for operators and passengers. High voltage lines must be isolated, so a short circuit between the high voltage electrical systems not trigger the overcurrent which it can damage bus components and endangering passengers and operators. Oneof them referred to by [5] standard EN 50153 (Railway applications- Rolling stock - Protective provisions Relating to electrical hazards), the classification level / band voltage is imposed on the trolley bus is shown in the table 1.

TABLEI.VOLTAGEBANDSFORTROLLEYBUS

No.	Band	VoltageRate	
		AC(V)	DC(V)
1	I	$U_N \leq 25$	$U_N \leq 60$
2	II	$25 \leq U_N \leq 50$	$60 \leq U_N \leq 120$
3	III	$50 \leq U_N \leq 1000$	$120 \leq U_N \leq 1500$

Based from table 1 the voltage rate used in Trolleybus at 550VDC included in voltage rate / band III (high voltage) categories,wherethespecificationofcablesthatareusedmust comply with the current carrying which is handled, has characteristics for the fire, such as not to be spread the fire, reducing smoke, gases and corrosive. Cable characteristics appliedforthecabletractiontype,themainbatterysupply, and upper orOHLvoltage lines (overhead lines) when applied to the Trolleybus.

In the manufacturing process of rolling chassis Trolleybus, working operating condition of high voltage on the battery installation is +- 550V, 132 A using a cable size 70 mm^2, NYAF type with the size of the current-carrying capability powerful 200 A and a maximum voltage of 750 V. The high voltage operatingconditions workonthe tractionsystemis +/- 355V / 264A using a cable 70 mm^2 cable type NYAF sizewith the size of the current-carrying capability 300A strong and a maximum voltage of 750V. NYAF cable is a type of flexible fiber cable and copper conductor PVC insulated with variousfibers,itismeantto facilitatethemoveofflexibilityin the area of rolling chassis, connect between panels which pass through the frame and frame-order components. NYAF cable types are usually used for the installation of electrical panels that require high flexibility.

In the process of installation, high-voltage wiring system using some protection equipment, such as: fuse, relay and breaker. The position of the connection or the connector is in the area and water-resistant panels, and a position in contact with the edge of the plate / frame is coated with an extra insulator.

V. ASSEMBLYPROCESS

A. BatteryInstallationProcess

The installation process is carried out of eight (8) pieces of battery pack into the battery module, the arrangement of batteries connected in series as shown in figure 7.

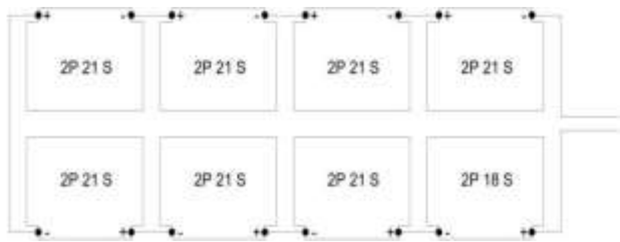

Figure7.BatteriesConnection

Batteries arranged in series in middle right and left side between the front axle and the rear axle on the rolling chassis, battery placement is placed and bolted to the frame rack with sliding system such as drawers. The connection cable between the battery using the cable types of NYAF size of 70 mm^2.

B. MotorControllerInstallationProcess

Installingthemotorcontrollercomprises:

- HighVoltageInstallation

High voltage in rolling chassis manufacture is the voltage that comes from the main battery with a voltage of +/- 550 VDC, and the output voltage of the motor controller towards AC servo motors rated voltage +/- 335 VAC.

Installation cable needs towards battery motor controller adjusts the working conditions +/- 550VDC, 132 Amp. Cable usedforcableinstallationwithasizeof200Aanda maximum voltage of 750 V using cable types NYAF size of 70mm^2 cable.

Cables for traction systems in motor controller toward the installationACservomotorsadjusttheworkingconditionsof +/- 335 VDC, 264 Amp. Cables for installation of cable traction system used with the size of 300 A and a maximum voltage of 750 V using cable types NYAF size of 95mm^{2}cable.

- LowVoltageInstallation

Low voltage meant here is use a 24VDC voltage, this voltageisusedasapowersupplyfor motorcontrollers,relays, andothersupportingcomponentsusing24VDCpowersupply. Installation for low voltage use cable types NYAF size of 2.5 mm^2 cable.

C. *ACTractionMotorInstallation*

This motor as the main motor of the rolling chassis trolleybus connected to the rear drive (rear axle) using fixed gear transmission.

TABLEII.ELECTRICALINTERFACEACTRACTIONMOTOR

S/N	Symbol	Connection
1	U	UphaseMotorcontroller
2	V	VphaseMotorcontroller
3	W	WphaseMotorcontroller

High voltage cable connection from the motor directly to the motor controller using the type of cable used NYAF size 95mm^2.

D. *MainPanelContactorInstallation*

Main panel has functions as a switching box. In whichthere are a series of several components such as contactors, relays, MCB, switch. Logic and switching control performed by the PLC unit. These panels are connected to:

- Themainbatteryoutput,
- Batteryinputtothemotorcontroller,
- Keyswitch,
- Relay,
- I/OPLC
- Voltage24VDC
- Voltageof220VAC

E. *AuxiliaryPanelContactorInstallation*

The panel serves as an auxiliary contactor control the power steering motor, compressor, fan motors and controllers. Inside the box, there are a series of panel components MCB, contactors, overload relays, and switches. input voltage using 24VDC and 220VAC.

F. *FusePanelInstallation*

Fuse used as a safety on the power supply line, either the mainorauxiliarypowersupply.Therearethree(3)piecesfuse box panels used on rolling chassis, among others:

- Mainfuse,2x200A,usedinprimarybatteryconn ection pathtoward the motor controller.
- Auxiliary fuse, 2x200A, used to track the batteries 24v / 200Ah to the auxiliary panel.
- Powersupplyfuse,2x35A,usedinpowersupplylines, accu 24V / 35Ah.

VI. OVERHEADLINETESTTRACKCOMPONENT

Here is a single line diagram design drawing that will be used on the OHL test track substation.

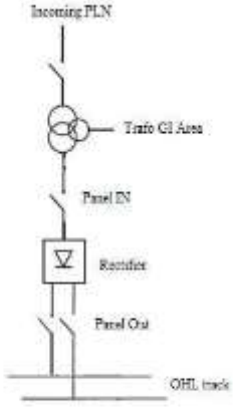

Figure8.OHLTestTrackSystem

Based on figure 8, the electrical component of asubstation trolleybus consists of several tools / components as follows:

A. *Powergridpanel*

Power grid panel is a panel that serves to set the input voltageof20kV.Thispanelisdirectlyconnectedtothe20kV power grid. This panel provides 20 kV voltage. This 20 kV output voltage becomes 20kV / 400V transformer input at the substation. In this design, this panel is alreadyavailable on the substation area.

B. *Transformer*

Transformer function is to reduce the voltage of alternating current. Transformer 20kV / 400V on thesubstation system is a transformer to supply 400 powersupply. In this design, the transformer is already available on the substation area.

C. *PanelInput*

The input panel serves as the input panel of the transformer and the output goes to the rectifier. Panels are composed of MCCB and fuse.

D. *Rectifier*

Rectifier is one of the main components of the traction substationthatservestorectifythevoltageintoavoltageof 550 VDC. The Rectifier is accordance with applicable standards or equivalent. Like IEC 60146 *(Semiconductor convertors)*,IEC62128*(Railwayapplications-Fixed* *installations-Electricalsafety,earthingandthereturn circuit).*

E. DCPanel(out)

DC panel is a panel that works to set the input and output voltage of 550VDC. The DC panel serves to receive a 550VDC positive input from the rectifier and provide the output to the OHL wire. This panel uses HSCB (High Speed Circuit Breaker) switches capable of disconnecting from the rectifier to the fast OHL network in the event of a fault condition on the system. The panel is equipped with a protective relay that serves to detect the various disturbances that may occur in the OHL network.

F. OHLwire

ThewireusedintheOHLhasthefollowing specifications:

- CableType:BC(Solid)
- Material :Copper (Cu)
- Diameter :110mm^2

G. HighVoltageCable

- Threephasecable

This cable is used to connect the transformer to the rectifier panel. Cable types can use one cable containing three coresoruseasinglecableofthreepieces.Forthisdesignused cable type NYAF 110 mm^2.

- DCCable

This cable is used to connect rectifiers, DC panels and terminal contacts to the OHL wire. For this design used cable type NYAF 110 mm^2.

H. InsulationSystems

The insulator used in the OHL is a porcelain insulators type. Porcelain insulators have the advantage of not easily broken and resistant to weather. In this design consists of 4 (four) Isolator fitted to the ends of the OHL pole and two pieces on the middle pole OHL. The isolator acts as a connector and isolation medium between the OHL wire andthe OHL support pole.

I. ContactTerminal

The Contact Terminal is used as a contact point between the bare copper OHL wires with high voltage DC cables from the DC out panel.

VII. DesignSpesificationOHLTestTrack

The OHL trolleybus specification adjusts to the load conditions and its area coverage. In the OHL design test track of this activity Initial parameters such as power capacity, voltage quantity, distance, altitude, width / gap between lines and others will also refer to trolleybus references already used in other countries and on rolling chassis and body trolleybus design which will be manufactured. The following are the design parameters of the OHL trolleybus network system, and the specifications of the components.

A. OHLHeight

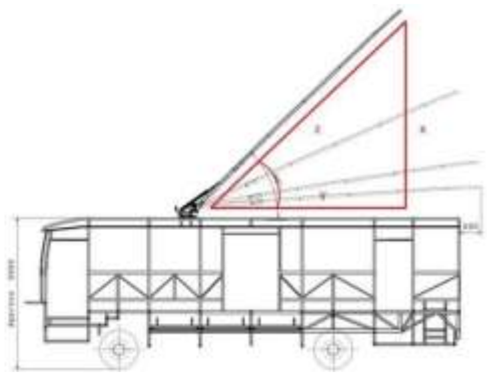

Figure9.OHLHeight

Figure9showsZisthelengthoftrolleypole±6,000mm. While X is the distance between OHL and the bus body is calculated based on trolley pole angle to the bus. The calculation of the trolley pole slope is done with several alternatives,sothattheOHLlevelisdeterminedontheground surface, which is 5,500 mm, the value is based on the calculation of the real condition of the equipment and the exploration of the general condition of OHL trolley bus network.

1) TheOHLlevelfromgroundlevelis5,500mm
2.Thetrolleypoleangletobusbodyis24.1˚.

B. GapLines

Based on the exploration results of OHL trolley busdesign that has been applied, the distance between the linegaps is 600 - 700 mm, and the design of trolley bus that has been made gap betweenlines is700 mm. Figure 10 shows gap between two trolley poles.

Figure10.TrolleyBusGapLines

C. OHLTestTrackLength

The length of the OHL test track is designed with a distance of 20 m between the ends of the OHL test track supportpole,anduses astraighttrack /track design.Sothat on the trolleybus road test can be done with a back and forthmotion using OHL power supply as far as the trajectory.

D. *OHLInstallationSystems*

In the initial design of OHL test track, 20 m long tracktest distance and straight road without turns. With these parameters the electrical supply system used is the supply system of a single substation.

In Installing the OHL cable, both cables are parallel, Positive cables are on the right and negative cables are on the left based on the direction of the arrival of the vehicle.

E. *OHLTestTrackConstructions*

The OHL test track construction is a pole construction for the OHL wire holder. Pole using round iron arranged in parallelseries.Usingthreepoleswith10 mpolespacing.High pole adjust to the OHL wire height.

For the foundation, on the pole mounted iron plate with four holes nut. Then the plate is bolted with the foundation ofa cast bolt. Figure 11 shows OHL test track design.

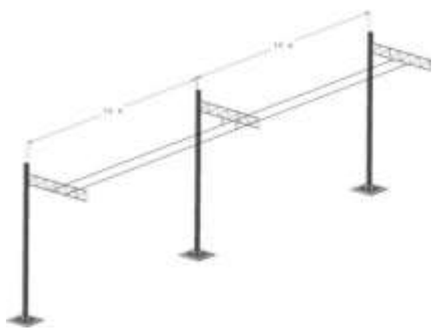

Figure11.OHLTestTrackLength

VIII. TrolleyBusTesting

System testing is performed to determine the motor movement response based on input fromtraction inverter. The Input is set via HMI inverter and the input value is frequency. If the motor's response has stabilized the frequency value is changed (raised or lowered)

The traction motor can rotate from 0 to 1080 rpm according to the input frequency at HMI, if the frequency is increased, then the rotation increases and if the frequency is lowered, then the rotation decreases.

From table 3 can be seen the results of traction system testing, where the motor has reached rated speed at 18 Hz frequency. From these results, it can be concluded that the motorcanfunctionbyusingatractionsystemthathasbeen designed, but from the specifications contained in nameplate only rated speed that can be achieved, while for frequency, voltage and current are different from the expected value.

TableIII.TestingResult

Parameter	Rated Value	TestingResult							
Frequency(Hz)	31	5	10	15	18	-5	-10	-15	-18
Voltage (V)	335	53	108	161	194	53	108	161	194
Current (A)	186	110	111	111	112	110	111	112	113
Speed (r/min)	1000	299	599	900	1080	299	599	899	1080

IX. Conclusions

Indonesia has developed some electric vehicles with main energy supply from battery. Trolleybus is one of alternative electric vehicle with hybrid suppliesenergy. Thispaper makes a design and manufacture for electrical system in trolleybus to be applied in Indonesia, especially for city buses, for example on city buses that have their own lane like Transjakarta, each bus line can be added OHL on it, so exhaust emissions in the city is reduced, and the city bus operational hours are more because there is no waiting time for refueling oil. Trolleybus has a supply from OHL or battery. The supply will be chosen with a switchbox. Motor controller is one of essential part in traction system must be setting based of system needs. This paper just explain design and manufacture for electrical propulsion system in trolley bus. The test results using the installed motor system can reach the expected speed of rotation.

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