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Efficiency Study Analysis of Electrical Energy in Container Stacking Equipment Rubber Tyred Gantry Crane (RTGC) Using Hybrid Energy Source Method

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Abstract: This research to perform Efficiency Study Analysis Of electrical energy In Container Stacking Equipment Rubber Tyred Gantry Crane (RTGC) Using Hybrid Energy Source Method. RTGC gets power supply from Engine Diesel Generator with capacity of 350 kW. However, Genset power source in RTGC has drawbacks, such as when RTGC condition does not move (stationary) can lead to waste of fuel on diesel engine drivers. the Hybrid Energy Source is one of the technology which combines electrical energy source from generators and batteries, The battery of hybrid system can obtain electric energy saving until 32%, where for the Hoist system 11,72 %, Trolley system 33,63 % dan Gantry system 7,58 %.

Keywords: Efficiency, Electrical Energy, Hybrid Engine, Port Heavy Equipment, Rubber Tyred Gantry Crane

INTRODUCTION

The port container has an important function and role in supporting the development of an area. The container stacking process depends on several factors such as the quality and quantity of equipment at the port. Heavy equipment is an auxiliary equipment that functions to move containers from the ship. One type of heavy equipment used in the port is Rubber Tyred Gantry Crane (RTGC), which functions the container lifting system goods in one unit of transport vehicle in the form of a container truck that will be arranged in Container Yard before being transported to ship and before being sent to the industry (Ekawati, 2016).

RTGC has 3 (three) main drive systems, namely the hoist system, trolley system, and gantry system. The hoist system functions for the movement up and down of the spreader, which is a system that makes it easier to lift containers. The trolley system functions for forward and backward movement in moving containers from trucks to container stacking. Meanwhile, the gantry system functions for the movement of RTGC to the right and left if the RTGC position is not in the slot to be worked on. Most the RTGC uses an electric power source from a Diesel Generator Set (Genset) Engine. This will make it easier for RTGC to move the workplace block area, the use of generators as an RTGC energy source is considered effective.

However, the generator power source at RTGC has disadvantages, namely when the RTGC condition is not moving (stationary) it still requires diesel fuel so it's not efficient. The Hybrid Energy Source is one of the technologies that is a solution as a source of electrical energy for RTGC, namely by combining two different sources of electrical energy. If in certain circumstances the engine does not need fullspeed to rotate the generator, then as a substitute for electrical energy by using batteries,this can save electrical energy up to 32%, where for the Hoist system 11,72 %, Trolley system 33,63 % dan Gantry system 7,58 %.

Hybrid System

Hybrid system is a power generation system consisting of two or more types of power plants with different energy sources.(Ana Nur Azizah, 2021). The hybrid system is a centralized system, namely the power plant is connected at one location, and the electricity generated is distributed through the distribution network. The hybrid system is basically a customized system. (Zuraidah Tharo,2019) The system is designed with regard to specific needs and targets to be achieved, so that the target can be achieved properly. The benefits of using a hybrid system are (Sugeng Purbawanto, 2021):

- Optimizing the use of the power generation system.
- Increase the economic efficiency of the plant.
- Increase the reliability of the plant.
- Increase the economical service time of electricity.

The RTGC has two different sources of electrical energy, namely by using Batteries and Engine Generator-Set.

Battery

A battery is an electric cell in which reversible electrochemical processes take place with high efficiency. What is meant by reversible electrochemical processes, is that in the battery can take place the process of converting chemistry into electric power (discharge process), and vice versa from electric power into chemical power, (Mushlih Nasution, 2021). The battery functions to store electrical energy in the form of chemical energy, which will be used to supply (provide) electricity to the electrical system. RTGC uses Lithium Ion batteries (called Li-ion batteries or LIB) a member of the rechargeable battery family (Fengky Adie Perdana, 2020). This RTGC uses GS YUASA International Ltd factory-made battery, with type Li-ion Battery (LIB) Module

Model	: LIM25H-8S3-H1	Voltage	: 28,8 Volt
Capacity	: 25,0 Ah (720Wh)	Weight	: 18,0 Kg
Manufacturing date	: 2015-2	Product	: Japan

Picture 1. Battery hybrid

Engine

As a main mover, an engine has an crucial role to produce kinetic energy as the generator drive which can produce electrical energy. (Muhammad Salim Siregar, 2022) The engine used for this RTGC is:

Merk : DEUTZ
Code : D20C224
Model : BF6M1013FC
RPM : 1800
Serial No : 11483662

Picture. 2. Engine RTGC

Generator

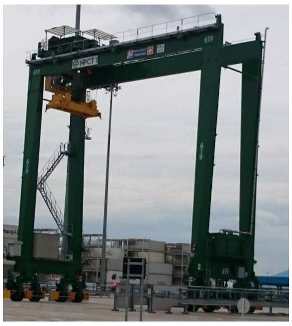
Generators are electrical machines that function as power plants with the concept of working to convert mechanical energy into electrical energy .(Surya Darma, 2020) The meaning of mechanical energy is motion energy, be it push, pull, pressure, or rotation. Usually, the generator requires mechanical energy in the form of rotation to get electrical energy. Electrical energy is generated from the electromagnetic induction process that occurs in the stator coils.

Merk : STAMFORD	Serial Number : X14K472620
Base Rating kVA : 311	Base Rating kW : 248,8
Voltage : 460 V	Current : 390,4 A
Phase : 3 Pf : 0,80	Frekuensi : 60Hz,
Voltage Excitation : 40V	Current Excitation : 2,2A

Rubber Tyred Gantry Crane (RTGC)

RTGC is one of the main cranes at the port that functions for stacking containers in the Container Yard before being loaded onto ships or unloading from ships that will be sent to industry (Kevin Yudhistira Pribadi, 2016), a tool that can lift containers moved from trucks to Container Yard and vice versa.

RTGC unit are made by Mitsui as manufacturer which originates from Japan. The RTGC has the length of ±23 meter, width of ± 12 meter and height of ± 26 meter, In its movement, RTGC has 3 (three) main movements, namely Hoist System, Trolley System and Gantry System.



Picture. 3 : Rubber Tyre Gantry Crane

Hoist system

Hoist system is a system which serves for the up and down movement of the spreader by utilizing 1 (one) induction motor induksi with 3 (three) phase as the mobilizer, operated by the operator using the Joystick and 2 (two) AC Inverter which is synchronized as the hoist motor controller.

Trolley system

Trolley system is a system utilized for the forward and backward movement by using 2 (two) induction motor with 3 (three) phase as the mobilizer, operated by the operator using the Joystick and 2 (two) AC Inverter as the trolley motor controller. The forward and backward movement is utilized for placing the container in accordance with the raw in the plan so that the container placement is in accordance with the plan.

Gantry System

Gantry system is a system utilized for right and left movement, using 4 (four) induction motors with 3 (three) phase as the mobilizer, operated by the operator using a Joystick and 4 (four) AC Inverters as the gantry motor controller.

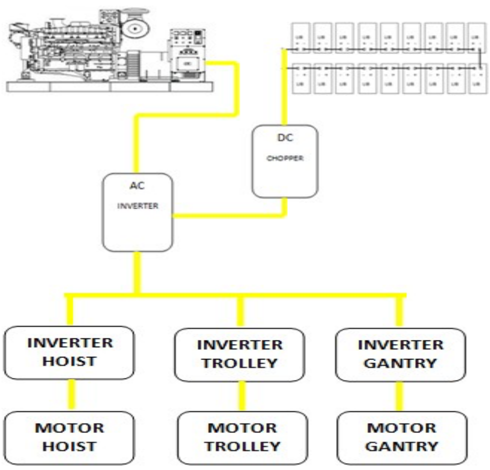
METHODS

Hybrid System

The steps that need to be taken to calculate the electrical energy efficiency of RTGC are:

1. Literature data collection is done by collecting and studying sources of information from books and electronic media (internet) which are used as reference materials related to the problem to be discussed, namely the Hybrid Energy Source system on Rubber Tyred Gantry Crane.
2. Calculating the data that has been obtained in order to get a value, and prove how much efficiency value is obtained. So that it is proven that RTGC with a hybrid system is more efficient in using electrical energy.

Below is the Hybrid system power supply line diagram on RTGC used:



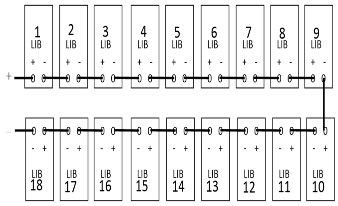
Picture. 4. RTGC power supply line diagram

3. Data collection in the field needed to calculate the efficiency of electrical energy. The data taken are as below: Battery Data, Engine Fuel Data, Generator Data, Hoist Motor Data, Trolley Motor Data, Gantry Motor Data, PLC Program Data, Control circuit diagram data, Data when RTGC operates for 5 (five) hours.

Battery Data

The battery serves to store electrical energy in the form of chemical energy, which will be used to supply (provide) electricity to the electrical system.

The number of batteries used is 18, all installed in series. The following is the battery configuration in RTGC:



Picture 5. Battery configuration in RTGC (series circuit)

Table 1. Battery Data

Battery Number	Voltage (Volt DC)	Current (Ampere)
1	28,8	25
2	28,8	25
3	28,8	25
4	28,8	25
5	28,8	25
6	28,8	25
7	28,8	25
8	28,8	25
9	28,8	25
10	28,8	25
11	28,8	25
12	28,8	25
13	28,8	25
14	28,8	25
15	28,8	25
16	28,8	25
17	28,8	25
18	28,8	25
19	28,8	25
Total	518,4	25

Source: Data of Research

Data Engine Generator

In an effort to produce electrical energy RTGC installed an engine generator. Each has a different role, the engine is the main driver of the generator, while the generator is a tool that can produce electrical energy by changing motion energy.

Table 2. Engine Condition Group

Status	RPM	Condition
Idle	750-900	1. When there is no movement on RTGC 2. When the hoist moves down 3. When operated at 1 knot on all prime movers
Normal	1450-1550	When operated at 2 -5 knots
Emergency	1800	When battery capacity is at 40%

Source: Data of Research

With this grouping, the fuel requirements needed to drive a diesel engine are different

Table 3. Generator Voltage

Engine Status	RPM	Voltage (Volt AC)
Idle	750-900	190 -200
Normal	1450-1550	400 – 430

Emergency	1800	460

Source: Data of Research

Electric Motor Power as Mover

Table 4. Hoist Motor Power (Inverter)

Hoist Without Load	Voltage (Volt AC)		Current (Ampere)	
	Up	Down	Up	Down
1knot	36	34	45	40
2knot	102	101	56	53
3knot	192	190	72	68
4knot	312	311	90	81
5knot	365	364	123	112
With Load	**Up**	**Down**	**Up**	**Down**
1knot	57	59	63	57
2knot	132	141	81	78
3knot	213	207	112	108
4knot	302	309	178	162
5knot	370	365	202	208

Source: Data of Research

Table 5. Average of dataTrolley Motor

Trolley Without Load	Voltage (Volt AC)		Current (Ampere)	
	Forward	Backward	Forward	Backward
1knot	40	41	11	11
2knot	102	114	14	13
3knot	182	217	17	18
4knot	342	321	21	20
5knot	365	364	24	23
With Load	**Forward**	**Backward**	**Forward**	**Backward**
1knot	54	52	13	15
2knot	112	121	18	17
3knot	192	203	20	21
4knot	345	349	27	26
5knot	370	365	32	31

Source: Data of Research

Based on the data, the average value of the four motors is:

Table 6. Average Data of Gantry Motor

Gantry	Voltage (Volt AC)		Current (Ampere)	
	Left	Right	Left	Right
1knot	34	36	32	33
2knot	102	102	46	43
3knot	201	207	51	49
4knot	342	337	61	60
5knot	365	364	70	73

Source: Data of Research

RTGC Operation Data

Operating data is data observed when RTGC is operating in ship or stacking & delivery activities. Data observation is carried out for 5 days, assuming data collection time for 5 hours per day. The data variables observed include:

a) RTGC operational time duration
b) Fuel capacity used
c) The number of boxes lifted and moved

The data is in accordance with RTGC operation activities. The following data was collected:

Table 7. Ship Unloading Operation Data (First Day)

Hybrid RTGC Operation Data			Description
Operational Hour	07.00 a.m.	12.00 p.m.	Vessel Fuji unloading activity
Fuel	820 liters	760 liters	
Total Boxes	0 Box	110 Boxes	
Non-Hybrid RTGC Operation Data			
Operational Hour	07.00 a.m.	12.00 p.m.	
Fuel	465 liters	400 liters	
Total Boxes	0 Box	38 Boxes	

Source: Data of Research

Table 8. Operation Data of Stacking And Delivery Activities (Second Day)

Hybrid RTGC Operation Data			Description
Operational Hour	07.00 a.m.	12.00 p.m.	Stacking and delivery activity
Fuel	753 liters	696 liters	
Total Boxes	0 Box	60 Boxes	
Non-Hybrid RTGC Operation Data			
Operational Hour	07.00 a.m.	12.00 p.m.	
Fuel	579 liters	514 liters	
Total Boxes	0 Box	39 Boxes	

Source: Data of Research

Table 9. Operation Data of Stacking And Delivery Activities Stage 2 (Third Day)

Hybrid RTGC Operation Data			Description
Operational Hour	07.00 a.m.	12.00 p.m.	Stacking and delivery activity
Fuel	485 liters	427 liters	
Total Boxes	0 Box	87 Boxes	
Non-Hybrid RTGC Operation Data			
Operational Hour	07.00 a.m.	12.00 p.m.	
Fuel	925 liters	860 liters	
Total Boxes	0 Box	65 Boxes	

Source: Data of Research

Table 10. Operation Data of Stacking And Delivery Activities Stage 3 (Fourth Day)

Hybrid RTGC Operation Data			Description
Operational Hour	07.00 a.m.	12.00 p.m.	Stacking and delivery activity
Fuel	815 liters	761 liters	
Total Boxes	0 Box	43 Boxes	
Non-Hybrid RTGC Operation Data			
Operational Hour	07.00 a.m.	12.00 p.m.	
Fuel	603 liters	538 liters	
Total Boxes	0 Box	102 Boxes	

Source: Data of Research

Table 11. Operation Data of Uru Bhum Vessel Loading Activities (Fifth Day)

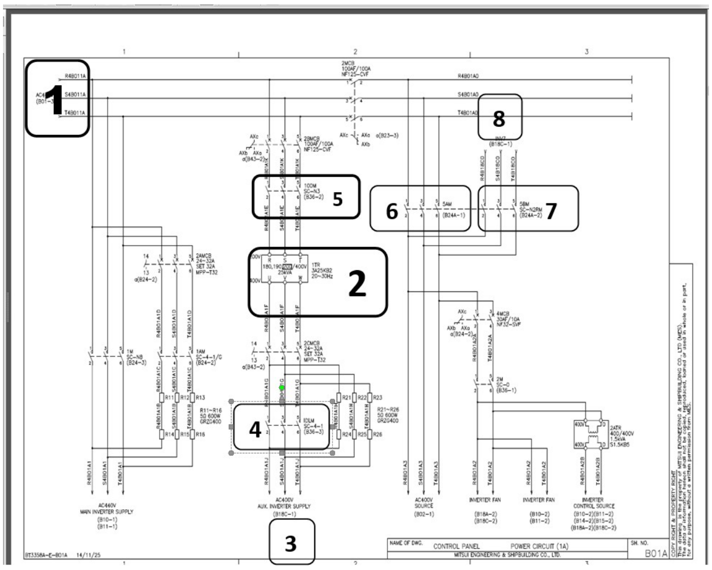
Hybrid RTGC Operation Data			Description
Operational Hour	07.00 a.m.	12.00 p.m.	Vessel Uru Bhum loading activities
Fuel	664 liters	607 liters	
Total Boxes	0 Box	72 Boxes	
Non-Hybrid RTGC Operation Data			
Operational Hour	07.00 a.m.	12.00 p.m.	
Fuel	276 liters	211 liters	
Total Boxes	0 Box	103 Boxes	

Source: Data of Research

RESULTS AND DISCUSSION

How RTGC Works

RTGC works with two different sources of electrical energy. \When the engine is running and the position is stationary (no movement), the diesel engine will be in idle position. In the idle condition the generator produces a voltage of 216.2 Volts. The generator output is connected to the step up transformer automatically to produce a voltage of 400 volts for power distribution control (see Picture 6.).



Picture 6. Control circuit wiring diagram

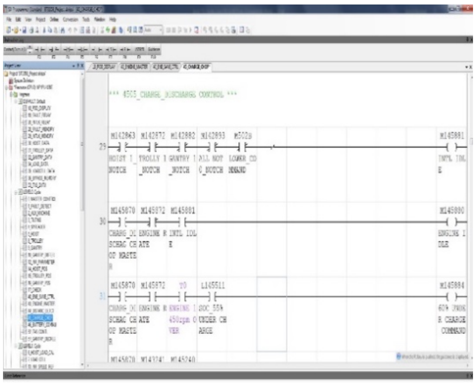
Description:

1. Generator Output
2. Step Up Transformer
3. Transformer Output for Power Inverter Input 7
4. Contactor (engine idle)
5. Contactor (engine idle)
6. Switching (Idle to Rate)
7. Switching (Rate to Idle)
8. Inverter Output 7

With this, if there is a change in the engine speed of the control circuit in RTGC, it will not have a problem when the engine is idle.

How The Engine Works

The idle engine can work on the equipment (hoist, trolley, gantry) when all movements are commanded by the operator at a speed of 1 knot and when the hoist moves down. Here is a picture of the control system in the Programmable Logic Control (PLC):



Picture. 7. PLC program display when the engine is idle

When the engine idle condition is active, a series circuit is created in the program with the following details:

1. M145870 (input which states DC Chopper is OK)
2. M145872 (Engine is not in normal and emergency rotation)
3. M145881 (Engine Idle Interlock is active) 4.

After that, the conditions for Engine Idle Interlock to be active are as follows:

1. M142863 (Hoist 1 knot)
2. M142872 (Trolley 1 knot)
3. M142882 (Gantry 1 knot)
4. X9.5 (No movement / All Not 0 Knots)
5. X9.7 (Hoist Down Command) 5.

From all equipment movements controlled by the operator based on speed, it can explain the work of diesel engines when RTGC is operated to work based on commands from the operator.

Table 12. Engine Condition During Operation

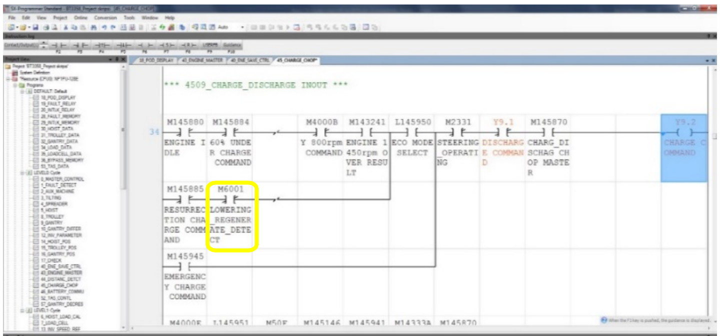
Movement	Idle		Fullspeed	
Hoist up	**Without Load**	**With Load**	**Without Load**	**With Load**
1knot	V	V	–	–
2knot	–	–	V	V
3knot	–	–	V	V
4knot	–	–	V	V
5knot	–	–	V	V
Hoist down	**Without Load**	**With Load**	**Without Load**	**With Load**
1knot	V	V	–	–
2knot	V	V	–	–
3knot	V	V	–	–
4knot	V	V	–	–
5knot	V	V	–	–
Trolley Forward	**Without Load**	**With Load**	**Without Load**	**With Load**
1knot	V	V	–	–
2knot	–	–	V	V
3knot	–	–	V	V
4knot	–	–	V	V
5knot	–	–	V	V
Trolley Forward	**Without Load**	**With Load**	**Without Load**	**With Load**
1knot	V	V	–	–
2knot	–	–	V	V
3knot	–	–	V	V

4knot	–	–	V	V
5knot	–	–	V	V
Gantry Right	**Idle**		**Fullspeed**	
1knot	V			
2knot			V	
3knot			V	
4knot			V	
5knot			V	
Gantry Right	**Idle**		**Fullspeed**	
1knot	V			
2knot			V	
3knot			V	
4knot			V	
5knot			V	

Source: Data of Research

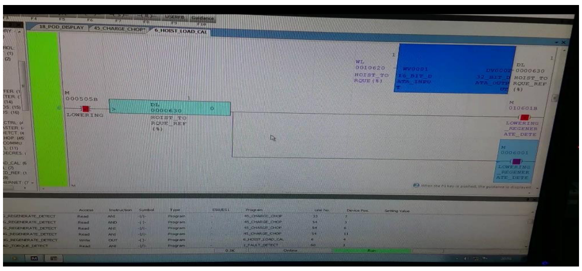
How The Battery Works

After knowing how the engine works, then next is to understand how the battery will charge/discharge.



Picture. 8. Battery charged/discharged

In the battery charge interlock, there is regenerative lowering (see Figure 5) which is caused when the hoist motor torque reference value given from the inverter is not more than 0 (zero) and there is hoist down movement.



Picture 9. Regenerative current PLC circuit

The regenerative current generated by the hoist motor during downward movement must be discharged so that there is no interference with the generator, then utilized to charge the battery. The following voltage and current values are generated when the hoist goes down:

Table 13. Voltage and Regenerative Current

Hoist Without Load	Voltage (Volt AC)	Current (Ampere)
	Down	Down
1knot	34	40

2knot	101	53
3knot	190	68
4knot	311	81
5knot	364	112
With Load	**Down**	**Down**
1knot	59	57
2knot	141	78
3knot	207	108
4knot	309	162
5knot	365	208

Source: Data of Research

Operation mode of RTGC movement when operated with explanation of steps in container lifting. RTGC has 6 steps to lift and move containers to Container Yard when it is operated.

Table 14. Operating Mode

Steps to Operate RTGC	Movement Type	Engine Status
1	Hoist Down	Idle
2	Hoist Up	Rating
3	Trolley Forward	Rating
4	Hoist Down	Idle
5	Hoist Up	Rating
6	Trolley Backward	Rating

Source: Data of Research

Picture 10. RTGC Operation Mode

Of the 6 (six) steps, there are two steps that can change the engine condition from rating to idle condition, namely when hoist down (see table 10 Operating Mode) because of these two steps the engine is in idle condition which means that engine fuel consumption is reduced / decreased, so if it is assumed that the savings on RTGC when operating are equivalent to 2:6 if simplified to 1:3, if the engine works for one hour non-stop, the fuel consumption spent is no longer 13 liters (non hybrid) per hour but rather:

(Engine Rating) 2/3 x 13l = 8,67 liter
(Engine Idle) 1/3 x 10l = 3,33 liter (1)

The fuel consumption required to work for 1 hour non-stop is
8,67 liter + 3,33liter = 12 liter (2)

Then the percentage (%) of fuel savings for 1 hour
13liter – 12liter = 1 liter
1/13 liter x 100% = 7,69 % (3)

If the RTGC operates for 6 hours non-stop, then:
Non-Hybrid = 13 L x 6 Hour = 78 L (4)

Hybrid = 2/3 x 6Hour = 4Hour x 13 liter = 52 liter
1/3 x 6Hour = 2Hour x 10 liter = 20 liter +
= 72 liter

Then the percentage of hybrid and non-hybrid savings efficiency is:

$$\frac{\text{Non Hybrid} - \text{Hybrid}}{\text{Non Hybrid}} x\ 100\%$$

$$= \frac{(78\ \text{L} - 72\ \text{L})}{78\ \text{L}} x\ 100\% = 7{,}69\% \tag{5}$$

This proves that hybrid systems are more fuel efficient.

Table 15. Fuel Usage Data

Fuel Usage Data for One Month of Nonstop Operation						
Operational Time	**Engine Condition**		**Total Fuel**		**Total Fuel (L)**	**Efficiency(%)**
	Idle (Hour)	**Rating (Hour)**	**Idle (10 L/Hour)**	**Rating (10 L/Hour)**		
1 Hour	0,33	0,67	3,33	8,67	12,00	7,69
6 Hour	2,00	4,00	20,00	52,00	72,00	7,69
24 Hour	8,00	16,00	80,00	208,00	288,00	7,69
168 Hour	56,00	112,00	560,00	1.456,00	216,00	7,69
720 Hour	240,00	480,00	2.400,00	6.240,00	8.640,00	7,69

Source: Data of Research

Electric Energy Efficiency

RTGC with Hybrid system may produce electric efficiency based on:

RTGC equipment speed

In an effort to increase efficiency, RTGC with a hybrid system is able to utilize batteries as the main source of electrical energy. According to table 3.1 Battery Data, the amount of power from the battery that may be used is as follows:

Vtotal = n x Vbattery
Vtotal = 18 X 28,8 Volt DC
Vtotal = 518,4 Volt DC

Because the battery circuit is connected in series, the total current value is the same, so the total current in the circuit is 25A, therefore the average power is

P = E x I
P = 518,4 x 25 = 12960 Watt / 12,96 kW

Thus, with a power of 12.96kW it is able to provide electrical energy to the Hoist, Trolley and Gantry at a speed of 1 knot. Based on table 3.4, the power consumption of the motor when moving based on speed can be calculated

The power consumption of hoist motor if assumed cos φ = 0,86

1 knot : P = E x I x cos φ
P = 57 x 63 x 0,86
P = 3.088,26 Watt

4 Knot : P = E x I x cos φ
P = 302 x 178 x 0,86
P = 46.230,16 Watt

Table 16. The power consumption of hoist motor

	Speed	**E (Volt)**	**I (Ampere)**	**Cos φ**	**P (Watt)**	**Notes**
Hoist Motor	1 Knot	57,00	63,00	0,86	3.088,26	B
	2 Knot	132,00	81,00	0,86	9.195,12	B+G
	3 Knot	213,00	112,00	0,86	20.516,16	B+G
	4 Knot	302,00	178,00	0,86	46.230,16	B+G

	5 Knot	370,00	200,00	0,86	63.640,00	B+G

Source: Data of Research

The power consumption of trolley motor with a total of 2 trolley motors (n=2) as drivers, also when assumed cos φ = 0,86

1 Knot : P = n x E x I x cos φ
P = 2 x 54 x 15 x 0,86
P = 1.393,2 Watt

2 Knot : P = n x E x I x cos φ
P = 2 x 121 x 18 x 0,86
P = 3.746,16 Watt

Table 17. The power consumption of trolley motor

	Speed	E (Volt)	I (Ampere)	Cos φ	P (Watt)	n.P (Watt)	Notes
Trolley Motor	1 Knot	54,00	15,00	0,86	686,60	1.393,20	B
	2 Knot	121,00	18,00	0,86	1.873,08	3.746,16	B+G
	3 Knot	203,00	21,00	0,86	3.666,13	7.332,36	B+G
	4 Knot	349,00	27,00	0,86	8.103,50	16.207,56	B+G
	5 Knot	365,00	32,00	0,86	10.682,40	21.364,80	B+G

Source: Data of Research

The power consumption of gantry motor, with a total of 4 gantry motors (n=4) as drivers, and is assumed cos φ = 0,86

1 Knot : P = n x E x I x cos φ
P = 4 x 36 x 33 x 0,86
P = 4.086,72 Watt

2 Knot : P = n x E x I x cos φ
P = 4 x 102 x 46 x 0,86
P = 16.140,48 Watt

Table 18. The power consumption of gantry motor

	Speed	E (Volt)	I (Ampere)	Cos φ	P (Watt)	n.P (Watt)	Notes
Gantry Motor	1 Knot	36,00	33,00	0,86	1.021,68	4.086,72	B
	2 Knot	102,00	46,00	0,86	4.035,12	16.140,48	B+G
	3 Knot	207,00	51,00	0,86	9.079,02	36.316,08	B+G
	4 Knot	342,00	61,00	0,86	17.941,32	71.765,28	B+G
	5 Knot	365,00	73,00	0,86	22.913,20	91.658,80	B+G

From Table 16-18, it can be concluded that the efficiency of the electrical energy which may be produced by batteries is

From Hoist system : 3.088,26 Watt or 3,09 kW
From Trolley system : 1.393,20 Watt or 1,39 kW
From Gantry system : 4.086,72 Watt or 4,09 kW

In the use of power for each movement of the RTGC generator and battery combined, the amount of power provided by the battery is 4.09 kW then the shortfall is supplied from the generator, therefore the efficiency value obtained from each system is:

- From hoist system (average power with hoist system at 2-5 knot = 34,895 kW)

$$Energy\ saving\ \text{battery} = \frac{Battery\ Power}{\text{average power when speed at } 2-5 \text{ knot}} X\ 100\%$$

$$= \frac{4{,}09\ kW}{34{,}895kW} X\ 100\%$$

$$= 11{,}72\%$$

- From trolley system (average power with trolley motor at 2-5 knot = 12,162 kW)

$$Energy\ saving\ \text{battery} = \frac{Battery\ Power}{\text{average power when speed at } 2-5\text{knot}} X\ 100\%$$

$$\frac{4{,}09\ kW}{12{,}162kW} X\ 100\% = 33{,}63\%$$

From gantry system (average power with gantry motor at 2-5 knot = 53,969 kW)

$$Energy\ saving\ \text{battery} = \frac{Battery\ Power}{\text{average power when speed at } 2-5\text{knot}}\ X\ 100\%$$

$$= \frac{4{,}09\ kW}{53{,}969 kW}\ X\ 100\% = 7{,}53\%$$

Therefore, it can be concluded that the energy efficiency of the battery varies depending on the movement and speed commanded by the operator.

Operation Mode

With the RTGC operating mode using the hybrid system, it can increase efficiency. When using a non-hybrid system, the generator (if cos φ = 0.86) produces power of:

P = E x I x cos φ
P = 420 x 230 x 0,86
P = 83.076 Watt

Then the energy consumption needed for 5 hours is:

Energy consumption = real power x duration of operation
= 83076 x 5
= 415.380 Wh or 415,38 kWh

In contrast to the hybrid system, the required power consumption (if cos φ = 0.86) is:

When engine rating, the power produced is:

P = E x I x cos φ
P = 420 x 230 x 0,86
P = 83.076 watt

When the engine is idle, the power produced is:

P = E x I x cos φ
P = 216 x 16 x 0,86 = 2.972,16 watt

The needed power consumption when operating for 5 hours is:

$$= 1{,}67\% Engine\ Idle = \frac{1}{3}\ X\ 5 = 3{,}33\% Engine\ rating = \frac{2}{3}\ X\ 5$$

Then the needed consumption is:

Engine rating: Energy consumption = Real Power x Duration of Operation
= 83.076 x 3,33
= 276.643,08 Wh
= 276,643 kWh

Engine Idle: Energy consumption = Real Power x Duration of Operation
= 2.972,16 x 1,67
= 4.963,5 Wh
= 4,963 kWh

Therefore, the total of electric energy consumption

= 276,643 + 4,963 = 281,606 kWh

$$= \frac{(415{,}38kWh - 281{,}606kWh)}{415{,}38kWh}\ X\ 100\%$$

Thus the energy efficiency value of the Hybrid and Non-Hybrid systems is obtained:

$$\frac{non\ hybrid\ enery - hybrid\ energy}{non\ hybrid\ energy}\ X\ 100\% = 32{,}205\%$$

Apart from efficient use of electrical energy, the hybrid system may also produce electrical energy for charging batteries from hoist down movements, based on Table 16 the regenerative voltage and current are: (voltage and current are obtained from an average value of 3-5 knots based on Table 16)

S = E x I

S = 288,3 x 84,6
S = 24.390,18 Watt
Thus, the total of energy produced for 5 hours is:
Energy produced = Power x time
= 24.390,18 x 1,67
= 40.731,6 Wh or 40,731 kWh

Therefore, with the calculation results above, the level of efficiency in using electrical energy for the hybrid system is quite high, namely producing 32.205% for 5 hours of operation, not adding the power produced from the regenerative current of 40.731 kWh, then the efficiency for the hybrid system reaches > 32.2%.

CONCLUSION

From the results of the discussion that has been carried out, it can be concluded as follows:

1. The rise and fall of engine Rpm does not affect the control system on RTGC.
2. Regenerative current can increase electric energy efficiency to 32,20 %
3. The battery of hybrid system can obtain electric energy saving of:
   a. Hoist system = 11,72 %
   b. Trolley system = 33,63 %
   c. Gantry system = 7,58 %

Suggestions

Suggestions for further development:

1. Change the PLC programming on the Trolley system, so that when the speed of 3knots the battery that supplies power to move the trolley without having to use the generator works optimally.
2. Need to do more regular and routine maintenance.

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