ANALYSIS OF MAXIMUM CAPACITY CALCULATION OF KOTA STATION TRACTION SUBSTATIONS TO MAXIMIZE MRT JAKARTA PHASE 2 TRAIN OPERATIONS

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ABSTRACT

MRT Jakarta is one of the providers of rail transportation services in Jakarta, which is an absolute solution to the problem of congestion in Jakarta because mass transportation can transport people in large quantities in one trip so that by calculating the electrical power capacity to supply electricity to the MRT Jakarta train it is very important with the aim of predicting the pattern of train operation.
This test includes calculating the use of traction substations with headway, namely 10, 7, 5, 3, and 1 minute, then the power usage of the train according to data from technical specifications and also required data on filling distances for Kota Station Traction Substations in Phase 2 construction documents, then an analysis is carried out for the ability of the traction substation that supplies train operators in Phase 2.
After calculating and analyzing, concluded that under normal conditions the Kota Traction Substation can operate continuously with a headway operating pattern of 10, 7, 5, and 3 minutes, then in disturbance conditions, 1 TSS Off the Kota Traction Substation can operate continuously with an operating pattern. headway 10, 7, and 5 minutes, then in disturbance condition 2 TSS Off.

Keywords: *Transportation, Traction Substation, headway.*

1. INTRODUCTION

The train is an effective and efficient rail-based transportation mode, because the train can transport large amounts of passengers and goods in one go, and has many other advantages, including energy-saving, low pollution, does not require a lot of lands, and is free from congestion. The railway is a unified system consisting of infrastructure, facilities, human resources, norms, criteria, requirements, and procedures for the operation of rail transportation. Railway infrastructure is a railway line, train station, and train operating facilities so that trains can be operated.

The fundamental difference from the electricity system compared to the existing rail system in Indonesia is that Mass Rapid Transit (MRT) Jakarta uses a voltage of 150 kV from the two line Perusahaan Listrik Negara (PLN) substations, namely Pondok Indah Substation and Gas Insulated Substation (GIS) Centrale Stichting Wederopbouw (CSW) which is supplied to the Phase 1 Substation, namely GIS Taman Sambas, which is then being planned. Later the Phase 2 Substation located at Monas will also be supplied from two PLN substations. At the Monas Substation, the voltage of 150 kV is reduced to 20 kV which is then distributed to the Traction Substation (TSS) and the Electrical Room (ER) Station Distribution Substation. MRT is a modern train that is being built in the city of Jakarta. Consists of 13 stations, 7 elevated stations, and 6 underground stations for Phase 1 and 7 underground stations for Phase 2A.

In the Operational MRT Jakarta Phase 1, the distance between trains is still within 5 minutes, while population growth in Jakarta is very rapid, therefore the calculation of the electrical power capacity to supply electricity to MRT Jakarta trains in the future is very important to predict the pattern operation. To find out the electrical power capacity at the MRT Jakarta traction substation, a research was carried out "Analysis of Calculation of Maximum Capacity of Kota Station Traction Substations to Maximize MRT Jakarta Phase 2 Train Operations" by reducing the headway to accelerate the accommodation of Jakarta residents to their destination and prepare for train operation in Jakarta. future.

The 20 kV output voltage from the RSS is received by the 20 kV Switchgear, then the voltage is lowered by the Rectifier to a nominal voltage of 1500 VDC. Furthermore, it is channeled to the DC Switchgear and removed through the feeder cable. This 1500 VDC voltage is used for catenary supply needs. Furthermore, the 1500 VDC voltage is used for power requirements for MRT Jakarta facilities/trainsets such as moving traction motors, lighting, air conditioning, and other needs to support daily train operations in carrying out their duties in mobilizing people to their destination.

To continue construction and extend the operational line of MRT Jakarta to continue integration in facilitating community mobilization for daily activities, in the construction of Phase 2A MRT Jakarta added 7 operational stations, of which there are 2 traction substations and can be seen in the appendix for more details, as follows: Station construction in Phase 2A:

Jakarta MRT Station Phase 2A (under construction), namely Thamrin, Monas, Harmoni, Sawah Besar, Mangga Besar, Glodok, Kota. MRT Jakarta Traction Station Phase 2A (under construction), namely TSS Monas and TSS Kota.

2. RESEARCH METHODS

In conducting research, the following supporting data are needed:

1. Jakarta MRT Train Data
   Overall data includes traction motor power, train facilities, fuel consumption ratio, and total trainload.
2. Headway used
   Headway data used in the calculation is in minutes.
3. Traction substation filling or distribution distance
   The distance between the Traction Substations in distributing the stress for the needs of the train according to the documents obtained.

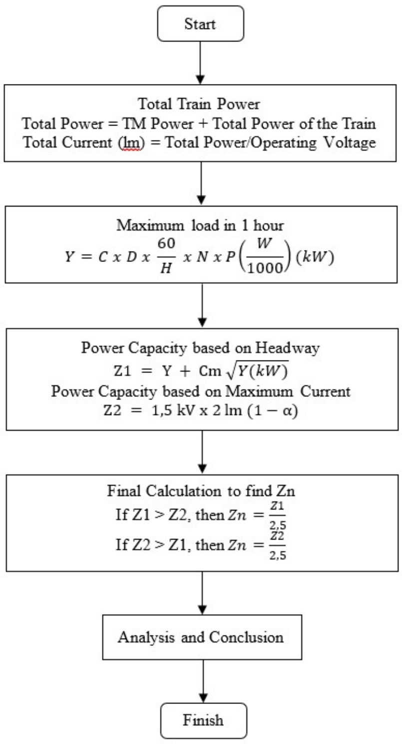

Figure 1. Research Flow

In the design flow, it is explained that the calculation starts from finding the total current data (Im) by calculating the total power of the train with the operating voltage, then calculating the maximum load in 1 hour (Y) using the data that has been obtained, then looking for the values of Z1 and Z2 using the resulting data. calculation of total current (Im) and maximum load in 1 hour (Y).

After the Z1 and Z2 values are obtained, they are compared to find the Zn value so that it can be analyzed and concluded by looking at the power consumption according to the capacity of the Kota Traction Substation, the Jakarta MRT train in phase 2 can be determined its operating pattern.

3. RESULTS AND DISCUSSION

Below is the traction motor data used in the calculation:

Table 1. Propulsion System Specification [1].

ITEMS	DESCRIPTION
Power converter	VVVF Inverter, 2-level IGBT inverter
Power capacity (Specification)	2,600 kVA
Traction Motor	3 phase AC Motor
Traction Motor Rating	
Continous Rating	125 kW
One hour Rating	140 kW
Pantograph	Single arm pantograph 4 set/train

The analysis used to find the data is by calculating the power requirements of the Jakarta MRT train and the power capacity of the Traction Substation, Calculation of Total Power on the train using the following formula [2]:

$$Im = \frac{total\ power}{operating\ voltage}$$

From the gapeka that has been made during the operation of the Jakarta MRT, it can be seen that the train travels for 1 trip and to find the headway, here is the formula [2]:

$$H = \frac{Time\ (T)}{Number\ of\ Trains\ (N)}$$

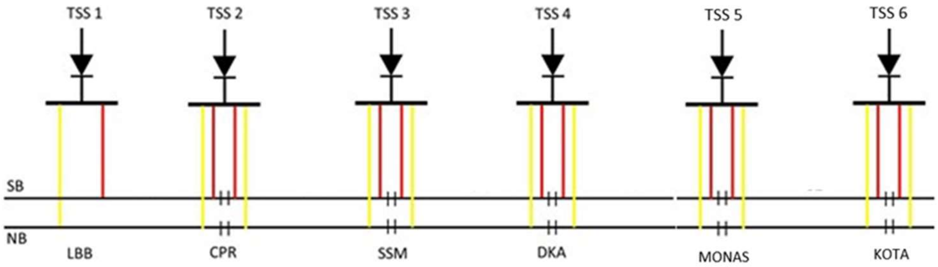

Figure 2. Phase 1 and Phase 2 Traction Substations [3].

Traction Substation Power Capacity is a calculation of the ability of a Substation to supply Voltage with a maximum load for 1 hour, the Rectifier capacity is taken from the value between the peak load or the maximum load.
The power capacity of the Traction Substation can be calculated based on the following formula [4]:

$$Y = C\ x\ D\ x\ \frac{60}{H}\ x\ N\ x\ P\ (\frac{W}{1000})\ (\text{kW})$$

Traction Substation Power Capacity based on the headway using the formula below [4]:

$$Z1 = Y + Cm\ \sqrt{Y}\ (Kw) \text{ and } Cm = 1.7\ x\sqrt{Im}$$

The power capacity based on the maximum current load uses the formula below [4]:

$$Z2 = 1.5kV\ x\ 2\ Im\ (1\text{-}\alpha)$$

The final calculation to get the maximum capacity value for the Traction Substation uses the Zn value, namely [4]:

$$Zn = \frac{Z1}{2{,}5} \text{ If Z1>Z2 and If Z2>Z1} Zn = \frac{Z2}{2{,}5}$$

In this calculation we look for the initial results of the maximum load in 1 hour, from the specifications obtained for 1 train there are 4 traction motors and for 1 train series there are 4 motor cars so that the power requirements are obtained as follows :

TM power = 16 x 140 kW = 2240 kW

The power for domestic use of the carriage is 371.9268 kW.
So the total power of 1 TS MRT is as follows :

Total power = TM Power + Power for car household use
Total power = 2240 kW + 371.9268 kW = 2611.93 kW

It is known that the total power of 1 TS of MRT facilities is 2611.93 kW (2902.14 kVA), then the load value of 1 TS is as follows :

Total current (Im) = Total power/Operating voltage
Total current (Im) = 2902.14 kVA /1.5 kV = 1935 Ampere

So, the current per 1 TS of MRT Jakarta (Im) facilities is 1935 Ampere.

Table 2. Traction Substation Filling Distance [5].

[o	Traction Substation Location	Supplied Line	Charging Length (km)	Total Charging Distance (km)
1	TSS Lebak Bulus	Lebak Bulus - Depot	0,229	2,142
		Lebak Bulus - Cipete Raya	1,913	
2	TSS Cipete Raya	pete Raya - Lebak Bulus	1,913	4,119
		Cipete Raya - Asean	2,206	
3	TSS Asean	Asean - Cipete Raya	2,206	4,879
		Asean - Dukuh Atas	2,673	
4	TSS Dukuh Atas	Dukuh Atas - Asean	2,673	4,032
		Dukuh Atas - Monas	1,359	
5	TSS Monas	Monas - Dukuh Atas	1,359	3,453
		Monas - Kota	2,094	
6	TSS Kota	Kota - Monas	2,094	2,094

Calculation of the maximum load in one hour (Y) at the Kota Traction Substation with the current headway based on GAPEKA 2021 and in the calculation below using data from one of the headways, which is 10 minutes under normal conditions:

a. Total Kota Filling Distance (D) : 2,094 km
b. Operating Household Composition (C) : 6 KA
c. Total Weight of Household and Passenger (W) : 322.12
d. *Headway* (H) : 10 minutes
e. Track Type (N) : 2 (double track)
f. Fuel Consumption Ratio (P) : 50

Maximum load calculation formula 1 hour [6]:

$$Y = C\ x\ D\ x\ \frac{60}{H}\ x\ N\ x\ P\ (\frac{W}{1000})\ \text{(kW)}$$
$$Y = 6 \times 2{,}094 \times \times 2 \times 50 \times \frac{60}{10}\frac{322{,}12}{1000}$$
$$Y = 2428\ \text{kW}$$

With the value of Cm (electrification factor) obtained the calculation value [7]:

$$Cm = 1.7 \times \sqrt{Im}$$
$$Cm = 1.7 \times \sqrt{1935}$$
$$Cm = 74.781\ \text{kW}$$

Instantaneous peak load based on headway (Z1) [7]:

$$Z1 = Y + Cm\ \sqrt{Y}$$
$$Z1 = 2428 + 74{,}781\ \sqrt{2428}$$
$$Z1 = 6113\ \text{kW}$$

Instantaneous peak load by load Maximum current (Z2) [7]:

$$Z2 = 1{,}5\ kV \times 2 \times Im\ (1-\alpha)$$
$$Z2 = 1{,}5\ kV \times 2 \times 1935\ (1-0{,}08)$$
$$Z2 = 5431\ \text{kW}$$

It can be seen the size of the substation capacity needed to supply the Monas - Kota Up Track and Down Track crossings with the comparison that the value of Z1 is greater than the value of Z2 using the following formula :

$$Zn = \frac{\mathbf{Z1}}{\mathbf{2{,}5}} = \frac{\mathbf{6113}}{\mathbf{2{,}5}} = 2445\ \text{kW} = 2717\ \text{kVA}$$

So the final result is that the required electrical power capacity at the Traction Substation for crossing Monas - Kota Up Track and Down Track is 2717 kVA.

After getting the final results in the calculation of the Traction Substation Power capacity, then the calculations are carried out again as before using different data as needed, namely headway 10, 7, 5, 3 and 1 minute with normal conditions, disturbance conditions 1 TSS off and disturbance conditions 2 TSS off . Then all the calculation results are entered into a table to make it easier to analyze and create graphs.

Table 3. Calculation Results Under Normal Conditions [8].

No	Traction Station Location	Supplied Track Grid	Charging Length (km)	Total Charging Distance (km)	Operating Trains (set)	Train + Passengers Weigh per set (ton)	Headway used	Track type (Single=1, Double=2)	Fuel consumption ratio (kWh/1000 ton-km)	Current usage (A)	Electrification factor (KW)	Maximum Load [Y](KW)	Headway Peak Load [Z1] (KW)	Maximum Current Peak Load [Z2] (KW)	Required Traction Substation Capacity [Zn]		Substation Capacity	Power Usage (%)
															(kW)	(kVA)	4850 x 2	
Normal Condition																		
1	Kota	Kota-Monas	2,094	2,094	6	322.12	10	2	50	1935	74,781	2,428	6,113	5,341	2,445	2,717	9,700	28.01%
2	Kota	Kota-Monas	2,094	2,094	6	322.12	7	2	50	1935	74,781	3,469	7,783	5,341	3,149	3,499	9,700	36.08%
3	Kota	Kota-Monas	2,094	2,094	6	322.12	5	2	50	1935	74,781	4,857	10,068	5,341	4,027	4,475	9,700	46.13%
4	Kota	Kota-Monas	2,094	2,094	6	322.12	3	2	50	1935	74,781	8,094	14,822	5,341	5,929	6,588	9,700	67.91%
5	Kota	Kota-Monas	2,094	2,094	6	322.12	1	2	50	1935	74,781	24,283	35,936	5,341	14,374	15,971	9,700	164.65%

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Table 4. Calculation Results in Condition 1 TSS Off [8].

No	Traction Station Location	Supplied Track Grid	Charging Length (km)	Total Charging Distance (km)	Operating Trains (set)	Train + Passengers Weigh per set (ton)	Headway used	Track type (Single=1, Double=2)	Fuel consumption ratio (kWh/1000 ton-km)	Current usage (A)	Electrification factor (KW)	Maximum Load [Y](KW)	Headway Peak Load [Z1] (KW)	Maximum Current Peak Load [Z2] (KW)	Required Traction Substation Capacity [Zn]		Substation Capacity	Power Usage (%)
															(kW)	(kVA)	4850 x 2	
Emergency Condition (1 Traction Substation off)																		
1	Kota	Kota-Monas	2,094	3,453	6	322,12	10	2	50	1935	74,781	4.004	8.763	5.341	3.494	3.883	9.700	40.03%
		DKA-Monas	1,359															
2	Kota	Kota-Monas	2,094	3,453	6	322,12	7	2	50	1935	74,781	5.720	11.376	5.341	4.550	5.056	9.700	52.12%
		DKA-Monas	1,359															
3	Kota	Kota-Monas	2,094	3,453	6	322,12	5	2	50	1935	74,781	8.008	14.701	5.341	5.880	6.534	9.700	67.36%
		DKA-Monas	1,359															
4	Kota	Kota-Monas	2,094	3,453	6	322,12	3	2	50	1935	74,781	13.347	21.987	5.341	8.795	9.772	9.700	100.74%
		DKA-Monas	1,359															
5	Kota	Kota-Monas	2,094	3,453	6	322,12	1	2	50	1935	74,781	40.042	55.006	5.341	22.002	24.447	9.700	252.03%
		DKA-Monas	1,359															

Table 5. Calculation Results in Condition 2 TSS Off [8].

After all data is collected and graphed, it can be explained that:

- At the time of operation using a 10-minute headway, the Kota Traction Substation received a load below 100% for normal conditions, 1 TSS off and 2 TSS off disturbances.
- At the time of operation using a 7-minute headway, the Kota Traction Substation received a load below 100% for normal conditions, 1 TSS Off and 2 TSS Off disturbances.
- At the time of operation using a 5-minute headway, the Kota Traction Substation received a load below 100% for normal conditions and 1 TSS Off disturbance and above 100% for 2 TSS Off disturbance conditions.
- During operation using a 3-minute headway, the Kota Station Traction Substation gets a load below 100% for normal conditions and above 100% for disturbance conditions of 1 TSS off and 2 TSS Off.
- At the time of operation using a 1-minute headway, the Kota Station Traction Substation gets a load above 100% for normal conditions, 1 TSS off and 2 TSS Off disturbances.

No	Traction Station Location	Supplied Track Grid	Charging Length (km)	Total Charging Distance (km)	Operating Trains (set)	Train + Passengers Weigh per set (ton)	Headway used	Track type (Single=1, Double=2)	Fuel consumption ratio (kWh/1000 ton-km)	Current usage (A)	Electrification factor (KW)	Maximum Load [Y](KW)	Headway Peak Load [Z1] (KW)	Maximum Current Peak Load [Z2] (KW)	Required Traction Substation Capacity [Zn]		Substation Capacity	Power Usage (%)
															(kW)	(kVA)	4850 x 2	
Emergency Condition (2 Traction Substation off)																		
1	Kota	Kota-Monas	2,094	6,126	6	322,12	10	2	50	1935	74,781	7.104	13.407	5.341	5.363	5.959	9.700	61.43%
		DKA-Monas	1,359															
		DKA-Asean	2,673															
2	Kota	Kota-Monas	2,094	6,126	6	322,12	7	2	50	1935	74,781	10.148	17.682	5.341	7.073	7.859	9.700	81.02%
		DKA-Monas	1,359															
		DKA-Asean	2,673															
3	Kota	Kota-Monas	2,094	6,126	6	322,12	5	2	50	1935	74,781	14.208	23.121	5.341	9.249	10.276	9.700	105.94%
		DKA-Monas	1,359															
		DKA-Asean	2,673															
4	Kota	Kota-Monas	2,094	6,126	6	322,12	3	2	50	1935	74,781	23.680	35.187	5.341	14.075	15.639	9.700	161.22%
		DKA-Monas	1,359															
		DKA-Asean	2,673															
5	Kota	Kota-Monas	2,094	6,126	6	322,12	1	2	50	1935	74,781	71.039	90.970	5.341	36.388	40.431	9.700	416.82%
		DKA-Monas	1,359															
		DKA-Asean	2,673															

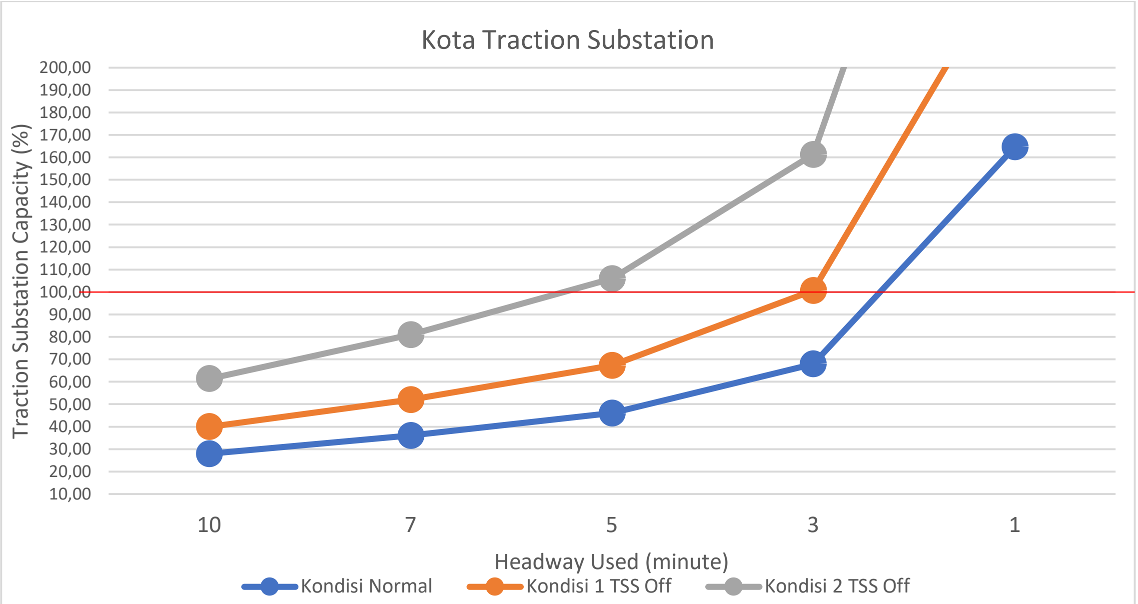

Figure 3. Graph of Kota Traction Substation Power Consumption

4. CONCLUSION

Based on the results of the calculation and analysis of the maximum capacity of the Kota Station Traction Substation, it can be concluded as follows:

1. Under normal conditions the Kota Station Traction Substation can operate continuously with a headway of 10, 7, 5, and 3 minutes. As for the 1-minute headway, it is not recommended because it exceeds 100% of the ability Traction Substation.
2. In the event of a disturbance when 1 TSS is off or the Monas Traction Substation is failure, the Kota Station Traction Substation can operate continuously with a headway of 10, 7, and 5 minutes. As for the 3 and 1-minute headway, it is not recommended because it exceeds 100% of the ability Traction Substation.
3. When 2 TSS is off or the Dukuh Atas and Monas Traction Substations are failure, the Kota Station Traction Substation can operate continuously with a headway of 10 and 7 minutes. Meanwhile, 5, 3, and 1-minute headways are not recommended because they exceed 100% of the capacity of the Traction Substation.

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NOTATION LIST

H = headway/distance between trains [minutes]
T = time [minutes]
N = number of trains [series]
Y = maximum load 1 hour
C = arrangement of the circuit [set]
D = Traction Substation filling distance [km]
N = 2 [double track], 1 [single track]
P = Ratio of train consumption
W = total weight of train + hood passengers. 200% [tons]
Im = maximum train current [A]
α = Current sharing ratio [used 0.08 for DC]
Cm = Electrification factor [kW]
Z1 = Instantaneous peak load based on headway [kW]
Z2 = Peak load based on maximum current [kW]
Zn = Substation capacity used [kW]

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