Planning and installation vertical electric transportation system

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Abstract. The construction of high-rise buildings in big cities, especially in Bandung is increasing. The elevator is a vertical electrical transportation system used to transport people or goods and serves to facilitate the activities of human life whose routines are more often inside buildings or high-rise buildings. Vertical electric elevator transportation is following SNI standards and knows the needs for elevator capacity in multi-story buildings which include empty train loads, draw weight loads, motor power, motor speed, and electricity costs. In this research, the problems to be discussed are regarding the load of the empty train, the load weight used, motor power, motor speed, and power costs. The results of this planning obtained important things such as the required empty trainload (Qk) = 1000 kg, the load weight used (Qp) = 1225 kg, motor power is used when the train is filled with maximum capacity (P output) = 3,15 kW = 4.22 hp, the traction motor rotational speed when the elevator is upward with full load = 913.5 rpm, the traction motor rotational speed when the elevator goes down with full load = 228.37 rpm, and the cost of electricity to be paid is Rp.23,765 / unit/day.

1. Introduction
The elevator is a vertical transportation system that is used to transport people or goods and serves to facilitate the activities of human life which routines are more often located in buildings or high-rise buildings, usually more than three or four floors [1]. Lower buildings or buildings usually only have stairs or escalators. Today, the elevator system has become significant vertical transportation for tall buildings in the last few decades [2]. The elevator is also a substitute for the function of the stairs to reach the next floor in a multi-story building that requires considerable energy and time. So with the elevator cannot be ruled out again because one of the advantages is that it can streamline energy as well as the time of the elevator user, easy to reach and easy to operate, has sufficient capacity and can quickly move passengers from one floor to another floor and completely automated [3].

Judging from the movement of the elevator can be divided into Electric lifts, Machine Room fewer lifts, and Hydraulic lifts [4]. The design of the elevator is based on various factors, including Passenger capacity, the number of floors served, the interior of the elevator, and the availability of the engine room. The number of floors served can be a basis for consideration in designing a vertical electric transportation system (elevator). The type of elevator propulsion used is Electric lifts that use electric motors as movers [5].

With the development of the era, the development of the elevator is also getting better. Where since it was first built, the elevator drive system starts with a simple method, namely in a crane with a rope
and at this time the elevator drive system uses a motor that has a large capacity that is controlled by a control panel so that the elevator can run automatically. Aside from the drive system, the elevator installation is currently using the latest system, where its use is more energy-efficient and has high efficiency as well as in international buildings. According to incomplete statistics, among more than 600,000 lifts used in the country in 2013, energy-efficient lifts accounted for only 1.92%. In 2015, if all elevators in the country still use elevators that are not energy efficient, the elevator will consume around 80 billion KWh more electricity, which is equivalent to the annual power plant of the Three Gorges Power Station (BAHD Elevator Engineering Co., Ltd).

In the process of designing lifts for passengers, according to SNI standards, it is necessary to consider the type and function of the building, including the number of floors, area and intervals. Apart from that it can be distinguished from capacity, several loads, and speed. So elevator planning must be tailored to the needs of users and their ability to mobilize on each floor [6].

2. Methodology

2.1. Flowchart research procedure

![Flowchart of the research procedure]

Based on Figure 1, the first thing in the research procedure that was carried out was the purpose of this study was to determine the design of a vertical electric elevator transport system that includes elevator construction. After that, conduct a literature study related to elevator design. The literature used is sourced from national and international journals such as (sciencedirect.com and IEEE explore) and comes from textbooks and then processed through Mendeley software.

After the literature is collected, the next process is to compile survey instruments which include data on lift capacity, total load, elevator speed, and electric power for the elevator. Then the data is collected at PT. Pillar Utama Contrindo on Jl. Ciliwung No.13, Bandung City and Health Development Office on Jl. Lengkong Kecil, Kota Bandung.
After the data is collected, the next process is to design the elevator using a gearless elevator drive machine.

2.2. Elevator data
Elevator data type VGP-6 (450) -C060-5 / 5 are obtained from the elevator catalogue as follows:

| Description                  | Planning                      |
|------------------------------|-------------------------------|
| Function                     | Passenger Elevator            |
| Building Height              | 5 Floor                       |
| Speed                        | 60 m/minute                   |
| Capacity                     | 450 kg                        |
| Traction Machine             | AC-VVVF                       |
| Hoistway                     | 1850 mm x 1850 mm             |
| Pit                          | 1500 mm                       |
| Car                          | (AxBxT) = 1400 mm x 1030 mm x 2450 mm |
| Gate                         | 800 mm x 2250 mm              |
| Machine room                 | (SxTxH) = 3600 mm x 4000 mm x 2000 mm |
| Height of each floor         | 3800 mm                       |
| Travel Elevator Height       | 15200 mm                      |
| Overhead Height              | 4100 mm                       |

Operation of lift VGP-6 (450) -C060-5 / 5 uses electric power with a 380-volt AC voltage, 3 phase, 50 HZ with a variable voltage variable frequency (VVVF) system. By using a gearless traction machine, this system of electric power used from PLN is so small that it makes the VGP-6 (450) -C060-5 / 5 elevators as an energy-efficient elevator.

2.3. Comparison of train weight to capacity
The weight of an empty train must meet certain conditions so that the rope stays tight so that the rope does not slip. In practice, lifts with a capacity below 600 kg have an empty train weight of 1.0 to 1.5 times its capacity. As for lifts with a capacity above 1300 kg, they have an empty train weight 1.8 times or even 2.2 times the lifting capacity.

The weight of the train to its capacity affects the rope tension, traction connection, and prevents slip.

2.4. Balance
There are two types of balance understanding:

- Dynamic Balance is a balance between the weight of an empty train plus a certain amount of load (overbalance) to the weight of a balanced weight (counterweight). Therefore, the weight of the draw must be heavier than the empty train. The excess weight on the train is called overbalance. The amount of overbalance is between 0.4 to 0.5 of the maximum load.

- Static Balance is the balance of the train body sitting on the frame and take off, which is supported by rubber vibration isolation absorbers. The upper end of the carriage is supported by rubber rollers on the right and left and "leaning" on the train frame (stiles). If the train is balanced, the rubber rollers do not press against the frame, unless there is vibration. Once on the guide roller (guide roller) is not too pressing on the rail surface, so that minimal obstacles.

- Calculation of draw weight with overbalance 0.5, namely:

\[ Q_{cw} = Q_k (0.5 \times Q_p) \]
2.5. Motor rotating speed

\[ N = 120 \times f \left(1 - \frac{s}{p}\right) \]

Where:
- \( N \) = Motor speed (rpm)
- \( f \) = Frequency of electric power source (Hz)
- \( s \) = Slip from the rotating speed of the magnetic field to the rotation of the motor, increase 3% for synchronous motors or 13% when lifting at full load.
- \( p \) = Number of poles, Usually = 4

2.6. Motor pulley wheel diameter

\[ D = V \times gr/\pi \times N \]

Where:
- \( D \) = Motor pulley wheel diameter (m)
- \( gr \) = Gear ratio
- \( V \) = Lift speed (m / minute)
- \( N \) = Motor rotational speed (rpm)

2.7. Efficiency and power

The efficiency of the elevator system consists of several elements of the efficiency of the subsystem:
- Pulling efficiency \( \eta_1 = \pm 0.90 \)
- Engine efficiency \( \eta_2 = \pm 0.95 \) gearless machine
- \( \eta_3 = \pm 0.55 \) to \( \pm 0.80 \) using a geared transmission
- \( \eta_3 = \pm 0.97 \) (3% is lost as heat loss).

How to calculate the total efficiency of the elevator system as follows:

\[ \eta_T = \eta_1 \cdot \eta_2 \cdot \eta_3 \]

Where:
- \( \eta_T \) = Total system efficiency

The power output from the installation can be formulated:

\[ P_{\text{output}} = \frac{Q_p \times V \times (1 - OB)}{6120 \times \eta_T} \]

Where:
- \( P_{\text{output}} \) = Power used (kW)
- \( Q_p \) = Normal lift capacity (kg)
- \( O_B \) = Nominal lift speed (m / min)
- \( \eta_T \) = Total system efficiency = \( \eta_1 \cdot \eta_2 \cdot \eta_3 \)
- 6120 = Conversion rate Kg.m / minute to kW
- 1 kW = 6120 kg / minute
- 1 hp = 4562 kg / minute or 0.746 kW

2.8. Elevator speed and frequency

In elevator installations that use VVVF (Variable Voltage Variable Frequency) speed control, it is possible to plan pulley diameters from a minimum of 40 to 60 times the diameter of a steel strap. The minimum diameter of the pulley diameter according to SNI is 40 times the diameter of the steel rope, but this tends to shorten the life of the rope. Therefore, planning the diameter of the pulleys is directed 55 to 60 times the diameter of the rope, by selecting the number of poles and the amount of frequency.

Calculation of the frequency of gearless and geared machines with the following formula:

\[ f = \frac{N \times p}{120 \left(1 - \frac{s}{p}\right)} \]

Where,
N = rotating speed (radial speed) of the pulleys (in rpm)
D = pulley diameter (m)
π = 3.14
f = Frequency of AC motor (Hz)
s = Slip (13%)
P = Number of pole pairs

3. Results and discussion

3.1. Multi-story building
Before planning the vertical electric elevator transportation system for health offices in Lengkong Kecil, Bandung, the data that has been collected needs to be identified first. The data has been obtained as follows:
- Building height = 5 floors
- Height of each floor = 3800 mm
- Travel lift height = 15200 mm
- High overhead = 4100 mm
- Hoistway size = 1850 mm x 1850 mm
- Machine room height = 2000 mm
- Pit space height = 1500 mm

3.2. Train load
Known:
- Maximum lifting capacity, \( Q_p = 450 \) kg
- Average load per person = 75 kg / person, hence, for the passenger elevator it can carry a maximum of 6 people.

\[
\text{Area of trains, } A_k = 1400 \text{ mm} \times 1030 \text{ mm} = 1442000 \text{ m}^2 = 1442 \text{ m}^2
\]

Average area per person
\[
A_{\text{people}} = \frac{A_k}{(\text{capacity of people})} = \frac{1442 \text{ m}^2}{6} = 0.240 \text{ m}^2
\]

Empty trainload must meet certain conditions to keep the rope tense so that slippage does not occur. In practice, the weight is usually empty, \( Q_k = 1,8 - 2,2 \times \text{lifting capacity} (Q_p) \).

Then it is assumed that the load is empty:
\[
Q_k = 2,2 \times 450 \text{ kg} = 990 \text{ kg} \approx 1000 \text{ kg}
\]

3.3. Counterweight
Counterweights are planned to be made of gray cast iron with density = 7190 kg/m\(^3\) FC 35 JIS G 5501. Draw weight weights can be calculated using the formula:

Known:
- Maximum lifting capacity, \( Q_p = 450 \) kg
- Empty car weight, \( Q_k = 1000 \) kg
- Overbalance, \( Q_b = 0,5 \) [7].

Then the weight of the draw weight is obtained by using the equation:

\[
Q_{cw} = Q_k(0,5 \times Q_p)
\]

\[
Q_{cw} = 1000 \text{ kg} + (0,5 \times 450 \text{ kg})
\]

\[
Q_{cw} = 1225 \text{ kg}
\]

Counterweight Volume, \( V_{cw} \):

\[
V_{cw} = \frac{Q_{cw}}{P_{cw}}
\]
\[ V_{cw} = 1225 \text{ kg} \]
\[ V_{cw} = \frac{7190 \text{ kg/m}^3}{m^3} \]
\[ V_{cw} = 0.170 \text{ m}^3 = 170 \times 10^6 \text{ mm}^3 \]

Planned:
- Draw weight length, \( P_{cw} = 1000 \text{ mm} \)
- Draw weight width, \( l_{cw} = 220 \text{ mm} \)
- Load one weighted draw = 50 kg
- Weighted balance, \( Q_{cw} = 1225 \text{ kg} \)

![Figure 2. Counterweight bar section.](image)

Then the height of the draw weight, \( t_{cw} \)

\[
t_{cw} = \frac{V_{cw}}{(P_{cw} \times l_{cw}) - 4(P \times l)} = \frac{170 \times 10^6 \text{ mm}^3}{(1000 \text{ mm} \times 220 \text{ mm}) - 4(100 \text{ mm} \times 60 \text{ mm})} = 885.41 \text{ mm}
\]

Total bars counterweight, \( \Sigma_{bat} = \frac{Q_{cw}}{m_{bat}} = \frac{1225 \text{ kg}}{50 \text{ kg}} = 25 \text{ bar} \)

Then the height of each counterweight bar is:

\[
t_{bat} = \frac{t_{cw}}{\Sigma_{bat}} = \frac{885.41 \text{ mm}}{25} = 35.41 \text{ mm}
\]

To simplify installation, this draw weight is made from cast iron bars, grooves made at both ends to facilitate binding.
3.4. **Pulley**

Known:
- Pulley density is made of cast iron = 7250 kg/m³
- Lift speed, \( V = 60 \text{ m/min} = 1 \text{ m/s} \)
- Electric power source frequency, \( f = \text{from PLN 50 Hz is changed to 35 Hz} \) using AC Induction motor variable frequency and reduction gear
- Slip up the rotational speed of the magnetic field to the rotation of the motor. \( S = 13\% \)
- Number of poles, \( P = 4 \)
- 1:1 rope system
- Gear ratio, \( gr = 20:1 \)

![Figure 3. Counterweight bar compiler.](image1)

![Figure 4. single wrap drive.](image2)
The magnitude of the rotational speed of the traction motor can be calculated by the formula:

\[ N = \frac{120 \cdot f \cdot (1 - s)}{p} \]

The rotational speed of the traction motor when the elevator is above the full load:

\[ N = \frac{120 \cdot f \cdot (1 - s)}{p} \]

\[ N = \frac{120 \cdot 0.35 \cdot (1 - 0.13)}{4} = 913.5 \text{ rpm} \]

When the elevator will land down to the intended floor, the number of poles will be changed to 4 times.

The rotational speed of the traction motor when the lift is down at full load:

\[ N = \frac{120 \cdot f \cdot (1 - s)}{4 \cdot p} \]

\[ N = \frac{120 \cdot 0.35 \cdot (1 - 0)}{4 \cdot 4} = 228.37 \text{ rpm} \]

Pulley drive diameter can be calculated by the formula:

\[ D = \frac{V \cdot g \cdot r}{\pi \cdot N} \]

\[ D = \frac{60 \times 20}{3.14 \times 913.5} = \frac{1200}{2868.3} = 0.418 \text{ m} = 418 \text{ mm} \]

3.5. Elevator drive

In the drive system chosen is the transmission system without gear reduction (gearless machine) with a 1:1 bounce system, then the static power of the installation system can be formulated:

\[ P_{\text{output}} = \frac{Q_p \cdot V \cdot (1 - OB)}{6120 \cdot \eta_T} \]

\[ P_{\text{output}} = \frac{450 \, \text{kg} \times 60 \, \text{menit} \times (1 - 0.5)}{6120 \times (0.82)} \]

\[ P_{\text{output}} = 2.7 \, \text{kW} = 3.62 \, \text{hp} \]

Efficiency Total, \( \eta_T = \eta_1 \cdot \eta_2 \cdot \eta_3 \)

\[ \eta_T = 0.90 \times 0.95 \times 0.97 = 0.82 \]

The power used at 6.7 kW occurs when the elevator is fully loaded and in an upward direction. The elevator with the empty train downward, then the power used (\( P_{\text{output}} \)) is:

\[ P_{\text{output}} = \frac{Q_p \cdot V \cdot (1 - OB)}{6120 \cdot \eta_T} \]

\[ P_{\text{output}} = \frac{450 \, \text{kg} \times 60 \, \text{menit} \times (1 - 0.5)}{6120 \times (0.82)} \]

\[ P_{\text{output}} = 2.7 \, \text{kW} = 3.62 \, \text{hp} \]

The average number per day is assumed to be 50% when the elevator is fully loaded up and the empty train is downward. And 50% of the lifts work in balance (balance) for 12 hours per day, the power used per day is:

\[ P_{\text{day}} = 0.5 \times \left( \frac{2.7 \, \text{kW} + 2.7 \, \text{kW}}{2} \right) \times 12 \, \text{hour} = 16.2 \, \text{kWh} \]

It is assumed that the PLN tariff is \( Rp. \, 1,467 / \text{kWh} \)

Then the price of electricity to be paid for one elevator per day is:

\[ 16.2 \, \text{kWh} \times Rp. \, 1.467 / \text{kWh} = Rp. \, 23.765 / \text{unit/day}. \]
The motor to be used is a power rating of 6.7 kW (9 hp) to lift the maximum capacity passenger lift.

### 3.6. Guide rail

**Known:**
- Maximum Lift Capacity, \( Q_p = 450 \text{ kg} \)
- Train load is empty, \( Q_k = 1000 \text{ kg} \)
- Gravity, \( g = 9.81 \text{ m/s}^2 \)
- Train travel height, \( TR = \{(4 \times 3800 \text{ mm}) + (3500 \text{ mm} \times 1)\} = 18700 \text{ mm} \)
- Overhead, \( OH = 4100 \text{ mm} \)
- Pit depth, \( P = 1500 \text{ mm} \)
- Train height, \( H = 2250 \text{ mm} \)
- Distance of train height on the top floor, \( p = \text{travel height} + \text{train height} = \{(3800 \text{ mm} \times 4) + (3500 \text{ mm} \times 1)\} + 2450 \text{ mm} = 20,950 \text{ mm} = 20.95 \text{ m} \)

The kinetic energy caused by the trainload (\( Q_k \)) plus the \( Q_p \) load capacity on the rails is:

\[
E_k = \frac{m \cdot v^2}{2} = \frac{Q_p + Q_k}{2 \cdot g} \cdot v^2_{\text{broken off}}
\]

Train travel speed when the rope is broken \( v^2_{\text{broken off}} \):

\[
\begin{align*}
v^2_{\text{broken off}} &= 2 \cdot g \cdot h \\
v^2_{\text{broken off}} &= 2 \times 9.81 \text{ m/s}^2 \times 20.95 \text{ m} \\
v^2_{\text{broken off}} &= 411,039 \text{ m}^2/\text{s}^2 \\
v^2_{\text{broken off}} &= \sqrt{411,039 \text{ m}^2/\text{s}^2} \\
v^2_{\text{broken off}} &= 20.3 \text{ m/s}
\end{align*}
\]

Then the kinetic energy that occurs in the guide rail is:

\[
E_k = \frac{Q_p + Q_k}{2 \cdot g} \cdot v^2_{\text{broken off}} = \frac{450 \text{ kg} + 1000 \text{ kg}}{2 \times 9.81 \text{ m/s}^2} \cdot (20.3 \text{ m/s})^2 = 30,455,17 \text{ kg.m}
\]

The length of the rails, \( s \) can be calculated by measuring the distance between pits to overhead is:

\[
s = \text{distance of pit depth} + \text{distance of train trip} + \text{overhead} \\
s = 1500 \text{ mm} + 18700 \text{ mm} + 4100 \text{ mm} \\
s = 24,300 \text{ mm} = 24.30 \text{ m}
\]

The forces acting along the guide rail for one guide rail are:

\[
R_{\text{max}} = \left(1 + \frac{v^2}{2 \cdot g \cdot s}\right) (Qp + Qk)
\]

\[
R_{\text{max}} = \left(1 + \frac{(20.3 \text{ m/s})^2}{2 \cdot 9.81 \text{ m/s}^2 \cdot 24.3 \text{ mm}}\right) (450 \text{ kg} + 1000 \text{ kg}) = 2.697 \text{ kg}
\]

So for the 2 guide rails are:

\[
2R_{\text{max}} = 2 \times R_{\text{max}} = 2 \times 2.697 \text{ kg} = 5.394 \text{ kg}
\]

### 3.7. Governor

This tool will work if the speed of the train moves beyond normal speed, usually, the speed is 115% times normal speed. A speed that exceeds the normal speed causes the governor wheel rotation to cause centrifugal force on two pendulums so that the pendulum will be twisted on the lever which causes the
hook to loosen, dropping the jaw so that the rope is pinched by the jaw falling. Calculation of centrifugal force can be calculated with the following formula:

\[ F_s = \frac{m \times v_0}{r} \]

**Planned:**
- pendulum mass, \( m = 0.2 \text{ kg} \)
- train speed, \( v = 1 \text{ m/s} \)
- the distance of the pendulum to the centre axis, \( r = 100 \text{ mm} = 0.1 \text{ m} \)

Then the speed of the car that causes the centrifugal force is:

\[ V_0 = 115 \% \times v \]
\[ V_0 = 1.15 \times 1 \text{ m/s} = 1.15 \text{ m/s} \]

Then the pendulum centrifugal force is:

\[ F_s = \frac{0.2 \text{ kg} \times (1.15 \frac{m}{s})^2}{0.1 \text{ m}} \]
\[ F_s = 2.6 \]

3.8. **Advantages and disadvantages of the elevator**

After carrying out the planning process above, this elevator has several advantages. Among others are:
- Size is more compact and lighter. The gearless motor does not require the size of the engine room that is too broad.
- More environmentally friendly. Besides being more economical electricity, the gearless motor was also more environmentally friendly because it did not require periodic oil changes to the gearbox. This is thanks to the use of a permanent magnet synchromesh system whose system no longer uses gears like motor geared machines. Aside from being more environmentally friendly, the absence of gearbox oil changes can also save elevator operating costs.
- Simple sliding chamber construction. Placement of the pendulum/counterweight and sliding rail are only placed on one side of the wall. This is certainly very influential on the construction costs incurred for the manufacture of elevator slides.

The disadvantages of this elevator are:
- The motor has the potential to burn. PLN's mains voltage which often fluctuates makes the gearless motor has the possibility of burning due to an overload of voltage.
- Still relying on wire rope. The current wire rope technology is better than the chain rope because the noise level is lower, the wire rope has a limited life span of around a maximum of 2.5 years, which is still within the safe limit of usage tolerance.

4. **Conclusion**

Based on the planning of the passenger elevator in a 5-story building with a planned capacity of 450 kg at a speed of 1 m / s using a gearless DC variable (AC VVVF) gearless (Variable Voltage Variable Frequency) that is operated using electrical energy in a roping system 1:1, the data obtained from the above calculations are:
- The required empty train load is 1000 kg.
- The counterweight load used is 1225 kg.
- The rotational speed of the traction motor when the elevator is above the full load is 913.5 rpm.
- The rotational speed of the traction motor when the elevator is down at full load is 228.37 rpm.
- Electricity costs to be paid are Rp. 23,765 / unit / day.

So it can be concluded that in choosing a passenger elevator in the office building of this medical device should be optimized as needed to reduce the cost of buying an elevator.

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