ENERGY EFFICIENT ESCALATORS AT TOURIST ATTRACTIONS

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KEYWORDS: Escalator, Tourist attraction, Energy consumption, wind turbine, Solar Panel, Variable Frequency Drive with Regenerator

1. ABSTRACT

In today’s world, we find the use of Escalators in Malls, Hospitals, Offices, Airports, Metro Stations. exceptional to this, Escalators are also serving as vertical means of transport in various Important high altitude Tourist Attractions allowing easy access to disabled, elderly and children navigate steep paths, reducing the time and effort required to visit the peak of a Tourist place.

Escalator applications at high altitude temples include Jakhu temple in Shimla, India. while to reach Caves include Batu Caves in Malaysia. Escalators are also helping people climb mountains in minutes like the Tianyu Mountain in China.

These Escalator locations are at High altitude, Forest areas, Rough Terrains, where electricity supply is not regular, this is due to the difficulty in installing and maintaining power lines and power transmission losses. this Paper focuses on Energy harvesting methods with mini-Grid system using Wind turbine and Solar Panel installation at Escalator site, reducing dependency on main electricity grid and resulting in no electricity bills. this paper also focuses on reducing the total energy consumption of large capacity Escalators which will encourage their usage at Tourist Attractions all over the world and the role of Variable Frequency Drive (VFD) with Regenerative units in achieving this.

2. INTRODUCTION

Unlike elevators, escalators don’t require waiting. People step on and are immediately on their way, which is perfect for busy environments. Escalators are simple to use. Just step on and ride to the next floor, no buttons, no waiting.

In the high-altitude Tourist attractions and pilgrimage sites, some current means of vertical transportation include use of Animals, cable car, Ropeway and helicopter ride. However, all the above options have safety risks and are least convenient for large capacity tourists, where Riding on an Escalator is a safe and convenient option. Hence it is important to consider the manufacturing, installing and Running cost of this special application Escalator, In the current paper we focus on improving the Energy Efficiency of Escalators for least Electricity consumption. And hence understand the factors affecting and calculate the Energy consumption of Escalators.

The formula for total energy consumption of escalator is defined as:

$$Et = Ef \pm Ev$$ (Uimonen, 2015)

Where, Ef – fixed energy consumption, which is the power drawn by the escalator when no passengers are travelling on it and depends upon the rise of Escalator. when Escalators lightings are considered, switching from fluorescent to LED lightings will help to reduce the fixed energy consumption.

The formula for Ef without considering mechanical losses is,

$$Ef = 0.55*re + 1.95$$ (Al-Sharif, 1998)

Fixed energy consumption is due to the friction in the handrail, which an Escalator must overcome, and depends upon the design of mechanical components like gearbox, bearings, guiding system for step and step chain. Table 1 shows the Escalator types based on design of Mechanical components. While Table 2 gives the formula for Ef based on Escalator type shown in Table 1.

Escalator type	Bearings	Guiding system	Gearbox
A	Ball bearings	Chain guidance	Involute
B	Ball bearings	Chain guidance	Cavex
C	Plain bearings	Wheel guidance	Involute
D	Ball bearings	Wheel guidance	Involute

***Table 1** Summary of machine categories in relation to mechanical features* (Al-Sharif, 1998)

Escalator Type	Equation for Ef
A (low rise)	Ef = 0.9* re - 0.19
A (high rise)	Ef = 0.79* re + 1.02
C	Ef = 1.56* re - 4.7
D	Ef = 0.47* re + 1.74
B	Ef = 0.49* re + 8.76

***Table 2**, Equations for fixed energy losses based on vertical rise* (Al-Sharif, 1998),

Studies show that Escalators with mechanical design type “D” has least value of fixed energy consumption. Followed by “A”, then “B” and then “C” (Al-Sharif, 1998).

Ev – variable energy consumption, in kWh and depends on the number of daily passengers, their average mass and the rise of Escalator.

$$E_{v/day} = \frac{p_{day} * g * r_e * m * k_{wf}}{3600000};$$

Formula for variable energy consumption per day of an Escalator (Uimonen, 2015)

Where:

- Ev/day – total variable energy consumption in kWh per day,
- $pday$ – number of passengers per day
- re – vertical rise in m
- g – acceleration due to gravity (9,81 $m/s2$)
- m – average mass of a passenger in kg
- kwf – walking factor

Some passengers walk up and down the escalator, they thus spend less time on the escalator, and consume less power when walking up, and return less power when walking down. This is the walking factor. (kwf) its value is taken between 0.7 to 1. Where 1 is used when no passenger is walking (Al-Sharif, 1998). However, for large vertical rise Escalators, walking should be prohibited from safety point of view.

Installation of Variable Frequency drive (VFD) and light weight steps in Escalators will reduce both Fixed and Variable Energy consumption. VFD is discussed in detail in Serial No.5.

Some characteristics of escalators at tourist attractions include implementation of a double drive system, outdoor Installed in pair with parallel arrangement, Large Vertical Rise, Large Wind Exposure and direct Exposure to Sunlight. For Escalators having access to natural sunlight during daytime and not covered with shaded areas reducing visibility, for them dedicated lighting for skirting, balustrade, or decking is generally not required due to clear visibility of sunlight.

Tourist attraction and Pilgrimage places are often situated away from the city, in high altitude open plains and Mountains where the Wind speed and Sun Intensity is large, these clean, renewable energy sources available at the location of Escalator installation can be effectively utilized to generate Electricity locally by creating mini grid system for suppling power required to run the Escalator, using Solar Panels or wind turbines. This will reduce the dependency and power losses from the grid. and help to save or cut electricity bill.

3. ESCALATOR OPERATION USING ELECTRICITY FROM WIND TURBINE

Wind Energy is Natural, free of cost and available 24x7 in any weather conditions. Some researchers proposed of harvesting energy at high altitudes by utilizing the strong winds existing in high atmosphere by using flying electrical generators (FEG). These are basically wind turbines collecting wind power at high altitudes.

The power available in the wind is proportional to the cube of its speed. This means that if wind speed doubles, the power available to the wind generator increases by a factor of 8 (2 * 2 * 2 = 8). A minimum wind speed of 4.0 m/s to 4.5 m/s is required for a small capacity wind turbine to operate efficiently. (Clarke, 2018).

The location selection of Wind turbine should be such that, at a minimum, it should be mounted high enough on a tower that the tips of the rotor blades remain at least 9 m above any obstacle within a horizontal distance of 90 m. Ideal tower height should be typically between 24–37 m high (Clarke, 2018).

The preliminary estimate formula for the performance of a particular wind turbine is:

AEO = 1.64 D2 V3 (Clarke, 2018)

where,

AEO = annual energy output, in kWh/year,

D = rotor diameter, in metres

V = annual average wind speed, in m/s

A modest increase in the rotor diameter will lead to significant increases in both the swept area of a turbine and the amount of electricity that the turbine generates (Clarke, 2018).Components of wind turbine with Electric setup are shown in Figure 1.

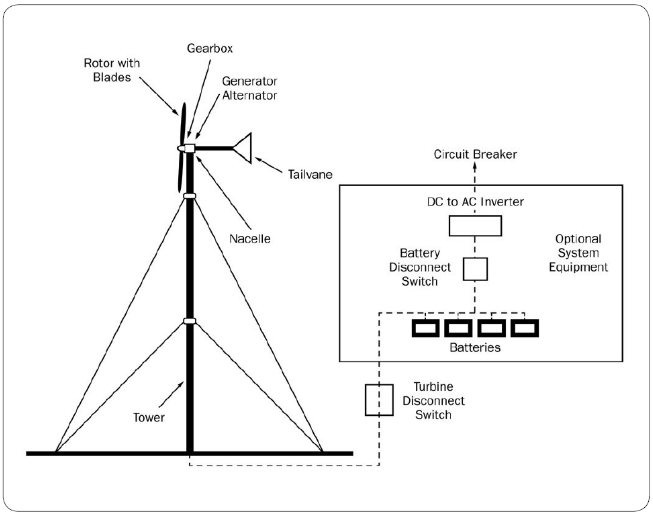

***Figure 1** Components of a stand-alone wind energy system, including the electronic portion.* (Clarke, 2018)

A wind turbine is a rotor consisting of blades with aerodynamic surfaces. When the wind blows over the blades, the rotor captures the kinetic energy of the wind and starts to turn, converting the kinetic energy into motion. This motion causes the generator in the turbine to rotate and produce electricity. The gear box is used to change the slow motion we see from the turning blades to the faster motion of the axis which drives the generator (Richardson, 2024). The Nacelle provides enclosure and protects the gearbox, generator and other components of the turbine. A Tail vane or yaw system aligns the turbine with the direction of wind. (Clarke, 2018).The generator produces DC electricity, which is then converted to AC by an inverter. this is stored in the battery and distributed further and will be used to drive the Escalators with large passenger capacity and vertical rise at offshore applications.

However, wind turbines have certain drawbacks like uneven wind speed, installation may affect the landscape, scenic view, history and quiet surroundings of their neighbourhoods due to noise from Mechanical components and Wind Aerodynamics. Cold climate or ice formation on the blades may reduce the power output and increase the load on the rotor. High Maintenance cost.

4. ESCALATOR OPERATION USING ELECTRICITY FROM SOLAR PANELS

For a particular region on Earth. at high altitudes areas, as the slope increases, we get more irradiation (direct radiation) and less diffusion. This forms an efficient PV system as compared to plain areas. Studies show that there is a linear relationship between voltage and temperature till the temperature reaches 25 deg. Celsius. after which the voltage starts to decrease with further increase in temperature. In high altitude regions, the ambient temperature decreases with height (Phanindra, 2018). Components of Solar Power Escalator system is shown in Figure 2.

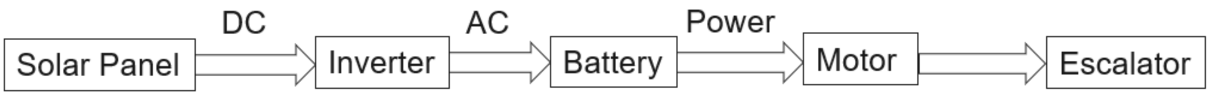

Figure 2 *Diagrammatic representation of an escalator powered by solar energy*

Solar Panels generate electricity from sunlight which is in the form of Direct current. This electricity is converted to Alternating current by the Inverter, which can reverse its direction and flow back and forth and can be stored in the battery or transferred to the grid. and used to power the escalator and other applications in a Tourist place. The Solar Panels can be installed in open areas on mountains or can also be mounted on the Roofs of Escalator Tunnels as shown in Figure 3. This will give the advantage of short distance electricity transfer with reduced energy losses and provide Inclination angle to the Solar Panel to absorb Solar energy efficiently.

Figure 3 *Escalators inside Tunnel in Outdoor Environment.* (Williams, 2016)

The intensity of solar radiation depends upon geographical location, sunshine hours, relative humidity, maximum and minimum temperatures, cloud coverage, Solar Panel direction, Solar Panel Inclination.

The global formula to estimate the electricity generated in output of a photovoltaic system is

E = A * r * H * PR, (Photovoltaic software, 2025) where,

- E =Energy(kWh)
- A = Total solar panel Area (m2)
- r = solar panel yield or efficiency (%), ratio of electrical power (in kW) of one solar panel divided by the area of one panel.
- H = Annual average solar radiation on tilted panels (shadings not included)
- PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75) Independent of Panel orientation and inclination. Includes losses like Inverter losses, DC and AC cable losses, shadings and weather conditions.

Regular Maintenance of Solar Panels consists of its periodical washing due to accumulation of dust. and the average lifespan of Solar Panels is around 30 years. It is a noise free operation. Does not require separate land, when mounted on Roofs.

The drawback is that the Solar energy intensity depends upon climatic conditions as mentioned above and is available only during daytime. If it is not possible to mount the solar panels on the Escalator Tunnel roof, then a large land area is required for installing of Solar Panels.

5. A VARIABLE FREQUENCY DRIVE WITH LINE REGENERATIVE UNIT

Figure 4 *Escalator pair in parallel arrangement at a scenic spot in Zhejiang, China* (Kitanovska, 2023)

Escalators in high altitude tourist places are in most cases installed in a pair parallel besides each other as shown in Figure 4. One moves Passengers in upward direction, while other moves passengers downwards. This allows crowd segmentation and direction control and separates entry and exit flows.

A Variable frequency drive (VFD) is an Important Component of such Large Capacity Escalators, due to its various advantages. A VFD is an AC Motor drive that controls the speed and torque of Escalator by varying the frequency of input electricity. VFD's provide advantage of different drive modes based on user traffic. like it runs the Escalator motor at Normal speed during passenger travel. then runs the motor at Low-Speed mode during passenger absence, where Power Consumption is close to half of the normal operating mode and finally switches the Escalator motor to STOP mode where the electricity consumption is at its lowest, only lighting and control systems are working. This can be seen in Figure 5.

Another advantage of VFD is that it provides Transient starting and stopping with smooth ramp-up and ramp-down speed profiles. which limits the inrush current at turn-on, preventing excessive wear and tear of mechanical components, and provides a comfortable ride for passengers. VFDs provide adjustable torque limits which help to protect mechanical components from being stressed because of a jam or other critical safety events (Pecha, 2018).

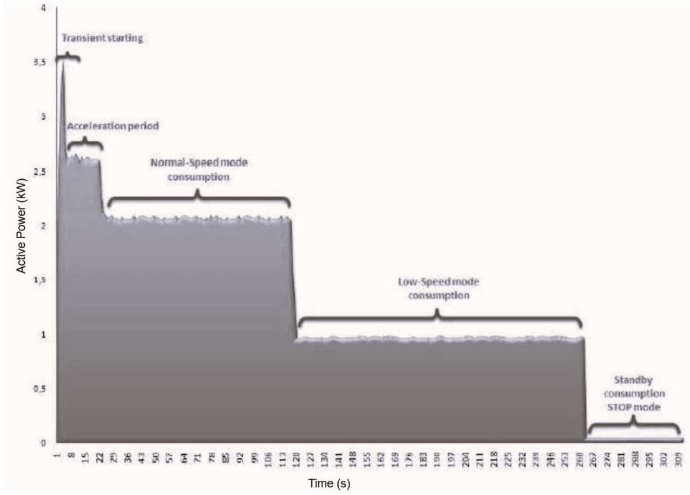

Figure 5 *Several states of operating of the escalator* (Uimonen, 2015)

The Power factor is a unitless number that represents the ratio between the power being put into useful work measured in watts and the total electrical power being transferred measured in volt-amps. A PF of 1 is ideal and indicates all power being delivered is being usefully consumed by the escalator motor. VFD provides benefit of low input current, specially under partial load. in this case, the no-load RMS current with a VFD is more than 50% lower than that of the line-fed motor. A higher input current requires oversized electrical components. a low PF will cause higher heating in electrical components, which can lead to reduced operating lifetime (Pecha, 2018). Using a high efficiency IE3 or IE4 motor which has minimum power losses along with VFD will further help to achieve higher Power factor.

Power flow in the motor is bi-directional. When an Escalator is travelling with Passengers in upward direction against gravity, the speed of the motor is in the direction of applied torque, this is a motoring operation and converts the electrical energy from VFD to mechanical energy at motor output shaft.

A high-capacity escalator moving large number of people in long downward travel distance, carries large gravitational potential energy defined as,

Gravitational Energy = mass x gravity constant x height of travel

Here the speed of the motor is in the opposite direction of applied torque, and the power required by the motor to run the Escalator in the direction of gravity is less than that supplied to it. This excess power must be dissipated, else it will damage the IGBT's, causing drive failure. This extra power is sent back by the motor to the braking resistors to dissipate the regenerated energy as heat shown in upper block of figure 6. Depending on the braking resistor location, the extra heat produced may require additional cooling or a larger controller cabinet. This could cause problems when designing the escalator control panel, if space is minimum.

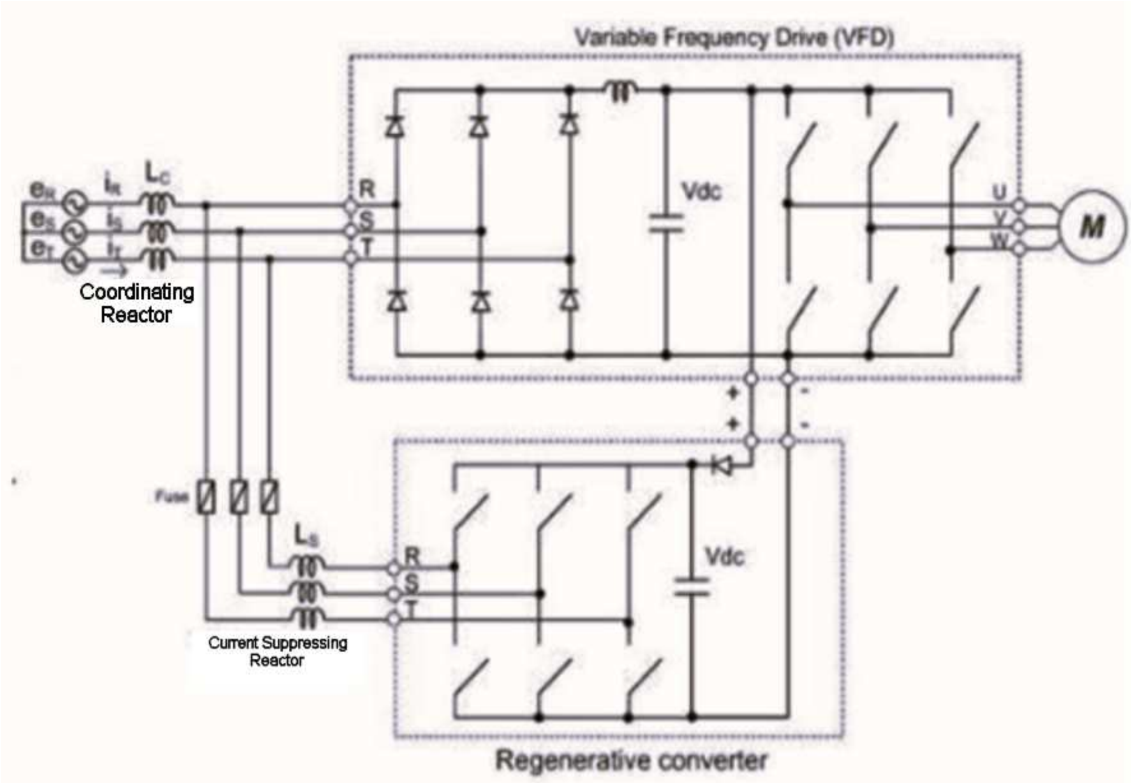

Figure 6 *Diagrammatic representation of VFD with resistor brake circuit and Line Regenerative unit* (Rasin & G, 2017)

As an alternative to braking resistors, a line regenerative unit is part of VFD, and can be connected to the VFD through a DC bus connection. When motor sends extra power to a regenerative unit, it sends the power back to the grid. allowing motor to act as a generator. The regenerative unit operates by measuring the line voltage and frequency. Once the DC bus voltage exceeds a predetermined threshold, the drive modulates, allowing current to flow back to the grid or battery, and creates 2-way street to power, from mains to the motor and vice versa as shown in the lower block of figure 6. Line-regeneration units thus help save energy and reduce control-cabinet space in overhauling escalators, while cutting down on additional heat generation caused by braking resistors (Pecha, 2018). The high traffic and large travel distance on the escalator will result to large energy savings in the Escalator. Variable-frequency drives (VFDs) paired with line-regenerative units are a great fit for escalator applications.

The Regenerative Drive works in tandem with the motor controller to manage both motoring and generating modes. Hence it can be used on an escalator moving in both upward and downward direction based on requirement. If the direction of the Escalator movement is fix, then it only applicable for downward moving Escalator. Example – Escalator moving in downward direction of the pair of a parallel escalator arrangement.

For a downward moving Escalator, installed in a tourist place. if the Passengers are guided to move together in groups with “No walking” instruction, it will allow the Escalator to run with full load and generate maximum power which can be sent back to the grid with the Regenerative drive.

6. CONCLUSION

There will be an increasing demand of Escalators at high altitude temples, Mountains and other types of high-altitude Tourist attractions due to their multiple advantages over current available vertical transportation options.

The formula for fixed energy consumption and variable energy consumption provides the factors affecting the energy efficiency of Escalators and help to evaluate the Power consumption of Escalators.

Renewable energy sources like sun and wind can be used to generate electricity locally using solar panels or wind turbines, creating a mini grid to supply power required for running the Escalator. thus, reducing or getting rid of the Electricity bills for Escalator operations.

Use of Variable frequency drives in Escalators provides various advantages like low starting current, Power factor improvement, providing smooth ride quality and safety benefits also variable speed modes based on Escalator traffic. Thus, reducing Fixed and Variable Energy consumption of Escalators.

Line-regeneration units supply excess power from motor back to the grid, during downward travel of escalator. Thus, reduces wastage of electricity. Used together, VFDs with line-regeneration units add significant value to escalator applications.

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8. BIOGRAPHICAL DETAILS

Mrs. Deepika Jagdale holds a master’s degree in mechanical design engineering from Pune University. She has a professional experience as design and development Engineer in Defence Vehicle R&D at Bharat forge Ltd. A Design Engineer of Hydraulic Couplings at Expert Global Group. and is currently working as Assistant Manager in Schindler India’s Escalator R&D division.