

The high voltage  
electricity  
transmission network  
engineering essay



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It is well known to many people that high voltage electricity transmission network represents the backbone of the whole regional power supply scheme in the country. The main purpose of this research is analyzing the most frequent common failures in the HV transmission lines and understanding the actual reasons behind these failures in the transmission network of a private electrical company in the Sultanate of Oman named OETC Oman Electricity Transmission Company. The business of that company is providing, developing and governing the Electrical Transmission System in the Sultanate of Oman. The data presented and information provided hereafter shall be considered extremely confidential and hence the assignment information is intended only for the use of this assignment and shall not be distributed to any other party without permission from the original source.

In the start, the assignment firstly provides a brief explanation about the company and its role of electricity distribution. Then, it further analyzes different types of equipment failures that are encountered with HV network operation and reported by a local company. It sums up on general findings, results, conclusion and the recommendation regarding future maintenance.

## **Electricity supply**

Oman Electricity Transmission Company OETC operates, organizes and maintains the majority HV transmission system in which electrical power is transmitted through 220kV and 132kV transmission lines to load centers in Muscat Governorate and the regions of Dakhliyah, Batinah, Dhahirah and Sharqiyah. It dispatches power from all Centrally Dispatched Generation Stations owned by the following companies: (1).

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1. Ghubrah Power & Desalination Station
2. Rusail Power Station
3. Wadi Jizzi Power Station
4. Manah Power Station
5. Al Kamil Power Station
6. Barka Power & Desalination Station
7. Sohar Power Station

The power transmitted by the company is delivered to the following distribution companies, which are licensed to distribute and supply power in a range lower than 132kV voltage (i. e. 66kV, 33kV, 11kV and 0. 415kV):

1. Muscat Electricity Distribution Company (MEDC) – for Muscat area
2. Mazoon Electricity Company (MZEC) – for South Batinah, Dakhliyah and Sharqiyah regions
3. Majan Electricity Company (MJEC) – for North Batinah and Dhahirah regions

## **Fundamentals of Power Generation and Transmission**

After the electricity leaves a power generation (1), the voltage is increased at a “ step-up” grid substation (2). Subsequently, the energy travels along a transmission line to the area where the power is needed (3). Once there, the voltage is decreased, or “ stepped-down,” at another primary substation (4),

and a distribution power line (5) carries the electricity until it reaches a home or business (8). (1)

Fig -1 Electrical Power System (1)

## **Overhead Lines**

The main components of the HV high voltage power transmission are; the overhead towers, conductors, insulators, lightning arrestors, CVT & CT and cable sealing ends. It has been well recognized since the starting of electric power generation that overhead transmission lines (OHL) have represented the most important component for the electric power transmission and distribution. The over head transmission line generally dedicated for high voltage range, while the buried type (underground cables) are commonly used in lower voltage range for the distribution purpose. However, in Oman, both systems are used in various applications depending on the cost, development conditions and topography constraints. OETC has planned, designed and erected overhead power lines for various voltage levels in many parts of the sultanate of Oman.

## **Line voltage Selection**

According to IEC 60038 there are standard voltage ranges used for the electric power transmission and distribution.

The following are the main voltage levels For 3-phase AC power supply:

-Low voltage range from 220v up to 1 kV AC

Medium voltage range from 1 kV to 36 kV AC

High voltage range from 52 kV to 765 kV AC) and higher

Generally the Low-voltage transmission and distribution networks serve households and other small business consumers. Networks on the medium-voltage level usually supply larger buildings and settlements, industrial plants and other large consumers; the power supply capacity is typically less than 10 MVA per circuit. The high voltage ranges up to 145 kV are usually used for sub-transmission of the electric power regionally, and also feed the medium-voltage electric network.

This level is frequently selected to support the medium-voltage level even when electric power is lower than 10 MVA. Moreover, some of high-voltage transmission lines are also used to transmit the electric power from medium size power plants, like hydro power plants on water streams, channel or rivers, and provide electric power for large-scale units, such as considerable power plants or steel factories. The bandwidth of electrical transported power corresponds to the broad range of utilization, but it rarely exceeds 100 MVA per circuit, while the surge impedance load is 35 MVA (approximately).

In most European countries, the high voltage lines of 245 kV were greatly used in interconnection of power supply systems and this before the 420 kV level was brought to this purpose. Nowadays, the usage of 245 kV lines is decreased to some extent due to the availability of the 420 kV transmission network. The 420 kV level represents the highest operation voltage used for AC transmission in Central Europe. It typically interconnects the power supply systems and transmits the energy over long distances. Some 420 kV

lines connect the national grids of the individual European countries enabling interconnected network operation (UCTE = Union for the Co-ordination of Transmission of Electricity) throughout Europe. Large power plants such as nuclear stations feed directly into the 420 kV network. The thermal capacity of the 420 kV circuits may reach 2, 000 MVA, with a surge impedance load of approximately 600 MVA and a transmission capacity up to 1, 200 MVA.

[SIEMENS Power Engineering Guide 2009]11

## **Selection of conductors and earth wires**

Electric conductors are the main important part in the overhead power line network and they must be selected carefully for the electric transmission lines because this will ensure economical and reliable transmission and contribute directly to the total line costs. Therefore, to achieve better economic solution, aluminum and its alloys have been used as conducting materials for power lines due to the favorable price, the low weight and the necessity of certain minimum cross-sections. On the other side, aluminum is a very corrosive metal. But when a dense oxide layer is formed it can stop further corrosion. Therefore, up to a certain level, aluminum conductors are well-suited for areas in which corrosion is an issue, such as humid climate in areas located near coastal zone. Generally, there are a number of different designs in use for aluminum conductors. As an advantage, All-aluminum conductors (AAC) have the highest conductivity for a given cross-section; however, they possess relatively low mechanical strength, which limits their installation to short spans and low tensile forces.

To increase the mechanical strength, aluminum wires are made of mixing with other alloys like aluminum-magnesium-silicon alloys. In this way, the <https://assignbuster.com/the-high-voltage-electricity-transmission-network-engineering-essay/>

strength can be increased approximately twice that of pure aluminum. But practically, all-aluminum and aluminum alloy conductors have exhibited some susceptibility to vibrations. To solve this problem, compound conductors with a steel core, so-called aluminum conductor, steel-reinforced (ACSR), can avoid this disadvantage. The ratio between aluminum and steel ranges from 4.3: 1 to 11: 1. An aluminum-to-steel ratio of 6.0 or 7.7 provides an economical solution. Conductors with a ratio of 4.3 should be used for lines installed in regions with heavy wind and ice loads. Conductors with a ratio higher than 7.7 provide higher conductivity. But because of lower conductor strength, the sags are bigger, which requires higher towers. Experience has shown that ACSR conductors, just like aluminum and aluminum alloy conductors, provide the most economical solution and offer a life span greater than 40 years. Conductors are selected according to electrical, thermal, mechanical and economic aspects. The electric resistance as a result of the conducting material and its cross-section is the most important feature affecting the voltage drop and the energy losses along the line and, therefore, the transmission costs. The cross-section has to be selected so that the permissible temperatures will not be exceeded during normal operation as well as under short-circuit condition. With increasing cross-section, the line costs increase, while the costs for losses decrease. Depending on the length of the line and the power to be transmitted, a cross-section can be determined that results in the lowest transmission costs. The heat balance of ohmic losses and solar radiation against convection and radiation determines the conductor temperature. A current density of 0.5 to 1.0 A/mm<sup>2</sup> based on the aluminum cross-section

has proven to be an economical solution in most cases. [SIEMENS Power Engineering Guide 2009] (9)

The table below shows the characteristics of AC overhead lines (data refer to a one circuit of a double-circuit line)

Table -1 characteristic of AC overhead lines (9)

High-voltage results in correspondingly high-voltage gradients at the conductor's surface, and in corona-related effects such as visible discharges, radio interference, audible noise and energy losses. When selecting the conductors, the AC voltage gradient has to be limited to values between 15 and 17 kV/cm. Since the

sound of the audible noise of DC lines is mainly caused at the positive pole and this sound differs from those of AC lines, the subjective feeling differs as well. Therefore, the maximum surface voltage gradient of DC lines is higher than the gradient for AC lines. A maximum value of 25 kV/cm is recommended. The line voltage and the conductor diameter are one of the main factors that influence the surface voltage gradient. In order to keep this gradient below the limit value, the conductor can be divided into subconductors. This results in an equivalent conductor diameter that is bigger than the diameter of a single conductor with the same cross-section. This aspect is important for lines with voltages of 245 kV and above.

Therefore, so-called bundle conductors are mainly adopted for extra-high-voltage lines. Table 2. 5-2 shows typical conductor configurations for AC lines. From a mechanical point of view, the conductors have to be designed for everyday conditions and for maximum loads exerted on the conductor by <https://assignbuster.com/the-high-voltage-electricity-transmission-network-engineering-essay/>



wind and ice. As a rough figure, an everyday stress of approximately 20 % of the conductor rated tensile stress can be adopted, resulting in a limited risk of conductor damage. The maximum working tensile stress should be limited to approximately 40 % of the rated tensile stress. Earth wires, also called shield wire or earth wire, can protect a line against direct lightning strikes and improve system behavior in the event of short-circuits; therefore, lines with single-phase voltages of 110 kV and above are usually equipped with earth wires. Earth wires made of ACSR conductors with a sufficiently high aluminum cross-section satisfy both requirements. Since the beginning of the 1990s, more and more earth wires for extra-high-voltage overhead power lines have been executed as optical earth wires (OPGW). This type of earth wire combines the functions just described for the typical earth wire with the additional facility for large data transfer capacity via optical fibers that are integrated into the OPGW. Such data transfer is essential for the communication between two converter stations within an HVDC interconnection or for remote controlling of power stations. The OPGW in such a case becomes the major communication link within the interconnection. OPGW are mainly designed in one or more layers of aluminum alloy and/or aluminum-clad steel wires. One-layer designs are used in areas with low keraunic levels (small amount of possible lightning strikes per year) and small short-circuit levels. [SIEMENS Power Engineering Guide 2009](9)

## **Selection of insulators**

Usually, insulators in the overhead line are subject to electrical and mechanical stresses, because they have to isolate the conductors from

potential to earth and must provide physical supports. Therefore, Insulators must be capable of withstanding these stresses under all conditions encountered in a transmission line.

Normally, the electrical stresses result from:

The steady-state operating power-frequency voltage (highest operation voltage of the system)

Temporary over voltages occurred at specific power frequency

Switching and lightning over voltages

## **Chapter -2**

### **Introduction**

Electrical insulators are very critical and important component in the electric power systems such as distribution & transmission lines. Previously, the electrical insulators which is made of ceramic and glass materials. But in 1963, a polymeric insulator were developed and its improvements in design and manufacturing in the modern years have made it attractive to utilities. polymeric insulator consists of a fibreglass core rod covered by weather-sheds or skirts of polymer such as silicone rubber, equipped with metal end fittings. It is also called composite insulators, which means made of at least two insulating parts - a core and housing equipped with end fittings.

Polymeric insulators have many advantages over the ceramic and glass insulators such as good performance in contaminated environment, light weight, easy handling, maintenance free, and considerably low cost etc.

Because of these properties it is gaining popularity worldwide and replacing

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the conventional ceramic and glass insulators in many countries. Therefore, our research shall focus the light on the silicon rubber insulator and the main advantages can be achieved by using such type of electrical insulators.

The following is a comparison showing the different factors between ceramic and composite insulators.

## FACTORS

### CERAMIC

### COMPOSITE

Resistance to flashovers in Polluted atmosphere.

Low

High

Resistance to puncture

Puncturable

(Class: B insulators)

Not puncturable

Resistance to Cracking and Erosion in Polluted atmosphere.

Low

High

## Contamination & Pollution

Highly affected

Performance not affected

Hydrophobicity

Non hydrophobic.

Unique Hydrophobicity character.

Self cleaning property

Due to Glaze and inclination of sheds.

Due to Hydrophobicity recovery characteristic.

Maintenance

Needs maintenance like cleaning, washing, greasing.

No maintenance is required

Weight

More

10% to 35% of Ceramic Insulator

Resistance to breakage and Vandalism

Breakable in Vandalism prone areas

Unbreakable

Artificial Pollution Test

Mandatory

Not applicable

Power Arc Test

Mandatory

Not mandatory

Table -1 comparison different factors between ceramic and composite insulators (10).

## **Insulator types**

There are various insulator designs used in different applications, depending on the requirements and the application with certain insulator types:

Cap-and-pin insulators (fig. 2) are made of porcelain or pre-stressed glass. The individual units are connected by fittings of malleable cast iron or forged iron. The insulating bodies are not puncture-proof, which is the reason for a relatively high number of insulator failures.

In Central Europe, long-rod insulators made from aluminous porcelain (fig. 3) are most frequently adopted. These insulators are puncture-proof. Failures under operation are extremely rare. Long-rod insulators show superior behavior, especially in polluted areas. Because porcelain is a brittle material,

porcelain long-rod insulators should be protected from bending loads by suitable fittings.

Composite insulators are the third major type of insulator for overhead power line applications (fig. 4). This insulator type provides superior performance and reliability, particularly because of improvements over the last 20 years, and has been in service for more than 30 years.

Fig -2 Cap and pin (disc insulator) (9)

Fig -3 Long-rod insulator with clevis cap (9)

Fig -4 Glass fibre reinforced composite insulator with ball and socket fittings (Lapp insulator) (9)

The composite insulator is made of a glass fiber reinforced epoxy rod. The glass fibers applied are ECR glass fibers that are resistant to brittle fracture (ECR = electrical grade corrosion resistant glass fibers). In order to avoid brittle fracture, the glass fiber rod must additionally be sealed very carefully and durably against moisture. This is done by application of silicone rubber. Nowadays, high temperature vulcanized (HTV) silicone is used.

The silicone rubber has two functions within this insulator type:

Sealing the glass fiber rod

Molding into insulator sheds to establish the required insulation

Metal fittings are compressed onto the glass fiber rod at both ends of the insulator, either with a ball socket or clevis connection fitting. Since the

1980s, compression fittings have been the prevailing type. The sealing of the area between fitting and silicone housing protecting the rod is most important, and is nowadays done with special silicone elastomer, which offers after vulcanization the characteristic of a sticky solid, similar to a fluid of high viscosity. Advantages of the composite long-rod insulator are:

Light weight, less volume and less damages

Shorter string length compared to cap-and-pin - and porcelain long-rod - insulator strings

Up to 765 kV AC and 600 kV DC, only one unit of insulator (practical length is only limited by the ability of the production line) is required

High mechanical strength

Vandalism resistance

High performance in polluted areas, based on the hydrophobicity (water repellency) of the silicone rubber

Advantages of hydrophobicity are:

Silicone rubber offers outstanding hydrophobicity over the long term; most other polymeric housing material will lose this property over time

Silicone rubber is able to recover its hydrophobicity after a temporary loss of it

The silicone rubber insulator is able to make pollution layers on its surface water-repellent, too (hydrophobicity transfer)

Low surface conductivity, even with a polluted surface and very low leakage currents, even under wetted conditions.

## **Insulator string sets**

Suspension insulator sets carry the conductor weight, including additional loads such as ice and wind, and are arranged more or less vertically. There are I-shaped (fig. 5a) and V-shaped sets in use. Tension insulator sets (fig. 5b, fig. 5c) terminate the conductors and are arranged in the direction of the conductors. They are loaded by the conductor tensile force and have to be rated accordingly. Multiple single, double, triple or more sets handle the mechanical loadings and the design requirements.

Fig -5a; I-shaped suspension insulator set for 245 kV (11)

T Fig -5b&c; Double tension insulator set for 245 kV (Elevation, Top & Plan, bottom) (9)

The general electrical layout of insulation is ruled by the voltages to be withstood and the pollution to which the insulation is subjected. The standards IEC 60071-1 and IEC 60071-2 as well as the technical report IEC 60815, which provides four pollution classes, give guidance for the design of the insulation. Because IEC 60815 is applicable to AC lines, it should be noted that the creepage distances recommended are based on the phase-to-phase AC voltage (UL-L). When transferring these creepage distances recommended by IEC 60815 to a DC line, it should be noted that the DC



voltage is a pole-to-earth value (UL-E). Therefore, these creepage distances have to be multiplied by the factor  $\sqrt{3}$ . Furthermore, it should be noted that the AC voltage value refers to a mean value, while the DC voltage is comparable to a peak value, which requires a further multiplication with factor  $\sqrt{2}$ . Insulators under DC voltage operation are subjected to more unfavorable conditions than they are under AC, due to a higher collection of surface contamination caused by the constant unidirectional electric field. Therefore, a DC pollution factor has to be applied. Table shown with figure 5a shows specific creepage distances for different insulator materials under AC and DC application, and is based on industry experience published by power supply companies in South Africa and China. The results shown were confirmed by an experienced insulator manufacturer in Germany. The correction factors shown are valid for porcelain insulators only. When taking composite insulators into consideration, an additional reduction factor of 0.75 can be applied. The values for a DC system must be seen as a guideline only, that must be verified on a case-by-case basis for new HVDC projects.

To handle switching and lightning overvoltages, the insulator sets have to be designed with respect to insulation coordination according to IEC 60071-1 and IEC 60071-2. These design aspects determine the gap between the earthed fittings and the live part. However, for HVDC application, switching impulse levels

are of minor importance because circuit-breaker operations from AC lines do not occur on DC back-to-back lines. Such lines are controlled via their valve control systems. In order to coordinate the insulation in a proper way, it is recommended to apply and use the same SIL and BIL as is used for the <https://assignbuster.com/the-high-voltage-electricity-transmission-network-engineering-essay/>

equivalent AC insulation (determined by the arcing distance). [SIEMENS Power Engineering Guide 2009](9)

## **Selection and design of supports**

Together with the line voltage, the number of circuits (AC) or poles (DC) and type of conductors, the configuration of the circuits poles determines the design of overhead power lines.

Additionally, lightning protection by earth wires, the terrain and the available space at the tower sites have to be considered. In densely populated areas like Central Europe, the width of right-of-way and the space for the tower sites are limited. In the case of extra-high-voltages, the conductor configuration affects the electrical characteristics, the electrical and magnetic field and the transmission capacity of the line. Very often there are contradicting requirements, such as a tower height as low as possible and a narrow right-of-way, which can only be met by compromises. The minimum clearance of the conductors depends on the voltage and the conductor sag. In ice-prone areas, conductors should not be arranged vertically, in order to avoid conductor clashing after ice shedding.

For low-voltage and medium-voltage lines, horizontal conductor configurations prevail; these configurations feature line post insulators as well as suspension insulators. Poles made of wood, concrete or steel are preferred. Fig. 6 shows some typical line configurations. Earth wires are omitted at this voltage level.

For high-voltage and extra-high-voltage power lines, a large variety of configurations are available that depend on the number of circuits (AC) or <https://assignbuster.com/the-high-voltage-electricity-transmission-network-engineering-essay/>

poles (DC) and on local conditions. Due to the very limited right-of-way, more or less all high voltage AC lines in Central Europe comprise at least two circuits.

Fig. 7 shows a series of typical tower configurations. Arrangement “ e” is called the “ Danube” configuration and is often adopted. It represents a fair compromise with respect to width of right-of-way, tower height and line costs. For AC lines comprising more than two circuits, there are many possibilities for configuring the supports. In the case of circuits with differing voltages, those circuits with the lower voltage should be arranged in the lowermost position (fig7g). DC lines are mechanically designed according to the normal practice for typical AC lines. The differences from AC Line layout are the:

Conductor configuration

Electric field requirements

Insulation design

For DC lines, two basic outlines (monopole and bipole), with variations should be considered. Fig. 7i-l show examples for HVDC line configurations that are valid for all voltage levels. The arrangements of insulators depend on the application of a support within the line. Suspension towers support the conductors in straight-line sections and at small angles. This tower type offers the lowest costs; special attention should therefore be paid to using this tower type as often as possible. Angle towers have to carry the conductor tensile forces at angle points of the line. The tension insulator sets

permanently transfer high forces from the conductors to the supports. Finally, dead-end towers are used at the terminations of a transmission line. They carry the total conductor tensile forces on the line side (even under unbalanced load condition, e. g., when conductors of one tower side are broken) and a reduced tension into the substations (slack span).

#### Fig. 6 Configuration of Medium voltage supports

Various loading conditions specified in the respective national and international standards have to be met when designing towers. The climatic conditions, the earthquake requirements and other local environmental factors are the next determining factors for the tower design. When designing the support, a number of conditions have to be considered. High wind and ice loads cause the maximum forces to act on suspension towers. In ice-prone areas, unbalanced conductor tensile forces can result in torsional loading. Additionally, special loading conditions are adopted for the purpose of failure containment, that is, to limit the extent of damage. Finally, provisions have to be made for construction and maintenance. Depending on voltage level and the acting forces of the overhead line, differing designs and materials are adopted. Poles made of wood, concrete or steel are very often used for low voltage and medium-voltage lines. Towers with lattice steel design, however, prevail at voltage levels of 110 kV and above (fig. 7). Guyed lattice steel structures are used in some parts of the world for high-voltage AC and DC lines. Such design requires a relatively flat topography and a secure environment where there is no threat from vandalism and theft. Guyed lattice steel structures offer a substantial amount of cost

savings with respect to tower weight and foundation quantities. However, a wider right-of-way has to be considered.

## **Foundations for the supports**

Usually, overhead power line supports are installed on concrete foundations. The foundations have to sustain the overall weight of the tower and should be designed in accordance with the local or international standard applicable for the particular project.

Fig. 7;(a-h) Tower configurations for AC high-voltage lines. (i-l) Tower configurations for DC high-voltage lines

The selection of foundation types and the design is decided by the:

Total weight resulting from tower

Location and Soil conditions

Accessibility to the line route

Availability of machinery

Constraints of the particular country and the site

Concrete blocks or concrete piers are in use for poles that exert bending moments on the foundation. For towers with four legs, a foundation is provided for each individual leg. Pad and chimney and concrete block foundations require good bearing soil conditions without groundwater.

Driven or augured piles and piers are adopted for low-bearing soil, for sites with bearing soil at a greater depth and for high groundwater level. In case

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of groundwater, the soil conditions must permit pile driving. Concrete slabs can be used for good bearing soil, when subsoil and groundwater level prohibit pad and chimney foundations as well as piles.

Fig. 8; Foundations for four-legged towers

## **Route selection and tower spotting**

Selection of route and planning represent increasingly difficult tasks, because the right-of-way for transmission lines is limited and many aspects and interests have to be considered. Route selection and approval depend on the statutory conditions and procedures prevailing in the country of the project. Route selection nowadays involves preliminary desktop studies with a variety of route alternatives, environmental impact studies, community communication hearings and acceptance approval from the local authorities. [SIEMENS Power Engineering Guide 2009](9)

## **Literature Survey**

The books and journals referred are detailed in references. The methodology has been decided after studying different literatures. The societal loss calculation have been taken from the paper Power Chain Management™ Audit Service Focus Professional Engineering Services/ [www.powerchainmanagement.com](http://www.powerchainmanagement.com). The effective of electrical systems is critical to the success of businesses and facilities. The electrical problems facing businesses today can often seem overwhelming, especially knowing that key elements of electrical systems are susceptible to failure. It can be costly and difficult to design a system that predicts failure and minimizes risks of

dangerous hazards such as arc flash and from the graph which shows how does it cost in the time of losing the power supply.

Fig -2 cost raven (2)

To approximate cost of transmission losses. The loss calculations are based on an peak load current for a line.(7)

**EC (Energy Cost) = 3 x R x I<sup>2</sup> x 8760 x LF x AIC x LIF,**  
and

**DC (Demand Cost) = 3 x R x I<sup>2</sup> x IDC x LIF**

### **Where**

EC = energy cost, \$ / yr

DC = demand cost, \$ / yr

R = conductor resistance (ohms/phase/mile) X line length (miles)

I = peak load current on the line (amperes)

8760 = hours / year

LF = loss factor (average loss / peak loss)

AIC = average incremental energy cost for the year (\$ / kWh)

LIF = loss increase factor (1 + PU system losses reflecting  
increase)

IDC = incremental demand cost (\$ / kW-yr)

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Diffident maintenance strategies considered are :

Run to failure

condition based monitoring

on line monitoring

Hot line maintenance

The cost relationship between materials based solely on purchase prices, the life cycle economics at all the factors and gives consideration to the time value of money based on a “ present value” analysis. The approach of using present value, life cycle costs is often considered the fairest means of comparison because it considers and properly weighs all the material variables. This life cycle cost study gives consideration to the following:(6)

Environmental conditions

Material costs and availability

Construction costs

Projected service life

Inspection costs / Inspection frequency

Maintenance costs / Maintenance frequency



For the purpose of present value calculations, a 4% inflation rate and a 10% discount rate are assumed. The equation used for computing the present value (PV) of a single expend