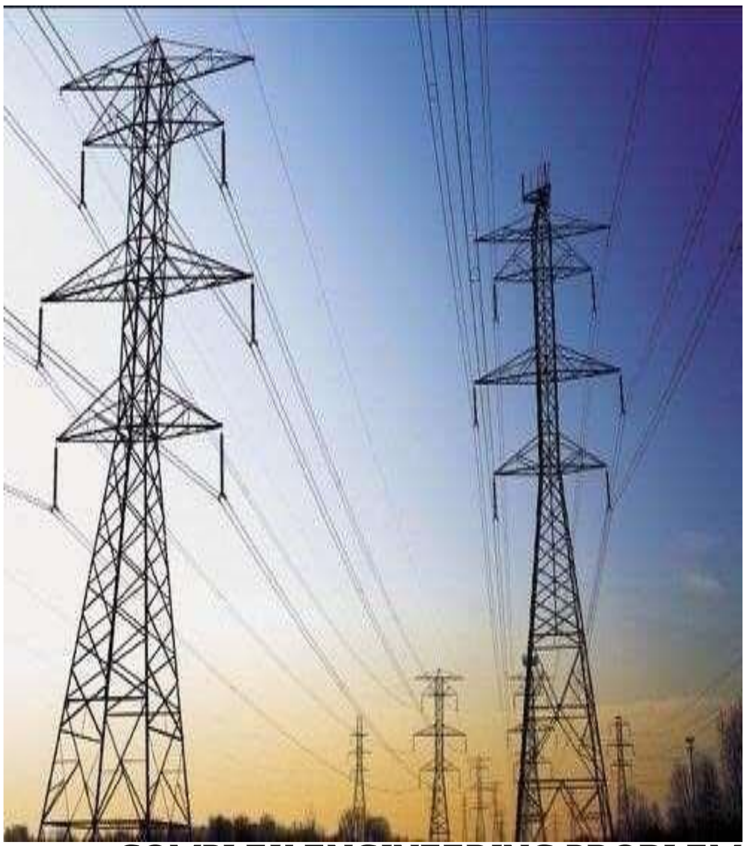

COMPLEX ENGINEERING PROBLEM

Electrical Power Transmission (EE-352)

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ABSTRACT

The transmission network serves the essential role of transferring electric energy generated at diverse locations to the distribution system, which subsequently caters to the overall demand. In addition to facilitating the economic dispatch of power within regions under normal circumstances, transmission lines also enable the emergency transfer of power between neighboring utilities. These lines consist of conductors with consistent cross-sectional profiles, utilizing air as an insulating medium between them. This study employs GUI software to conduct a comprehensive technical analysis of electrical and mechanical parameters for six distinct practical geometries. Furthermore, it introduces two innovative electrical/mechanical designs specifically tailored for one of these geometries.

PROCEDURE

For this assignment, we examined six distinct practical geometry systems, assessing their electrical and mechanical parameters based on our acquired theoretical knowledge. Employing GUI (Graphical User Interface) software, we initially crafted a code to calculate diverse electrical and mechanical parameters using various formulas. The GUI is configured to accommodate the six different geometries, enabling users to select and analyze any specific geometry of interest. Additionally, we identified a particular geometry for which we put forth two effective Electrical/Mechanical design proposals.

CONCEPTUAL FOUNDATION

Following are The concepts employed to solve the Complex Engineering Problem given below

Types of Circuits

Single Circuit Transmission Line: Single Circuit Transmission Line refers to an arrangement of conductors over the Transmission Tower. In a single-circuit transmission line, there will be three conductors for three phases.

Double Circuit Transmission Line: Double Circuit Transmission Line refers to the arrangement in which a total of six conductors are provided to make two different transmission circuits. In Double Circuit Transmission Line, there are two circuits each consisting of three conductors corresponding to three phases. Double-circuit transmission lines usually contain bundled conductors with the conductors placed as far as possible to minimize inductance.

Types of Electric Poles

The line supports used for the transmission and distribution of electric power are of various types including:

Wooden Poles: Wooden poles are appropriate for power lines with a moderate cross-sectional area. These supports are cost-effective, readily accessible, offer insulation, and are extensively utilized for distributing electricity in rural regions. However, their usage is limited to voltages not exceeding 20 kV.

Reinforced Concrete (RCC) Poles: They have greater mechanical strength, longer life, and permit longer spans than steel poles. They give a good outlook, require little maintenance, and have good insulating properties. Normally used for the 11 kV, 22kV, and 33 kV transmission lines.

Tubular Poles: These are commonly employed as an alternative to wooden poles, offering enhanced mechanical strength, increased lifespan, and the ability to use longer spans. Typically, these poles find application in urban areas for electricity distribution.

Latticed Poles: A lattice tower requires only half as much material as a free-standing tubular tower with a similar stiffness. It is easily adjusted to accommodate several electric circuits and various types of conductor configurations. It is normally used for 33 KV transmission lines.

Steel Tower: In practice, wooden, steel, or reinforced concrete poles are generally used for distribution purposes at low voltage say up to 11 kV. However, for long-distance transmission at higher voltages, steel towers are used. They have greater mechanical strength, longer life, can withstand most severe climatic changes, and permit the use of longer spans.

Types of Insulator

Pin Insulator: Pin insulators are used for voltage levels up to 33 KV.

Post-insulator: Post-insulators are used in bus bar connections for voltage levels up to 66 KV.

Strain Insulator: Strain insulators are used for Voltage levels greater than and equal to 66 KV, where deviation in transmission span is observed, they are more commonly used at terminal points. They are flexible to remove or add discs in case of maintenance and future expansion of load. To achieve higher mechanical strength, two sets of suspension insulators are used in parallel.

Suspension Insulator: Suspension insulators are used for Voltage levels greater than and equal to 66 KV. They are flexible to remove or add discs in case of maintenance and future expansion of load for achieving higher mechanical strength, two sets of suspension insulators are used in parallel.

Shackle Insulator: Shackle insulators are used for less than 11KV poles.

Types of Conductor Material

- AAC (All Aluminum Conductor)
- AAAC (All Aluminum Alloy Conductor)
- ACAR (Aluminum Conductor Alloy Reinforced)
- ACCC (Aluminum Conductor Composite Core)
- ACSR (Aluminum Conductor Steel Reinforced)

Aluminum Conductor Steel Reinforced:

This is a stranded conductor with high capacity, primarily employed in overhead power lines. Its external layer is crafted from pure aluminum, selected for its excellent conductivity, lightweight, cost-effectiveness, resistance to corrosion, and satisfactory mechanical stress resistance. Meanwhile, the internal part of the conductor consists of steel, providing additional strength to support the conductor's weight.

TRANSMISSION LINE PARAMETERS

1. Line Voltage
2. Inductance
3. Conductance
4. Conductor Type
5. Conductor Weight
6. Critical Disruptive Voltage
7. Irregularity Factor
8. Air Density Factor
9. Pressure
10. Temperature
11. Breeding Stress
12. Tension
13. Span
14. Ground Clearance

- Operating Voltage

Commonly used transmission voltages are 66 kV and 133 kV. On large utility systems, there are bulk transmission and interconnection circuits at 400 kV, 500 kV and more recently 765 kV [1]. The use of UHV (ultra-high voltage) lines is now being explored for equipment and lines rated for 1100 kV. The line voltage can be obtained from:

$$V = 5.5 * \left(\frac{L}{1.6} + \frac{P}{100}\right)^{0.5} \quad (kV)$$

L= Distance or length in km P= Rated power in KW

- Rated Power

It is the highest power allowed to flow through particular equipment. There are three different types of transmission lines on the basis of length.

Type	Length	Voltage Level
Short Transmission Line	Up to 80 km (Up to 50 miles)	less than 69 kV
Medium Transmission Line	80 – 240 km (50 – 150 mile)	from 69 kV to approx. 133 kV
Long Transmission Line	Above 240 km (> 150 miles)	above 133 kV

- Inductance

Inductance is the tendency of an electrical conductor to oppose a change in the electric current flowing through it.

- Capacitance

Transmission line conductors constitute a capacitor between them. The conductors of the transmission line act as a parallel plate of the capacitor and the air is just like a dielectric medium between them. The capacitance of a line gives rise to the leading current between the conductors. It depends on the length of the conductor.

- Types of Conductors

  There are three types of conductors:

  - Solid Conductors
  - Stranded Conductors
  - Bundled Conductors

- Bundled Conductors

  To mitigate the corona effect, employing multiple conductors per phase, known as bundled conductors, is recommended. Bundled conductors contribute to a reduction in the reactance of the electric transmission line, as well as a decrease in voltage gradient and surge impedance. The creation of a bundled conductor leads to an increase in the geometric mean radius (GMR) of the conductor. With an elevated self GMR, the inductance of the conductor experiences a decrease.

Number of Conductors	Single Circuit
2	$D^b{}_{sc} = \sqrt{r * d}$
3	$D_{bsc} = {}_3\sqrt{r * d_2}$
4	D_{bsc}

- Critical Disruptive Voltage

  It is the minimum phase to neutral voltage required for the Corona discharge to start.

$$E_o = 21.2 * 10^5 * m_o * r * \delta * \ln\left(\frac{D}{r}\right) \; V/Phase$$

Where,

m_o = Irregularity factor

δ = Air density factor

- Irregularity Factor

  The irregularity factor is the measure of the smoothness of the conductor which can affect the critical disruptive voltage. If the surface factor is negligible, it leads to a reduction in the critical disruptive voltage.

- Air Density Factor

  It is the ratio of air density density at any given barometric pressure and temperature to that at 25 degrees C and 760 mm of mercury of pressure. It also determines the corona loss in transmission lines. The corona loss is inversely proportional to the air density factor.

$$\delta = \frac{0.392}{273+t}$$

- Sag

  The sag is the variance in elevation between the supporting point and the lowest point along the conductor. When the conductor is tautened extensively between poles, there is a risk of it breaking. To ensure secure tension and prevent breakage, overhead lines incorporate sag.

$$s = \frac{wl^2}{8T}$$

Where

w= weight of conductor

T= Tension

l= span length

- Weight of Conductor

The total weight of conductor per unit length is determined by:

$$w_t = \sqrt{(w + w_i)^2 + (w_w)^2}$$

w= weight of conductor per unit length

w= conductor material density (volume per unit length)

wi= weight of ice per unit length

wi= density of ice x volume of ice per unit length

ww= wind force per unit length

ww= wind pressure per unit area (projected area per unit length)

- Pressure

Line pressure is just one of the components that contribute to the torque capacity of the transmission. It is the holding strength once the clutch is applied that contributes to strength.

- Tension

Tension on the conductor is inversely proportional to sag. If the tension is higher the conductors are connected very tightly between the tower structures and hence sag is less. On the other hand, if tension is less the conductors are connected loosely hands sag more.

$$T = \frac{Stress * Conductor\ Area}{Safety\ factor}$$

- Temperature

When a transmission line is carrying a lot of power, it heats up. The metal conductor in the line expands, causing the line to droop. Therefore, the transmission lines are designed in such a way that they can bear the atmospheric temperature of the area at all conditions.

- Stress

Stress within the power system is intricately defined by the proximity of demand to the capacity or operational limits of the system. This dynamic parameter reflects the operational challenges and constraints faced by the power grid, taking into account the demand for electricity and the capacity available for transmission and distribution. The stress level is a critical measure of the system's ability to handle the load and potential variations in demand, ensuring a delicate balance between supply and consumption. In practical terms, stress manifests when the demand for electrical power approaches or surpasses the existing capacity, potentially leading to operational issues, grid instability, or the risk of exceeding safety margins.

- Span

The distance between the two adjacent poles is known as span length. It increases proportionally with the line voltage. It plays an important role in the efficiency of transmission lines due to the dependency of sag on it.

- Minimum Ground Clearance

An adequate clearance of a conductor from the ground under all loading conditions is to be maintained for safety reasons. The clearance distance depends upon the transmission voltage. As per Indian Electricity Rule 1956,

$$GC = 5.2 + 0.3048 \; per \; 33kV$$

TECHNICAL ANALYSIS PARAMETERS

1. Corona Losses:

The occurrence known as the corona effect, marked by a hissing sound and a violet glow, is frequently witnessed in high-voltage transmission lines. When high voltage is applied to the conductors, ionized particles present in the outer atmosphere gain substantial velocity, leading to increased ionization and the manifestation of corona, which can potentially result in sparks. Understanding the corona characteristics of conductors becomes particularly crucial in the context of Extra High Voltage (EHV) transmission lines exceeding 33kV or 220kV.
According to Peterson's Formula:

$$P_c = \frac{21 * 10^{-6} * f * En^2}{(log_{10} \frac{D}{r})} * F \quad KW/KM/Phase$$

This formula is valid when corona losses are predominant and the ratio (*En/ Eo*) is less than 1.8.
F = F is a factor that varies with the ratio (*En/ Eo*) as under

—-	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2
F	0.012	0.018	0.05	0.08	0.3	1.0	3.5	6.0	8.0

2. Line Efficiency:

Transmission efficiency is a metric that quantifies the percentage of input power at the sending end that reaches the receiving end. As power is transmitted to the load, losses occur due to the resistance of the line conductors, resulting in the power delivered at the load end being lower than the power supplied at the sending end.

$$\eta = \frac{P_R}{P_s}$$

3. Voltage Regulation:

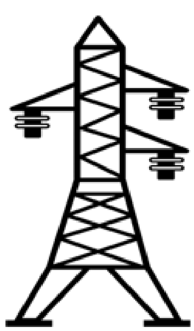
Upon supplying the load, the line experiences a voltage drop caused by the resistance and inductance of the line, leading to a typically lower voltage at the receiving end compared to the sending end. Voltage regulation is defined as the alteration in the voltage magnitude between the sending and receiving ends of the transmission line.

$$\%V.R = \frac{V_{R,nl} - V_{R,fl}}{V_{R,fl}} * 100$$

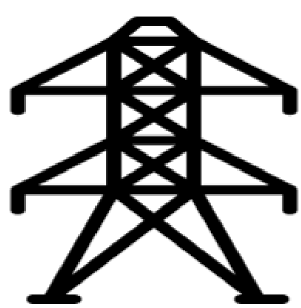
Where, V_R = Receiving end voltage

GEOMETRIES

Single Circuit Unbundled Conductor

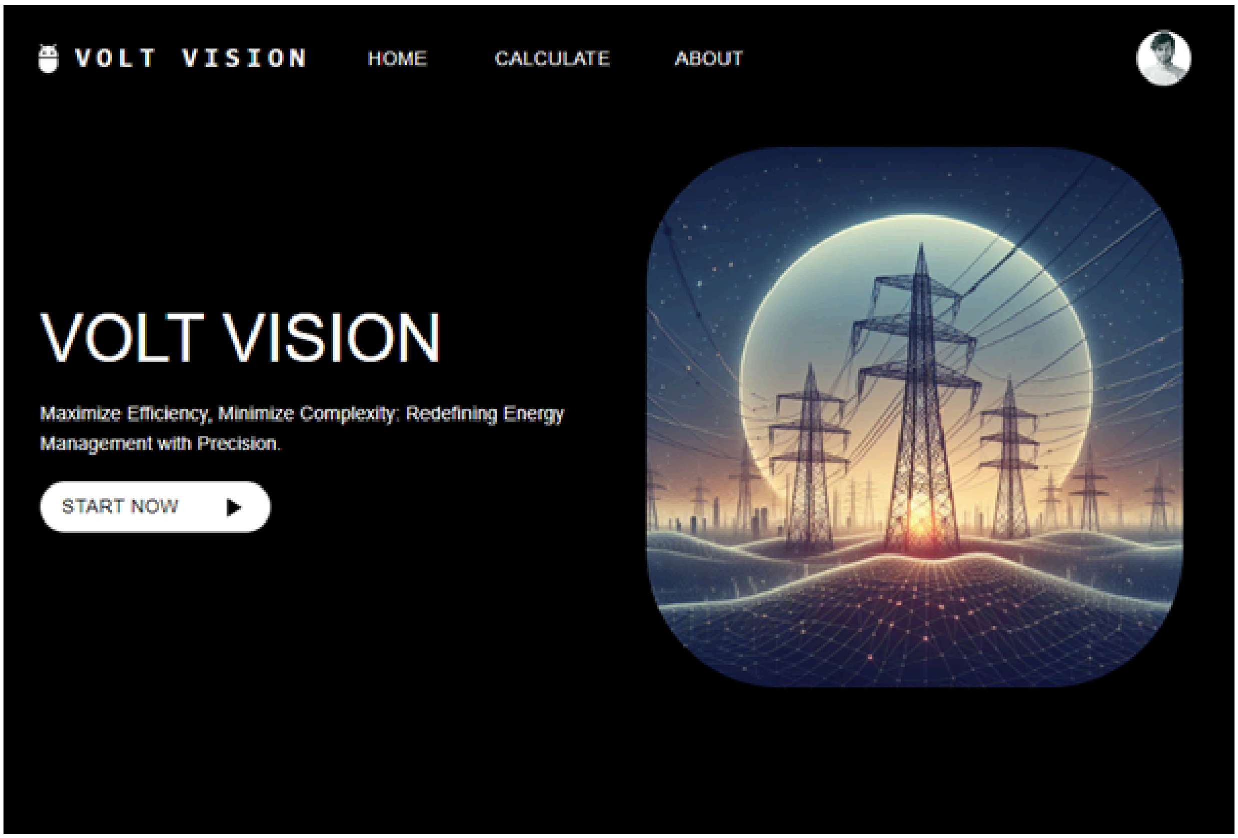


3-phase Circuit Unbundled Conductor



Graphical User Interfaces (GUI)

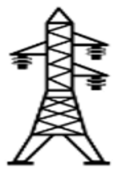
For the task, two different graphical user interfaces were developed on an app having different inputs and outputs for six specific geometries with one homepage. The GUI takes inputs of different parameters and provides relative output for the design. It consists of different panels including a picture, electrical parameters tab, mechanical parameters tab, and recommendations tab.



GUI For Conductors:

Inputs taken are ACSR code power, length of transmission, power factor, length of cross arms, vertical spacing, stress, wind pressure, irregularity factor, pressure, and temperature to generate desired output for designing.

3-phase Single Circuit Unbudled Conductor



Output Power: 50MW

Voltage: 132KV

Length: 100KM

Power Factor: 0.6

SELECT

INITIAL PARAMETERS

Output Power
50 MW

Length
100 KM

Power Factor
0.6

Ambient Temperature
40 °C

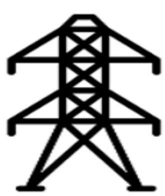
Heating Temperature
75 °C

Required Efficiency
94 %

Wire
Lynx

CALCULATE

1-phase Single Circuit Unbundled Conductor



Output Power: 100MW

Voltage: 220KV

Length: 200KM

Power Factor: 0.9

SELECT

INITIAL PARAMETERS

Output Power
100 MW

Length
200 KM

Power Factor
0.9

Ambient Temperature
40 °C

Heating Temperature
75 °C

Required Efficiency
94 %

Wire
Lynx

CALCULATE

Optimization

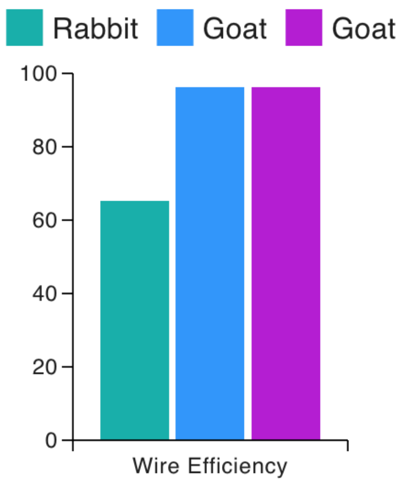
1. Initial Conditions and Upgrading Wire:

Initially, the power factor value stood at 0.6, and the wire in use was Rabbit ACSR. At this power factor and with Rabbit ACSR, the wire efficiency achieved was 65.33%, the system efficiency measured 49.2%, corona losses reached 1,267 kW, and voltage regulation was 34.5%. Subsequently, improvements were made by upgrading the wire from Rabbit ACSR to GOAT ACSR. After this enhancement, the line efficiency increased from 65.33% to 96.25%, and the system efficiency rose from 49.2% to 57.467%. Furthermore, corona losses saw a significant reduction to 14.28 kW, and voltage regulation decreased to 16.7%.

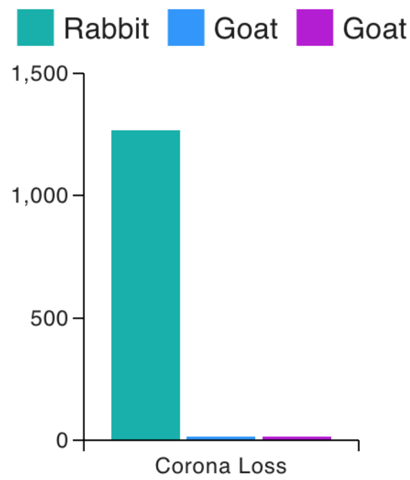
2. Power Factor Enhancement:

In the second phase of improvements, the power factor was increased from 0.6 to 0.9. Although wire efficiency and corona losses remained unchanged, the system efficiency experienced a notable increase, reaching 92.24%, and voltage regulation decreased to 7.673%.

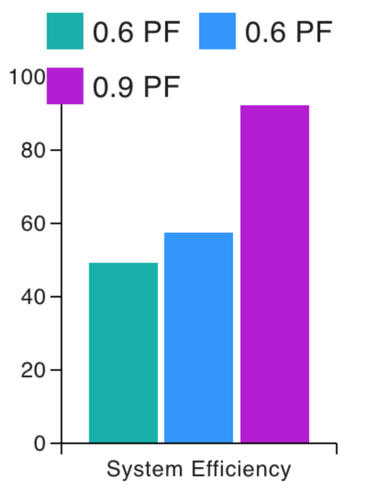
Graphs



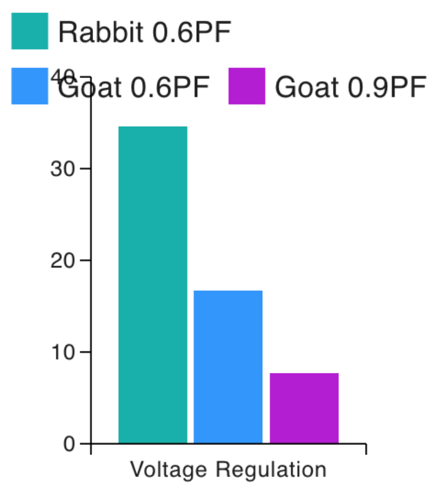
Rabbit
Goat
Goat
100
80
60
40
20
0
Wire Efficiency



Rabbit
Goat
Goat
1,500
1,000
500
0
Corona Loss



0.6 PF
0.6 PF
0.9 PF
100
80
60
40
20
0
System Efficiency



Rabbit 0.6PF
Goat 0.6PF
Goat 0.9PF
40
30
20
10
0
Voltage Regulation

Environmental Effects:

The described improvements in the electrical system, specifically upgrading the wire and enhancing the power factor, can have several environmental effects, both positive and potentially negative. Here are some considerations:

Positive Environmental Effects:

Increased Efficiency:

The overall increase in system efficiency implies that less energy is wasted during the transmission and distribution of electrical power. This can lead to a reduction in the total amount of energy required, contributing to lower overall energy consumption and potentially decreasing the environmental impact associated with power generation.

Decreased Losses:

The reduction in corona losses and improved efficiency in the system mean less energy is dissipated in the form of heat during power transmission. This contributes to a more effective utilization of energy resources and can result in a decrease in greenhouse gas emissions associated with power generation.

Lower Voltage Regulation:

The decrease in voltage regulation signifies a more stable voltage supply. This stability can improve the overall reliability of the electrical grid and reduce the need for excess power generation to compensate for voltage fluctuations, potentially leading to lower environmental impact.

Potential Negative Environmental Effects:

Materials and Manufacturing Impact:

The production and manufacturing processes involved in creating new wires, such as the transition from Rabbit ACSR to GOAT ACSR, may have environmental implications. These could include resource extraction, energy consumption, and waste generation associated with the production of new materials.

End-of-Life Disposal:

The disposal of old wires and materials from the Rabbit ACSR could have environmental consequences if not handled properly. Recycling or appropriate disposal methods should be considered to minimize the environmental impact.

Power Factor Correction Devices:

While improving the power factor contributes to efficiency, the installation of power factor correction devices might have associated environmental considerations. The production and operation of such devices could have environmental implications.

Conclusion:

In conclusion, while the overall trend suggests positive environmental effects due to increased efficiency and reduced losses, it is crucial to consider the entire life cycle of the system improvements, including manufacturing, operation, and disposal, to accurately assess the environmental impact.

Considerations for Safety:

Installation and Maintenance:

The process of upgrading wires and implementing power factor correction measures may involve installation and maintenance activities. Ensuring that these activities are carried out following proper safety protocols is essential to prevent accidents and injuries.

Training and Awareness:

Personnel involved in the upgrade and maintenance activities should receive adequate training to handle the new equipment and systems. Increased awareness of the changes and potential safety risks is crucial for maintaining a safe working environment.

Emergency Preparedness:

It's important to have emergency response plans in place in case of unforeseen events. This includes procedures for handling power outages, equipment failures, or other emergencies to minimize risks and ensure the safety of both personnel and the public.

Compliance with Standards:

Adhering to safety standards and regulations in the electrical industry is critical. Compliance helps ensure that the implemented changes meet recognized safety criteria and guidelines.

LIMITATIONS:

- Unable to change configuration.
- Voltage selection is automated through calculation; manual selection is not possible.
- Power increase is not supported.
- Conductor spacing cannot be manually selected; the system determines it through direct calculation.
- Time constraints prevented the addition of user-initiated features.
- Users should be able to edit all displayed parameters from the GUI to observe the effects.
- Encountering errors when attempting to change temperatures and power factor below 0.6 due to insufficient data available or found on the internet.

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