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Prototype Android Application for Electromechanical Dimensioning of Glass Insulator Strings under IEC-60071 and IEC-60815 (2008) Standards

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ABSTRACT

In this study, a new Android application was developed to help users accurately determine the dimensioning of a string insulator through the analysis of the evaluation of two methods based on IEC-60071 and IEC-60815 (2008) standards. The first method uses equations from IEC-60815-2 (2008), while the second method considers parameters such as relative air density and pressure. To ensure reliability, both methods are evaluated: the first through the creepage factor to determine if the chosen profile is suitable, and the second through lightning and switching critical flashover voltages to avoid insulator flashover. Tests were carried out using data from real projects, and those results were compared with the results obtained from the application. The number of string insulators obtained from the tests was exactly the same as the number obtained from the application, except in two cases. Of the three evaluations, all cases complied satisfactorily with at least two tests.

Keywords: insulator, application, creepage distance, correction factor, dimensioning.

INTRODUCTION

Transmission and distribution lines are the means of transport for electrical energy. They are mechanically fastened to insulator strings to prevent the structure from being energized. For this reason, proper dimensioning of the string is required. However, the calculation is challenging for both engineering students and designers on real projects, as different environmental, mechanical, and regulatory factors are considered. In addition, human error is possible. Therefore, it is necessary to incorporate all these factors into an interface that allows direct dimensioning through data entry and selection.

The objective of this study is to develop the correct calculation sequence for suspension insulator strings and based on that, create a prototype Android application to select suspended glass insulator strings according to International Electrotechnical Commission standard 60815 (IEC, 2008a, 2008b) and 60071-2 (IEC, 1996) in order to provide a tool to the electrical engineering community that can be used anywhere to size the insulator string and also verify if existing strings are adequate.

The contribution of this article to scientific knowledge is to provide a tool that can be used by engineers in projects and by students in their professional academic development through the comparison of their calculations with the results of the application.

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This contribution is novel because it is an easy-to-use Android application with results that verify its reliability.

Calculation and Selection Method

The calculations for the dimensioning of the insulator string are made so that they meet the necessary requirements for the correct operation of the transmission line. According to Orellana and Poma (2014), the requirements consist of having high dielectric strength to avoid flashovers between the conductor and the support, as well as decreasing the creepage current between the insulator and the support, even in unfavorable conditions due to weather.

The application flowchart (Figure 2) was structured based on the development of mathematical expressions that make it possible to obtain desired results from manually entered data and data selected from the database extracted from the VERESCENCE (2019) and Sediver (2018) catalogs.

Electrical Calculation

Parameters affecting the electrical calculation of the glass insulator string were considered. Therefore, the number of insulators obtained must support the conditions given by the user. For this reason, there will be two calculation methods. The first is based entirely on the updated IEC-60815-2 standard (IEC, 2008b). The second method determines the result considering pressure and relative air density. It should be noted that both the first and the second method will use the contamination levels shown in Table 1, where the creepage distance according to each pollution level is presented.

Table 1. *Pollution Levels - Reference Unified Specific Creepage Distance (RUSCD).*

Pollution Level	Basic RUSCD (mm/kV)
Very light	22.0 mm/kV
Light	27.8 mm/kV
Medium	34.7 mm/kV
Heavy	43.3 mm/kV
Very heavy	53.7 mm/kV

Source: RUSCD pollution level parameter based on the pollution severity of the area. (IEC, 2008b).

Method 1: Number of Insulators Based on Creepage and Arcing Distance

In this method, the mathematical equations found in the updated standard mentioned above will be shown. Also, the data to be entered in the application will be shown.

A. Creepage distance at maximum operating voltage according to IEC-60815-2 standard (IEC, 2008b):

$$C_{D-V} = USCDx\frac{Um}{\sqrt{3}} \quad (1)$$

The mathematical expression of USCD is:

$$USCD = RUSCDx(Ka)x(Kad) \quad (2)$$

Now, from (1) and (2) the following is obtained:

$$C_{D-V} = RUSCDx(Ka)x(Kad)x\frac{Um}{\sqrt{3}} \quad (3)$$

B. Altitude correction factor

Due to the influence of air pressure and density variation at higher altitudes, which affects operating voltage, IEC-60815-2 standard (IEC, 2008b) mentions that an altitude correction factor must be applied, in accordance with Díaz and Narváez (2015). This factor is shown in the following equation (IEC-60071-2, 1996):

$$Ka = e^{m\left(\frac{H}{8150}\right)} \quad (4)$$

C. Correction factor for insulator average diameter

The IEC-60815-2 standard (IEC, 2008b) also considers a correction factor based on the insulator diameter. In this sense, there are two conditions defined by expressions (5) and (6).

$$Kad = 1, \left(Da < 300mm\right) \quad (5)$$

$$Kad = 0.0005xDa + 0.85, \left(Da \geq 300mm\right) \quad (6)$$

D. Number of insulators based on the creepage distance

The following equation (7) considers the phase-to-earth creepage distance, as specified in the IEC-60815-2 standard (IEC, 2008b). RUSCD only considers phase-to-earth voltage, not line-to-line as in the previous version of the standard.

$$N_{C.distance} = 1.15x\frac{C_{D-V}}{cd} \quad (7)$$

It is worth noting the following:

1.15 = Safety factor to avoid flashover in insulators.

Number of insulators based on creepage distance

To obtain a complete mathematical expression, the equations presented above will be joined. The correction factorsn Ka and Kad will be placed in expanded form, therefore two final equations are displayed for the calculation of the number of insulators of method 1, which will depend on the condition of the diameter of the insulator, therefore the equations are as follows:

- If the diameter is less than 300 mm

$$N_{C.distance} = 1.15x\frac{RUSCDxe^{m\left(\frac{H}{8150}\right)}}{cd}x\frac{Um}{\sqrt{3}} \quad (8)$$

- If the diameter is greater than or equal to 300 mm:

$$N_{C.distance} = 1.15x\frac{RUSCDxe^{m\left(\frac{H}{8150}\right)}x(0.0005xDa+0.85)}{cd}x\frac{Um}{\sqrt{3}} \quad (9)$$

It should be considered that Ka will be greater than 1 when the altitude is greater than 1000 m.a.s.l., otherwise, the value of the unit will be considered.

Equations (8) and (9) will be used in the application by entering and selecting data, which are mentioned below.

Data to be selected:

- $RUSCD$: Reference Unified Specific Creepage Distance (mm/kV).
- m: 0.5 (normal), 0.8 (anti-fog) or 1 (spherical or aerodynamic) according to IEC-60071-2 (1996).
- Um: maximum operating voltage.
- cd: creepage distance of the insulator (catalog).
- Da: average insulator diameter (nominal diameter if the insulator does not have different diameters).

Data to enter:

- H: height above sea level (m.a.s.l.).

Number of insulators based on arcing distance

The choice of the number of insulators must be adequate so that the length of the complete insulator string is greater or equal to the critical phase-to-ground distance. In this sense, the calculation of the minimum number of insulators is done using equation (10).

$$N_{Arc\ d.} = 1 + \frac{(L-200)}{La} \quad (10)$$

While the vertical spacing "La" is catalog data, "L" is the critical phase-to-earth distance that relates to the IEC-60815-2 creepage factor (IEC, 2008b). This distance will be given by table A-1 of IEC-60071-2 (1996).

Data to be selected:

La: insulator vertical spacing (mm).

L: critical phase-to-earth distance (mm).

Evaluation of method 1 based on the creepage factor

In order to determine whether the choice of the insulator string profile has been optimal, the present evaluation, based on the creepage factor, is used and is calculated with the following equation (11):

$$CF = \frac{l}{S} \quad (11)$$

Where:

l: total nominal creepage distance of the insulator

S: arcing distance of the insulator (critical distance)

Although these variables are different from the ones used in the previous equations, they have the same meaning:

$$d_f x N_1 = l \quad (12)$$

$$L = S \quad (13)$$

$$CF = \frac{d_f x N_1}{L} \quad (14)$$

It should be noted that N_1 is the number of insulators resulting from method 1.

The CF is useful to determine the suitability of the profile, as shown in Figure 1, where the CF value must be kept in the white zone. If the CF value moves to the gray or black zone, an insulator string with a different profile is selected.

Method 2: Number of isolators by pressure and relative air density

In this section, the calculation for the number of insulators will be determined considering the relative

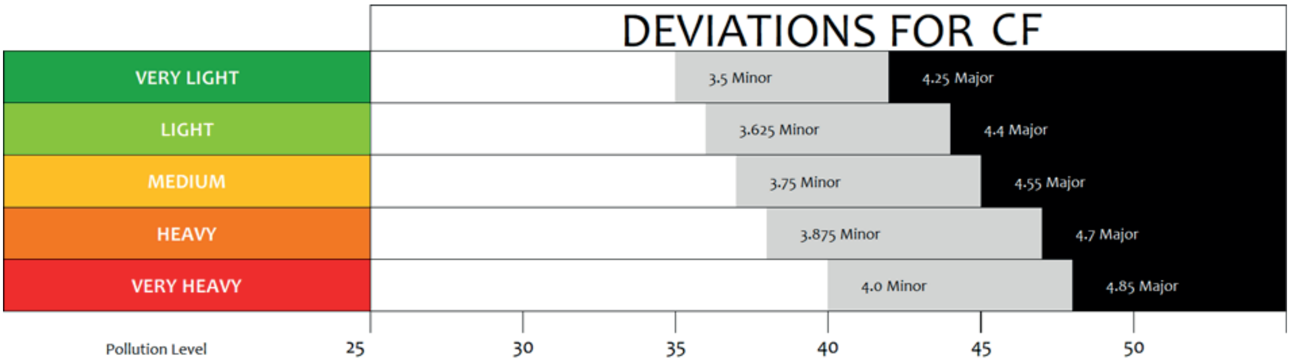

Figure 1. Deviations for the creepage factor (CF) according to each pollution level.

Source: Adapted from *Deviations for CF* from IEC 60815-1. (IEC, 2008a).

air density (with pressure and temperature), where A, B, and C are based on Portero (2019).

Equation (18) will be used in the application, where the data to be entered and selected will be shown. In addition, the correction factors to be used will be shown based on tables.

A. Barometric pressure

$$B_p = 0.885^{h(km)} x76 \text{ (cm/hg)} \quad (15)$$

B. Relative air density

$$\delta_{air} = \frac{3.92xB_p}{273.15+T°C} \quad (16)$$

C. Number of insulators with maximum voltage (N)

$$N = \left[\frac{Um\times 1.15}{\sqrt{3}\times(cd)x(\delta_{air})^n}\right] \times RUSCD \quad (17)$$

D. Precipitacion correction factor (*fll*)

Table 2 shows a correction factor according to precipitation. This correction factor is added to the equations in the form of multiplication.

Table 2. *Precipitation Correction Factor.*

Rainfall Intensity	Correction Factor
0.00 mm/min	1.00
1.00 mm/min	0.95
1.27 mm/min	0.83
2.50 mm/min	0.77
3.80 mm/min	0.73
5.10 mm/min	0.71
6.30 mm/min	0.68

Source: Taken from Cotto (2021).

E. Humidity correction factor (*fh*)

The *fh* depends on the relative humidity and temperature. For a frequency of 60hz, a double-entry table (Table 3) was made using two curve graphs to obtain the value of the *fh* which makes it an important database in the development of the application.

Equation for the number of insulators based on pressure and relative air density

La ecuación (18), que se usará en la aplicación, permite hallar el número de aisladores por tensión máxima.

$$N = \left[\frac{Um\times 1.15}{\sqrt{3}\times(cd)x\left(\frac{297.92\times 0.885^{\left(\frac{H}{1000}\right)}}{273.15+T°C}\right)^n}\right] \times RUSCD \quad (18)$$

Where:

- Data to select:

  Um: maximum voltage in kV, according to IEC 60071-1 (IEC, 1993)

  RUSCD: Reference Unified Specific Creepage Distance (mm/kV) – IEC-60815-2 (IEC, 2008b)

  cd: creepage distance of the insulator (catalog)

  n: if $Um \leq 230$ kV, n = 1 y if $Um > 230$ kV, n = 0.9

- Data to enter:

  T°C: ambient temperature

  H: height above sea level (m.a.s.l.)

Table 3. *Humidity Correction Factor..*

°C	Relative Humidity									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
0	1.14492694	1.14089224	1.11979946	1.12015942	1.11255994	1.10714298	1.09736524	1.09417581	1.08752743	1.07666906
1	1.14363001	1.13861078	1.11910865	1.1176695	1.10984326	1.10362938	1.09381732	1.08954026	1.08258559	1.07191786
2	1.14239911	1.13641712	1.11828013	1.11515852	1.10703346	1.10005624	1.09014831	1.08484951	1.07755023	1.06699671
3	1.14122649	1.13430128	1.11730835	1.11260943	1.10411497	1.0964082	1.08634458	1.0800814	1.07240115	1.06188822
4	1.14010448	1.13225343	1.11618792	1.1100055	1.10107265	1.09267041	1.08239315	1.07521476	1.06711926	1.0565763
5	1.13902548	1.13026391	1.1149136	1.10733036	1.09789186	1.08882854	1.07828165	1.07022945	1.06168665	1.05104624
6	1.13798196	1.12832319	1.11348036	1.10456801	1.09455847	1.0848688	1.07399846	1.06510644	1.0560866	1.04528481
7	1.13696643	1.12642187	1.11188335	1.10170284	1.09105893	1.08077819	1.0695327	1.05982785	1.05030405	1.03928037
8	1.13597148	1.1245507	1.11011794	1.09871966	1.0873803	1.07654408	1.06487433	1.05437706	1.04432492	1.033023
9	1.13498975	1.12270052	1.10817974	1.09560378	1.08351032	1.07215474	1.06001419	1.04873875	1.03813698	1.02650461
10	1.1340139	1.12086232	1.10606462	1.09234099	1.07943749	1.06759911	1.0549440	1.04289907	1.03172956	1.01971908
11	1.13303667	1.1190272	1.10376871	1.08891763	1.0751511	1.0628669	1.04965675	1.03684566	1.02509375	1.01266234
12	1.13205085	1.11718635	1.10128843	1.08532065	1.07064128	1.05794894	1.04414613	1.03056782	1.01822248	1.00533254
13	1.13104926	1.11533112	1.09862051	1.08153768	1.06589913	1.05283655	1.03840722	1.02405656	1.01111068	0.99773016
14	1.13002479	1.11345295	1.09576203	1.07755704	1.06091674	1.04752233	1.03243627	1.01730476	1.00375537	0.98985811
15	1.12897036	1.11154341	1.09271038	1.07336782	1.05568729	1.04199982	1.02623082	1.01030728	0.99615574	0.98172183
16	1.12787898	1.1095942	1.08946333	1.06895997	1.0502051	1.0362637	1.01978974	1.00306105	0.98831332	0.97332943
17	1.12674369	1.10759714	1.08601906	1.06432434	1.04446573	1.03030981	1.01311334	0.9955652	0.98023203	0.96469176
18	1.12555762	1.10554421	1.08237611	1.05945278	1.0384660	1.02413522	1.00620342	0.98782116	0.9719183	0.95582247
19	1.12431396	1.10342754	1.07853347	1.05433816	1.03220427	1.01773833	0.99906331	0.97983279	0.96338118	0.94673811
20	1.12300599	1.10123939	1.07449057	1.0489744	1.02568012	1.01111889	0.9916979	0.97160645	0.95463235	0.93745811
21	1.12162706	1.09897223	1.07024729	1.04335697	1.01889479	1.00427808	0.98411399	0.9631511	0.9456862	0.9280048
22	1.12017064	1.0966186	1.06580399	1.0374821	1.01185111	0.99721858	0.97631971	0.95447841	0.93656014	0.91840374
23	1.11863028	1.09417159	1.06116153	1.03134771	1.00455353	0.9899446	0.96832519	0.9456027	0.92727399	0.9086829
24	1.11699967	1.09162398	1.05632127	1.02495304	0.9970082	0.9824620	0.96014227	0.93654131	0.91785063	0.89887339
25	1.11527261	1.08896914	1.0512851	1.01829885	0.98922325	0.97477828	0.95178461	0.92731409	0.90831567	0.8890089
26	1.11344304	1.0862005	1.04605547	1.01138745	0.98120829	0.9669025	0.9432676	0.91794391	0.8986974	0.87912593
27	1.11150506	1.08331202	1.04063536	1.00422278	0.9729750	0.9588457	0.9346088	0.9084563	0.8890269	0.86926298
28	1.10945292	1.0802975	1.03502833	0.9968104	0.9645370	0.95062057	0.9258270	0.8988799	0.87933753	0.8594609
29	1.10728106	1.07715161	1.02923853	0.98915794	0.9559098	0.94224136	0.91694335	0.8892454	0.86966511	0.84976232
30	1.10498412	1.0738687	1.02327069	0.98127434	0.94711067	0.93372434	0.9079803	0.8795866	0.8600475	0.84021127
31	1.10255692	1.0704440	1.01713015	0.9731707	0.9381589	0.92508747	0.8989622	0.8699393	0.8505247	0.83085283
32	1.0999945	1.0668728	1.01082287	0.9648599	0.9290759	0.91635045	0.8899150	0.8603416	0.84113776	0.82173254
33	1.0972922	1.06315096	1.00435539	0.9563568	0.91988473	0.9075346	0.8808661	0.8508334	0.83192914	0.81289585
34	1.0944456	1.05927453	0.9977349	0.9476782	0.91061016	0.8986632	0.87184425	0.84145628	0.82294194	0.80438741
35	1.0914504	1.05524017	0.9909692	0.9388425	0.90127893	0.8897607	0.86287941	0.83225274	0.81421932	0.79625034

Source: Adapted with AutoCAD and Excel from the “Dry Blub Temperature - °C” chart and “Absolute Humidity – g/m3” charts of LaForest (1982).

Evaluation of the number of insulators based on switching critical flashover voltage (CFO switch.)

The number of insulators to be calculated in method 2 must be adequate to withstand the switching critical flashover voltage. For this calculation, the following equation will be used, based on Mendoza et al. (2013), which considers climatic factors such as rain and humidity.

$$CFO_{switch.} = \frac{BSL \times fH \times fh}{0.992 \times \delta_{air} \times fll} \quad (19)$$

The altitude correction factor fH, as well as Ka, will be greater than 1 when the altitude is greater than 1000 m.a.s.l. Otherwise, the value of the unit will be considered.

For direct data entry as in the previous equations, the equation will be defined as follows:

$$CFO_{switch.} = \frac{BSL \times fh \times \left(1 + \left(\frac{H-1000}{10^6}\right) x125\right)}{0.992 \times \left(\frac{297.92 \times 0.885^{\left(\frac{H}{1000}\right)}}{273.15 + T°C}\right) \times fll} \quad (20)$$

For equation (20), the following will be considered:

- Data to be selected:

  BSL: basic switching impulse insulation level, according to standard IEC-60071-1 (IEC, 1993)

  fh: humidity correction factor

  fll: precipitation correction factor

- Data to be entered:

  H: height above sea level (m.a.s.l.)

  $T°C$: ambient temperature

The switching critical flashover voltage must be less than the voltage that the insulator string will withstand. Therefore, the following condition is proposed, which will be used for the evaluation of method 2:

$$NxV_{Withstand.ind.fr.} > CFO_{switch.} \quad (21)$$

Where the data to be selected will be:

$V_{Withstand.ind.fr.}$: withstand voltage at industrial frequency (catalog)

Evaluation of the number of insulators based on lightning critical flashover voltage (CFO lightning)

In the same way as in the previous evaluation, the following equation based on Mendoza et al. (2013) will be used. This equation will also consider climatic factors.

$$CFO_{lightning} = \frac{BIL \times fH \times fh}{0.961 \times \delta_{air} \times fll} \quad (22)$$

The altitude correction factor fH, as well as Ka, will be greater than 1 when the altitude is greater than 1000 m.a.s.l. Otherwise, the value of the unit will be considered.

For direct data entry as in the previous equations, the equation will be defined as follows:

$$CFO_{lightning} = \frac{BIL \times fh \times \left(1 + \left(\frac{H-1000}{10^6}\right) x125\right)}{0.961 \times \left(\frac{297.92 \times 0.885^{\left(\frac{H}{1000}\right)}}{273.15 + T°C}\right) \times fll} \quad (23)$$

For equation (23), the following will be considered:

- Data to be selected:

  BIL: basic impulse insulation level, which is the lightning impulse voltage according to standard IEC-60071-1 (IEC, 1993)

  fh: humidity correction factor

  fll: precipitation correction factor

- Data to be entered:

  H: height above sea level (m.a.s.l.)

  $T°C$: ambient temperature

The lightning critical flashover voltage must be less than the voltage that the insulator string will withstand. Therefore, the following condition is proposed, which will be used for the evaluation of method 2:

$$NxT_{withst.} > CFO_{Lightning} \quad (24)$$

Where the data to be selected will be:

$T_{withst.}$: withstand voltage at industrial frequency (catalog)

Resulting number of insulators

Based on the previous results, the resulting number of insulators will be the largest of the three numbers obtained, which have had to pass the evaluations shown, mathematically the final result can be expressed as follows.

$$If:$$

$$N_{Creep.d.} < N_{Arc.d.} < N \vee N_{Arc.d.} < N_{Creep.d.} < N \rightarrow N_{re} = N \quad (25)$$

$$If:$$

$$N_{Creep.d.} < N < N_{Arc.d.} \vee N < N_{Creep.d.} < N_{Arc.d.} \rightarrow N_{re} = N_{Arc.d.} \quad (26)$$

$$If:$$

$$N < N_{Arc.d.} < N_{Creep.d.} \vee N_{Arc.d.} < N < N_{Creep.d.} \rightarrow N_{re} = N_{Creep.d.} \quad (27)$$

Where:

N_{re}: umber of insulators resulting from the calculation

Mechanical calculation

For the mechanical calculation, the equations used by the application to calculate and select insulators, based on López (2018) and De la Fuente (2016), will be shown. Therefore, the accessory that mechanically joins the insulators with the transmission lines, called a fitting, must be taken into account. The weight of the insulator string and the fittings will be calculated through the following ratio:

$$W_{st+F} = W_{st} + W_{Fitting} \quad (28)$$

$$W_{st} = N_{re} \times M_{ins} \times \frac{9.81 m/s^2}{10} \quad (29)$$

Where:

Wst: string weight (daN)

N_{re}: number of insulators in the resulting string

W_{st+F}: Weight of the insulator string plus fitting (daN)

- Data to be selected:
  - M_{ins}: mass of an insulator (kg)
- Data to be entered:
  - $W_{Fitting}$: fitting weight (daN)

For the mechanical calculation, the factor of safety for failure of glass insulators Fos must be greater than 3. The insulator must withstand the normal loads acting on it.

$$Fosv = \frac{Q_a}{(P_v + W_{str+F})} > 3 \quad (30)$$

Where:

- Fosv: factor of safety for failure of insulators under normal loads
- Data to be selected:
  - Q_a: breaking load of the insulator (daN)
- Data to be entered:
  - P_v: vertical stress transmitted by the conductors to the insulator (daN)

Likewise, the insulator withstands abnormal loads that are found by means of the following expression:

$$Fosh = \frac{Q_a}{(T_{oh} \times ncf)} > 3 \quad (31)$$

Where:

- Fosv: factor of safety for failure of insulators under abnormal loads
- Data to be selected:
  - Q_a: failing load of the insulator (daN)
- Data to be entered:
  - T_{oh}: maximum horizontal tension under the most unfavorable conditions (daN)
  - n_{cf}: number of conductors per phase (daN)

Following this, the string length will be calculated with the following expression:

$$L_{ca} = N_{re} \times La \quad (32)$$

Where:

- L_{st}: string length (mm)
- N_{re}: number of insulators of the resulting string (number obtained from calculations)
- La: length of insulator or spacing (mm)

Finally, it gives the following expression for the wind stress generated on the insulator string:

$$S_{st} = 70 \left(\frac{w}{120}\right)^2 \left(\frac{Da}{1000}\right) L_{st} \quad (33)$$

Where:

- S_{st}: wind stress on the insulator string (daN)
- L_{st}: length of string (mm)

- Data to be selected:
    - D_a: maximum diameter of the insulator (mm)
- Data to be entered:
    - W: wind speed (Km/h)

Selecting the insulator profile

The considerations on the items 9.1. 9.2 and 9.3 of the standard IEC-60815-1 (IEC, 2008a) must be taken into account when selecting the insulator profile. The profiles are the following:

- **Standard:** Used in lines whose pollution is light or medium.
- **Anti-fog:** Used in areas with medium to heavy pollution.
- **Spherical:** Similar to an open or aerodynamic profile.
- **Open or aerodynamic:** It has a flat area, which is very useful in desert areas since the wind cleans the surface of the insulator.

Testing the app

To determine the reliability of the application based on a real situation, different data extracted from calculation memories of real and completed projects will be used as a reference, as shown in Table 4. The table also shows the number of insulators resulting from these calculation memories.

Hypotheses

1. The resulting number of insulators coincides in at least 90% with the results of the calculation memories.
2. At least two out of the three evaluations of the calculation methods will result in the term “Acceptable” that will be shown in the app.

METHODOLOGY

Objective and Justification

This work was carried out with the objective of optimizing the dimensioning of glass insulator strings by means of a prototype of an Android

Table 4. *Data from Real Projects.*

TESTS	1	2	3	4	5	6
	Transmission Line 500 kV La Niña – Piura Nueva	**Transmission Line 2 x 220 kV Piura Nueva – Piura Oeste**	**Sub-Station Friaspata**	**Sub-transmission line to 69 kV Songa**	**Transmission Line 220 kV Reus – Tarragona**	**Transmission Line 220 kV Reque – Nueva Carhuaquero**
T (°C)	30	30	16	20	-	-
Relative humidity (%)	75	75	80	80	-	-
m.a.s.l.	39	39	3730	6	-	-
BIL (kV)	1550	1050	1300	325	1050	1050
BSL (kV)	1175	460	460	140	460	460
Umax (kV)	550	245	245	72.5	245	245
Spacing (mm)	159	146	146	146	170	146
Diameter (mm)	330	330	280	254	320	280
Creepage distance (mm)	620	545	445	290	530	445
Pollution level	Heavy	Heavy	Heavy	Heavy	Very heavy	Very heavy
Number of insulators (calculation memory)	28	14	23	5	15	18

Source: Data extracted from Comité de Operación Económica del Sistema Interconectado Nacional (COES, 2016a, 2016b), SIEMENS (2016), Orellana and Cevallos (2019), COES (2018), and Olives (2016).

application with a didactic interface for academic and professional use. The choice of an application is based on the practicality it offers, since users can download it and access it from their cell phones. Initially, the development of the calculation was made in Excel, however, the scope of the prototype is greater if it is used on a cellphone, which functions as a computer, which greatly increases its accessibility.

Development

The development of the app was based on the standards mentioned before and environmental factors were taken into consideration. For this reason, two calculation methods that complemented each other were developed to give a better result. The calculation evaluations were developed together and fulfill the objective of providing knowledge about the acceptability of the type of insulator and its characteristics.

Obtaining the Table "Humidity Correction Factor"

AutoCAD and Excel were used to approximate two tables in order to obtain the humidity correction factor. In this way it was possible to obtain the curves of the tables and create a double-entry table to find the humidity correction factor. This value is extracted from crossing the relative humidity row and the temperature column of Table 3.

Order of the Calculation Process

Once the calculation base was obtained, the flowchart shown in Figure 2 was developed. This flowchart is the visual representation of the operation made by the Android app, which was developed with a database uploaded to the cloud. Finally, the product obtained is an application that generates a report of the calculations.

The flowchart shown contains input and output variables that can be seen in Table 5, where the meaning of each variable can be found.

App Development and User Interface

The Android application was developed in Java language using Android default libraries and control structures, which are mostly conditional and loops. In this way the equations were placed and connected following the structure of Figure 2. In addition, the database containing tables and insulator data was uploaded to the cloud using the platform Firebase.

The equations previously shown for the dimensioning of the insulator string will be entered into the application together with the database containing the necessary parameters for the selection. Figures 3, 4, 5, 6 and 7 show the user interface where the data will be entered and selected in the application. This will be done in each of the fields shown, which have boxes, drop-down lists and buttons for easy use. The name of the application will be "Untels Insulator".

Limitations of the Application Prototype

During the development and implementation of the application, certain limitations were found. These are mainly related to the database since there are only two glass insulator catalogs. Also, an option for manual data entry has not yet been developed since it considerably increases the complexity of the programming. It is worth mentioning that the application is also limited only to glass insulators and does not cover those made of polymers.

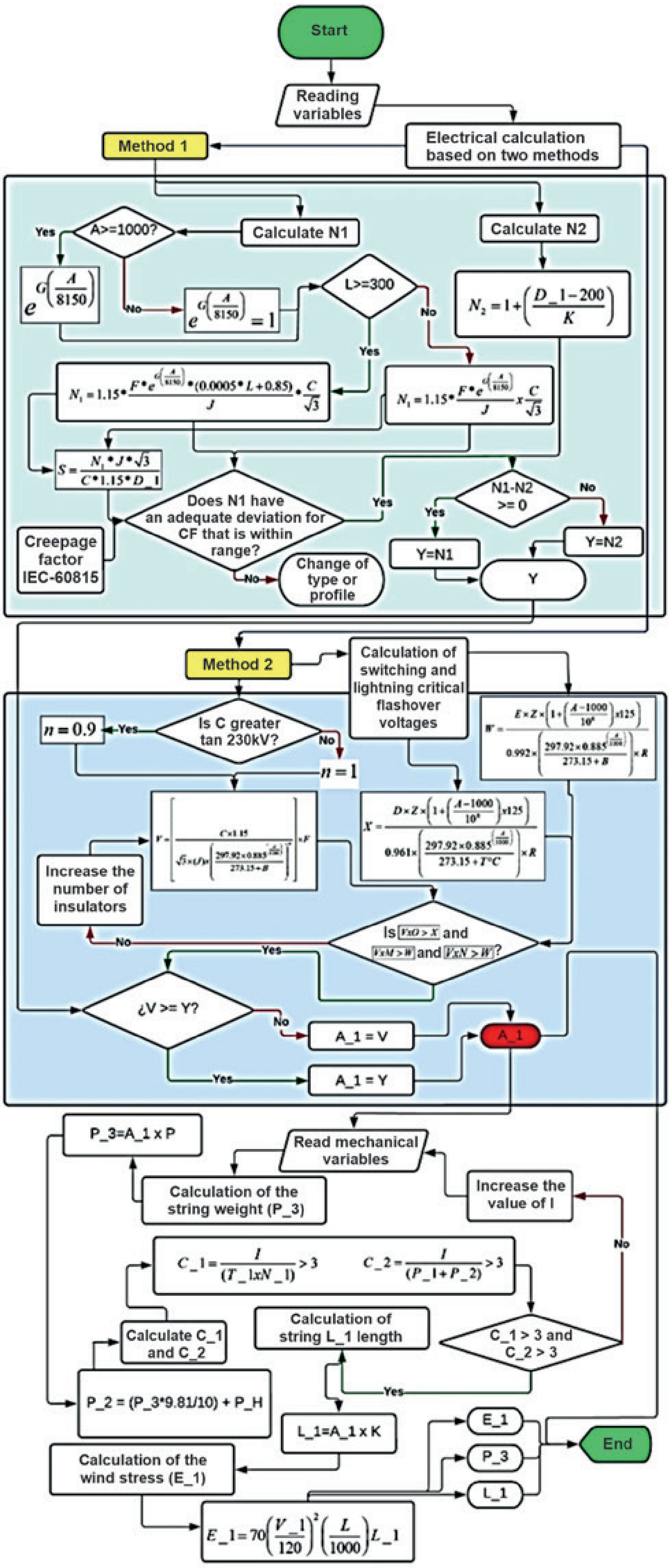

Figure 2. **Flowchart for the application.**.

Source: Prepared by the authors using Lucid.app.

Table 5. *Variables Declared on the Flowchart.*

Input and Output Variables	Variables' Meaning
A	Altitude (m.a.s.l.)
B	Temperature (°C)
C	Maximum voltage (kV)
D	Basic insulation level (kV)
D_1	Critical distance (mm)
E	Basic switching impulse insulation level (kV)
F	Pollution level (mm/kV)
N_1	Number of conductors per phase
T_1	Maximum horizontal tension (daN)
G	Profile or type of insulator
H	Insulator code
I	Failing load (daN)
J	Creepage distance (mm)
K	Spacing (mm)
L	Diameter (mm)
M	FT-dry (kV)
N	FT-precipitation (kV)
O	FT-lightning (kV)
P	Insulator mass (kg)
Q	Relative humidity
R	Precipitation correction factor
P_H	Fitting weight (daN)
Z	Humidity correction factor
C_1	Safety coefficient to the breakage of the insulators with abnormal loads
P_1	Factor of safety for failure of insulators under abnormal loads (daN)
T_1	Maximum horizontal tension (daN)
P_2	Weight of the insulator string and fitting (daN)
C_2	Factor of safety for failure of insulators under normal loads (daN)
L_1	Length of insulator string (mm)
P_3	Mass of the insulator string (kg)
E_1	Wind stress on the string (daN)
V_1	Wind speed (km/h)

Source: Prepared by the authors.

Figure 3. Main User Interface.

Source: Prepared by the authors (screenshot).

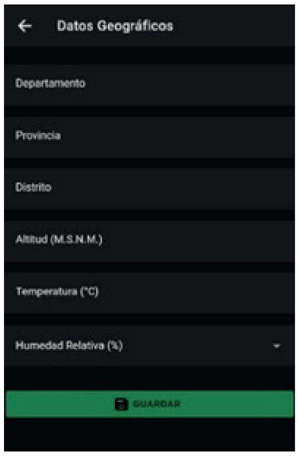

Figure 4. User Interface for Geographic Data.

Source: Prepared by the authors (screenshot).

Figure 5. User Interface for Transmission Line Data.

Source: Prepared by the authors (screenshot).

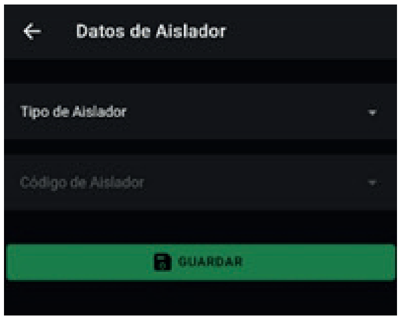

Figure 6. User Interface for Insulator Data.

Source: Prepared by the authors (screenshot).

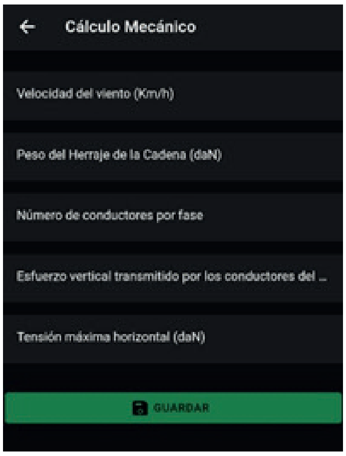

Figure 7. User Interface for Mechanical Calculation.

Source: Prepared by the authors (screenshot).

RESULTS

To verify the correct functioning of the application, actual data were taken from Table 4. These data were entered into the application following the order of the user interface in each of its four sections of data to be entered and selected. Finally, a report was generated with each case presented in Table 4.

Tests 1, 2 and 4 considered "anti-pollution" or "anti-fog" profile insulators based on "heavy" pollution level and the insulator characteristics shown in Table 4. The insulator model chosen for the tests has very similar characteristics to the ones shown in the table, since the same model is not found in the database. It is worth mentioning that the insulator model with the same characteristics was applied in test 3 since it is in the database.

Case 3 calculation:

The manual calculation process will be done using the data of case 3.

Method 1

$$N_{c.distance} = 1.15x\frac{43.3\ mm/kVxe^{0.8\left(\frac{3730}{8150}\right)}}{445}x\frac{245}{\sqrt{3}} \approx 23$$

$$N_{Arc\ d.} = 1 + \frac{(2600-200)}{146} \approx 20$$

Method 2:

$$N = \left[\frac{245\times1.15}{\sqrt{3}\times(445)x\left(\frac{297.92\times0.885^{\left(\frac{3730}{1000}\right)}}{273.15+16}\right)^{0.9}}\right]\times 43.3 \approx 23$$

With both methods, the number of insulators is 23.

Evaluation of method 1:

Equation 14 is used considering the data of case 3 finding that:

$$\text{CF} = 3.53$$

This result is contrasted with Figure 1 and is observed to be within limits.

Evaluation of method 2:

It is evaluated with equations 21 and 24, so that:

Switch critical flashover voltage evaluation (equations 20 and 21)

$$23x50 > \frac{460\times1.03056782\times\left(1+\left(\frac{3730-1000}{10^6}\right)x125\right)}{0.992\times\left(\frac{297.92\times0.885^{\left(\frac{3730}{1000}\right)}}{273.15+T°C}\right)\times0.95}$$

$$1150kV > 1032.84kV$$

As the withstand voltage of the string at the switch critical flashover voltage (1150 kV) is higher than that calculated in the phase, it will be considered as an acceptable evaluation.

Lightning critical flashover voltage evaluation (equations 23 and 24)

$$23x125 > \frac{1300\times1.03056782\times\left(1+\left(\frac{3730-1000}{10^6}\right)x125\right)}{0.961\times\left(\frac{297.92\times0.885^{\left(\frac{3730}{1000}\right)}}{273.15+T°C}\right)\times0.95}$$

$$2875kV > 3013.06kV$$

As the withstand voltage of the string in lightning critical flashover voltage (2875 kV) is lower than that calculated in the phase, it will be considered as an unacceptable evaluation.

Note: This process is performed with the data required in the equations and within the application. The results of all cases are shown in Figures 8, 9, 10 and 11 through screenshots taken during the tests.

The contrast of results is shown in Table 6, where it is possible to appreciate both the results obtained by the application according to the number of resulting insulators, and the result of the evaluations of the methods described above. From this it can be seen that tests 1, 2, 3 and 4 have 100% certainty and tests 5 and 6 have 93.75% and 90% respectively, which shows that hypothesis 1 is correct.

For hypothesis 2, the range of acceptability is above 66%. It means that at least two of the three evaluations of the calculation method have the term "Acceptable", which validates the hypothesis.

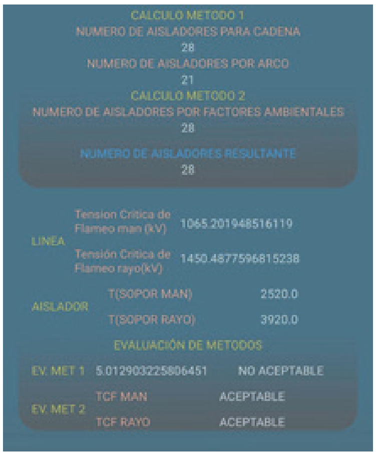

Figure 8. Results of Test 1.

Source: Prepared by the authors (screenshot).

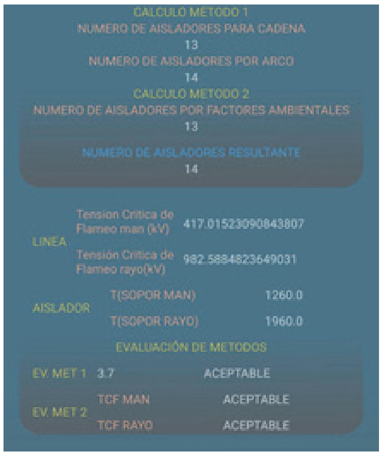

Figure 9. Results of Test 2.

Source: Prepared by the authors (screenshot).

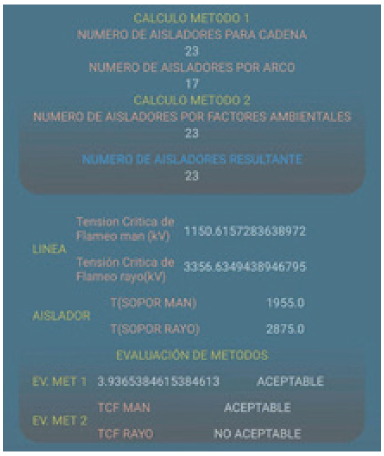

Figure 10. Results of Test 3

Source: Prepared by the authors (screenshot).

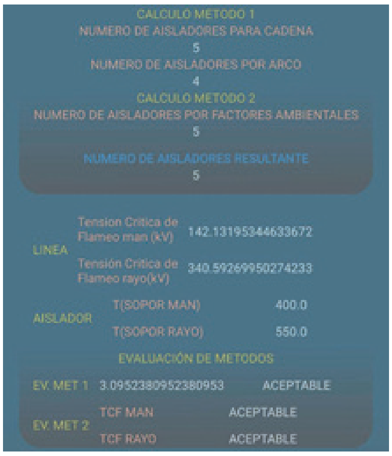

Figure 11. Results of Test 4.

Source: Prepared by the authors (screenshot).

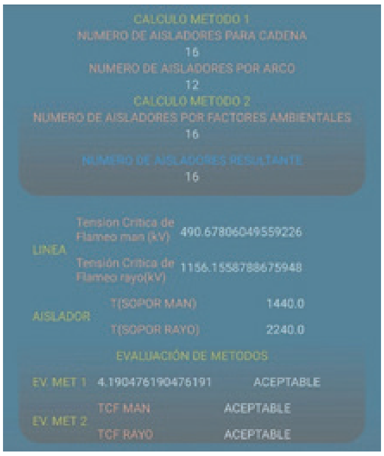

Figure 12. Results of Test 5.

Source: Prepared by the authors (screenshot).

Figure 13. Results of Test 6.

Source: Prepared by the authors (screenshot).

Table 6. *Contrast of results according to calculation memories and those obtained from the application.*

TESTS	1 Transmission Line 500 kV La Niña – Piura Nueva	2 Transmission Line 2 x 220 kV Piura Nueva – Piura Oeste	3 Sub-Station Friaspata	4 Design and Construction of Sub-transmission line to 69 kV Songa	5 Transmission Line 220 kV Reus – Tarragona	6 Transmission Line 220 kV Reque – Nueva Carhuaquero
Number of insulators (calculation memory)	28	14	23	5	15	18
Number of insulators (application)	28	14	23	5	16	20
Percentage of closeness to actual results	100%	100%	100%	100%	93.75%	90%
Creepage factor evaluation	Non acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
CFO switching Evaluation	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
CFO lightning Evaluation	Acceptable	Acceptable	Non acceptable	Acceptable	Acceptable	Acceptable
Acceptability percentage of results	66%	100%	66%	100%	100%	100%

Source: Prepared by the authors.

DISCUSSION

The results of the application presented in Table 6 exactly coincide with COES (2016a, 2016b), SIEMENS (2016) and Orellana and Cevallos (2019), whose calculations are based on actual projects. However, the results of the application disagree with tests 5 and 6. Likewise, in the evaluations of the calculations, it is highlighted that tests 2, 4, 5 and 6 show results termed “Acceptable” in the three evaluations. However, test 1 failed in the evaluation of the creepage factor, which determines that the profile of the anti-pollution insulator is not acceptable. Likewise, test 3 failed in the evaluation of the lightning critical flashover voltage, therefore the lightning withstand is not adequate. In this regard, it should be emphasized that the limitation of the application is not being able to enter the data of a new insulator, since, for this reason, in tests 2 and 4, insulators with very similar characteristics had to be used. This does not mean that the calculated string does not work, but that changes in the insulator model can and should be made to obtain a better response from the evaluation of calculation methods.

CONCLUSIONS

The calculation optimization through the prototype application shown in this study meets the proposed objective, which was to optimize the dimensioning of glass insulator strings by means of a prototype application. In addition, the two hypotheses proposed were demonstrated and validated through the tests performed using real data from transmission line projects, where the results obtained from the application were mostly totally satisfactory. In addition, the practical use of the application makes it a very interesting and didactic tool with a great potential for the user, who only needs their cell phone to perform the dimensioning. In this way, the objective of easy accessibility and correct dimensioning is achieved.

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