Research and Development process in replacing Aluminum Conductor Steel Reinforced cable.

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Mechanical Engineering and Production Technology Abstract
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During the steady growth of technology in this industrial 2020s era, products must be improved at an extremely intensive pace to meet the demand of users, while also keeping up the competitive strength of the company in the growing market. This also applied in the cable market where the demand is increasing significantly. The goal of this thesis is to illustrate the Research and Development methodology in producing and applying the new concept/ design of aluminum conductor composite core cable into the production chain.

This thesis report will illustrate and explain all decision-making during the market research and implementation of the new conductor design that leads to improvements in solving the market demand. It contains the comparison in performance and mechanical properties of existing solutions on the market including different materials or product designs. In addition, the evaluated selection is applied, manufactured, and tested in the module production concept to justify the feasibility of the chosen solution.

Therefore, the thesis can be applied to most cable companies in developing countries, especially in Vietnam. Further development and potential ideas for the upgrade after this thesis will be regularly updated to ensure a better quality cable product.

Keywords Cable, ACCC cable, ACSR conductor, Quality Control, Cable Production system,
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List of Abbreviations.

ACSR – Aluminum conductor steel reinforced

ACSS – Aluminum conductor steel supported

GTACSR – Gap-type thermal-resistant aluminum alloy conductor steel reinforced

GZTACSR – Gap type super thermal-resistant aluminum alloy conductor steel reinforced

ACFR – Aluminum conductor field reinforced

ACCC – Aluminum conductor carbon fiber composite core.

1 Introduction

As a fast-growing country, Vietnam has made significant adjustments in the technology application to catch up with the steady growth of the world. As a consequence, the demand for resource consumption and the need for cost optimization plays an important role in keeping a solid foundation for Vietnamese companies to keep competing and holding a higher position in the production market. One of the most urgent and crucial requirements is electricity, which cannot catch up with the growing pace of the whole heavy industry due to the old system and using old technologies of the early 1990s. The electricity supply capacity on the high-voltage power line is still staying at the same quantities as in the early 1990s connecting to industrial areas and providing power to cities across the geographic density of the nation. If there is no adjustment, upgrade, or replacement, this will prevent the ability to apply new technologies into the heavy industry or production chain system, as well as limit the possibility for expansion which can lead to hesitation for new investors from foreign countries. This may cut or postpone the growth speed of the country and loss the potential cooperation with many leading organizations, companies, or unions from developed continents. Additionally, this will push Vietnam far more behind nearby competitors such as China, Thailand, Malaysia, Indonesia, and Singapore, especially in the manufacturing field where the competitive strength of Vietnam is its low manufacturing cost. So, this has become a key point decision that will define the ability to grow and keep up with the competition with other countries in the market for at least the next 5 – 10 years.

To find a solution, the government has to research and finalize a strategic plan to optimize or improve the current electricity system to ensure the growing ability of Vietnam in heavy and manufacturing industries (Powermag, 2012). The assigned companies are well-known as the leading company in terms of powerline production in both high-voltage wire and household cable suppliers in Southeast Asia and the dominator of this field in Vietnam. With a great number of experts and experienced employees, this company has maintained its dominant position for the last 40 years on a national scale and planned to expand more wisely in the global market by cooperating with leading companies across all continents.

1.1 Project Goals

The goal of this thesis is to illustrate the learning from the Research and Development process from cable manufacturer aspects with a specific problem to determine the best outcome across all potential solutions in multiple scenarios to meet most of the demand of the markets. This thesis will identify all designated concepts and analyze the advantages and limitations of each solution, then explain the factors behind it. The thesis will also include a comparison to indicate the most optimal option which will satisfy all the needs of the industry before applying the final design to the production chain. The application to manufacturing will compare the improvement of the designated idea from the old product's design in the design, production process, and testing stages. And lastly, the conclusion about the idea and then potential research will be finalized before estimating the development in the future.

1.2 Thesis Structure

This thesis structure is inspired by the Double Diamond design process model in examining each step stage by stage (Möller, 2015). The thesis will explain the current solution of the electric network in a local case as well as how the problem is generated by inspecting the technical specification of the current application. The thesis then proceeds to explore the root cause of the problem by scoping down the possible scenario and concentrating on the important points. From this point of view, potential solutions with specific testing or calculating will be created to testify to the possibility of the idea and optimize it to fit the market demand of the practical case. All solutions will be compared to finalize and conclude the best answer which will shape and solve the problem in all aspects including possibilities in production and the cost involved.

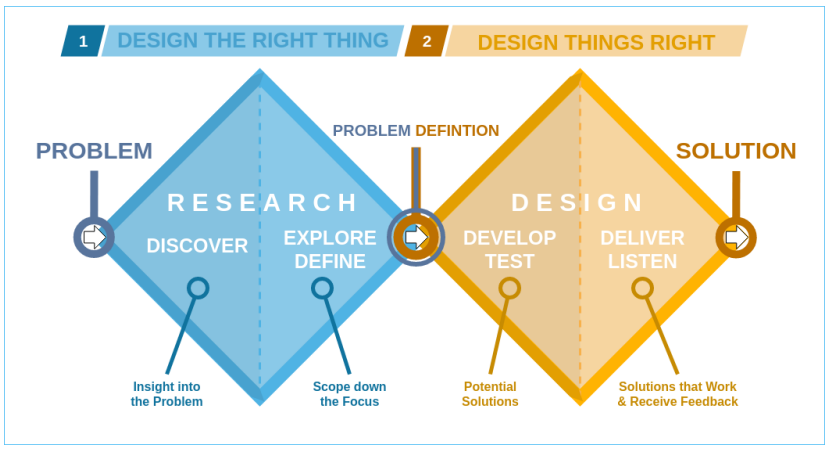


Figure 1 *- Double Diamond design methodology.*

To justify the design concept idea, the comparison between the solutions and the current products will be used to validate both producing different and practical testing before jumping to the conclusion of the potential idea to meet the market demand or predict future research or development. Its limitations or obstruction during the practical application will verify the feasibility of the design solving the problem. This thesis will also include all needed resources that can be found online during the research to validate the theoretical proof of the idea before applying it to practice.

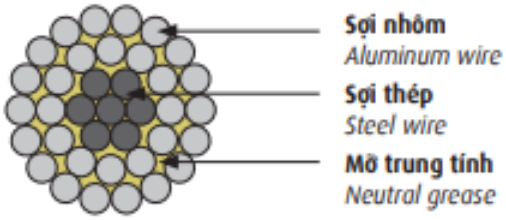
2 Research into the problem

2.1 The limitation of the ACSR cable

2.1.1 What is Aluminum conductor steel-reinforced cable?

The most used electric cable for high-voltage delivery across the transmission network of Vietnam is ACSR, which is also known as Aluminum conductor steel-reinforced cable. The ACSR is widely used in the Vietnam overhead power lines due to its mechanical properties including high capacity for power transferring, high strength to be placed at different pressure levels to fit the average altitude of the power line, and good resistance to prevent damage from external environments.

Figure 2 *- ACSR cable structure.* (Jinshui Cable Group, n.d.)



The ACSR consists mostly of 2 parts: Aluminum wire for electricity transmission and Steel wire in the core as the holder of the whole conductor as shown in Figure 2. The outer strands are high-purity aluminum to ensure good conductivity, as well as lower weight and cost compared to other materials. Additionally, aluminum properties include good resistance to corrosion and mechanical stress which improve the durability of the conductor for a longer lifecycle. At the center of the line is steel wire which acts as a hanger when putting cable on the overhead power lines. It provides the strength to support the weight of the whole conductor and the strength of the mechanical tension to reduce the deflection of the cable between high-voltage transmission line towers. In addition, steel has lower elastic and inelastic deformation than aluminum, so it ensures the weight carrying of the power line. To improve the competitive strength of this cable type, neutral grease with a high melting point of not less than 120˚C has been added to provide better resistance against environmental damage which is extremely helpful in coastal or corrosive regions like Vietnam. And depending on the required characteristics of each region, the grease can be added only on the steel core, all the conductors except the outer layer, all conductors including the outer layer, or all the conductors except the outer surface of the wires in the outer layers. The grease enhances the resistance of the whole conductor against the external environment, reduces the friction between wires inside the cable, and improves the corrosion resistance of the line. Additionally, it plays as a cooling chemical to weaken the heat power generated from the electric transfer during its operation.

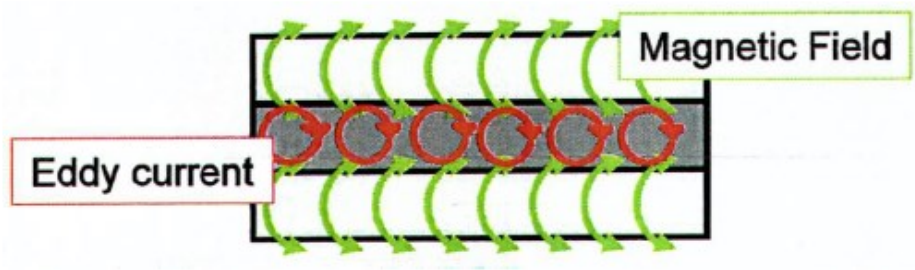
All of these properties, made ACSR suitable to be used across the whole national connection of electricity since Vietnam has various types of climates and terrain within the 2000 kilometers length of national territory from the north to the south. The flexibility of Aluminum conductor steel-reinforced fits well in both highlands and coastal areas with different types of weather and climate which can save a lot of time, labor force, and money

to apply, install and maintain. So, all in all, this cable type has performed well for at least 50 years and played a crucial role in the growth of the heavy or manufacturing industries of Vietnam before the 2010s.

2.1.2 The limit

Due to the growth of the local market, the demand for electricity providing has risen significantly in Vietnam, which required an urgent adaptation to avoid any postponement of the developing pace of the electrical industry. This has led to an overload of power supply in many areas, especially in the industrial area and large cities where the demand is rising every day due to the flow of population relocation. The exceeding ampacity rating on the power line caused the overheating of cables and slowly damage parts that will affect the ability to transmit at the power transformer during the performing period. In addition, the overheating at high frequencies melts the material inside the conductor which causes the deflection of the line and makes it slowly fall to the safety height threatening the existence of neighboring society. Consequently, a power cut or disconnect must be used as a solution to fix the damaged part or maintain the system frequently to minimize the potential damage to the whole local area. To sum up, an upgrade to the current power system is required to guarantee the safety and steady development of the local area.

Figure 3 *- Eddy's current visual illustration.*



During the continuous operation of the electric supply network, the energy flow through the aluminum wire creates a magnetic field that rotates around the length of the wire through time. This magnetic field generates an effect on the steel wire in the center and attracts the atom movement inside the steel wire which establishes an eddy current inside the power line (Vagner et al., 2003, pp.73). This reaction generates heat to damage the components

inside and form a reverse direction current which neglects the electric capacity during the transmission. This amount of power lost became a great loss during the long-term operation period which occur the wasting of money and resources on electric generating and overhead power system maintenance.

2.2 Defining the problems

Despite the highly fit among the capacity, strength, and resistance abilities in the operational ages, the Aluminum conductor steel-reinforced has slowly lagged due to its structure. The design of the ACSR cable does not contain rich options to upgrade or improve to issue a better outcome for the situation.

The structure is simple since it is built from only two parts and twisted tight, so adding any extra material or parts in between the steel wire and aluminum wire will potentially break the strong bonding formation of the conductor. Covering the cable with higher melting material is not an optimal option since most materials have higher melting points than aluminum and steel is expensive to apply to the design. In addition, those materials change the electrical resistance (Ω) of the power line which reduces the current capacity of the power flow during the operation.

Therefore, there is not much choice that can be made to adjust the design of the current Aluminum conductor steel-reinforced cable but to change the wire density or replace the wire material. Increasing the quantity of aluminum wire on the conductor is a considerable option to explore as a solution since it is easy to install and avoids the adjustment of the product design. Adjusting the wire material is also a feasible idea due to the availability of alloys on the market which can easily be found and adapted into the manufacturing process.

Another option is to install more series capacitors across the power line of the whole system; however, it aggravates the weight of both the power tower and cable, as well as requires the high cost of protecting cover on each capacitor. It led to the requirement for frequent maintenance on all parts consuming a great amount of labor force and cost to sustain the option.

And finally, replacing the ACSR power line with a better design is also an option because of the attainability of many existing products from external markets, especially from the developed market such as European, American, or East Asian countries. The variety of potential designs brings the possibilities to meet the market demands with the most efficiency in resource consumption.

2.3 Analyzing potential solutions

2.3.1 Wire density adjustment

Ideally, wire density adjustment is the easiest solution in terms of design, however, it faces a lot of limitations and obstructions when applied to practice. Adding aluminum wires to the outer layer is simple since it only required putting more wire into the twisting process which will enlarge the surface of the cable as the final product. This will help reduce the ampacity rating running through each aluminum wire during the transmission and neglect the workload to prevent overheating. But every toleration during the development of the market will require adding more wire into the power line including further installation and maintenance. This action also aggravates the total weight of the cable line which heavily impacts the safety deflection of the overhead power line.

As a way to prevent deflection, adjusting the distance between power towers is the most feasible solution by moving or adding more power towers to reduce the gap and lighten the pressure as well as minimize the sag height on the steel wire. However, this option is not optimal in a high population density country like Vietnam since it demands a lot of human relocations and money for the land clearance ability of the local area. Clearing the field for the installation is not only a challenging mission for the distributor but also a predicament for the government due to the disability in the relocation of the surrounding society especially when the population density has reached 4375 per kilometer square at the megalopolis. As a result, this idea is applicable for design and manufacturing but impossible to install in the given practice area.

2.3.2 Material adjustment

Within the development of technology, a variety of material selections has been found, which has given a wider range of options for wire replacement giving better efficiency, but also improving the existing technical specification of aluminum and steel inside the conductor structure. The most widely used aluminum class in producing conductors is 1350-H19 which will be used as a benchmark to validate the feasibility of potential materials (The Aluminum Association, 1989).

- **Outer layer**

For the outer layer, the availability of replacement is wide within the better electric conductivity than the aluminum wire, especially with gold, silver, and copper. However, gold and silver are rare metals that the mining industries already have difficulty finding so applying them to the cable manufacturing chain will raise the cost significantly. This led to the crashing of the feasibility to import this material into mass production since it will exceed the possible budget for the infrastructure field, especially for developing countries like Vietnam.

Table 1 *- Resistivity and Conductivity of materials at 20 ^0C*

Material	Resistivity ρ (Ω.m) at 20 °C	Conductivity σ (S/m) at 20 °C
Silver	1.59×10^{-8}	6.30×10^{7}
Copper	1.68×10^{-8}	5.96×10^{7}
Gold	2.44×10^{-8}	4.10×10^{7}
Aluminium	2.82×10^{-8}	3.5×10^{7}

With copper, the great advantages in terms of mechanical properties make it a prominent candidate to replace the existing aluminum wire with various available candidates such as CW004A or CW008A consisting minimal percentage of oxygen. The 40 percent better tensile strength compared to aluminum reduces the vulnerabilities of ACSR wire against external

pressure during the operation (Paramount Wires & Cables, n.d.). Besides that, copper has lower thermal expansion which ensures a longer lifecycle and higher electricity loading through the line during the connection since the amount of exceeding power is lower. However, similar to gold and silver, copper is an expensive solution for manufacturing and installation since it is harder to produce than aluminum and requires more investment in logistics. Another disadvantage of this solution is the weight of copper, which heavily impacted the sag height of the power during operation and required the installation of a power tower or adjustment between the transmission pylons. It also faces difficulty in the land clearance process that significantly stalls the growing ability of the local area similar to the previous solution mentioned above.

Another solution in the current heavy industry is soft annealing aluminum due to the attainability of aluminum's competitive strength which enhances the performance during operation. All the technical specifications of the current product design have remained but the soft annealing aluminum slightly improves the electrical conductivity (63% compared to 61% of current aluminum wire) providing a possible replacement for the outer layer of the cable.

- **Core wire**

The wire holds the whole power line against gravitational attraction and therefore requires an excellent tension force provided by the material which guarantees the safety of the overhead power line and diminishes the potential sag height. Therefore, the fundamental of alloy outperformed the metal due to the atomic bonding structure making them the best option to be used as a replacement.

With the growth of technology, the selection of alloys is broad providing different physical properties to solve the weakness of the current steel wires such as nickel, titanium, chromium, or cobalt. However, the availability and required cost of these options is a great obstruction in applying to mass production due to doubting the sustainability of manufacture. Therefore, coating steel wire can be considered an option since the full replacement of the core wire material encountered difficulty during the development of the

idea. One of the possibilities is the steel coated with Zinc-5% Aluminum-Mischmetal alloy (Zn-5Al-MM alloy) on the surrounding surface of the steel wire which retains all the good technical specifications of steel. This material improves the weakness of the current design which is the limit of continuous operating temperature providing a higher ability in electrical conductivity (250˚C for Zinc-5% Aluminum-Mischmetal Alloy-coated steel core wire compared to 90 – 120 ˚C of the Steel Wire using in Aluminum Conductors Steel Reinforced) (Electric Power Research Institute, 2008).

- **Possible Solution**

A few sample designs are using the material replacement on each part of the power line on the cable market at the moment with better thermal expansion points or higher electric conductivity. From the material selection above, Aluminum Conductor Steel Supported (ACSS) is an available model that applied the theory of combining the soft annealing aluminum on the outer line of the wire to replace the previous option, and Zinc-5% Aluminum-Mischmetal Alloy-coated steel to oust the old steel wire as the core wire.

The ACSS cable provides better performance in power conductivity during operation because of the upgrade from soft annealing aluminum. The core wire can have a longer life cycle compared to the previous model since the coated-alloy steel enhances the thermal melting limit from steel which gives them the availability to be installed at higher electrical transmission volume. According to those competitive strengths, it is widely used in American countries with the major supplier being General Cable, Southwire, or Sterlite and the commonly applicable standard for this conductor design is ASTM B 856 (ASTM International, 2002).

2.3.3 Design adjustment

In this growing era of the 21st century, within the application of design engineering techniques in the Research and Development Department, the upgrade in the existing product is no longer limited to replacing parts or materials to inventing a new product series to solve the weakness of the previous model as well as meeting the market demand. Using

the reverse engineering technique, the possible improvement will come from the optimization of the two constituent components of the power line design to enhance the performance as well as neglect the current restrain from the continuous operation period. In summary, the focus of the design enhancement will be the change in the shape of the outer layer and the core wire of the current overhead power cables to solve the weaknesses.

From the current design of Aluminum Conductor Steel Reinforced cable or even the Aluminum Conductor Steel Support, the power capacity transferred during the electrical delivery through the power line has not been fully exploited yet due to the unused space between the aluminum wire on the electric conductive layer. The gap between the round wire is a non-producing area which gives not much value to the performance of the transmission but also weakens the internal bonding between parts of the line since it provides space for air or dust which can damage the wire in a long operation period and increase in the vibrating during windy weather can cause the friction clash between wires.

So, to respond to the weak point of the conductor structure, changing the shape of the cable or redesigning the shape of the wire are the ideal solution to benefit all the cross sections of the line. Adjusting the aluminum fiber shape to another formation such as a triangle, square or diamond is possible, however, it creates a great challenge during the manufacturing stages due to the changing die shape or adding more heat treatment work such as die, punch, or press techniques to form up the final shape before putting into the twisting step to consolidate the bonding between the wire. In addition, the round dies for round cable have greater stress resistance as well as spread the wire more evenly.

Moreover, replacing wire shapes is more reasonable and feasible to execute and affordable to test without adding unnecessary extra costs to the Research and Development process. Square and triangle shapes are available to produce but the friction at the twisting cable stage wears off the wire quality and loss of the full capacity of the power transmission. Therefore, the trapezoidal-shaped wire has been tested and applied as a solution since it can prevent friction damage during the twisting and fully stick to each other without generating any gap between wires. The cross-section area of the new shape is even smaller compared to the round shape using the same number of wires which is shown in Figure 4. This design

provides better resistance to external damage from the climate and simple requirements for logistics and installation. As a perfect example of this design adjustment compared to the previous round shape power line, the Aluminum conductor steel supported/ trapezoidal wire (ACSS/TW) has been invented and applied in mass production due to its better result during the operation period.

- **Aluminum Conductor Steel Supported/ Trapezoidal Wire (ACSS/TW)**

Figure 4 *- Aluminum Conductor Steel Supported/ Trapezoidal Wire (ACCC/TW) cross-section structure. (Huatong Cable Inc, n.d.)*

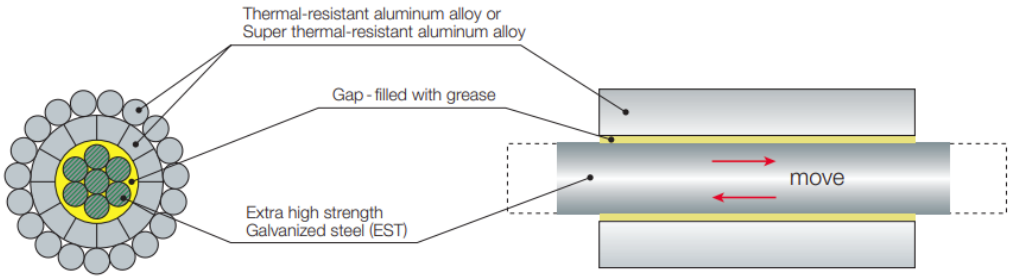
Following the inheritance of the previous generation ACSS, the ACSS/TW retains all upgrades in terms of mechanical properties compared to the ACSR case including the higher electrical conductivity and greater thermal melting point. With the new wire shape combination, the ACSS/TW has a small diameter scale but enhances the resistance ability to vibrate than the previous design during windy weather or the movement of the surrounding environment and geography. Another benefit of having a smaller diameter than the preceding generation is the availability of expansion by adding more wire into the layer to strengthen the electric transmission capacity. In conclusion, the ACSS/TW cable at the same diameter scale as ACSR often has a greater aluminum cross-section space and higher ampacity rating carried through the line. The ACSS/TW is widely used for the overhead power line system and applied in mass production in American countries with the common applicable standard ASTM B 857 (ASTM International, 2002).

2.3.4 Design and material replacement

the variety in improving the product is available within the reserve engineering techniques by examining the constitutive elements of the old Aluminum conductor steel-reinforced cable. However, it has not reached the maximum capacity due to missing the possibility of combining adjustments to figure out the availability of further improvement for the current design. And as the perfect example of the combination of both fundamental adjustments, the Gap-type thermal-resistant aluminum alloy conductor steel reinforced (GTACSR), Aluminum conductor fiber reinforced (ACFR) and Aluminum conductor carbon fiber composite core (ACCC) has been invented with the compounding on both design adjustment and wire material replacement.

- **Gap-type thermal-resistant aluminum alloy conductor steel reinforced (GTACSR or GZTACSR)**

Figure 5 *- Gap-type thermal-resistant aluminum alloy conductor steel reinforced design (Slegers, 2011)*



The GTACSR or GZTACSR is the upgrade of the ACSS/TW design because it applies the same design concept but replaces the material of the wire and compounds an extra layer on top of the outer layer. It adjusts the inner structure of the core wire to optimize and strengthen the stress resistance from the center of the whole power line by replacing the old steel wire with extra high-strength galvanized steel. This adjustment provides extra toughness, durability, and strength to carry the weight and reduce the deflection of the cable line during the operation period. Covering the core wire is the trapezoidal shape aluminum wire with a similar design concept to ACSS/TW but acts as a gap maker to establish movement space and neglect the friction damage between the galvanized steel wire and the outer aluminum

layers. As a solvent to neglect the friction damage between the movement of the aluminum layers and the core wire, high-temperature grease is used to ensure smooth vibration and fill the gap between the 2 parts which encourages their independent displacement of them. On top of the trapezoidal shape, the layer of round shape wire acts as an additional conductivity source for the wire which increases the ampacity rating of the conductor for greater electricity conductivity. Another adjustment of materials compared to the one previously mentioned is the replacement of thermal-resistant aluminum alloy or super thermal aluminum alloy for the soft annealed aluminum for heat resistance enhancement.

As a result of inheritance from the previous design ideas, the GTACSR or GZTACSR cables can resist the operating temperature up to 250˚C allowing higher electric conductivity and great vibration resistance under the air movement defect as well as maximizing the efficiency over the using cross-section of the power line (Wareing, 2011). In addition, because it uses the later material technology, it provides better corrosion resistance and ensures a longer lifecycle compared to previous models. However, the downgrade of this generation is the higher resistance, which tolerates the power loss during the transmission due to the aluminum alloy materials. The GTACSR or GZTACSR cables are produced in mass scale under the applicable standard ASTM B 857 (ASTM International, 2002) at a broader market than previous options including Asian countries such as Vietnam and Japan which verified the product's competitive strength.

- **Aluminum Conductor Fiber Reinforced (ACFR)**

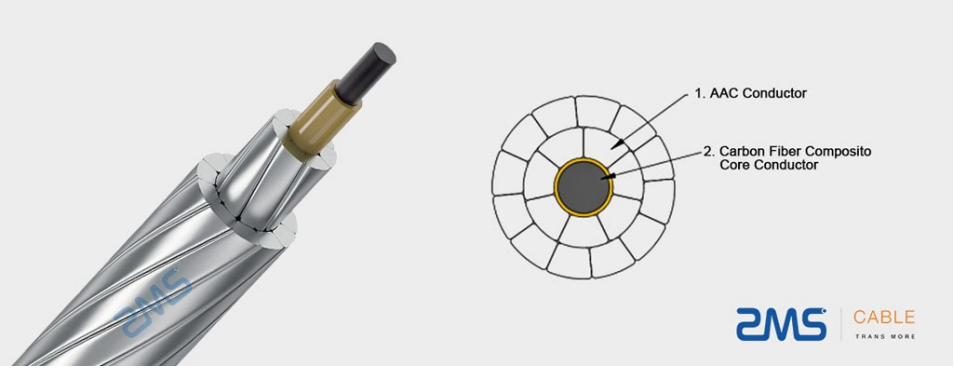
Figure 6 *- Aluminum Conductor Fiber Reinforced Design. (Jsk Industries Pvt. Ltd, n.d.)*

Another concept design upgrade from the ACSS model is the Aluminum conductor fiber reinforced (ACFR) cable design where the outer aluminum layer remains the same, while the core wire is replaced with different material. Instead of focusing on fixing the friction clash occurring between the layers which raised the resistance inside the line, it focused on solving the limit of steel or steel alloy center wire which is causing the inner alternating current of the conductor. The aim is to find another material that will not generate the Eddy current inside to neglect the electrical conductivity of the cable.

A solution offered by Japanese companies such as Showa Electric Cable is replacing the steel material with carbon fiber composite core wire. It contains 7 or 19 carbon fiber lines that twist tight together after dipping inside the epoxy resin liquid to enhance the electrical corrosion resistance and protect the carbon from damage to the external environment. The applicable standard for this cable design is not yet issued but following the instruction of the Japanese manufacturers who invented it – Tokyo Rope (Sato & Ebiko, 2002). The outer core has the same functionality and ability as ACSS due to similarity structure, so the main upgrade comes from the core wire adjustment. Due to the protection of epoxy resin outside of the fiber composite, it prevents the Foucault current and avoids generating energy which guarantees better electric conductivity. Additionally, it provides an improvement in corrosion resistance which can be adapted in humid or salty environments compared to the previous model. The only restraint of this design is the lower continuous operating temperature compared to an existing product like ACSS or GTACSR/ GZTACSR (180^0C compared to 250^0C of other models). This is the major factor preventing it from being applied to mass production and only staying in testing in a few Asian markets such as China, Japan, or Indonesia.

- **Aluminum Conductor Carbon Fiber Composite Core (ACCC)**

Figure 7 *- Aluminum Conductor Carbon Fiber Composite Core design.*



Based on the advancement of the ACFR cable design, CTC Global (formerly Composite Technology Corporation) has used its competitive strength, which is composite manufacturing technology, to invent a new type of composite core wire to replace the attached composite wire pack. The new wire is produced as isolated wire (rod type) made of carbon fiber composite dipped in epoxy resin covered by fiberglass reinforced composite material which is also dipped in the epoxy resin to ensure the electrical corrosion resistance of the power line. The ACCC retains all the advantages of its inspired models including higher electrical conductivity due to the annealed aluminum layer, a higher operating temperature limit at 250^0C allowing higher capacity in electric transmission, and a smaller cross-section area compared to the ACSR cable design. In addition, because it fully replaced the steel wire at the center of the cable line, ACCC is lighter than ACSR weight with a smaller thermal expansion coefficient reducing sag deflection of the conductor (Berjozkina et al., 2013). This prevents unnecessary building on extra power pylon installation or extra electric transformer across the overhead conductor line. It also neglects the potential power lost during operation same as ACFR cable due to avoiding generating Eddy current inside of the length of the high-voltage overhead transmission line.

Figure 8 *- Magnetic reaction inside ACCC cable during operation.*

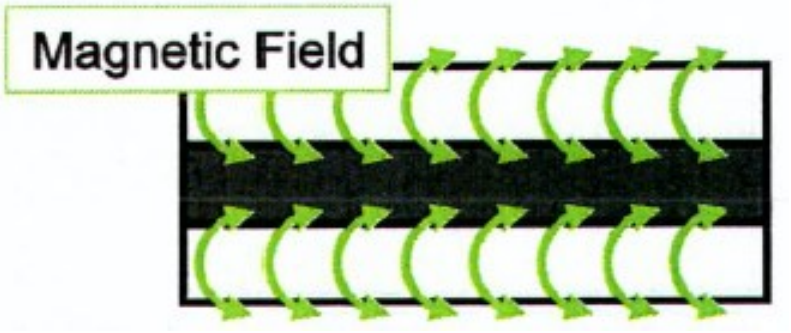
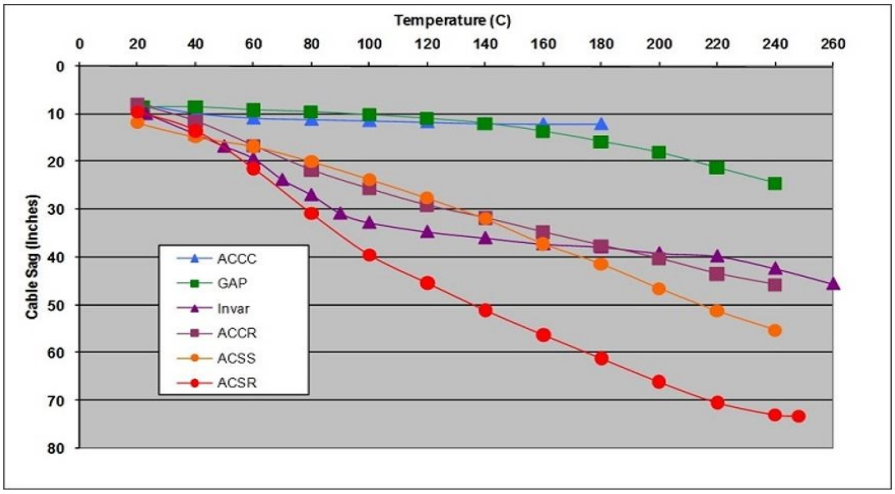


Figure 9 *- Sag deformation of different cable types on a 65-meter span at 1600 Amps (Bryant, 2017)*



Sag / Temperature Comparison Performed by Kinectrics Lab on 65 Meter Span at 1,600 Amps Comparing Drake Size Conductors. (Note the ACCC Conductor's cooler temperature reflects substantially improved efficiency)

Due to the competitive strength of the ACCC cable, this design has been applied and produced in a broader market globally than the previously mentioned model. Around 40 countries have been starting to test and manufacture it providing a better scope on the real performance of this design idea including Belgium, Indonesia, China, Denmark, etc. And because of using new composite material technology, ACCC cable uses different applicable standards for isolated components which are ASTM B 987 (ASTM International, 2020) and CTC-Global (CTC Global, 2016) for the carbon fiber composite core wire, ASTM B 609 for annealed aluminum (ASTM International, 2004), and ASTM B 857 for ACCC/TW cable (ASTM International, 2002).

2.4 Technical comparison

The comparison aims to finalize an upgrade for the ACSR cable which reached its limit but avoided the options which required land clearance due to the impossibility of relocating the great density of population in the majority of the urban area. The consideration is the flexibility between enlarging the cross-section area of the power line or fully replacing the old power line with an up-to-date model which guarantees better performance. The availability of replacement for Aluminum conductor steel-reinforced cable types is varied, however, not many options can meet the local market demand fully and are suitable for the climate region except GTACSR, ACFR, and ACCC cable design. Therefore, the scope of the selection will be narrowed down between the three models to finalize the most suitable solution to replace the inefficient overhead power line system – ACSR. The comparison will be made on both the technical specifications of each power line design and the difficulty of applying it to practical manufacturing, as well as justify the ability of mass production to fully upgrade the national electricity transmission system.

2.4.1 Technical specification

The first consideration is the technical statistics based on the existing model to illustrate the best option to solve the demand of the local market. Due to the similarity between the ACCC and ACFR structure and operational design (both are carbon fiber composite core wire and trapezoidal shape annealed aluminum as an outer layer), it will have close to equal technical specifications so the main comparison will be between the models of ACCC and GTACSR/GZTACSR cable design.

Table 2 *- Technical specification of cable models having a similar cross-sectional diameter.*

Cable models specifications comparison					
Number	**Technical properties**	**Unit**	**Cable specification**		
1	**Model**		TACSR-410	GZTACSR-370	ACCC-477
2	**Applicable standard**		JEC 3409/95	JCS 405	
3	**Conductor cross-section**	mm^2	480.8	447.6	477.2
	Aluminum layer	mm^2	413.4	368.2	425.3
	Core layer	mm^2	67.35	79.38	51.9
4	**Measured diameter**	mm	28.5	27.3	25.1
5	**Weight**	kg/km	1.673	1.666	1.275
6	**Maximum tensile force**	KN	136.41	179.5	136.1
7	**Module of elasticity**	daN/mm^2	8360	8740	11000
8	**Thermal expansion coefficient**	$10^{-6}/^0C$	19	18.2	1.61
9	**Allowed Ampacity at highest Temp.**	A	1322	1414	1534
10	**Direct current at 20^0C**	Ω/km	0.0714	0.0798	0.0659
11	**Highest operating Temp.**	^0C	150	210	180
12	**Deflection at highest operating Temp.**	m	12.99	13.9	7.1

According to Table 2, the benefit of having carbon fiber composite stood out compared to the GZTACSR and ACSR in terms of aluminum coverage percentage due to less required diameter for the core wire, weight, and greater allowed ampacity rating at the highest operating temperatures because of the preventing potential Eddy current during the transmission. However, it reveals the weakness of the composite in toughness and heat resistance contests. The maximum tension force of the aluminum conductor carbon fiber composite core is approximate to the user model ACSR declared the failure in enhancing toughness and strength to resist the damage from inclement weather conditions. The highest allowed temperature during the operation is also not efficient as in the steel core wire products but the thermal expansion coefficient and the deflection rate are outstanding factors that determine the key factors that contribute to the decision-making of the research phase. As a result, the ACCC became an ideal solution for electric conductivity improvement which does not require the extra installation of the power pylon or electric transformer across the length of the overhead power line.

2.4.2 Manufacturing comparison

Theoretically, ACCC is the most suitable option to meet the current demands of the Vietnamese market, however, it requires product evaluation to justify the feasibility of the local heavy industries to manufacture this product to replace the old aluminum conductor steel-reinforced cable system on a national scale.

- **Material requirement**

The annealed aluminum for the outer layer is an existing material in local industries due to the history and experience of manufacturing previous models of conductors including the ACSR cable line so the material difference is concentrated in the core wire. The extra high-strength galvanized steel being produced in metallurgy companies that are often located inside the industrial zone provides easy access and reduces costs in the logistics chain. On the other hand, composite materials are not recognized popularly due to the developing material technology which triggers the limitation and unstable supply source to sustain long-

term manufacture. Additionally, the core technology to produce carbon fiber composite is manipulated by CTC Global and Tokyo Rope, so the production chain is fully committed to the supply capacity by the provider, which in turn heavily impacts the logistic time and the product cost. But within the bilateral relationship with the supplier's original countries, the potential partnership and commitment are feasible to lighten the unnecessary tributed cost on both sides.

- **Machine and tools requirement**

The GZTACSR requires a yarn-twisting machine for galvanized steel to bind the wire together and a spinning drawing machine with a trapezoidal shape to form the aluminum wire for the outer layer. Then, the current twisting machine used for the aluminum of the ACSR model will be adjusted to be suitable for the new trapezoidal shape.

The carbon fiber composite core wire will be outsourced to external companies so the concentration of the manufacturing process will be the annealed aluminum formation only. Therefore, the requirement for the spinning drawing machine and twisting machine for the new trapezoidal shape is similar to GZTACSR. Both ACFR and GZTACSR require a high-power annealing furnace to produce suitable quality annealed aluminum for the external wires or outsource the annealing process to metallurgy companies.

- **Manufacture process difference**

For the GZTACSR cables, the galvanized aluminum steel yarn will be twisted to condense and consolidate the mechanical bonding of the core to lift the weight of the whole conductor during the hanging scenario. The thermal-resistant aluminum alloy used for external layers with a 9.5mm diameter will be pushed and dragged through the trapezoid shape hole on the spinning drawing machine to format the design and structure of each fiber. After that, the galvanized aluminum core will be put in the middle of the trapezoid string before putting all parts together into a twisting machine where the formation of the cable structure will be made by the tightly twisted force of the trapezoid shape pressed and holding the twisted galvanized aluminum fibers and produce the GZTACSR according to the design.

The ACCC type is less complex in terms of manufacturing due to the reduction in processing for the composite core since it is a straight solo string at the center. The difference is the external fibers: after the spinning, the drawing machine will be put into an annealing furnace of around 300 to 350 degrees for approximately 10 to 20 minutes and then quenched in cold water. Then the composite core will be put in the center between the trapezoid shape yarn before proceeding into the twisting machine at the assembly stage to finalize the planned shape of the Aluminum conductor carbon fiber composite core cable type.

3 Research conclusion

According to the previous research and comparison, the ACCC has stood out as a better solution compared to the GZTACSR cable type due to the preeminence of mechanical properties of the composite-centered core. It helps neglect the handling process for the galvanized aluminum fibers which will shorten the manufacturing system chain and reduce the additional cost for those stages. Additionally, the composite string requires less grease to minimize internal friction between layers during the operation which leads to a cut down on cost, logistics, and periodic maintenance. In conclusion, the ACCC cable type is seen as the optimal replacement for the old ACSR cable system in both required input and performance evaluation.

3.1 Performance comparison

According to resistance calculations for electrical wire, we have the following formula (Hibbeler, 2017):

$$R = \rho \times \frac{L}{S}$$

Where:

- R is the resistance value of the whole wire.
- ρ is the resistivity of the wire.
- L is wire length.
- S is the cross-sectional area of the wire conductivity.

This means that if both 1-meter length ACCC wire and 1-meter length ACSR wire are tested in the same condition under the same electric current, the difference in resistance value between the models mainly comes from the cross-sectional area of the electrical conductivity since the length are equal and resistivity is similar due to using the same production material which is aluminum. Therefore, it leads to the better performance of Aluminum conductor carbon fiber composite core cable because of the larger aluminum cross-section area which is saved by the improvement in design optimization and neglect of wasted gap between fibers produced by the ACSR cable model and the twisted steel core.

Table 3 *- Resistance of 2 models at the same diameter tier.*

	Unit	ACSR 400/51	WARSAW 510
Wire diameters	mm	27.6	27.7
Weight	kg/km	1510	1519
Aluminum cross-sectional area	mm^2	400	507
	%	100	127
Resistance	Ω/km	0.0723	0.0553
	%	100	76

Two examples used in justifying these methodologies are ACSR 400/51 model and WARSAW 510 which already exist and are applied widely in different markets. These models share the same diameter tolerance and similarity in production weight for wire per one-kilometer length. However, the superiority of the better design for cross-sectional optimization of WARSAW 510 with the 507-millimeter square of aluminum electrical conductivity area

compares to the 400-millimeter square from ACSR 400/51 which is 27% extra space taken for aluminum core leads to the gigantic reduction for the wire resistance with about 24% deduction for each kilometer length.

And according to the power calculation in electric current, we have (Hibbeler, 2017):

$$P = I^2 \times R \text{ and } Q = R \times I^2 \times t \text{ (Joules' law)}$$

Where:

- *P* is consumptive power transferring inside the wire.
- *I* is the electric current that goes through the wire delivered to the local electric distributor station.
- *R* is the resistance of the electric cable.

The 24% decrease in resistance of the ACCC model helps reduce the same amount of consumptive power which is 24% fewer kilowatts wasted per hour than in the ACSR design. In addition, this improvement impacts the heat produced on the cable because it reduces the heat generated during the operating time which ensures a longer life cycle for the wire by neglecting the temperature strain.

Furthermore, as mentioned above, the replacement of a composite single core for the old, twisted steel fiber helps discard the additional power loss during the operation based on the Eddy current rule which cuts down the unnecessary resistance inside the conductor.

Another comparison to consolidate the mentioned improvement in the design model is between ACSR 185/29 and ACCC COPENHAGEN 220. Both produce a similar deduction value from the Aluminum conductor carbon fiber composite core model to the old ACSR in wasted power during the practical application and operation.

Table 4 *- Power consumption of 2 cable designs at similar diameter class.*

	Unit	ACSR 185/29	COPENHAGEN 220
Wire diameters	mm	18.8	18.2
Electric current	A	510	510
Temperature	^{0}C	90	80
Resistance	Ω/km	0.2048	0.1591
Consumptive Power	kW/km	53.3	41.4
	%	100	78

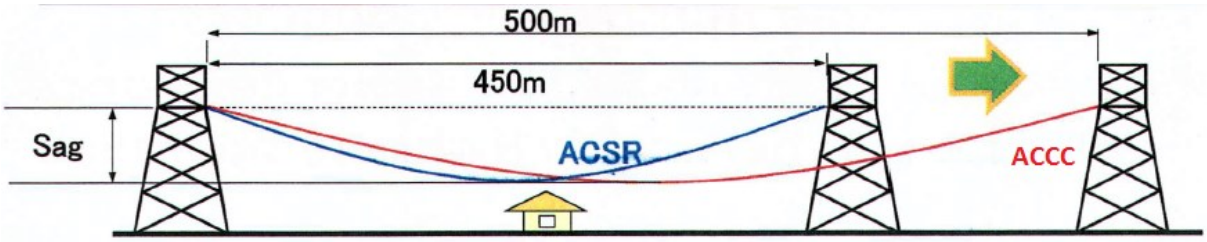
3.2 Sag comparison

Table 5 *- Physical specification of different materials*

	Unit	Composite core	Steel core
Traction-breaking stress	MPa	2000 to 2600	1200 to 1800
Thermal expansion coefficient	/^{0}C	1.61×10^{-6}	11.5×10^{-6}
Weight	g/cm^3	1.9	7.8

According to the material measurement, the composite material of the ACCC model has utilized a hybrid carbon and glass fiber embedded in a high-performance thermoset epoxy matrix, which makes it lighter by about 70% in weight in comparison to cast steel of the same size but has higher traction-breaking stress based on the advantages properties of carbon. In addition, as part of the hereditary form of carbon's physical properties, the composite material's thermal expansion coefficient is 10 times lower than cast steel material used in ACSR design. As a result, it leads to a great improvement in adjusting sag deformation and reducing the required power tower installation to meet the market demands which is illustrated in the below figure:

Figure 10 *- Power pylons adjustment required for each ACCC and ACSR cable type.*



Due to the extremely low sag ability during the operation period and its high strength but lower weight, the ACCC design allow the enhancement in distance between power poles which significantly plummets the required number of installation towers leading to a saving on cost and time to upgrade the current power system without changing the height of the poles. For example, within 4500 meters length of ACSR cable, requires 11 power pylons to adapt and carry the weight but with the ACCC cable type, the need to cut down to 10 high voltage power towers. It immediately solves the relocation crisis for the population and adds to the feasibility of the replacement without causing additional conflicts for any parties.

By replacing the ACSR system with ACCC models having similar installation requirements, the ACCC models with a 20% smaller sag rate can be installed on wider selections of power poles. If the area does not allow the gap between the towers to be adjusted, then this solution will offer feasibility to fit with even existing power pylons which are smaller and shorter than the expected size for the new ACSR power line. As a consequence, it will have a great impact on cost-saving, installation time, and social conflicts by cutting off the relocation budget or discarding additional funds for tower replacement.

3.3 Conductivity comparison

Another solution offered by Aluminum conductor carbon fiber composite core models is the conductive capacity during the operation according to the greater conductivity rate of annealed aluminum compare with 63% compared to 61% of ACSR or 60% of GTACSR by neglecting the eddy current which causes power loss during transfer internally. In addition, the allowed temperature for ACCC cable is up to 180˚C instead of 90˚C of the ACSR version, and the extremely small thermal expansion coefficient impacts the bearing ability of ACCC and lifts the maximum allowed electric current going through the wire to satisfy the tolerating demand of the growing regional market.

Table 6 *- Comparison table between ACSR and ACCC cable types at different diameter standards.*

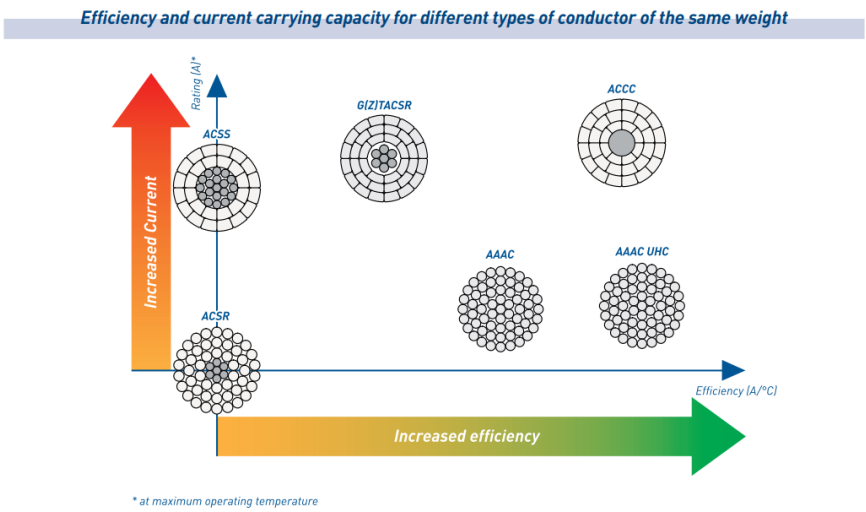
Type	Model	Diameter (mm)	Weight (kg/km)	Tensile force (kN)	Resistance (Ω/km)	Ampacity (A)
ACSR	185/29	18.8	727	62	0.1591	510
ACCC	REYKJAVIK	18.8	694	98	0.1256	986
ACSR	DOVE	23.6	1138	101	0.1027	638
ACCC	AMSTERDAM	23.6	1101	122	0.0762	1355
ACSR	400/51	27.6	1510	123	0.0723	815
ACCC	WARSAW	27.7	1519	158	0.0553	1673

From Table 6, the feasible current for ACCC is approximately double the capability of ACSR at each diameter tier. In conclusion, it guarantees a greater expanding potential to fit higher electrical delivery demand in the future without requesting any replacement or relocation.

3.4 Early conclusion

From the above comparisons and the product specification, the ACCC cable model type has emerged as a perfect replacement for the current Aluminum conductor steel-reinforced cable system in all aspects. It conserves 24% consumptive power which will be an advantage for both energy production and is environmentally friendly but can also carry a double load of allowed current during operation. These differences fully adapt and meet the rising demand of the local market but require less adjustment, relocation, and additional budget for installation and further maintenance. All in all, these factors have validated the perfect candidate - ACCC cable type - to satisfy the market need and is worth considering applying to mass production and replacement.

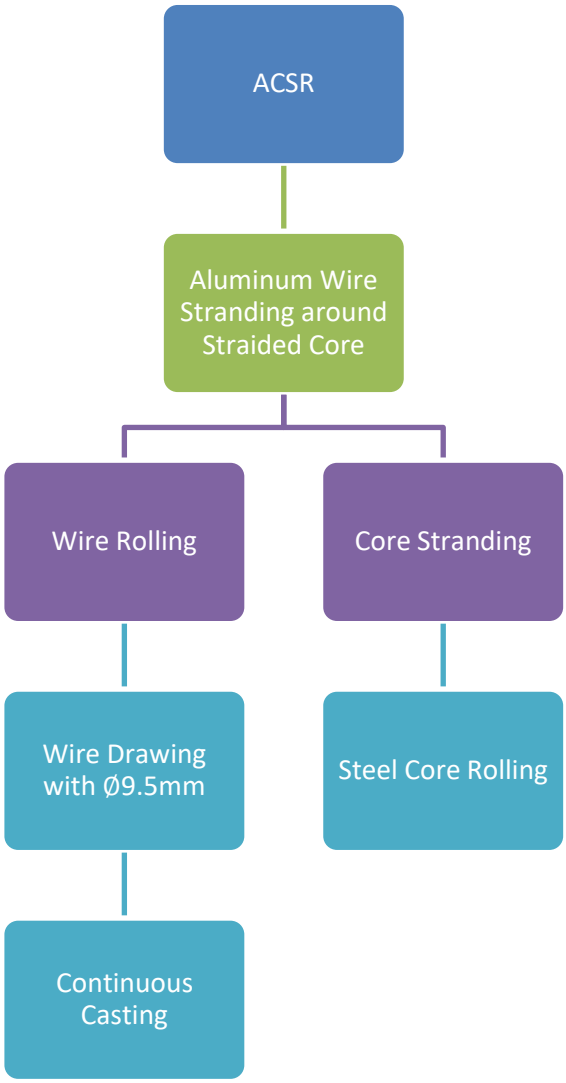
Figure 11 *- Efficiency and current carrying capacity for different types of conductors of the same weight (Lamifil Inc., 2011)*



4 Application of the idea to manufacturing

As an heir to ACSR cable, the manufacturing process of the ACCC cable model has a lot of similarities to its inspired model including the procedure of the process as shown in Figure 11.

Figure 12 *- Manufacturing procedure of ACSR cable line.*

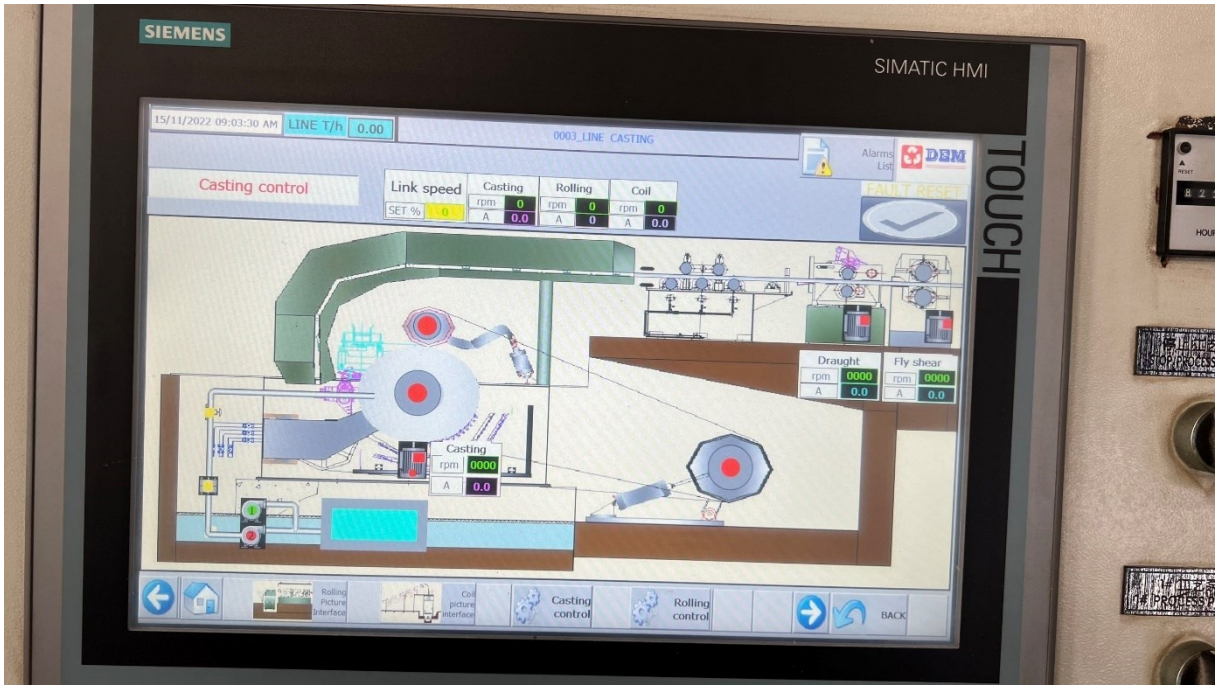


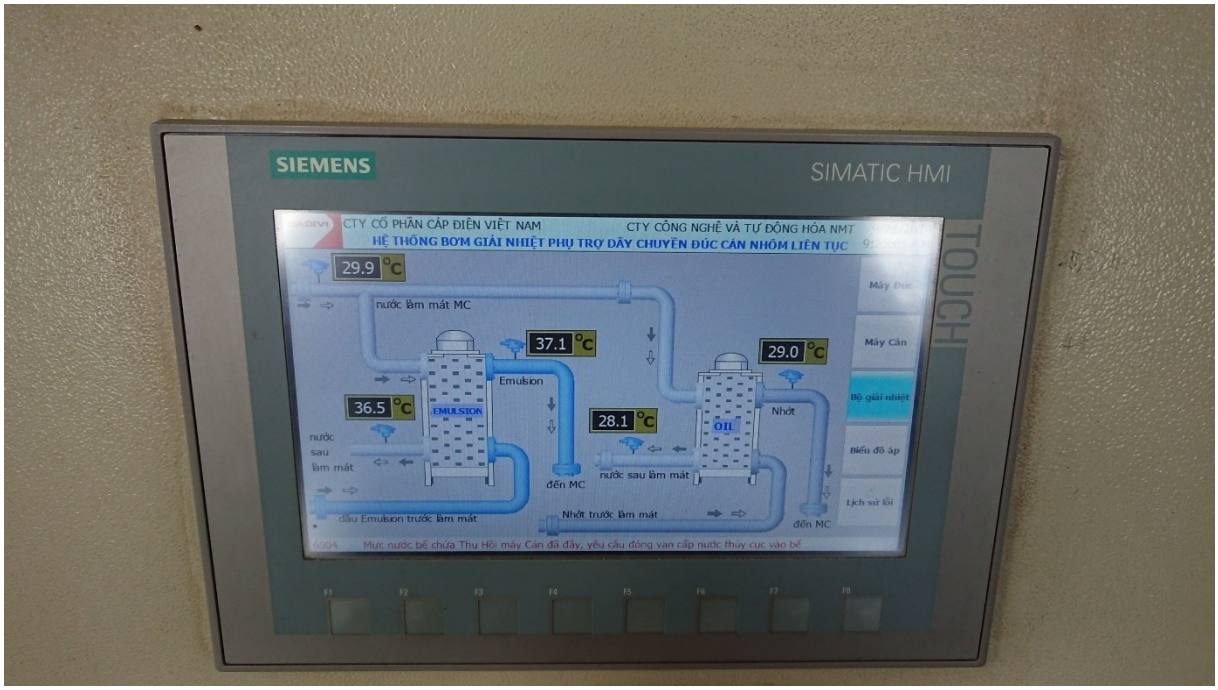
Both designs begin with aluminum bars which are melted in the furnace before pulling into the casting and rolling machine to format the hard round shape fiber with a 9.5 millimeters diameter at the cross-section area. At the same time, the steel core fiber goes through the same routine to form the core yarn for the inner layers. However, this process requires high

costs for energy consumption or machine installation so many cable manufacturers choose to import the steel wire from external suppliers to reduce manufacturing budgets and enhance the competitive cost. The steel core will be spun in the stranding machine to twist the wires and establish a solid physical attachment for the internal layers before placing it in the middle of the stranding machine for aluminum wires. And at the output of the stranding process, the ACSR cable is produced.

Figure 13 *- Casting and rolling process for traditional ACSR cable.*

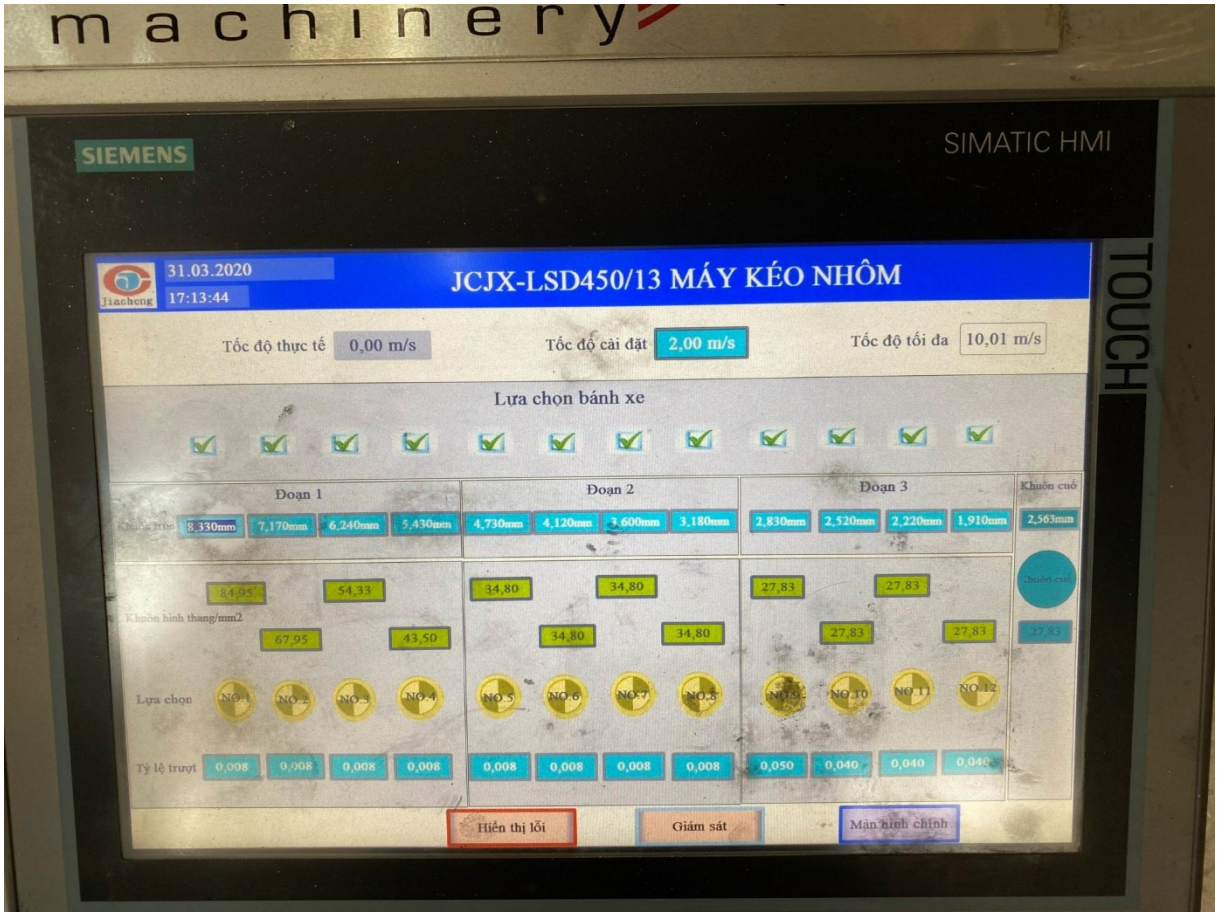
Figure 14 *- Recorded temperature casting furnace.*





- ***Figure 15*** *- Recorded rolling performance.*

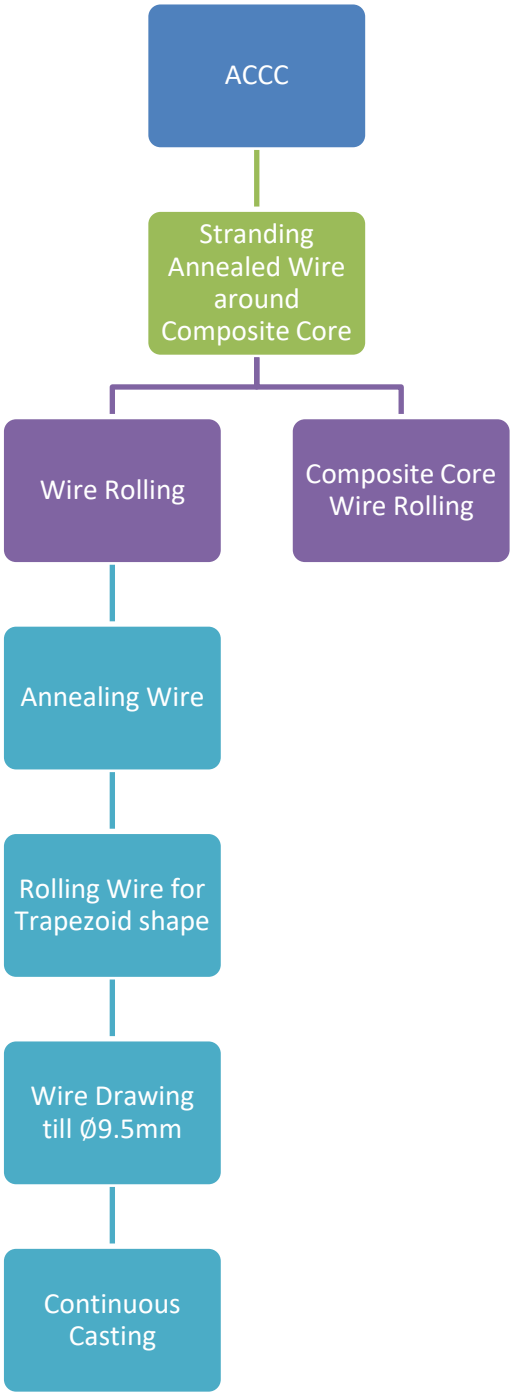
Figure 16 *- 9.5-millimeter diameter wire drawing manufacturing.*



4.1 Changing in the manufacturing process

Despite sharing the majority of the steps in the manufacturing process, the ACCC cable requires additional stages to designate its unique external layer shapes such as die adjustment, additional annealing stages, and wire stranding optimization.

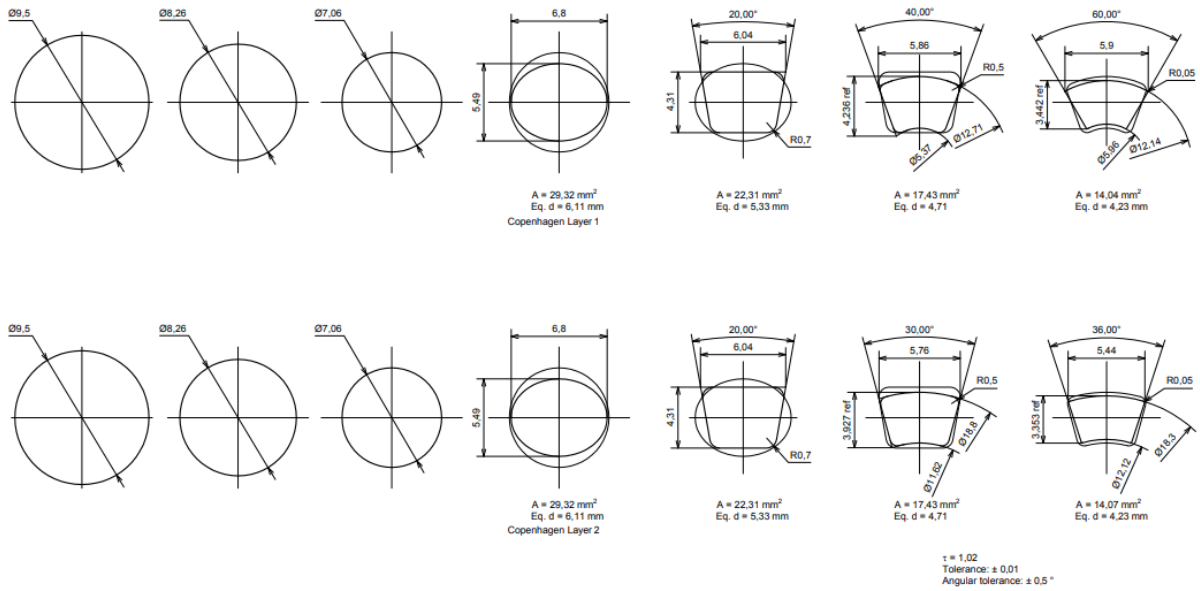
Figure 17 *- Production procedure of new ACCC cable type.*



4.1.1 Die Adjustment

The first difference between the two cable types is that the Aluminum Conductor Carbon Fiber Composite Core uses a more complex die combined with two isolated inner tolerance for each layer of the aluminum part of the cable to guarantee the maximum squeeze pressure instead of a simple round one for all fiber in ACSR. The Ø9.5mm round drew wire will be steadily rolled into those dies and depending on the layers, it will be sorted into layers 1 and 2 to avoid incorrect placement during the stranding phase.

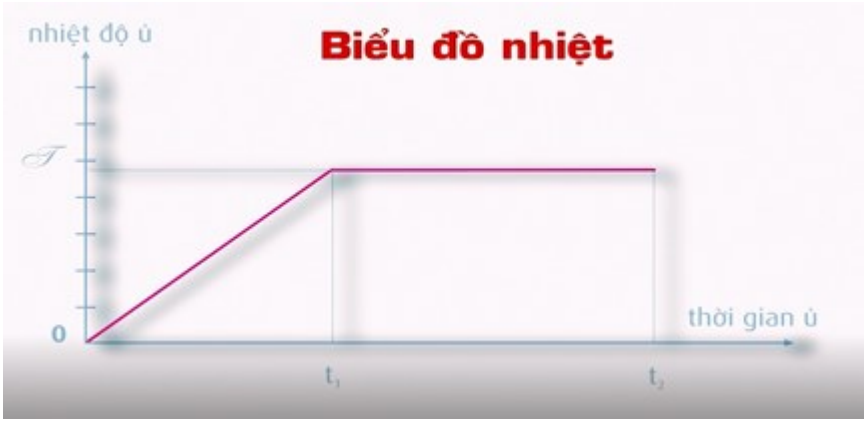
Figure 18 *- 2-layer die design for COPENHAGEN 220 model.*



4.1.2 Annealing Wire

Rolled trapezoid wire will be continuously inserted into an annealing furnace in patches and treated under heat in different phases to avoid damage or defect due to sudden temperature change as well as remain good extensibility, good durability, high electric conductivity, and easy processing forward. The heat adjustment of each phase commits to the rules which can be illustrated in Figure 18 below.

Figure 19 *- Thermal and time measurement logic in the annealing phase.*



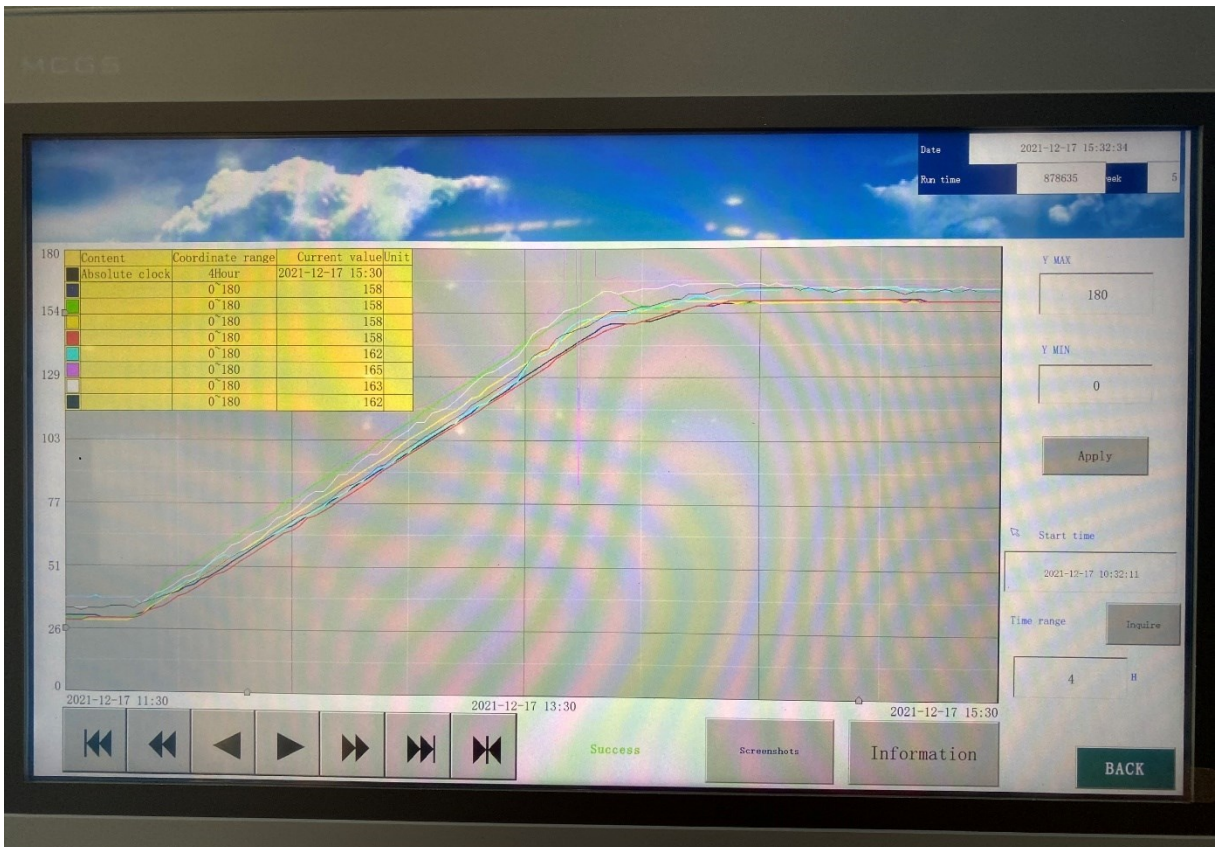
With:

- T is the annealing temperature.
- t_1 is the moment the furnace hit the input heat level.
- t_2 is the ending moment of the annealing phase.
- $t_2 – t_1$ is the annealing period.

The heating of the furnace starts at a 1˚C/min rate to reach 125 to 130˚C and stays at this temperature for about 20 minutes before speeding up the heat tolerating speed to 5˚C/min until 185˚C then keeps this level for another 1 hour. Then it raises to 15˚C/min to reach 225˚C then heat the wire for 1 hour period before slowing down the heat enduring to 10˚C/min to achieve 285 to 380˚C with 1 hour of incubating afterward. The finish at this level will activate the cooldown process with slow adjustment at 1˚C/min down to room temperature and maintain it in static pressure condition for hours at around 40˚C and avoid direct contact with water, chemical, or oil.

Table 7 *– Annealing specification data of different ACCC cable models.*

Model	**Cross-section area** (mm^2)	**Annealing time** (hour)	**Annealing temperature** (°C)	**Tensile strength** (MPa)
COPENHAGEN 220	INNER: 14.719	4.5 ± 10%	380 ± 5	60 - 95
	OUTER: 14.952			
GLASGOW 237	INNER: 15.713			
	OUTER: 16.209			
AMSTERDAM 367	INNER: 19.513			
	OUTER: 20.271			
BRUSSELS 421	INNER: 22.339			
	OUTER: 23.275			
WARSAW 507	INNER: 15.075			
	MIDDLE: 15.609			
	OUTER: 16.013			


Date
2021-12-17 15:32:34
Run time
878635
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5
Content
Coordinate range
Current value
Unit
Absolute clock
4Hour
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158
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158
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158
0~180
162
0~180
165
0~180
163
0~180
162
180
154
129
103
77
51
26
0
2021-12-17 11:30
2021-12-17 13:30
2021-12-17 15:30
Y MAX
180
Y MIN
0
Apply
Start time
2021-12-17 10:32:11
Time range
Inquire
4
H
Success
Screenshots
Information
BACK

2021-12-17
13:49:06
English
Chinese
Logon
Logoff
Current step
2
RUN_TIME
0002.0
M
TOTAL_RUNNING_TIME
0122.0
M
Start
Stop
148
0158
162
0158
154
0158
145
0158
Conditions are available
monitoring1
152
℃
monitoring2
149
℃
monitoring3
161
℃
monitoring4
152
℃
HT curve
Report
Edit

Figure 20 *- Annealing phase simulation.*

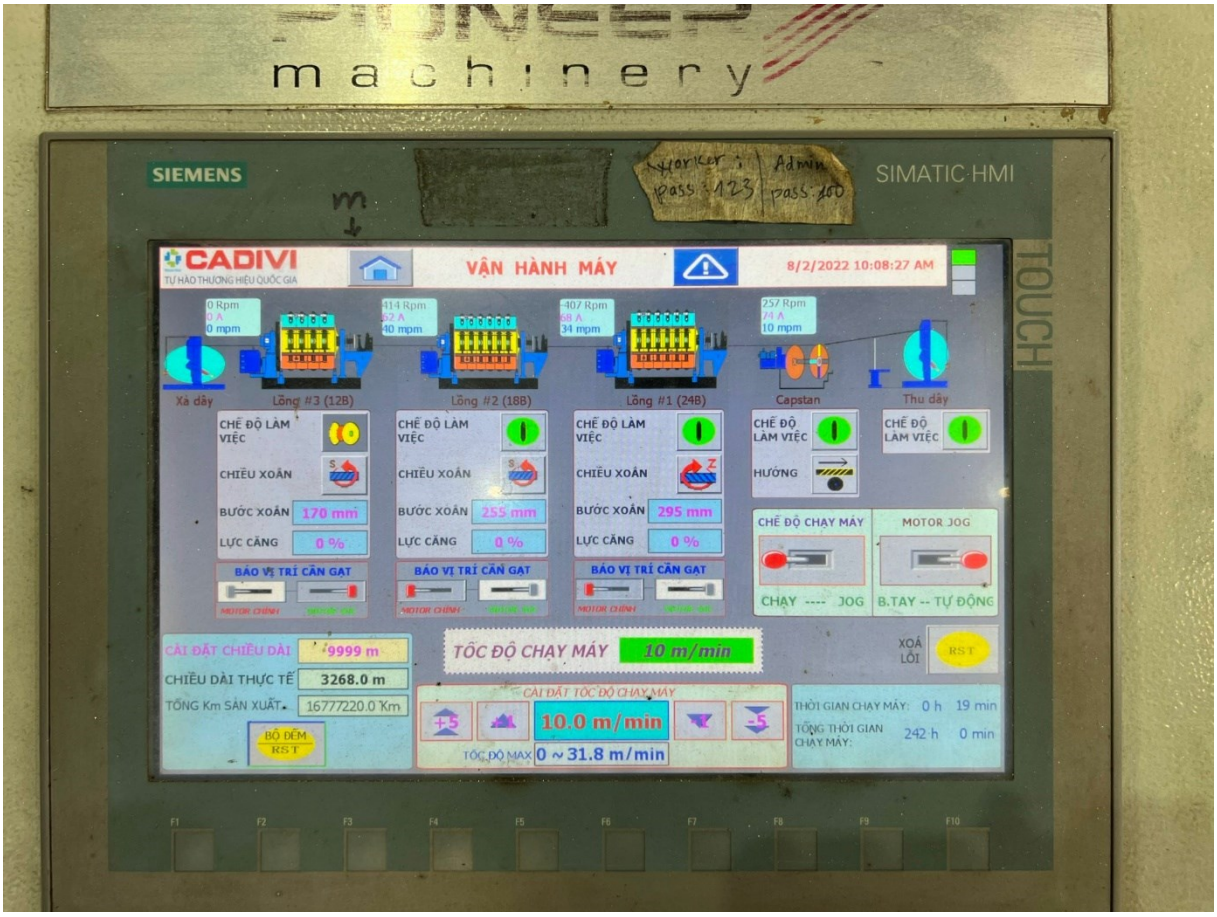
4.1.3 Wire Stranding

The composite core is provided by external suppliers due to the limited access of the local marker under coiled packs, so it is feasible to place it into the production system immediately after arrival. The stranding machine for the Aluminum conductor steel-reinforced cable model can guarantee perfect performance on Aluminum conductor carbon fiber composite core design with very limited adjustment as well due to the working logic of the machine.

The machine contains rollers on both the start to release the conductor from the reel and the end to coil the stranded wire to the final package. In between included 3 tubular stranding machines and a capstan to modify the designed shape of the wires. The unpacked composite single fiber will be placed in the center of the tubular stranding machine and go through all tubular machines. The layer 2 trapezoid coiled fibers will be placed and connected to all stranding positions at the second tubular while layer 3 applied for the third. Each tubular will reserve a different lay length due to the specific position of the layer in the cable and the diameter position across the cross-section at the final product.

The lay length is guaranteed based on the similar length parallel along the axis of all individual stranding elements in each machine. But since ACCC is the solo core so the twisting in the first machine is not mandatory compared to ACSR which required stranded steel wire to harden the weight holder for all conductors. Layer 2 in the second tubular operator starts to strand with a fixed spinning direction and tightens the squeeze pressure of trapezoid fibers. However, the last tubular machine with the layer 1 wire will be performed in a reverse rotating direction and at a bigger lap length to neglect the glide possibility which can break the perfect formability of the external layer as well as strengthen the inner twisting force of layer 2 to remove all potential gap during the stranding phases or operation period. The output of the third tubular stranding machine will go through the capstan and coil at the export reels before transferring to the testing and delivery stages.

Figure 21 *- Data adjustment for ACCC cable stranding machine.*



4.2 Manufactured products testing.

At the end of the manufacturing application, quality tests are compulsory to verify and guarantee the fully functional ability to operate normally under practical conditions. The testing phase will inspect four different categories of the finished product including the

spinning ability of the composite core, the electrical resistance of the cable, the ratios of the lay length, and validify the product properties according to the mechanical specification of global standards.

4.2.1 Rotation feasibility testing

The spinning ability testing is to guarantee the permanent bonding of the whole cable structure, especially the aluminum layers will remain as expected design regardless of the movement or deformation of the inner composite core. The testing methodology is performed manually by choosing a random cable length in the finished products and marking it on the linear axis of the composite core before connecting it to a ground grip. The grip will be inserted with an extension bar with a handle to test the rotation ability of the core in the line. The marker on the linear axis is the visual reference for the test result, if it is feasible to rotate easily, it means the stranding pressure is incapable of tight the aluminum to the composite core to form a permanent attachment which can cause the design to collapse during delivery, installation, or operation.

Figure 22 *- The tester uses a hammer to push the composite core ahead of the aluminum layers.*

Figure 23 *- The marker is set on both the composite core and aluminum layer as a reference for the spinning test.*

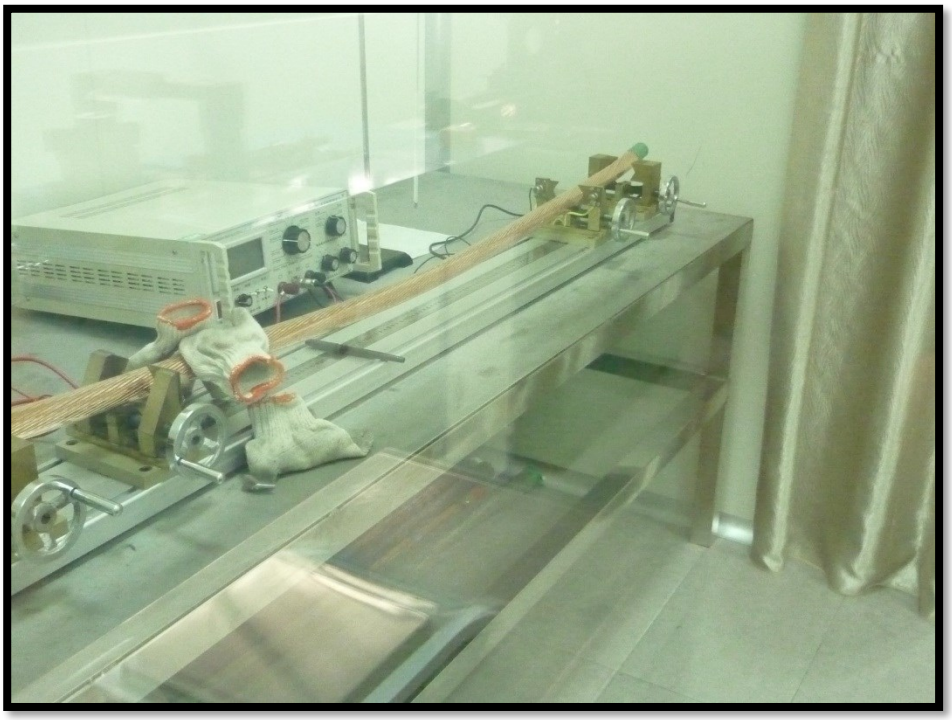
Figure 24 *- Round grip inserted as nailing point for the manual twisting force.*

Figure 25 *- Twisting force is applied manually to testify the marker movement ability.*

4.2.2 Electrical resistance testing

This test serves to demonstrate the performing ability of the produced conductor in expected scenarios and under different external environmental impacts. A 1-meter length of cable will be chosen randomly from the finished parts and placed in the electrical testing machine. It will simulate the electric current and voltage under similar conditions as the operating environment to validate the conductive feasibility of the cable under practical pressure.

Figure 26 *- Electrical simulation tools and machine verifying cable performance.*



4.2.3 Lay ratios measuring

The purpose of the measurement is to compare and evaluate the stranding performance as well as estimate the potential tensile strength of the cable. The testers install the picked 1-meter length of cable into the measuring machine or scale it manually by checking the number of lay lengths at a small monitoring linear axis area of the conductor. If the result is similar to the reference table from the global standard, which is tested and verified across the world, the stranding input value in the tubular machines is valid and the cables are

qualified to operate and deliver. The lay ratios fit with the recognized standard proving the cable is well-stranded and suitable to serve the required performance.

Figure 27 *- Lay length reference for lay ratios measurement (Owl Wire & Cable Inc., n.d.).*

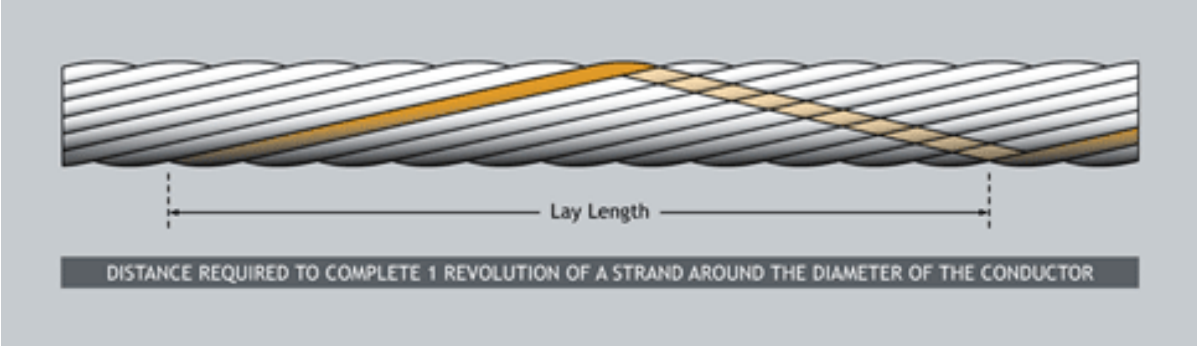


Figure 28 *- Lay ratios measurement.*

Table 8 *- Lay ratio of different ACCC models.*

Model	Diameter (**mm**)	Layer fibers in each stranding layer (**yarn**)	Lay ratios	Diameter of stranding die (**mm**)	Diameter after stranding	Maximum stress cap (**kN**)	Resistance at 20 °C (**Ω/km**)	Cable Weight (**kg/km**)
COPENHAGEN 220	5.97	INNER/ 6	10 ÷ 16	12.10		72.8	0.1272	661 ± 2%
		OUTER/ 10	10 ÷ 13	18.20	**± 1%**			
GLASGOW 237	7.75	INNER/ 6	10 ÷ 16	13.35		115	0.1184	741 ± %2
		OUTER/ 10	10 ÷ 13	19.44	**± 1%**			
AMSTERDAM 367	7.75	INNER/ 8	10 ÷ 16	15.98		122.4	0.0762	1101 ± 2%
		OUTER/ 12	10 ÷ 13	23.45	**± 1%**			
BRUSSELS 421	8.13	INNER/ 8	10 ÷ 16	17.02		135.7	0.0666	1265 ± 2%
		OUTER/ 12	10 ÷ 13	25.05	**± 1%**			
WARSAW 507	8.76	INNER/ 8	10 ÷ 17	15.12		158.7	0.0553	1519 ± 2%
		MIDDLE/ 12	10 ÷ 16	21.4				
		OUTER/ 16	10 ÷ 13	27.62	**± 1%**			

4.2.4 Product specification verifying

Lastly, one of the most important tests for manufactured products is verifying the product specification according to the global recognition data to finalize the readiness status of the package before delivery to the markets.

Figure 29 *– Mechanical specification of ACCC cable COPENHAGEN 220 model for manufacture reference purposes.*

Mechanical Specifications		Metric	
Conductor values.			
Nominal Cross-sectional area of aluminium *	mm^2	219.9	
Nominal Cross-sectional area of Core	mm^2	28.0	
Number of wire in layer 1	mm	6	Al
Number of wire in layer 2	mm	10	Al
Minimum filling factor of the aluminium cross section	%	93	
Lay ratio of inner layer(s)		10 – 16	
Lay ratio of outer layer		10 – 13	
Overall diameter	mm	18.29	
Diameter of Core	mm	5.97	
Diameter to tolerance of Core	mm	± 0.05	
Rated Tensile Strength of Conductor (RTS as per ASTM B 857) (1),(2)	kN	72.9	
Extreme Load Safety Strength of Conductor (with 40% of the aluminium strength)	kN	65.6	
Rated Tensile Strength of Core	kN	60.4	
Nominal Mass per unit length – Total	kg/km	661.0	
Nominal Mass per unit length – Aluminium **	kg/km	607.0	
Nominal Mass per unit length - Core	kg/km	54.0	
DC resistance at 20°C max. (conductivity 63% IACS)	ohm/km	0.1272	
DC current rating at maximum continuous surface operating temperature (calculated with maximum DC resistance at 20°C)	A, °C	1014	175
Maximum allowable continuous operating temperature (surface)	°C	175	
Maximum allowable continuous operating temperature (core) (3)	°C	180	
Coefficient of linear expansion above thermal kneepoint	/°C	1.61E-06	
Coefficient of linear expansion below thermal kneepoint	/°C	1.88E-05	
Modulus of elasticity above thermal kneepoint	GPa	112.3	
Modulus of elasticity below thermal kneepoint	GPa	64.1	

4.3 Challenge case during the implementation

Despite the superior capabilities in the performing ability and its solution to the massive dilemma of upgrading the power supplying system to meet the market demands, the ACCC model is not a reliable option to apply in mass production due to dependence on the distribution ability of the suppliers. The concentration of composite core design at very few companies has limited the exportation volume of this product, which in turn has had a tremendous impact on the production ability of the whole high-voltage cable industry. A

case study is during the COVID peak infectiousness period, the zero COVID policy of China has caused great damage to the logistics ability to surround countries and enlarged the required delivery time (Lim, 2022). This can lead to the stoppage of manufacturing this cable type at many companies across the world due to the reliance on monopoly companies like CTC Global and TOKYO ROPE. The postponement of this research and testing during 2020 and 2021 is also a consequence of this domino effect. The performing company struggles to set a deadline to adjust the old production chain for ACSR to manufacture the new solution under the urge and pressure from the local market about the replacement of an inefficient power supply system.

5 Evaluation

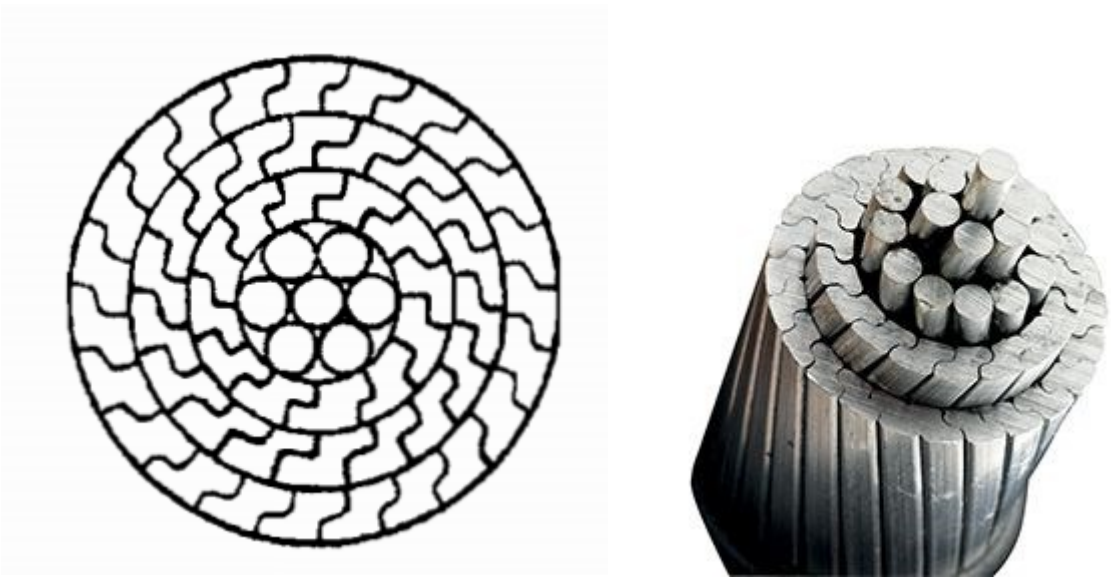
5.1 Evaluations of the application feasibilities

According to the research evaluation and practical production on a minor scale, Aluminum conductor carbon fiber composite core cable models have provided a perfect solution for the electric supply uprising demand due to the dominance over its inspired model - ACSR - on both performance and operational requirements. And with limited adjustments in manufacturing procedure from the existing system for the Aluminum conductor steel-reinforced model, it is a simpler solution to apply in mass production for the local manufacturer without computing additional cost. Another honorable mention is the nonobligatory requirements for replacing existing power pylons to serve other solutions or dealing with local relocation to adjust the electricity transformer distribution. All the factors determine the decision-making combined and lead to the guarantee of this application's feasibility. The ACCC cable model is a solid and optimal answer for all the mentioned root problems but also enlarges the potential of the electrical supply industry due to the further exploitation of the allowed capacity of this wire type.

5.2 Potential Improvement and Future of ACCC

The remarkable feature of the cable has earned the recognition of the majority of experts from the cable market, and it is a guaranteed solution for even the fastidious markets. Besides the issue of insufficient composite core fiber providers, many areas reported the detachment of aluminum conductors at external layers during the delivery, installation, or maintenance because of the vertical sliding ability of the trapezoid shape. Therefore, the short-term negotiation for this question is adjusting the aluminum wire shape to endure the tightening of stranded aluminum layers. One potential design is replacing the trapezoid die in the casting phase with a Z-shape version which neglects the sliding activity under the impact of the external environment. This elimination provides tighter stranding options for the aluminum layer and removes the deformation ability of the aluminum in the vertical axis because of the heat during operation.

Figure 30 *– Z-shaped aluminum form with steel core following ACSR design concept (Avatok Inc., n.d.)*



6 Conclusion

The ACCC cable design has been revealed as the perfect candidate for solving the electrical power upgrade at the local market through the Research and Development process. Its ability and performance are justified, validated, evaluated, and proven throughout the thesis concentration leading to the clarification and certification of feasibility in mass production for the Vietnamese market. The great improvement in the power supply and power saving during the performance of ACCC opened a larger potential capability for the growing market to adopt and adapt more companies in the production industry both internally and externally. The immense reduction of the cost in applications and operation of this model can be held and distributed into other investments to generate and exploit the higher ampacity rating of the upgrading power line. A few suggestions are replacing or upgrading the existing transformers or enhancing the coverage of the national grid to minority or rural areas to qualify the growth objectives of the United Nations.

In conclusion, the thesis successfully demonstrated the strengths and weaknesses of applying the new ACCC cable as a modern solution for the power supply crisis as well as identified the struggle during that application in manufacturing. This cable design will inspire the future development of the overhead conductor industry in the Vietnamese market and set a new reference for further comparison in later improvement. The ability in adjusting the material or wire shape to construct the cable opens an ultimate potential for enhancement and ensures higher upgrades in near future. Finally, the ACCC model is not the latest model produced but it is proven as the best applicable solution for the local market which is granted as an official solution for power supply in Vietnam for at least the next 10 to 20 years.

References

Avatok (n.d.). *OPL Conductors*. Accessed 5 August 2022 at https://avatok.tech/products/opl-conductors

ASTM International (2020). *Standard Specification for Carbon Fiber Thermoset Polymer Matrix Composite Core (CFC) for use in Overhead Electrical Conductors*. Retrieved from the internal network.

ASTM International (2004). *Standard Specification for Aluminum 1350 Round Wire, Annealed and Intermediate Tempers, for Electrical Purposes*. Retrieved from the internal network.

ASTM International (2002). *Standard Specification for Shaped Wire Compact Concentric-Lay-Stranded Aluminum Conductors, Coated-Steel Supported*. Retrieved from the internal network.

ASTM International (2002). *Standard Specification for Electric-Resistance-Welded Carbon Steel and Carbon-Manganese Steel Boiler and Superheater Tubes.* Retrieved from the internal network.

Berjozkina, S., Sauhats, A., Vanzovichs, E. (2013). *Evaluation of the Profitability of High-Temperature Low Sag Conductors*. Accessed 21 July 2022 at https://ortus.rtu.lv/science/lv/publications/16563/fulltext

Bryant, D. (2017, March 3). ACCC conductors can reduce line losses and why everyone should care. Accessed 15 June 2022 at https://ctcglobal.com/accc-conductor-reduces-line-losses-everyone-care/

CTC Global (2016). *ACCC Specification Data Sheets*. Accessed 5 August 2022 at https://www.ctcglobal.com/wp-content/uploads/2016/06/ACCC_International_Data_Sheets-Rev_E.pdf

Electric Power Research Institute (2008, July 29). *Demonstration of Advanced Conductors for Overhead Transmission Lines*. Accessed 15 June 2022 at https://www.epri.com/research/products/1017448

Huatong Cable, Inc (n.d.). *Conductor Catalogue ASTM Standard*. Accessed 21 July 2022 at http://www.huatongcable.com/d/files/download/conductor-astm-standard.pdf

Jinshui Cable Group (n.d.). *The structure and characteristics of ACSR conductor*. Accessed 21 July 2022 at https://www.jsgroupcable.com/the-structure-and-characteristics-of-acsr-conductor/

JSK Industries Pvt. Ltd., (n.d.). *ACFR – Aluminium Conductor Fiber Reinforced.* Accessed 21 July 2022 at http://www.jskindia.in/products-services/acfr.htm

Lamifil, Inc (2011). *Overhead Conductors*. Accessed 5 August 2022 at https://lamifil.be/wp-content/uploads/2011/04/Overhead-Conductors.pdf

Lim, P.H. (2022, May 26). *China's Strict Zero-COVID Policy Creates Supply Chain Chaos*. *VOA News*. Accessed 15 June 2022 at https://www.voanews.com/a/china-s-strict-zero-covid-policy-creates-supply-chain-chaos-/6591227.html

Möller, O. (2015, January 9). *The Double Diamond*. Accessed 15 June 2022 at https://blog.methodkit.com/the-double-diamond-16c74e3c4869

Paramount Wires & Cables (n.d.). *Copper Wire Vs Aluminum Wire*. Accessed 21 July 2022 at https://paramountcables.com/blog-posts/copperwire-aluminum-wire/

Powermag. (2012, May 1). *Vietnam Works Hard to Power Economic Growth*. Accessed 15 June 2022 at https://www.powermag.com/vietnam-works-hard-to-power-economic-growth/

Owl Wire & Cable, Inc (n.d.). *Conductor Classification*. Accessed 5 August 2022 at https://internationalwire.com/wp-content/uploads/OWL-Product-Catalog.pdf

Russell C. Hibbeler (2017). *Engineering Mechanics Dynamics (Fourteenth Edition)*. Retrieved 1 July 2022.

Sato, F. & Ebiko, H. (2002). Development of a Low Sag Aluminum Conductor Carbon Fiber Reinforced for Transmission Lines. Retrieved 1 July 2022.

Slegers, J. (2011, October 18). *Transmission Line Loading: Sag Calculations and High-Temperature Conductor Technologies*. Accessed 21 July 2022 at https://home.engineering.iastate.edu/~jdm/wind/TransmissionLineLoadingDesignCriteriaAndHTS.pdf

The Aluminum Association. (1989). *Aluminum Electrical Conductor Handbook*. Accessed 15 June 2022 at http://www.rmjtcable.com/d/file/manual/Aluminium_Electrical_Conductor_Handbook.pdf

Vagner, I.D., Lembrikov, B.I., Wyder, P.R. (2003, November 17). (2003, November 17). *Electrodynamics of Magnetoactive Media. Springer Science & Business Media* pp.73. Accessed 15 June 2022 at https://books.google.fi/books?id=E8caSplsF28C&pg=PA73&redir_esc=y#v=onepage&q&f=false

Wareing, B. (2011, February 28). *Types and Uses of High-Temperature Conductors.* Accessed 5 August 2022 at http://www.aeolus.bz/Seminar%202011/Brian%20-%20New%20Conductor%20use%20Tutorial%20in%20CIGRE%20format%2028%20Feb%202011.pdf