NEW MATERIAL FOR COMPACT SECONDARY SUBSTATIONS ENCLOSURES

Carlos MARTINEZ NIETO
ABB AS – Estonia
carlos.nieto@ee.abb.com

Ivan C. PEDERSEN
ABB A/S – Denmark
ivan.c.perdersen@dk.abb.com

Ants PALGI
ABB AS – Estonia
ants.palgi@ee.abb.com

ABSTRACT

This paper presents a new material used for compact secondary substations enclosures. The material is glass-fiber reinforced polyester, known as GRP. A comparison has been made using GRP versus steel and concrete, two materials that are currently widely used for this kind of substation. The comparison has been based on mechanical and thermal properties as well as in terms of durability, concluding that the GRP combines the best key properties of steel and concrete CSS such as corrosion resistance, strength, durability and the best behaviour in terms of thermal properties based on the concept of a double layer design. Therefore the GRP is feasible for the new trends in smart substations and it is a reality in the distribution networks.

INTRODUCTION

Compact secondary substations (CSS) became practical when distribution utilities transitioned from overhead power lines to underground cables.

Since the 1960s CSS have gained worldwide use in distribution networks. From the beginning, the corrosion properties were one of the key aspects in the development. However, in the 1980s, the CSS business became cost-oriented which led to the introduction of cheaper materials, creating major problems in terms of corrosion.

Nowadays, the term smart secondary substation [1] provides a strategic position to the CSS into distribution networks because service quality improvement is achieved due to the possibility of flow monitoring, Distributed energy resources (DER) management, and network automation and control.

The key role of a CSS in distribution networks forces a CSS to be modular and ensure fast reconfiguration after a failure, to be corrosion proof for increased lifetime and reduced maintenance cost, not to interfere in the communications for control and monitoring, and to meet the relevant standard, IEC 62271-202 [2], in terms of safety and ensure the appropriate operation of the equipment.

In order to address the above mentioned basis for the design and development of a CSS, and more precisely, with the aim of dealing with corrosion and to provide improved mechanical strength, reduced effect of solar radiation and weathering, the trend with distribution networks is to opt for concrete solutions [3]. However, some of the basis, such as modularity, are not totally fulfilled which can be achieved by means of steel CSS.

In this paper a new material for a CSS enclosure is presented that combines the properties of both concrete and steel and covers all the key points that the enclosure of a smart substation inherently requires.

NEW MATERIAL FOR CSS

Glass-fiber reinforced polyester (GRP) is a composite material made of polyester with a high content of glass. The GRP is a well-known material used for lightweight, strong, corrosion proof and easily shapeable constructions all around the world. GRP is proven in several industries that have high demands on performance and strength – including wind turbine blades and cable distribution cabinets as examples in the electrical industry. GRP is used wherever high strength-to-weight ratios and rigidity are required. GRP is a material with excellent properties for outdoor enclosures making it an ideal solution for CSS housing.

With the aim of understanding the key aspects of the GRP material, the following aspects are analysed and compared with steel and concrete materials used in CSS' enclosures: mechanical properties, thermal properties, durability considering corrosion and modularity of the CSS.

The comparison carried out through the following sections considers a typical wall element in steel and concrete. In the case of a steel CSS, the thickness of the steel has been set up at 1.5mm, while the concrete has been considered as reinforced concrete with a wall thickness of 90mm.

For the GRP CSS, the wall element, as well as other main structural elements such as doors and roof, is made with a double layer design. This concept of a double layer provides different benefits in terms of increased strength and better thermal behaviour as explained below. The cross-section of a typical wall element can be seen in Figure 1. The thickness of the GRP material is 4mm.

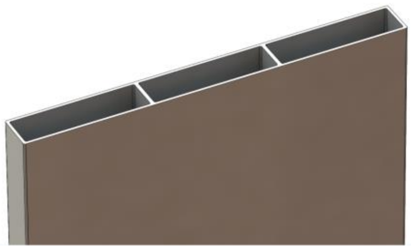

Figure 1: GRP main element in double layer design

Mechanical properties

The GRP used for the CSS application is composed mainly of resin, roving and mat. Polyester resins are combined with suitable fillers, catalysts, UV inhibitors and pigments to formulate the resinous matrix, binding the fibers together and providing the structural corrosion resistance and other required properties.

The high longitudinal strength of the final material is provided by the fiberglass roving. In the design stage the amount and location of these reinforcements is determined to provide the correct physical properties to the final product.

Continuous strand mat layered together with the roving provides the required degree of transverse physical properties. The ratio of mat to roving determines the relationship of transverse to longitudinal physical properties.

In Table I, the mechanical properties of a one layer GRP compared to steel and concrete are shown. It should be noted that for a double layer design this strength is higher.

TABLE I: Mechanical properties

	GRP	STEEL	CONCRETE
Tensile strength (MPa)	398	420	12
Flexural strength (MPa)	302	420	12
Density (kg/m^3)	1850	7900	2500
Specific strength (kN*m/kg)	215	53	5

As shown in the table above, the GRP is the material with the highest specific strength and at the same time the one with the lowest density, making it a feasible solution for CSS enclosures in terms of mechanical properties.

In order to better understand how a wall element behaves under a mechanical load for the three compared materials, a simulation has been carried out. It is based on a load of 700Pa, which corresponds to a wind pressure of 34m/s as mandatory in IEC 62271-202. Results can be seen in Figure 2, where the deflection of the element is shown. The Figure 2 shows that the GRP behaves as the concrete. In the case of steel, due to the large deflection (10mm), additional supports and shapes would be needed to give the needed resistance to the element.

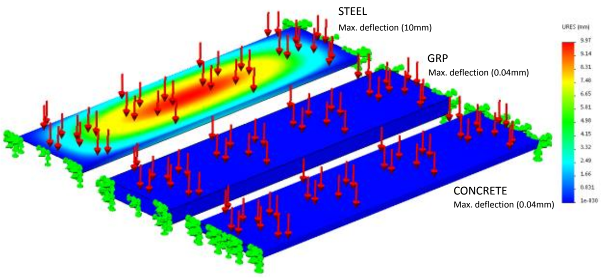

Figure 2: Deflection comparison under a load of 700Pa

Thermal properties

Thermal conductivity

The GRP has the lowest thermal conductivity compared with steel and concrete as depicted in Table II. The higher the thermal conductivity, the more heat is transferred by conduction. This, in the case of GRP, provides the benefit of a heat exchange blocker as the inner surface is separated from the outer environment by a high thermal resistance, allowing then for the CSS to not be influenced by fast changes in the outer environment, such as sun radiation, as it is the case of a steel CSS.

TABLE II: Thermal conductivity in W/(m*K)

Steel	54
Concrete	1,7
GRP	0,3

Specific heat

In terms of specific heat, or in other words, the capacity of the material to keep the energy, for a one-meter length wall element, the GRP is much lower than concrete and just slightly higher than steel as shown in Table III.

TABLE III: Specific heat in kJ/K for a 1m length wall element.

Steel	12
Concrete	396
GRP	40

A lower value of the specific heat is related to a low thermal inertia of the material in terms of heat radiation. In the case of the night operation of a CSS, in which the temperature at night is lower than during the day time, in addition with a low load in the distribution network and thus less losses in the CSS, using a concrete CSS results in difficulty to evacuate the heat inside the walls, thus cooling down the transformer in a longer period. If steel or GRP are considered as the enclosure material, the heat inside the enclosure will be radiated to the environment much faster, helping the power transformer to cool down.

Effects of ambient conditions

Besides the inherent characteristics of the GRP material, the above mentioned concept of a double layer design provides additional benefits in terms of thermal behaviour when considering the effects of the ambient conditions because the inner layer is separated by the outer one by means of an isolation medium which in the current case is air.

The simulation in Figure 3 shows the thermal distribution in a portion of a wall element of steel, concrete and GRP for hot climate conditions. The boundary conditions have been set up to an outside wall temperature of 80°C (likely to occur when sun radiation is present) and the ambient air temperature in the inner part of the wall has been set up to 40°C. The simulation has been run until the stabilization of the temperatures was achieved.

Outside wall temperature	+80°C
Inside ambient temperature	+40°C
Steel inside temperature	+79°C
GRP inside temperature	+56°C
90 mm concrete inside temperature	+66°C

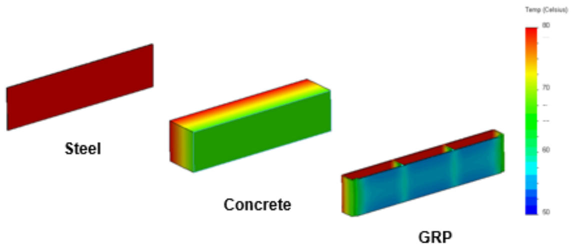

Figure 3: Temperature distribution for a hot climate

As depicted in Figure 3, the GRP has the lowest temperature in the inner side of the wall. This fact is important in terms of cooling down the transformer, as the heat evacuated by means of radiation of a GRP CSS is higher than in the case of steel or concrete enclosures.

For a cold climate with boundary conditions of -20°C in the outer wall and an ambient air temperature in the inner side of the wall of 30°C, the results are shown in Figure 4.

Outside wall temperature	-20°C
Inside ambient temperature	+30°C
Steel inside temperature	-19°C
GRP inside temperature	+15°C
90 mm concrete inside temperature	-5,6°C

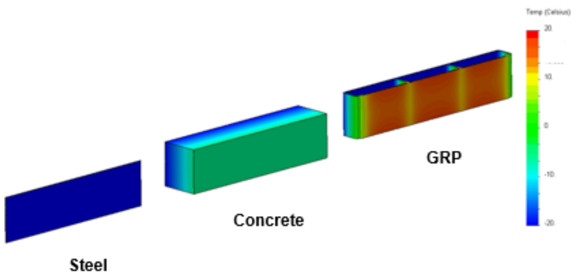

Figure 4: Temperature distribution for a cold climate

As seen in Figure 4, the GRP material has the highest temperature for a cold climate and this temperature is above zero degrees Celsius. This fact is a benefit in terms of condensation, which would occur in steel and concrete CSS' and not in a GRP CSS. In very cold climates or when the CSS is in idle mode, the enclosure has to be heated up in order to keep the electronics installed inside for the Smart Grid running.

Durability

In terms of the durability of a CSS there are two main aspects to be considered such as corrosion (oxidation) and cracks, which can affect the lifetime of a CSS considerably.

Corrosion:
In the case of a steel CSS, the exposure of the material to harsh environments might initiate the corrosion phenomenon the moment the raw material is in contact with oxygen (ambient). This would occur in the case of scratches in the material surface or deterioration of the protection coat such as paint.

As GRP is based on polymer reinforced with glass, the corrosion by oxidation of the material will not appear. In the case of polymers, in fact, it is more appropriate to talk about degradation of the material. This degradation is mainly based on the UV influence. In order to protect the GRP, a pigment is added to protect the final material.

In spite of this pigment a degradation is present in terms of material strength. A decrease in the strength can be up to 20% in the side of the wall facing the outer environment with UV influence. Due to this reason all the fasteners are fixed in the inner layer of the GRP, where no influence will be present and thus no decrease in material strength occurs.

Nowadays, rural and environmentally harsh locations usually require low-maintenance equipment because of remoteness and difficulty of access. In addition, the smarter networks now being installed around the globe can be controlled and monitored remotely, so CSSs are visited less often and this reinforces the requirement that equipment be as maintenance free as possible. This maintenance is a key aspect when comparing a steel CSS versus a GRP CSS, as the exterior of the GRP can withstand severe conditions better than a typical steel CSS enclosure, it is corrosion-resistant and never has to be repainted.

Cracks:
With a concrete CSS, a poor reinforcement or poor manhandling during lifting and transportation might cause cracks in the concrete elements, thus reducing the strength of the material and the CSS.

These cracks are a direct way for the water to penetrate the concrete element. Water penetration on the concrete is undesirable, as the reinforcement could then be exposed to oxidation and in the case of freezing cycles, the water could become ice inside the concrete, increasing the volume and breaking a large portion of the affected element, thus reducing the durability of the substation.

Making a comparison of the lifting and transportation of a concrete CSS versus a GRP CSS, shows that due to the light weight of GRP, these processes are easier, ensuring that no crack will appear on the composite CSS.

Modularity

Smart substations inherently require modular enclosures in order to accommodate equipment that varies in shape and size, depending on the manufacturers. The modularity can be achieved easily with GRP and steel enclosures, but is not feasible for a concrete CSS.

Combining modularity and the mechanical behaviour under load shown above together with the need of no additional supports, GRP CSS provides a modular self-supporting structure that can be reconfigured easily depending on the needs of the equipment installed inside. The proposed concept of GRP CSS can be seen in Figure 4.

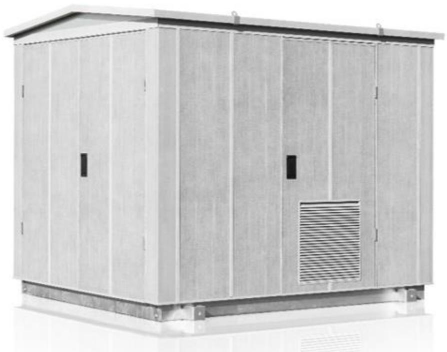

Figure 4: Proposed modular CSS made of GRP

CONCLUSIONS

A new material for CSS enclosures and a comparison with concrete and steel, materials currently used in the design of a CSS, has been presented.

In terms of mechanical properties, the GRP presents the highest specific strength and under mechanical load it behaves like concrete. Therefore there is no need to add supporting structures to the walls, making the CSS design simpler and cost-oriented.

Regarding thermal properties, the GRP presents the best behavior versus steel or concrete due to the low conductivity of the material and the benefits of the double layer concept.

The durability of the material in the CSS provided by the GRP is the best in terms of corrosion compared with a steel CSS and in terms of cracks compared with concrete, allowing then a very low maintenance during the lifetime of the CSS.

As a summary of the comparisons, the Table IV shows the analyzed properties for the three materials.

TABLE IV: Comparison between CSS enclosure materials.

	GRP CSS	Concrete CSS	Steel CSS
Corrosion resistance	++	++	−
Modularity	++	−	++
Strength	++	++	+
Weight	++	−	++
Weathering	++	+	+
Thermal properties	++	+	−
Maintenance	++	++	−

The proposed modular GRP CSS has successfully passed the type-tests required by the IEC 62271-202, providing safety to operators and public, and ensuring that the installed equipment will operate in the correct conditions.

The advantages of the GRP used for CSS enclosures and the proven reliability in terms of safety makes this innovative concept feasible for the new trends, becoming a reality in the distribution networks.

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