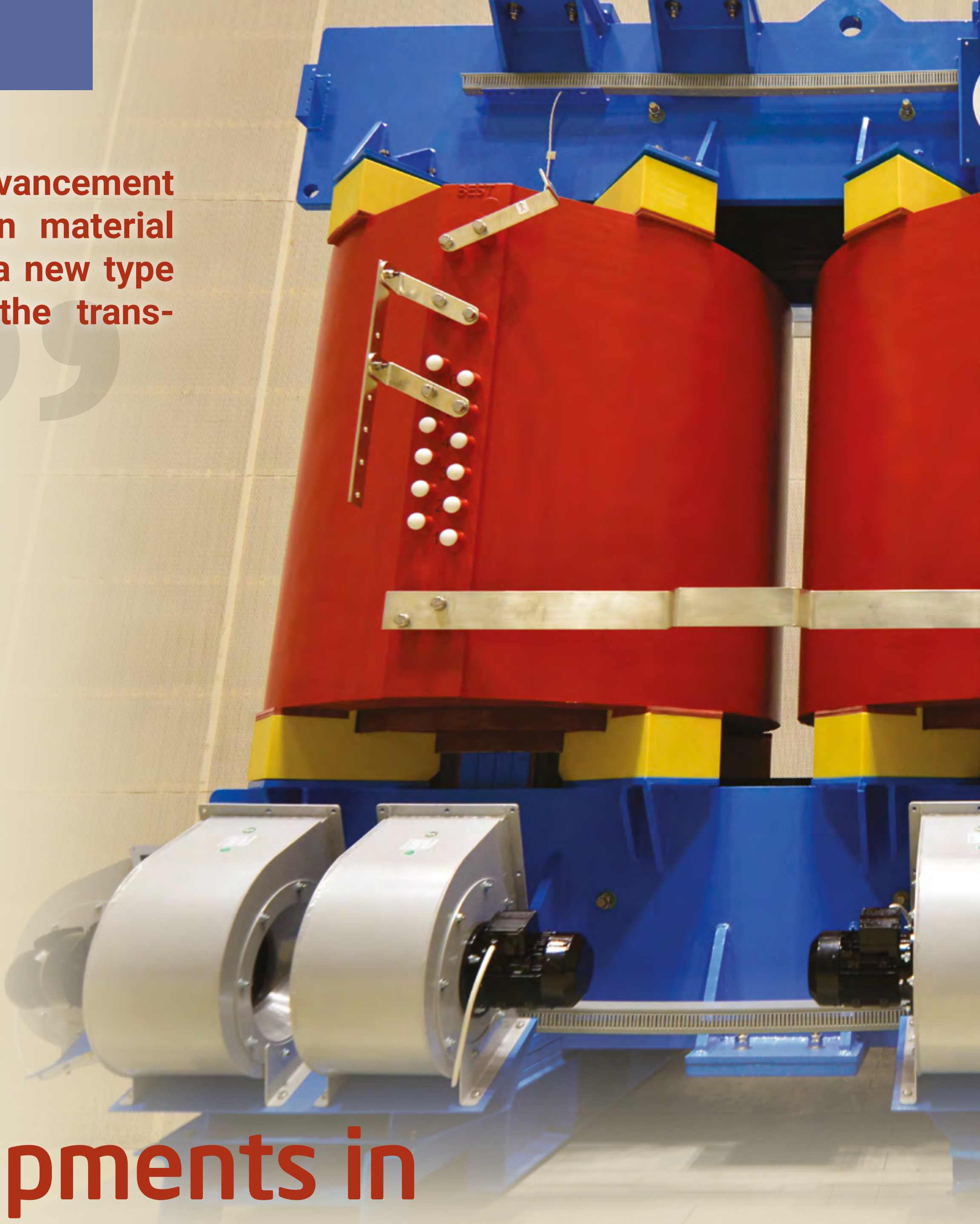
> Technology advancement and focusing on material research led to a new type of solution in the transformer market



New developments in dry-type technology

Dry-type transformers are enlarging in size and voltage - are we ready for a challenge?

ABSTRACT

Today, dry-type transformers ratings could go up to 63 MVA, and voltage levels of 145 kV are achieved. This article will share some new trends in dry-type transformers and some challenges that technology faces. Technology is developed with new demands of the market, and manufacturers are racing with each other to find optimization points for both manufacturing and design. Dry-type technology is mostly quartz-filled, or glass-fibre reinforced, but recently, VPI became a popular solution for some specific applications. The size of the transformer differs with the application; new materials challenge the old ones depending on demands. When compared with oil-filled equivalent, dry-type is larger in size and generally more expensive, but when it comes to fire safety, vibration withstand ability, less maintenance, and blast(ex)-proof applications, dry-type is the number one choice.

KEYWORDS

dry-type transformer technology, manufacturing of dry-type transformers, new applications in dry-type transformers

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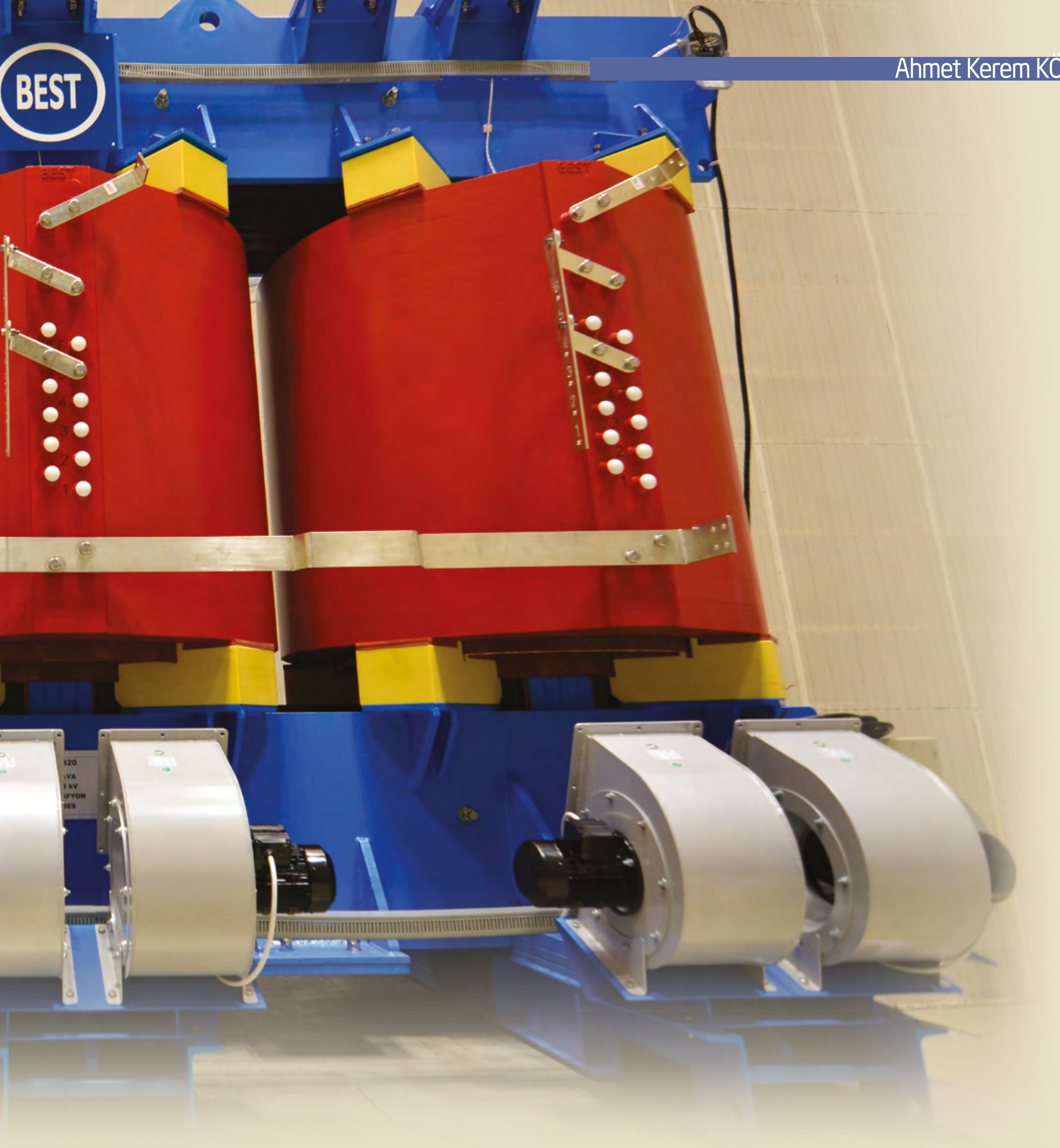

1. Introduction

Transformers are essential components in the energy sector. With long manufacturing times and high first investment costs, they are the first equipment to consider in energy solutions. Technology advancement and focusing on material research led to a new type of solution in the transformer market. The technological developments are likely to continue in the following years with advanced simulation and computation tools that are used in the design stage to meet customer requirements and complexities for the power systems. On the other hand, optimization of the material costs and getting a larger market share is a challenge [1]. At manufacturing, quality and speed are essential. For this purpose, automated manufacturing processes are developed every day. Lifetime expectancy is long for transformers, but with hybrid insulation systems life expectancy of transformers is getting longer [1].

Even with efficiency ratings of more than 99.9 %, regulations focus on environmental and economic considerations, so lowering losses and considering Total Ownership Costs (TOC) is always the number one comparison point for transformers [2]. Another trend is the effect of decentralization. This will probably strengthen the tendency towards smaller rated oil and dry-type transformers as well as the dry-type transformers, which will be one of the major options [3]. With requirements such as power quality and fast reaction to disturbances in the network, transformer withstand ability must be developed.

The most significant topics for the simulation of dry-type transformers are thermal calculations and aging studies

Dry-type transformers have a significant advantage in the application where there is a risk of fire, such as large biomass plants

Dry-type technology is generally experienced with small prototype manufacturing. When the results are satisfactory, big investments follow up.

When a new investment is on the horizon, every manufacturer plans for "What's new, what's next?" This will allow manufacturing to be up-to-date and future-proof. Dry-type transformer investments need more expertise because chemistry is at the heart of technology. So, it is not easy to increase power ratings and voltage levels with larger capacity equipment. Simulation of dry-type systems is not easy neither, so experimental know-how is a key asset in manufacturing and design. The most significant topics for the simulation of dry-type transformers are thermal calculations [4] and aging studies [5].

There are still ongoing developments for dry-type transformers standardization studies. No IEC or ANSI / IEEE standard exists for dry-type transformers for the voltage classes above 72.5 kV. Thus, the respective standards for dry-type and oil-immersed transformers are considered for higher voltage applications whenever relevant [6]. Reference [7] shows an experimental and FEM study for the dielectric performance for new concepts that have been evaluated by applying electrostatic simulation on very detailed 3-D models. The first step is the electric field computation, and the second step is the discharge mechanisms in the air. To predict the withstand voltage, these were included in a simulation tool. Discharge mechanisms such as streamer propagation, streamer inception, and leader inception were considered in a study [7].

2. Large transformers

Power rating is the first parameter to consider before manufacturing or designing a transformer. It is the same for the dry-type, but this type of application started with small power ratings. So, increasing the rating of the dry-type transformer is mainly a challenge for manufacturing facilities. Curing ovens, mixers, resin type, mixing facility, moulds, mould design, winding machines are the first things to be considered. When the size of the transformer increases, the probability of cracks in the transformer windings increases due to heavyweight and large mass. Thus, additional reinforcements such as glass-fibre solutions are needed. Cooling duct design is key at this point for both cooling and cracks probability. It is always a challenge to remove cooling duct spacers after manufacturing dry-type transformers. The 40 MVA transformers are manufactured as large examples, and the one-piece sample is shown in Fig. 1 as a giant dry-type transformer with a one-piece winding. This was a challenge for manufacturing and design, mainly because the space limitation was a challenge, so the design team solved the problem using one piece HV windings. The shape of cooling ducts arranged according to easy removal and potlife of resin is calculated carefully with a considered casting time of large windings. Cooling ducts with grids helped the sturdiness of the transformer and ducts. The mould design was also made according to the total weight of windings, so structural precautions are taken on the mould. As a general procedure, we cast the dry type with no colour because it is easier to detect defects during winding manufacturing. For this giant transformer, there were none.

It is a great advantage to use such dry-type transformers in large biomass plants. Fire risk is at maximum for such plants, so dry-type technology is the right fit. It is not clear what the limit is, but some companies mention their top rating as 63 MVA [11]. Since the size of the dry-type transformer is in general larger than the same rating oil-filled technology, going beyond 40 MVA could lose price and size / weight advantage. Material technology, market demand, and optimization will show the limit. But it is known that large transformers with ester oil-filled or silicone oil-filled transformers are manufactured. Their performance and advantages are similar to dry-type transformers: reduced fire

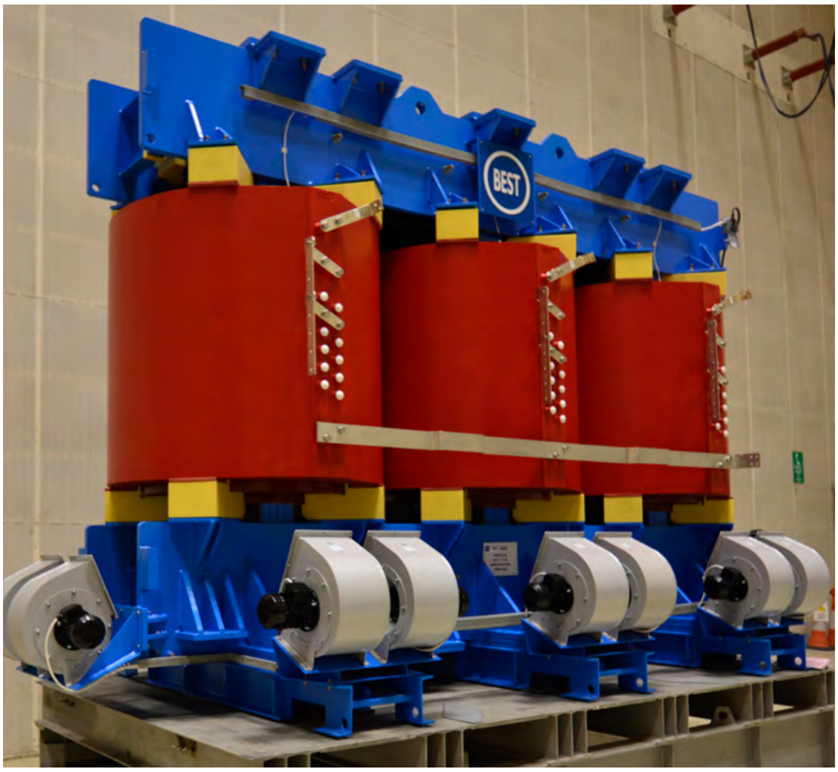

Figure 1. 34 MVA dry-type transformer with a one-piece HV coil

Dry-type transformers are durable due to the casting process if they are designed and manufactured carefully

risks. For large transformers, the biggest challenge is cooling, and this performance could be evaluated with 3D CFD analysis (Fig. 2).

3. Withstand ability

Transformers face many fault occasions in service, such as lightning disturbances, over-voltages, short circuits, vibrations, earthquakes, and many more. Dry-type transformers are durable due to the casting process if they are designed and manufactured carefully.

Dry-type solutions are very commonly used in wind turbines, both in the nacelle and at the bottom of the tower side. This means a lot of vibration. Both designs of transformer and supports are critical. In 2018, a transformer was designed and earthquake tested with a 2500 kVA rating without carrying supports. The total weight was 7.8 tonnes and tested at third-party laboratories in Germany.

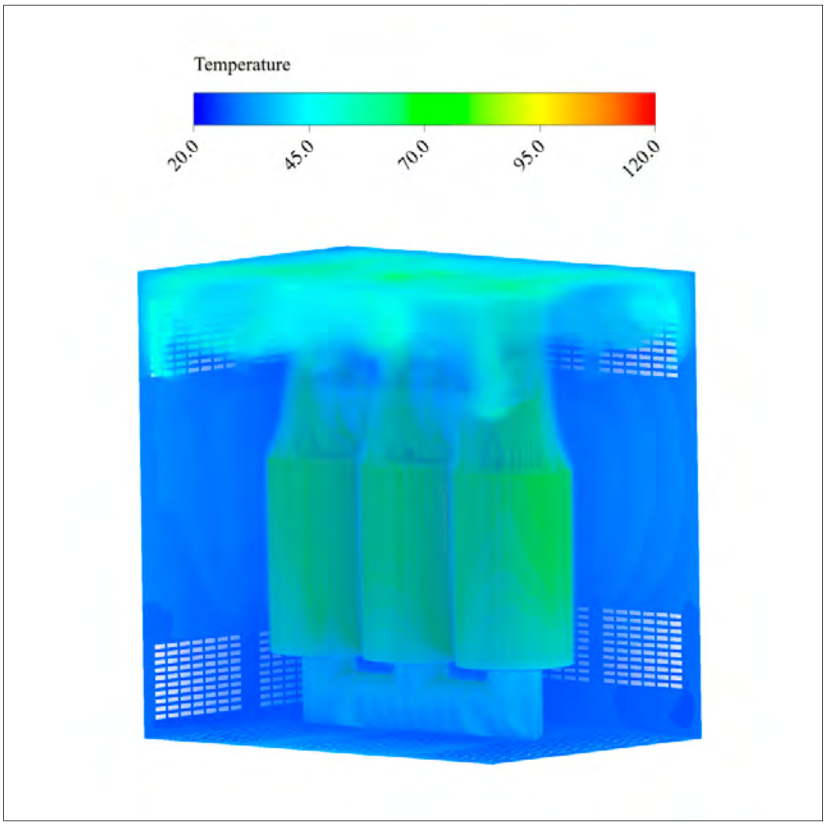

Figure 2. Dry-type transformers in rooms or cabins could be evaluated with 3D CFD analysis.

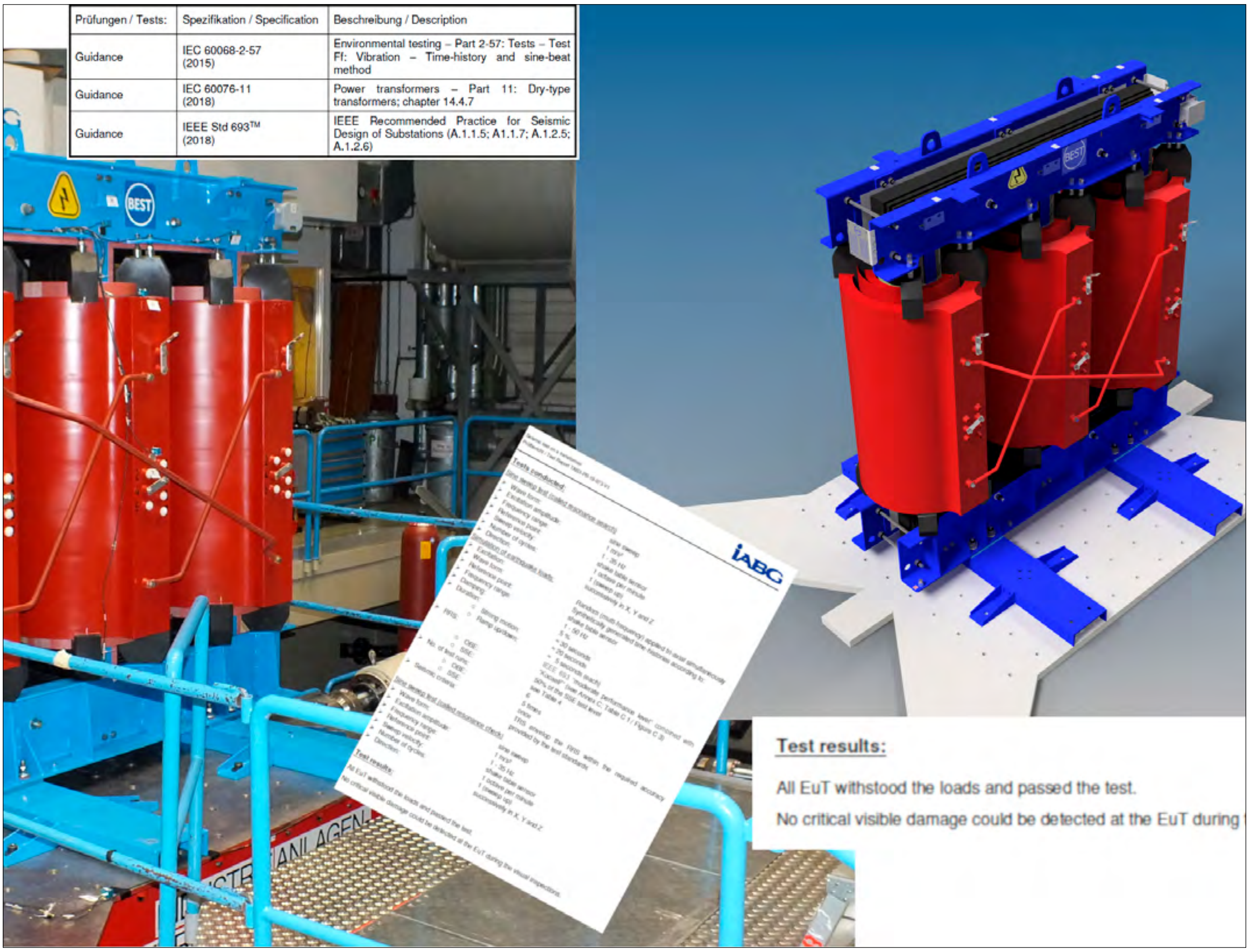

Figure 3. Shaking table test for a dry-type transformer and FEM analysis performed

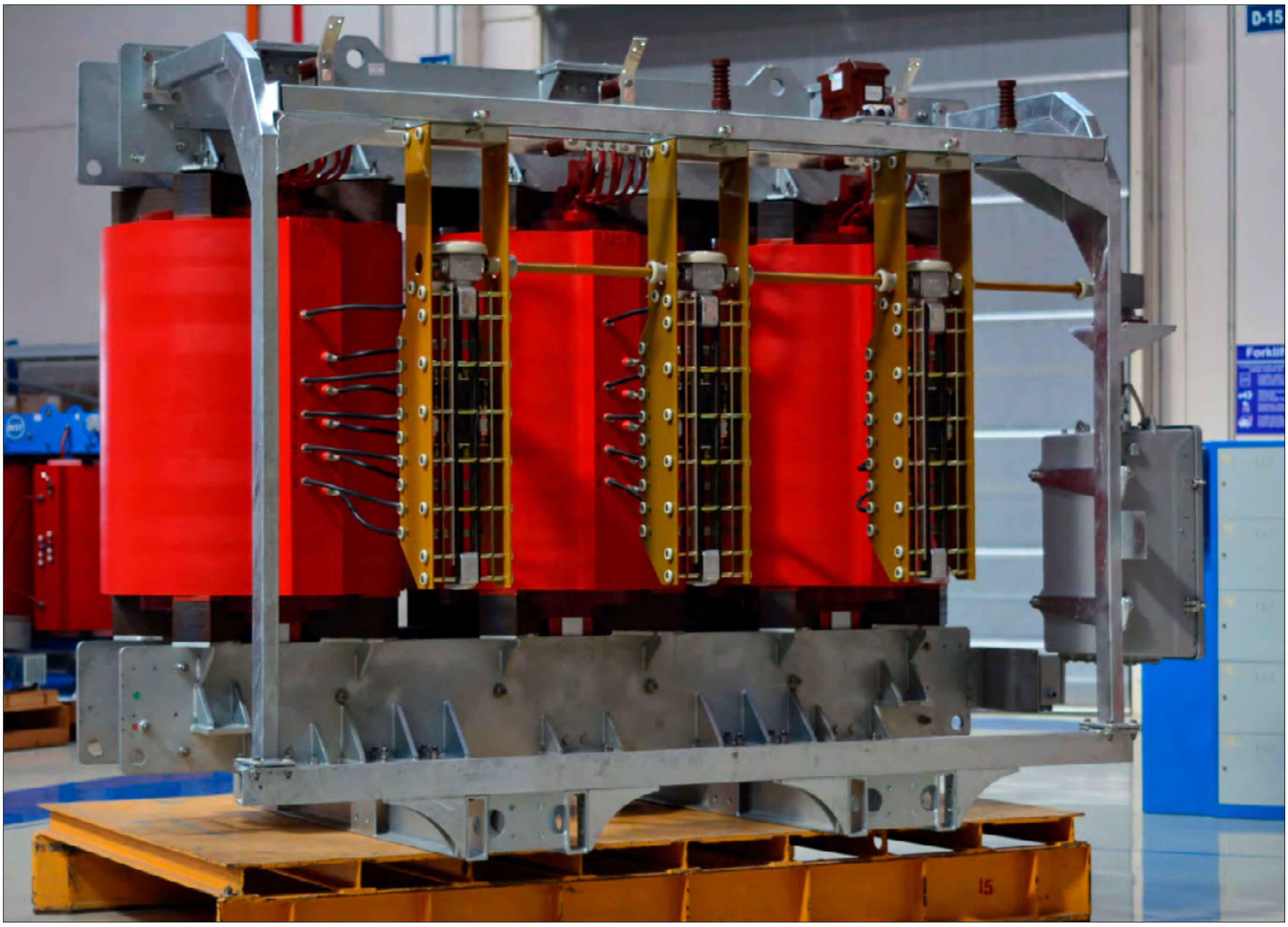

Figure 4. Dry-type transformers with OLTC for İstanbul Airport

Challenges of large scale dry-type transformers manufacturing are the capacity and speed of winding machines, the number of molds and parallel production, casting machine speed, resin pot life, and many more

This challenge was tackled with a detailed simulation of the transformer. With FEM analysis, all forces in dry type unit were distributed to every single part of the transformer. The static and modal analysis helped Best to design an earthquake-resistant transformer that has no additional supports. Additional supports are mostly used between the top stacking plate and ground. A simple solution for most transformer manufacturers costs more and holds a larger area.

For other challenges, dry-type transformers are pretty durable. Damping pieces could damp the main forces that occur during carrying and short circuits. Heat transfer is a major concern for overload, additional fans could solve such requirements. Also, detailed CFD simulation for cabinet design and heat transfer could increase cooling performance a lot. A very detailed study on cabin roofs performed in [8] has shown that a patented roof design improves thermal heat dissipation.

4. Manufacturing

In the distribution transformer market, transformers are ordered and manufactured in large batches. The number of dry-type transformers is increased in the demand stage from tens of units to hundreds of units. This creates a challenge between manufacturers. Thus, manufacturing capacity and faster manufacturing methods are critical. Due to chemical requirements, casting and curing dry-type transformers takes time. Fast casting machines and correct curing curves are crucial before manufacturing starts. Some challenges during manufacturing a large number of units are the capacity and speed of winding machines, the number of moulds and parallel production, casting machine speed, resin pot life, curing oven heat distribution, stock/storage, and many more. The capacity is mainly an investment-related problem. If the factory has enough machines and skilled labour, it is easy to achieve faster speeds. But this cannot be done in one night because the training of a skilled worker, especially for dry-type transformer manufacturing, which needs a broad experience, is not that easy. Applying a detailed apprenticeship program for all workers and a detailed orientation process could be a developing option. Also, to educate newcomers, the company with experienced staff should have a prepared training program. Mould design should be a perfect fit for the price and durability. Dry-type transformer moulds are used more than once. For serial production, they are used a lot more than a single unit manufacturing. Thus, the thickness and durability design of moulds should be considered carefully for serial manufacturing.

Some alternative methods such as Vacuum Pressure Impregnation (VPI) or similar alternatives depending on voltage levels such as Vacuum Impregnation (VI) are commonly used in manufacturing. Especially in Europe and Asia, VPI transformers for low voltage applications are very popular in demand. VPI is a faster method since there is no casting process according to the author's experience. The manufacturing and design of VPI transformers are still in discovery, but it is obvious that we will see VPI solutions more in the future. Best Transformers have a VPI facility, manufacturing special solutions such as mining energy solutions, converter transformers, air-core reactors, and move on.

There was a timing challenge in the biggest airport of the world construction process (İstanbul Airport, Turkey). The airport is powered with nearly 400 dry-type transformers, all manufactured by and all transformers manufactured within six months (Fig. 4). The order was completed in time, and the airport has been in operation since 2018.

Figure 5. Special coloured BJK Vodafone Park transformer

5. Technology

There are many try-outs or "new trends" in dry-type transformer design. One of the most popular ones is hexagonal transformers. It is yet not too common in Europe, but Asia is investing in such units in these years. Shape, space, and core design have advantages for these transformers.

Different geometry studies and different rectangular forms are also popular. Cast resin technology allows different geometries, but moulds must be considered when a new shape is produced. For manufacturing, the casting process is similar for different materials. Some different resin types and insulation material developments are always under study. This depends on the manufacturer of resin and hardener; they conduct independent research and offer new solutions. Casting speeds, curing times, etc., are experienced in companies, and many different companies have their own secret pro-

Subway solutions, mining solutions are common places where dry-type transformers are used due to their blast-proof technology and fire safety, which make them ideal for such applications

Dry-type transformers are a new solution compared with oil-type technology, but they have proven their performance with obvious advantages

duction procedures. For moulds, some companies prefer to make casting vertical, and some make it horizontal. Vertical moulding is preferred when it is hard to lift the sided coil to a vertical position or parallel casting. Most of the casting facilities do not allow mid-range multiple horizontal casting due to size limitations. Depending on the design, windings are produced in one piece or multiple pieces. This will help for a quick repair, too, also helps to manufacture larger transformers in pieces. But it means more casting, more moulds if manufactured in bulk. Factories must consider which method they should use depending on the demand.

Subway solutions, mining solutions are also common places to use dry-type transformers. Blast-proof technology and fire safety are the keys to such applications. Most underground transformers are dry-type. Also, transformers under electric trains could be produced as dry-type transformers with some new technology. Best Transformers manufactured subway transformers that connect Asia and Europe continent, transformers that used in Marmaray project [9]. Also, public buildings like hospitals, skyscrapers, and stadiums, such as Vodafone Park Besiktas Arena [10], have transformers manufactured by Best Transformers with custom colours (black, like team colour).

6. Conclusion

Dry-type transformers are a new solution compared with oil-type technology, but they have proven their performance with obvious advantages. Many applications prefer especially dry-type transformers such as mining, airport, skyscraper, hospitals, and many more. With increasing demand, manufacturing of mass units, design of larger units, and special applications are some challenges that factories will tackle. There are many new things to test and discover with dry-type technology in both manufacturing and design. The fast rise in ester-filled transformers is another challenge that dry-type technology will face since they are a kind of rival product.

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