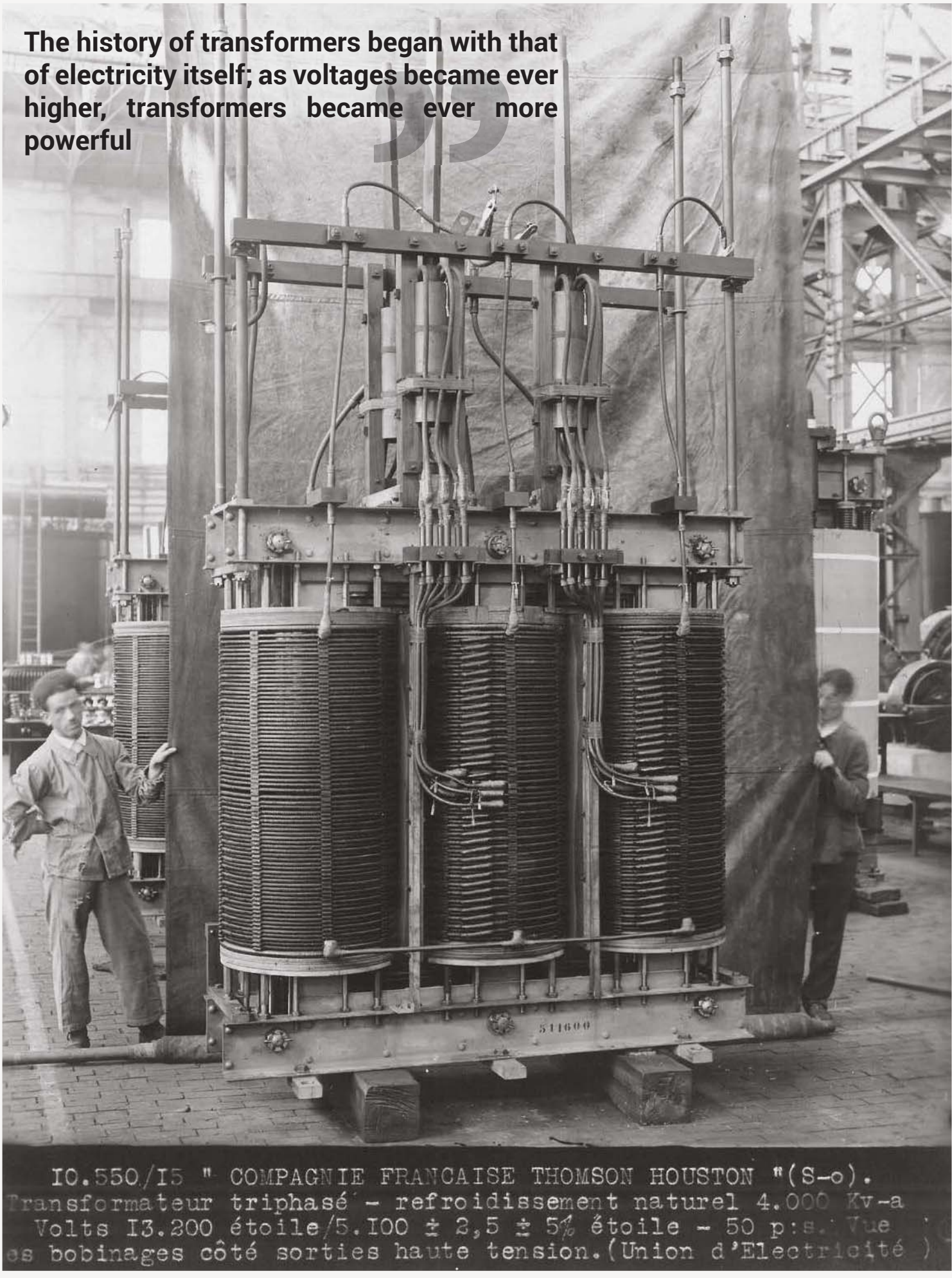
The history of transformers began with that of electricity itself; as voltages became ever higher, transformers became ever more powerful



> Though it was considered a DC device, the spark inducer – the forerunner of today's transformer – contributed significantly to the development of transformer technology

The transformation of transformers

A short history of power transformers through the age

1. Introduction

Little did Michael Faraday know that his observation of electromagnetic induction in 1831 would revolutionize the application of electricity and lead to the development of transformers as a key segment of the electric power industry.

A number of pioneers (Nicolas Callen, Charles Page, Antoine Massen and Heinrich Ruhmkorff, among others) took Faraday's discovery further, inducing a high voltage using a spark inductor – the forerunner of today's transformer. Though it was considered a DC device, the spark inducer contribut-

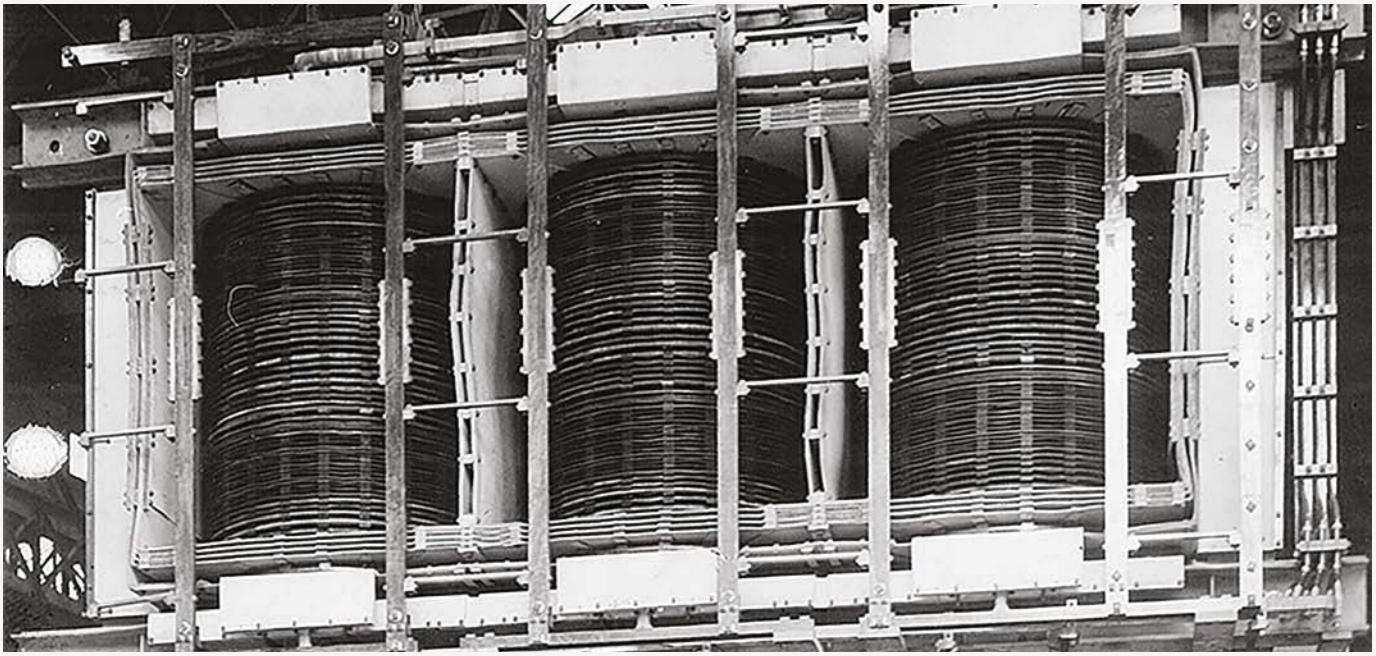


Figure 1. 1932 - ALS.THOM's three-phase transformer destined for customer Énergie Électrique du Rhin also manufactured in Saint-Ouen

ABSTRACT

From Michael Faraday's observation of electromagnetic induction in 1831 through today's largest standard, converter and industrial power transformers, this article summarizes the major steps realized in the development of transformers since the beginning. It also showcases how GE Renewable Energy's Grid Solutions' ancestor companies such as DELLE, British Electric, Thomson-Houston, GEC Alsthom, AEG to name few of them, played a pioneering role in that evolution.

KEYWORDS

history, power transformers, green transformers, HVDC converter transformers

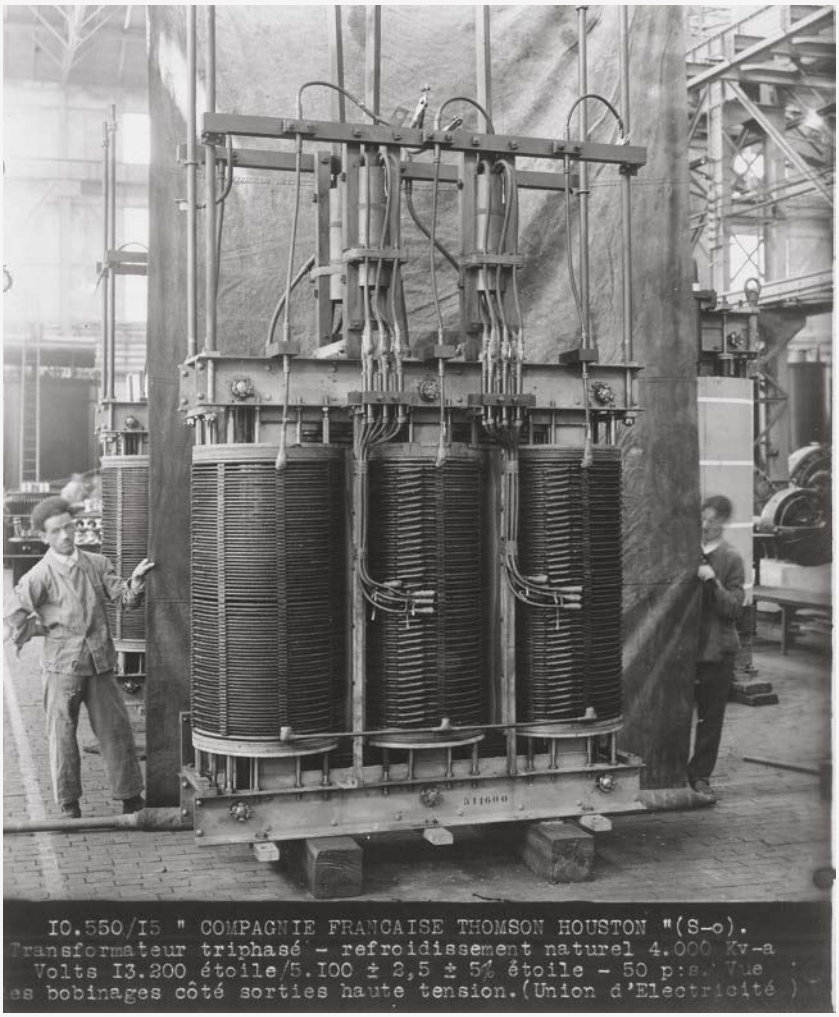


Figure 2. A 1928 air-cooled three-phase transformer (4,000 A / 13.2 kV) manufactured by GE Grid Solutions' ancestor company CFTH in Saint-Ouen, France

The Ganz Company in Budapest patented a closed-core device (the "ZBD" system) and referred to it as a "transformer"; the name has stuck ever since

ed significantly to the development of transformer technology.

By the 1850s, alternating current finally found its application in the form of electric lighting. In 1882, Lucien Gaulard from France and the Englishman, John Dixon Gibbs, patented a distributing power system that used alternating current with two-coil induction devices linked by an open iron core. By 1883, devices, now known as secondary generators, were used in the first alternating current distribution system to light a 12 km section of the London Underground. At the same time, in Italy, all the stations of the Torino-Lanzo railway line where equipped with electric lighting, the most distant lamp being situated 40 km away from the 2000 volt generator operating at 133 Hz frequency. The following year, George Westinghouse realized the potential of secondary generators and developed the first high-powered device that could be manufactured cost-effectively. This device was the first commercial application of the "induction coil", lighting offices and shops in Great Barrington, Massachusetts.

Around the same time, the Ganz Company in Budapest created a closed-core device (the "ZBD" system). In its patent application, it was referred to as a "transformer". The name has stuck ever since.

2. The transformer's commercial era

As production lines started up at the end of the 19th century, the transformer became an essential device for the transmission and distribution of electric power. One of the manufacturing pioneers was Compagnie Francaise Thomson-Houston (CFTH) in Saint-Ouen near Paris, an ancestor company of GE's that began production in 1893.

At this time, manufacturers worked largely with local utilities for local industrial needs. Rated power was only a few thousand kVA and voltage levels a few kV.

The huge increase in demand for electric power led to more generation, more transmission and considerably higher voltages.

The beginning of the 20th century saw a major voltage leap to 220 kV as well as the merger of CFTH and Société Alsacienne de Construction Mécanique leading to the creation of ALS.THOM in 1928. The 40 MVA – 220 kV three-phase transformer destined for customer Énergie Électrique du Rhin in 1932 is a great example of the transformers that were manufactured by the company during this period (Fig. 3). Another major step was achieved as transformers reached 400 kV by the 1950s, while the 1960s witnessed the first 800 kV networks. This huge and rapid development was only possible thanks to improvements in transformer technology, design, manufacturing and materials. In particular, insulating materials – paper, pressboard, oil, silicon steel – have made great advances; in fact, it can be said that transformer development helped to boost the steel, paper, and oil industries.

3. Grid Solutions' contribution

As one of the pioneers of transformers, GE's Grid Solutions business and its legacy Grid companies have made major contributions to the sector with patents and technological breakthroughs. For example, as the requirement to factory test transformers for resilience to the transient voltages from lightning strikes on the overhead transmission lines became commonplace, the interleaved

A major step was achieved as transformers reached 400 kV by the 1950s, while the 1960s witnessed the first 800 kV networks

disc winding was patented by English Electric in the UK in 1947 (British Patent 587997 "Improvements in inductive windings"). The first 1,050 kV transformer for extra-high voltage test lines was delivered to EDF for its test platform at Les Renardières, France in the 1960s.

In the subsequent five decades, Grid Solutions factories in Saint-Ouen (France), Stafford (UK), and Gebze (Turkey) showcased some of the world's largest power transformers. They have produced some of the most complex and advanced special transformers and reactors (including Quadrature Boosters, Series and Shunt Reactors and transformers for industrial and traction applications). To shed more light, in the late 1960s Stafford manufactured the largest 600 MVA generator step-up transformers at that time for UK Central Electricity Generating Board for new power stations such as Didcot A and Pembroke. Since 1997, nine quadrature booster transformers were supplied to UK National Grid Co with ratings up to 2750 MVA (throughput). In 2010, the largest special transformer in the world, the 300 MVA 34.5 / 1,683-1,119 kV electric arc furnace transformer, was manufactured at the Grid Solutions' site in Gebze, Turkey.

As large emerging economies have begun expanding or strengthening their networks, so the need to transmit high-voltage DC power over long distances has also been growing rapidly. This has meant investing in the development and production of new, more powerful transformers for DC networks. Since delivering HVDC converter transformers for the 2 000 MW France-UK HVDC link in 1981, Grid Solutions has been in the vanguard of this evolution, developing transformer technology to match the specifications of direct current applications.

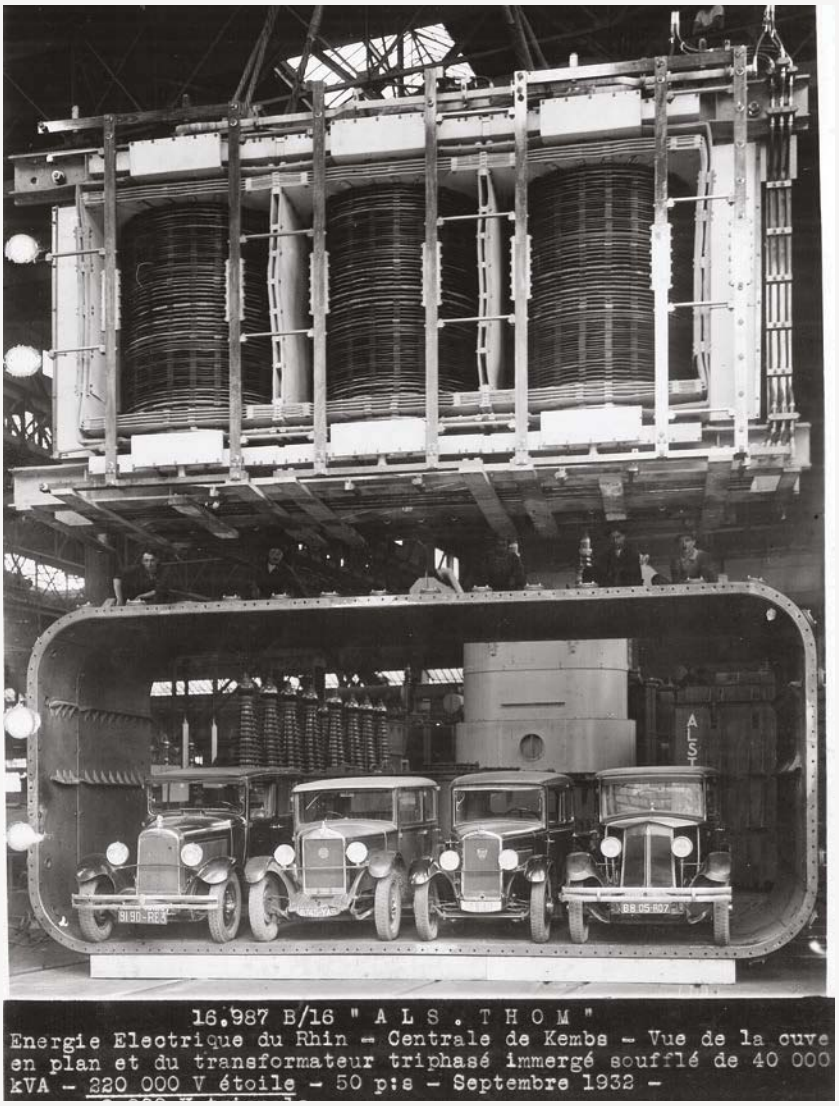


Figure 3. 1932 - ALS.THOM's three-phase transformer destined for customer Énergie Électrique du Rhin was manufactured in Saint-Ouen

Figure 4. 1958 - The world's most powerful transformer at that time: 345 MVA 22.5 / 160 kV. Reference: New Scientist, April 2nd 1959

4. Timeline

1831	Michael Faraday demonstrates the principle of electromagnetic induction
1836	Nicolas Callan increases the voltage generated by using a two-coil converter
1853	Heinrich Ruhmkorff builds a spark inductor – a high-voltage transformer
1882-83	Lucien Gaulard and John Dixon Gibbs patent a distributing power system that uses alternating current with two-coil induction devices. In 1883, secondary generators are used to light a 12 km section of the London Underground
1885	K. Zipernowsky, O. Bláthy and M. Déri patent the “ZBD transformer”
1886	George Westinghouse produces the first commercial “induction coil”
1893	Creation of Compagnie Française Thomson Houston; start of the transformer production in Paris in cooperation with the future General Electric Corporation of the USA
Early 20th century	Voltage leap to 220 kV
1928	Merger of CFTH and Société Alsacienne de Construction Mécanique to create ALS.THOM
1929	3.5 MVA-100 / 27.7 kV inter-connection transformer
1933	40 MVA-220 / 8.8 kV three-phase transformer
Mid 20th century	400 kV voltage level achieved
1947	Interleaved disc winding patented by English Electric in the UK
1960s	Advent of the first 800 kV networks
	Grid Solutions manufactures largest 600 MVA generator transformers
End 1980s	Manufacture of amorphous core distribution transformers
End 1990s	Hermetically sealed power transformers
2006	First vegetable-oil 245 kV shunt reactors
2007	The world’s largest electric arc furnace transformer (300 MVA)
2010	UHVDC 800 kV prototype transformer produced and tested for the planned Chinese UHVDC network
2015	GE acquires Alstom Grid which becomes Grid Solutions

The first 1,050 kV transformer for EHV test lines was delivered to EDF for its test platform at Les Renardières, France in the 1960s

Conclusion:

Since developing transformer technology to match the specifications of different transmission and distribution as well as industrial applications through the decades, Grid Solutions has been in the vanguard of the transformer evolution.

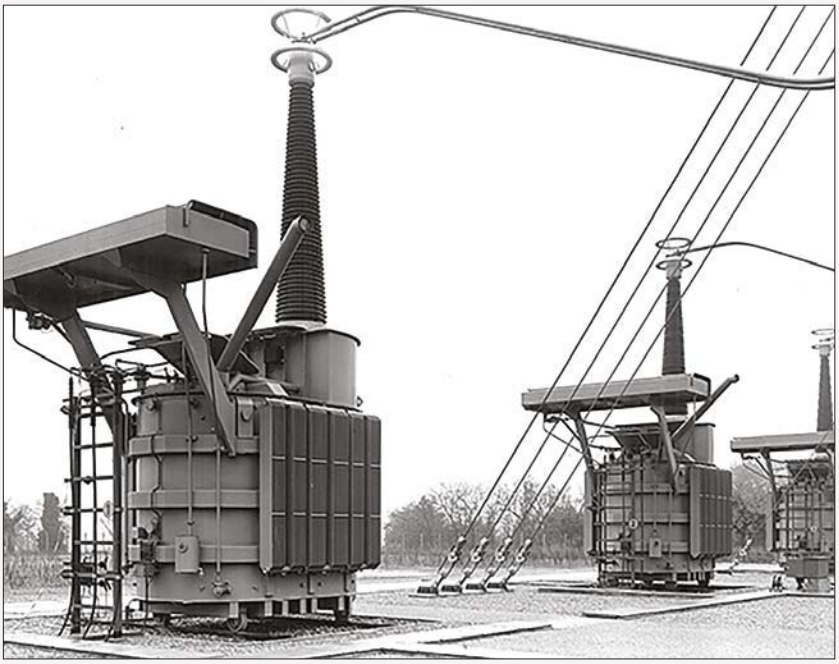


Figure 5. GE's first 1,050 kV transformer for extra-high voltage test lines in the 1960s

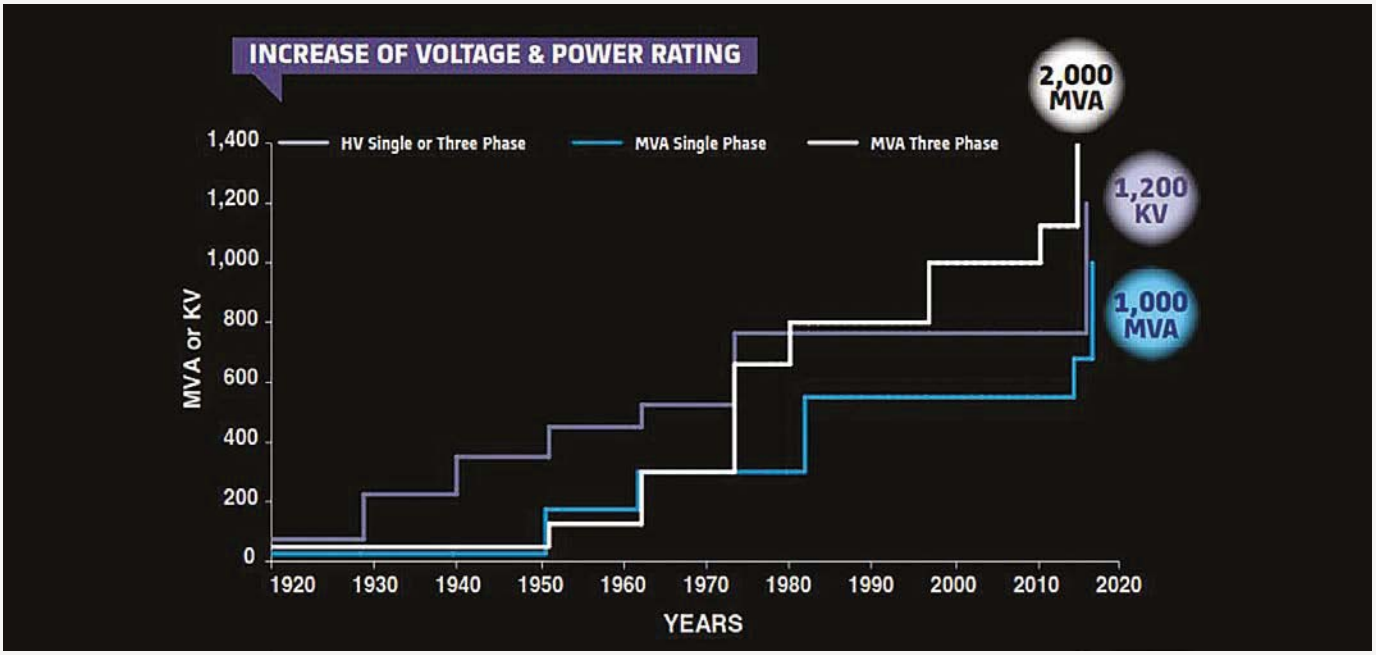


Figure 6. Increase of voltage and power ratings over the century

As one of the pioneers of transformers, GE's Grid Solutions business and its legacy Grid companies have made major contributions to the sector with patents and technological breakthroughs

Author

François Devaux graduated in 1982 from different French generalist engineering schools. He joined Alstom in 1984 as a transformer development engineer. In the 1980s, he was the head of Saint-Ouen transformer factory's engineering department. Then from 2000, he has been working at different positions in transformer applied research. His current position is "Technology, Innovation and Competence Development Centre Manager" and he has more than 35 years of experience in the technical field of power transformers. He has contributed to more than 30 publications and 3 patents. He is a "distinguished Member" of CIGRE, French Member of CIGRE-A2 from 2006 to 2012, IEEE PES Senior Member and Senior Member of SEE (French Electrical Association).