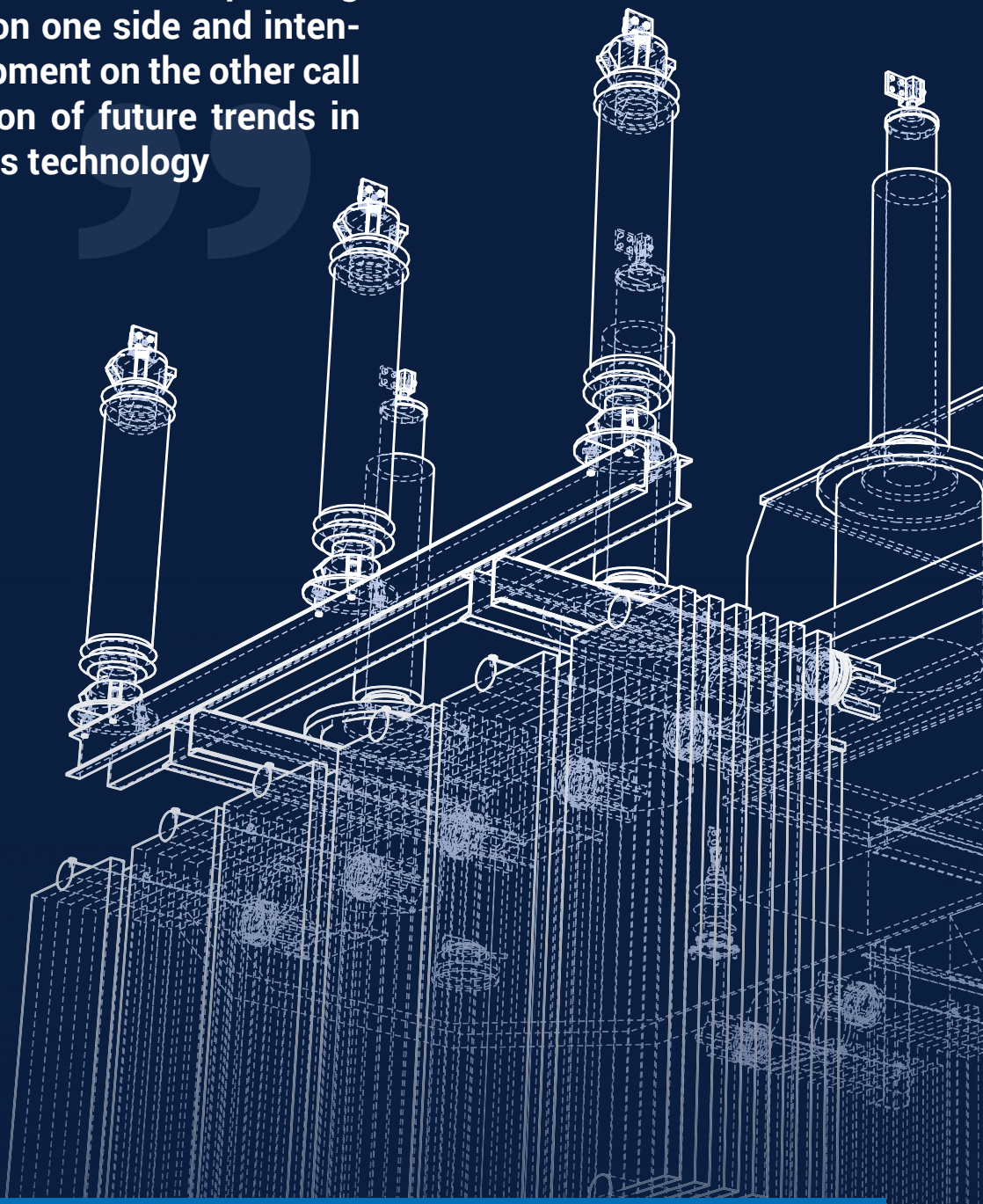
Changes in transformer operating conditions on one side and intensive development on the other call for evaluation of future trends in transformers technology



ABSTRACT

Many papers and reports show that the operating conditions of transformers in the grid are becoming more and more severe while the impacts and costs of loss of power supply are high and growing, forcing utilities to improve the requirements for transformers. This opens the space for innovations in transformers technology. The promise of main trends in transformers technology seems to be huge, and while there are many publicly available reports that analyse and forecast markets trends, there are no similar reports that focus on transformers technology trends despite the need for them in the industry. One of the reasonable means to evaluate trends is survey. This article describes a survey which was prepared and conducted with an aim to obtain an unbiased insight into the future trends in transformers technology over the next five years.

KEYWORDS

survey, transformer, technology

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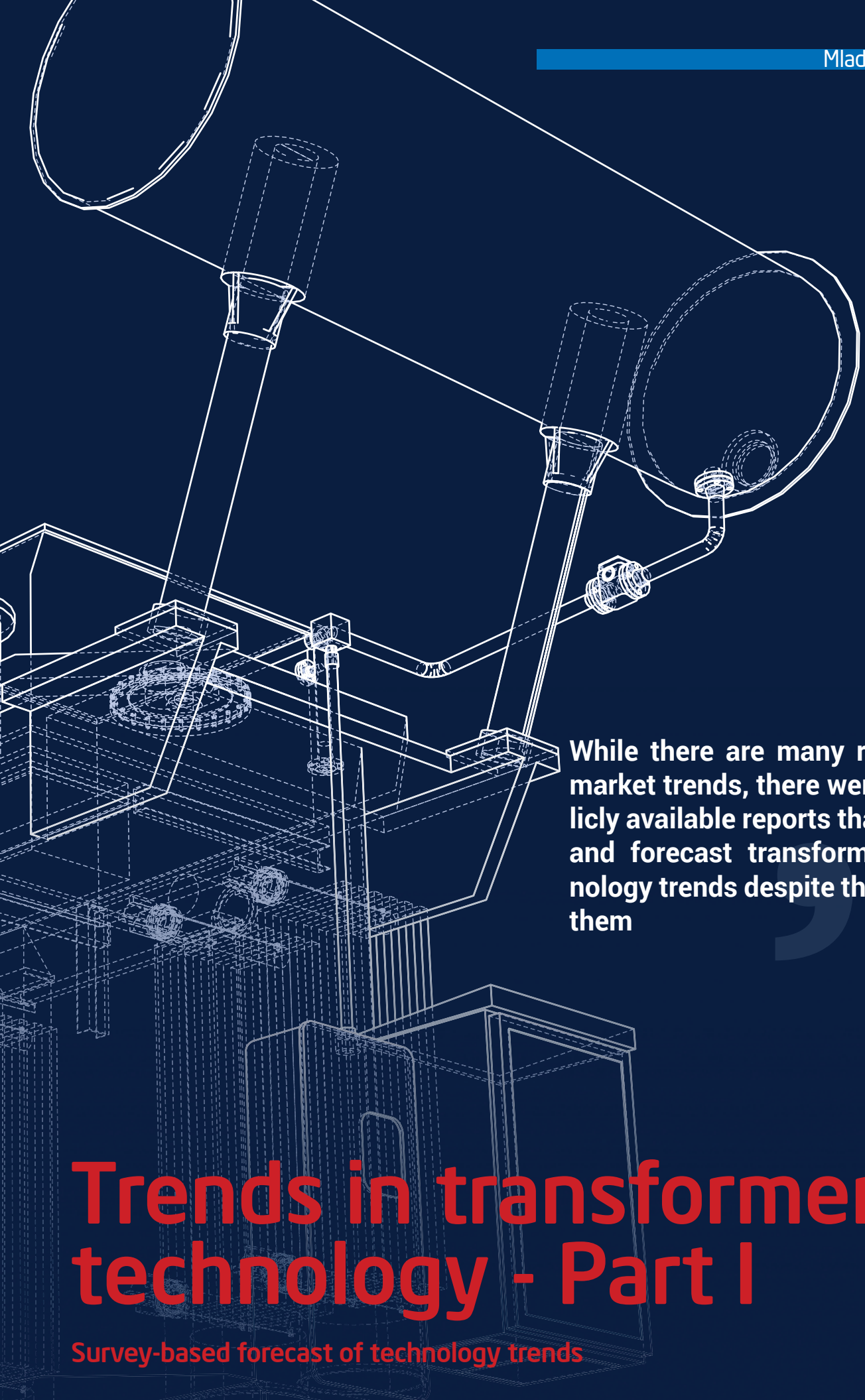

While there are many reports on market trends, there were no publicly available reports that analyse and forecast transformers technology trends despite the need for them

Trends in transformers technology - Part I

Survey-based forecast of technology trends

Responses from six continents provide geographical balance and enable almost global application of the results

1. Introduction

Many papers and reports show that the operating conditions of transformers in the grid are becoming more and more severe. More severe operating conditions imply more catastrophic transformer failures which can lead to massive blackouts. In addition, the risks associated with severe weather conditions and threats of terrorism are also becoming more and more pronounced [1]. This results in high and growing costs and impacts of loss of power supply. An estimated cost of interruptions in the electricity supply only for the USA is $150 billion a year [2]. The changes in the operating conditions force utilities and other transformer users to improve the requirement specifications for transformers, as well as for transformer materials and components. All this opens the space for innovations in transformers technology [3].

2. Motivation

The promise of main trends in transformers technology seems to be huge. The concepts like digital transformers, pluggable transformers, eco-designed transformers, high-temperature and superconducting transformers, solid-state transformers, nanomaterials, etc. are only some of the sound notions portraying potential revolution in transformers technology in the near future. However, while there are many publicly available reports bringing forecasts and analyses of market trends (e.g. transformer market reports, bushing market reports, transformer oil market reports, steel market reports, etc.), there are no publicly available reports that analyse and forecast transformers technology trends despite the need for evaluation of these trends in the industry. Such reports would better depict the real potential or likelihood for success of these new concepts and trends, which would surely be beneficial for stakeholders across the entire value chain.

On one side, transformer manufacturers look at the needs and pain points of transformer end-users, and on the other they look for materials and components which will enable them to develop right solutions for these end-users, taking into account their overall abilities, tools, processes, etc. In turn, suppliers of transformer materials and components need relevant information from transformer manufacturers and transformer end-users in order to develop right materials and right components. Finally, transformer end-users need relevant information about available solutions in order to be able to choose and test those among them that will solve their pain points with a highest possible likelihood.

3. The survey

A reasonable means to obtain the rankings of the trends and new concepts in transformers technology is survey. This article presents a survey that has recently been prepared and conducted with an aim to obtain an unbiased insight into the future trends in transformers technology over the next five years. In order to achieve this, the survey was designed so as to identify the key problems in selected areas in the past ten years, and collect opinions of industry professionals on future trends over the next five years. Questions about past problems were included in order to:

- have the opportunity to better evaluate the responses on future trends;
- have the opportunity to conduct more detailed analytics which can better depict future trends in transformers technology; and
- get broader applicability of the results.

With this approach in mind, the survey questionnaire included questions from the following areas:

- transformer manufacturing
- transformer operation
- current state of transformers technology
- future trends in transformers technology

In order to ensure consistency among responses, we defined the following:

- Failure means the loss of a critical transformer function which resulted in the automatic de-energization of the transformer (tripping) or removal from service within 30 minutes of problem detection.
- Timeframe: only the failures and problems experienced in the last 10 years were considered.

4. Results

4.1 Summary of responses

The survey received responses from 123 respondents. Roughly two thirds of respondents provided information about their country, resulting in a list of respondents from 36 countries across six continents, which ensures geographical balance of responses. With this information missing for about one third of respondents, the number of countries could be higher.

Among the respondents, the vast majority are employed or self-employed, 93.9 %; 3.7 % are retired; 1.2 % are students, and 1.2 % are unemployed. In terms of their experience in the field of transformers, 37.8 % of respondents have more than 20 years of experience; 35.4 % have between 11 and 20 years of experience; 25.6 % have between 3 and 10 years of experience, and only 1.2 % have less than 3 years of experience. Roughly three quarters of respondents have more than 10 years of experience in the field of transformers, adding credibility to responses.

The highest number of respondents are in the age range of 50 years or older – 40.2 %; 23.2 % are between 40 and 49 years; 31.7 % between 30 and 39 years, and 4.9 % are between 20 and 29 years of age. About two thirds of respondents are 40 years or older. This figure combined with the figure above on the respondents' experience in the field of transformers additionally enhances credibility of the responses.

In terms of the influence in current work position, more than half (52.4 %) of the respondents stated that they have influence beyond the scope of their work; 39.0 % have influence within their projects or teams, while 8.5 % have influence only on their own work.

The number of responses and the respondents' stated experience, age and influence give relevance and strong credibility to the obtained results.

The distribution of primary responsibility among the respondents is as follows: 39.0 % engineering, 13.4 % consulting/advising, 11.0 % research and development, 9.8 % corporate/executive management, etc.

The respondents' organizations include: manufacturers of transformers, consultants, service companies, manufacturers of monitoring, diagnostic or testing equipment, EPC companies, power generation companies, transmission system operators, energy distributors, manufacturers of materials and components for transformers, research and development, industrial plants that own or operate transformers, agents/distributors and testing laboratories.

A recently conducted survey that collected responses to 35 questions sufficiently covers the range of aspects that may influence future trends in transformers technology

4.2 Opportunity for analytics

Having a sufficient number of responses, the survey provides opportunity for various analyses. It is possible to analyse results with respect to the attributes of respondents. For example, if your market is Europe, then it would make sense to look only at responses from Europe. If you are doing business with transformer OEMs, then it makes sense to extract and analyse only their responses. If your business depends on decisions made by engineering and procurement people, which is often the case, it is useful to extract only those responses and analyse them. If you are interested in a view of transformer end-users (utilities, industrial plants), then it is possible to extract only their responses for analysis.

Another possibility, which in some cases is quite useful, is to look at the data by analysing the relations between responses. For example, looking at respondents who selected 'gassing' as the most frequent problem in transformer operation, how does this response relate to what

The survey yielded sufficient number of responses, providing opportunity for various analyses

they say about monitoring? How about those who didn't select 'gassing' as the most frequent problem, what do they say about monitoring? Similar analytics can be done for 'overheating' or any other problem.

Or, taking for example respondents who selected 'materials' or 'components' as the most frequent problem in transformer manufacturing, what do they say about necessary improvement of materials and components?

What is common to the respondents who say that on-line condition monitoring of transformers is not important?

Considering the number of questions in the survey, there are many correlations to be made, and they can be useful in understanding the potential of individual concepts and depicting the future trends.

4.3 Transformer manufacturing

Based on the responses from all respondents, the two most frequent problems experienced in transformer manufacturing over the past 10 years are problems with specifications and insufficient personnel training and education. Looking only at transformer OEMs and service companies, they identified the same problems as the most frequent. However, for end-users of transformers, the most frequently encountered problems are poor quality of received components and improper or incomplete documentation.

Looking at the problems experienced in the last 10 years that resulted in highest financial damage, the respondents identified poor quality of received materials and transformer failure at testing as the two most significant problems.

According to the results, the most frequent problem with transformer specifications, and at the same time the problem that resulted in highest financial damage, was 'over-specification or specifications containing contradictory requirements'.

To illustrate, let us look at the question on most frequent problems experienced in transformer manufacturing over the past 10 years, followed by the results of different analyses applied to this question as shown in Table 1 through Table 3. Only five of the most pronounced problems are shown here. The results displayed in Table 1 show the ranking on the basis of all responses. Table 2 shows the resulting rank based on the responses from people working with a transformer OEM or a service company, while Table 3 displays results based only on the responses from transformer end-users (power producers, transmission and distribution utilities and industrial plants that own or operate transformers).

Items in blue show the difference between various analyses. For example, 'Problems with specifications' are more pronounced when we consider all responses and responses from transformer OEMs and service companies, but when we only examine the responses from transformer end-users, this problem is not that pronounced. Likewise, 'Transformer failure at testing' is more pronounced in the first (Table 1) and third (Table 3) analyses than in the second (Table 2) analysis.

Question: What were the most common problems in transformer manufacturing that you have experienced in the last 10 years? Select up to five MOST FREQUENT problems that you have experienced:

Table 1. Most frequent problems in transformer manufacturing – results based on all responses

	%	Rank
Problems with specifications	51.2 %	1
Insufficient personnel training and education	46.3 %	2
Poor quality of received components	39.8 %	3
Improper transport, storage or handling	39.0 %	4
Transformer failure at testing	37.4 %	5

Table 2. Most frequent problems in transformer manufacturing – results based on responses from transformer OEMs and service companies

	%	Rank
Problems with specifications	69.8 %	1
Insufficient personnel training and education	46.5 %	2
Poor quality of received materials	41.9 %	3
Poor quality of received components	41.9 %	3
Improper transport, storage or handling	39.5 %	5

Table 3. Most frequent problems in transformer manufacturing – results based on responses from transformer end-users:

	%	Rank
Poor quality of received components	60.0 %	1
Improper or incomplete documentation	60.0 %	1
Insufficient personnel training and education	40.0 %	3
Improper transport, storage or handling	40.0 %	3
Transformer failure at testing	40.0 %	3

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If you are doing business with transformer OEMs, then it is useful to extract and analyse only their responses

In order to get a deeper understanding of problems in transformer manufacturing, in terms of their frequency and their financial impact, we paired the questions on most frequently encountered problems with questions on the highest financial damage of these problems. These two questions are almost the same, the only difference being that in one case respondents had to select the most frequent problems, and in the other they had to select the problems that resulted in *highest financial damage*.

So, in this example, the question on most frequently encountered problems in transformer manufacturing over the past 10 years was paired with the question on the most frequently encountered problems in transformer manufacturing that resulted in *highest financial damage* over the past 10 years. The results of different analyses applied to the latter question are shown in Table 4 through Table 6. Only five of the most pronounced problems are shown here.

Looking at these results, 'Problems with specifications' are no longer as pronounced as in the case when only the frequency of the problem is considered. This problem ranks among the first five problems only for transformer OEMs and service companies, as shown in Table 5. However, 'Transformer failure at testing' is now a more pronounced problem when all responses and responses from transformer OEMs and service companies are considered, while for transformer end-users it is no longer ranked among the first five problems.

Also, with this question some other problems ranked high, such as 'Poor quality of received materials' based on all responses (Table 4) and responses from transformer OEMs and service companies (Table 5), 'Insufficient personnel training and education' (Table 4), 'Problems with equipment in transformer manufacturing', 'Problems due to imperfect design criteria', and 'Improper or incomplete documentation' based on responses from transformer end-users (Table 6).

Question: What were the most common problems in transformer manufacturing that you have experienced in the last 10 years? Select up to five problems that resulted in highest financial damage that you have experienced, regardless of who covered the cost of the damage.

Table 4. Problems that resulted in highest financial damage in transformer manufacturing – results based on all responses

	%	Rank
Poor quality of received materials	43.9 %	1
Transformer failure at testing	41.5 %	2
Improper transport, storage or handling	39.0 %	3
Poor quality of received components	37.4 %	4
Insufficient personnel training and education	36.6 %	5

Table 5. Problems that resulted in highest financial damage in transformer manufacturing – results based on responses from transformer OEMs and service companies

	%	Rank
Poor quality of received materials	60.5%	1
Transformer failure at testing	51.2%	2
Poor quality of received components	48.8%	3
Improper transport, storage or handling	46.5%	4
Problems with specifications	41.9%	5

Table 6. Problems that resulted in highest financial damage in transformer manufacturing – results based on responses from transformer end-users

	%	Rank
Poor quality of received components	50.0%	1
Improper transport, storage or handling	40.0%	2
Problems with equipment in transformer manufacturing	30.0%	3
Problems due to imperfect design criteria	30.0%	3
Improper or incomplete documentation	30.0%	3

Engineering and procurement personnel often carry major influence in decision making, so it is useful to extract only their responses for analysis

4.4 Transformer operation

Based on all responses, failures in transformer operation experienced over the last 10 years which were not imminent, so the transformer could continue operating, were most frequently a result of oil leak and gassing – which, in turn, were also the problems that resulted in highest financial damage.

The most frequent problems with monitoring systems were those related to monitoring hardware.

Among the failures which required the transformer to be tripped or switched off unexpectedly, gassing and bushing issues were identified both as most frequent and as the problems that resulted in highest financial damage.

As an example, let's look at the question on most frequent problems in transformer operation experienced in the last 10 years. The results of different analyses applied to this question are shown in Table 7, through Table 9. Only five of the most pronounced problems are shown here.

The results in Table 7 show the ranking according to all responses. Tables 8 and 9 show results based only on responses from people who work with a transformer OEM or a service company, and responses from transformer end-users, respectively.

The results show that 'Overheating' is seen as a more pronounced (more frequent) problem when all responses are considered (Table 7) than when we only extract responses from transformer OEMs and service companies (Table 8) or transformer end-users (Table 9). On the other hand, 'External cause' is more pronounced in the second and third analyses (Tables 8 and 9), than in the first analysis (Table 7).

Question: What were the most common problems in transformer operation that you have experienced in the last 10 years (failure was not imminent and the transformer could continue to stay in operation)? Select up to five most frequent problems that you have experienced:

Table 7. Most frequent problems in transformer operation – results based on all responses

	%	Rank
Oil leak	50.4 %	1
Gassing	47.2 %	2
Bushing problem	34.1 %	3
Tap-changer problem	30.9 %	4
Overheating	27.6 %	5

Table 8. Most frequent problems in transformer operation - results based on responses from transformer OEMs and service companies

	%	Rank
Gassing	60.5 %	1
Oil leak	58.1 %	2
External cause	39.5 %	3
Bushing problem	37.2 %	4
Tap-changer problem	30.2 %	5

Table 9. Most frequent problems in transformer operation – results based on responses from transformer end-users

	%	Rank
Oil leak	60.0 %	1
Bushing problem	50.0 %	2
Tap-changer problem	50.0 %	2
Gassing	40.0 %	4
External cause	30.0 %	5

The question from the example above can be paired with the question on the most frequently experienced problems in transformer operation that resulted in *highest financial damage* over the last 10 years. The results of respective analyses applied to this question are shown in Table 10, through Table 12. Only five of the most pronounced problems are shown here.

Compared to the case of the frequency of the problem, here 'Overheating' is no longer that pronounced when all responses are considered (Table 10), and 'Oil leak' is not that pronounced when we look at end-user responses (Table 12). For transformer OEMs and service companies, it is 'Partial discharge' that is more pronounced now (Table 11).

Question: What were the most common problems in transformer operation that you have experienced in the last 10 years (failure was not imminent and the transformer could continue to stay in operation)? Select up to five problems that resulted in highest financial damage, regardless of who covered the costs:

Table 10. Problems that resulted in highest financial damage in transformer operation – results based on all responses

	%	Rank
Gassing	39.8 %	1
Oil leak	38.2 %	2
Bushing problem	35.0 %	3
Tap-changer problem	29.3 %	4
External cause	29.3 %	4

Table 11. Problems that resulted in highest financial damage in transformer operation - results based on responses from transformer OEMs and service companies

	%	Rank
Oil leak	55.8 %	1
Gassing	51.2 %	2
External cause	37.2 %	3
Bushing problem	32.6 %	4
Partial discharge	30.2 %	5

Table 12. Problems that resulted in highest financial damage in transformer operation – results based on responses from transformer end-users:

	%	Rank
Bushing problem	70.0 %	1
Tap-changer problem	50.0 %	2
Gassing	40.0 %	3
External cause	40.0 %	3
Unexplained cause of alarm or trip	30.0 %	5

Survey results are available for all other questions, along with the possibility for tailored analytics.

Conclusion

With 35 questions in total, the survey sufficiently covers the range of aspects which can influence future trends in transformers technology. The details of the respondents' profiles provide basis for evaluation of the quality of responses, but also for different types of analyses which will shed new light on relations that can influence future trends.

The survey obtained responses from at least 36 countries and six continents, ensuring geographical balance and enabling almost global usage of the results.

The sufficient number of responses collected in the survey provides opportunity for various analyses. While it is possible to analyse results with respect to attributes of the respondents' profiles, it is also possible, and in some cases quite useful, to analyse the relations between responses.

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