Immediate Benefits of Winding Direct Hot-Spot Temperature Measurements
直接接触式测量变压器绕组热点温度带来的好处

MONITORING, DIAGNOSTICS & DIGITALIZATION
监测、诊断和数字化

Transformers are critical assets within power networks. Monitoring of transformers for imperative fault and accelerated aging prediction has become a standard in our industry. With the ever-increasing growth of electrical power demand, integration of renewables, and the attempt to protect the assets of the electrical grid, more precise monitoring and diagnosis capabilities are being added to these large electrical assets [1, 2].
变压器是电网中的重要设备。 变压器监测势在必行，变压器的故障和加速老化预测已成为行业的标准。 随着电力需求的不断增长、可再生能源的整合以及电网关键设备保护的加强，这些大型电力设备越来越需要更精确的监测和诊断能力。

There is an evolution of monitoring strategy occurring right before our eyes. Monitoring systems are not only employed to ensure the asset lasts longer, but they are also being deployed to enable more efficient operations and business decisions. “Will this transformer last forty years” is being appended by questions such as, “Could we increase loading above the nameplate rating to meet short term demand increases?”, or “How will the transformer’s life expectancy be impacted by increased harmonics and/or distributed generation”. Having real data on which to make these assessments is crucial.
当前，随着监测手段的进步。 监测系统不仅用于确保设备持续时间更长，参考这套监测系统，也可以提高业务和业务决策的效率。 “这台变压器会持续四十年吗？”后面是这样的问题：“我们能不能增加铭牌额定值以上的负荷，以满足短期增加的电力需求？”或“变压器的预期寿命将如何受到谐波和/或发电需求增加的影响”。需要进行这些评估，掌握设备状态真实数据至关重要。

Transformer monitoring has many aspects to consider. Moisture, dissolved gases, magnetization current, partial discharge, bushing capacitance and power factor, OLTC loading, movement and contact care, load current, cooling operation, oil, tank and winding temperatures are the most well-known parameters to monitor. The proverbial “mountain of data” produced needs to be collected accurately, stored, filtered and analyzed into both fault conditions as well as health condition indices, to be managed by expert resources [3].

Evaluation of technologies and methodologies for moving from time-based to condition-based maintenance can take years to define and then implement [4]. In the meantime, simple steps can be taken to improve the quality of new transformers being introduced to the existing fleet.
变压器监测有很多方面需要考虑。 水分，溶解气体，磁化电流，局部放电，电容和功率因数，OLTC 有载调压，振动，负载电流，冷却系统，油，油箱和绕组温度是典型的的监测参数。 众所周知的“海量数据”需要准确地收集、存储、过滤和分析到故障条件和健康状况指数中，由专家资源管理评估，从基于时间的维护转向基于条件的维护的技术和方法需要数年的时间来定义和实施。 一套监测系统就可以用来评估或改善现有变压器的质量。

Here we propose one of those simple steps: **The direct measurement of winding hot-spots using fiber-optic sensors during factory acceptance testing (FAT) provides asset owners with several benefits that can have an immediate payback**.

在这里，我们提出了其中一个简单的步骤：在工厂验收测试(FAT)期间，使用光纤传感器直接测量绕组热点，为设备用户提供了几个好处，可以立即见到成效。

In short, even if the benefit of safely loading the transformer during service life and the long term benefits related to on-line real-time condition monitoring are excluded, the immediate benefits of installing these sensors can justify the investment.
You don't necessarily need a mountain of data to improve the safe-use and health of the transformer asset, just a select few smart data choices can sometimes suffice. Measuring winding hot-spot temperatures directly during temperature rise testing is one of those "smart data" choices.
总之，除了在使用寿命期间安全装载变压器的好处和与在线实时状态监测相关的长期好处，安装这些传感器的带来的直接好处，足以证明这项投资是合理的。
您不一定需要大量的数据来改善变压器的安全使用和健康，有时只是选择几个智能数据就足够了。 在温升测试中直接测量绕组热点温度是这些“智能数据”选择之一。

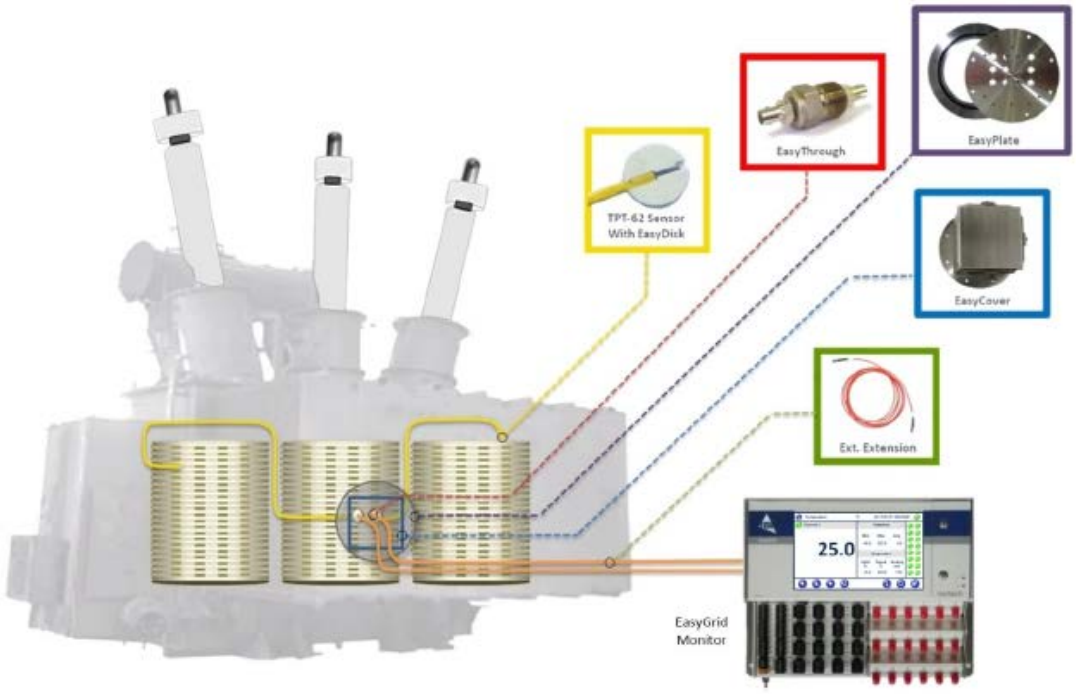
"Better to spend time on weeding out the problems at the beginning or you'll pay for it later. Installing fiber-optic sensors and relying on their data for temperature rise testing was a wise decision we made and we would never go back to not using them.
——Quote from a Major Australian Transmission System Operator (TSO)"

"最好在一开始就花时间把潜在问题排除掉，否则以后你会为此买单。 安装光纤传感器并依靠它们的数据进行温升测试是我们做出的明智决定，我们永远使用它们。
——来自澳大利亚传输系统操作员(TSO)"

Informative IEC 60076-2 Annex E
参考信息：IEC 60076-2 附录 E

The application of winding direct hot-spot measurements using fiber-optic sensors has been around since the 1980s, with one of the pioneers being Nortech [5]. Today's state-of-the-art EasyGrid system utilizing IEC/ITU/TIA standard optical fiber is pictured in Figure 1 with the elements which are part of transformer (sensors, tank-wall plate, fiber-optic feedthroughs, and cover) along with the elements outside the tank (fiber-optic cable extensions and monitor) illustrated.
自 20 世纪 80 年代以来，利用光纤传感器进行绕组热点温度直接测量的应用一直很广泛，其中一个先驱是 Nortech。 今天最先进的是使用 IEC/ITU/TIA 标准光纤的 EasyGrid 系统如图 1 所示，其中包括变压器的一部分（传感器、油箱壁板、光纤贯通器和保护箱)以及油箱外的元件(外部光纤和监视器)。

Figure 1. Complete winding direct hot-spot temperature monitoring system
图 1 绕组热点温度直接测量监测系统



In 2011 IEC released an update to IEC 60076-2 "Temperature rise for liquid-immersed transformers" with a new Appendix E, "Application of optical fiber sensors for winding hot-spot measurements". Now recognized by authorities, this important publication by IEC changed the perception and future adoption rate significantly. Table 1 is an example of the recommended minimum number of sensors to be installed in different types of transformers depending on rated power, cooling system, and number of phases, according to IEC [6].
在 2011 年，IEC 发布了对 IEC60076-2"油浸变压器温升"的更新，并增加了一个新的附录 E"光纤传感器在绕组热点测量中的应用"。 现在得到当局的承认，表 1 是根据 IEC，根据额

定功率、冷却系统和相数，建议在不同类型的变压器中安装的传感器的最小数量的例子。

Table 1. Table E.1 from IEC 60076-2 Annex E defining minimum number of sensors based on transformer type

Rated power MVA	Cooling system	Number and phases of installation				
		Total	On central phase		On each lateral phase	
			HV winding	LV winding	HV winding	LV winding
≥ 100	All system	8	2	2	1	1
From ≥ 20 to <100	ON.. - OF..	6	1	1	1	1
	OD..	8	2	2	1	1

Immediate Return on Investment
投资回报即时见效

One of the largest users of FO sensors today for direct hot-spot monitoring did not plan a detailed condition monitoring strategy and install sensors from the beginning with a completely defined health index grading program in place. Instead, they became a super-user quite by accident.
目前用于直接热点监测的 FO 传感器的最大用户之一，没有规划详细的状态监测策略，从一开始就安装传感器，并制定了全套的的健康指数分级程序。然而，他们意外地成为了超级用户。

After release of the new IEC 60076-2 standard this utility decided to install fiber-optic sensors as part of a Type Test of a new transformer design coming from a large multi-national transformer manufacturer. Temperature Rise test was conducted in accordance with IEEE PC57.12.90 and the results were surprising [7].
在发布了新的 IEC60076-2 标准后，本标准规定安装光纤传感器，作为来自大型变压器制造商的新变压器设计类型测试的一部分。 温度上升试验是按照 IEEE PC57.12.90 执行的，现场实际运用效果是令人赞叹的。

Temperatures were far higher than expected from the thermal modeling. After the first Type Test result, the utility requested that all transformers in a new order be fitted with FO sensors and data again acquired during the temperature rise test. When the results came in, all the transformers were well above the thermal model. What happened next is a matter of contract re-negotiation and remains proprietary, but the end result was the cost of sensor installation was paid back immediately, through discounts provided for transformers which would not last 40+ years at the nameplate rated load.
从热模拟实验中，温度远高于预期。 在第一次测试结果之后，实用程序要求所有新订单中的变压器都安装 FO 传感器，并在温升测试期间再次获取数据。 当结果出来时，所有的变压器都远高于热模型实验。 接下来发生的事情是订单的重新谈判协商，，但最终的结果是传感器安装的费用立即得到补偿。通过给变压器提供折扣来实现，因为这些变压器在铭牌额定负荷下不会持续工作 40 年。

After this experience, this asset owner required fiber-optic sensors to be installed on all new power transformers from all suppliers, and in the last few years has moved to continuous real-time monitoring on all transformers. In fact, this user case follows well the "Evolution of Adoption" that the typical user of fiber-optic temperature sensors experiences, see Figure 2.
在这一次经历之后，这位设备拥有者要求在所有供应商供应的所有新的电力变压器上安装光纤传感器，并在过去几年中转向对所有变压器进行连续实时监测。 事实上，这个用户案例很好地遵循了光纤温度传感器的典型用户所经历的"采用的演变"。

Figure 2. Evolution of adoption
采取光纤测温的演变

Start with Type Testing
起始于型式试验

Type testing is an inexpensive means by which to assess the OEM manufacturer's design accuracy and in the case of winding temperatures to confirm the thermal model provided during the design review is accurate. IEEE standard 1538a-2015, "IEEE Guide for determination of maximum temperature rise for liquid-immersed transformers" has detailed instructions on where and how many fiber-optic sensors to install on a transformer for this purpose.
型式试验是一种低成本的实验方法，可以用来评估 OEM 制造商的设计精度，在绕组温度的情况下，确认设计评审期间提供的热模型是准确的。 IEEE 标准 1538a-2015，"IEEE 油浸变压器最高温升测定指南"，详细说明了在变压器上安装用于此目的光纤传感器的位置和数量。

With regards to the quote attributed earlier to a large Australian utility, the concept of "spending time at the beginning to avoid the problems later" has its origin from Type Testing. During Temperature Rise tests one of the sensors on the first transformer of a four-transformer substation project was measuring 7°C hotter than expected at rated load. The traditional winding temperature indicator (WTI) which was to be used for control (alarm and fan cooling) showed a normal temperature. "That sensor is running a bit hot today" was the explanation from the transformer OEM. In this case the utility was not accepting the explanation and asked for the oil to be drained and the transformer to be investigated. This was not a small task, but the 7°C difference could not be explained and so the OEM reluctantly agreed.
关于早些时候澳大利亚一个大型公用事业的引文，"在开始时花时间，避免以后发生的问题"的概念源于型式试验。 在温升试验中，一变电站项目中一台变压器上的一个传感器测量的温度比额定负荷下预期的温度高 7°。 传统的绕组温度指示器(WTI)显示正常温度。 "那个传感器今天运行有点热"是变压器 OEM 的解释。 在这种情况下，公用事业公司不接受这一解释，并要求对石油进行排水和变压器进行调查。 这不是一项小任务，但 7°C 的差

异无法解释，因此 OEM 勉强同意。

The resulting investigation revealed that the outer surface on an oil duct used to direct flow at the bottom of the windings had delaminated. The delaminated material wedged itself in the oil flow and diverted the cooler oil away from a portion of the winding where one of the sensors had been installed. All the transformers on that order were drained and all were found to have the same delamination on the oil ducts causing the same type of blockage. The OEM changed the oil ducts to a new material, tests were redone, and the transformers subsequently passed.
由此得出的调查结果表明，用于在绕组底部直接流动的油管的外表面已分层。 脱层材料在油流中楔入，并将冷却器油从安装了传感器的绕组的一部分移开。 该订单上的所有变压器都被排水，发现所有变压器都在油管上有相同的分层，导致相同类型的堵塞。 OEM 将油管改为新材料，重新进行测试，变压器随后通过测试。

If the Type Test had not been done with such accuracy, the original transformers would have been energized in the field and had a lifetime much shorter than expected. Finding the design problem at the beginning avoided the financial loss associated with their early replacement, easily equivalent to a few hundred fiber-optic monitoring systems.
That Australian utility has since progressed to 100% Temperature Rise Quality Check during FAT using the data from the fiber-optic sensors.
如果型式试验没有如此精确，原始变压器将在现场通电，寿命比预期短得多。 在一开始就发现设计问题，避免了早期更换相关设备带来的经济损失，该损失等效于几百个光纤监测系统。 该澳大利亚实用程序已经发展到 100%的温度上升质量检查期间，脂肪使用数据从光纤传感器。澳大利亚公用事业已经发展到 100%的要求所有变压器安装光纤传感器做做温度上升型式试验。

100% Quality Check during FAT
工厂验收测试期间 100%的质量核查

Transformer design and material workmanship are major causes of transformer failures. Since an asset owner cannot be on-site the entire time a transformer is being manufactured, factory acceptance tests witnessed by the asset owner or contracted delegate are vital [8, 9].
变压器的设计和材料工艺是变压器故障的主要原因。 由于设备拥有者在制造变压器的整个过程中不在现场，设备拥有者或合同委托方的工厂验收测试是至关重要的。

What to do if the results are not as expected? Higher temperatures mean that either the transformer cannot be run at rated load, or if run at rated load, the lifetime of the transformer will be reduced. Compensation for reduced life expectancy can be calculated and financial penalties can be assessed and pre-agreed contractually. An example of such a financial agreement is described in Table 2.
如果结果不像预期的那样怎么办？ 较高的温度意味着变压器要么不能在额定负载下运行，

要么在额定负载下运行，变压器的寿命就会降低。 对预期寿命缩短的补偿可以计算，根据事先商定的合同经济处罚可以评估。 这种财务协议的一个例子见表 2。

Table 2. Compensation from temperature rise test results
来自温升测试结果的补偿

Temperature rise over the permissible limit (°C)	Compensation as a percent of total FOB price of the transformer
0-2.99	0%
3.00-4.99	5.50%
5.00-6.99	10%
7.00-8.99	14.50%
9.00+	Right of refusal

If deviation of 3+ degrees is measured, then payback on the installed sensors is immediate. Further, after being installed and used in the factory test, the sensors can be accessible later on site. The temperature probes can be measured using a portable monitor before the transformer warranty period ends and compared to its beginning of life “fingerprint” performance. Having field tested transformers enables a second opportunity for the transformer manufacturer quality check, and more data by which the asset owner can base future transformer purchasing decisions. Are there some transformer OEM that perform better or worse than others? Having real-time field data from the fiber-optic temperature sensors will help provide the answer.
如果测量温度结果有 3 度的偏差，那么安装的传感器就会立即得到补偿。 此外，在工厂测试中安装和使用后，传感器可以在现场访问。 温度探头可以在变压器保修期结束前使用便携式监视器测量，并与其寿命开始时的“特征”性能进行比较。 经过现场测试的变压器为变压器制造商的质量检查提供了第二次机会，并提供了更多的数据，使设备拥有者能够根据这些数据作出未来的压器的采购决定。 是否有一些变压器 OEM 表现比其他更好或更差？从光纤温度传感器获得实时现场数据将有助于提供答案。

“Our Ideal transformer includes direct hot-spot monitoring using fiber-optic sensors. The temperature tests done during FAT provide the beginning of life fingerprint against which to compare the on-line temperature data.

——Senior Risk Consultant of a Major Commercial Property Insurer”

“我们理想的变压器包括使用光纤传感器的直接热点监测。 在 FAT 期间进行的温度测试提供了温度参数，以比较在线温度数据。

——商业财产保险公司的高级风险顾问”

Other Immediate Side Benefits
其他即时福利

Although quality check of the transformer OEM is the key motivation for Type Test and 100% Temperature Rise QC adoption strategies there are other compelling technical and commercial benefits.
虽然变压器 OEM 的质量检查是型式试验和 100%温升 QC 采用策略的关键动机，但还有其他令人信服的技术和商业利益。

Benefit: Used to Correct Hot-Spot Simulators
好处：用于修正热点模型

Listing the deficiencies of traditional winding temperature indicators (WTI) is beyond the scope of this article, but for any user of these devices the process of calibrating them is seen as a bit of a dark art. Their precision is dependent wholly on parameters entered by the transformer OEM. Sources of error exist, such as the calculated value being dependent on ambient temperatures, due to changes in oil viscosity, and that variation is not considered in the model [10]. Further, the calculations made to estimate winding temperatures using this method are based on below rated load conditions, and in order to know the actual accuracy at above rated load requires further modeling and validation testing for that specific transformer class and design.
传统绕组温度指示器(WTI)的缺陷超出了本文的范围，但对于这些设备的任何用户来说，校准它们的过程被认为是一门黑暗的艺术。 它们的精度完全取决于变压器 OEM 输入的参数。 由于油粘度的变化，存在误差来源，例如计算值取决于环境温度，而算法模型中没有考虑这种变化。 此外，使用这种方法估计绕组温度的计算是基于低于额定负载条件的，为了知道高于额定负载的实际温度，需要对该特定变压器类别和设计进行进一步的建模和验证测试。

Some clever asset owners have taken to use the accurate fiber-optic probe measurements obtained during the temperature rise tests and use that to calibrate the WTI at the rated load condition. The real measurement from the fiber-optic sensors essentially corrects the WTI measurement at a critical temperature where cooling of the transformer is critical and the loading of the transformer needs to be managed closely.
一些聪明的设备拥有者已经采取使用在温升测试中获得的精确的光纤探针测量，并使用它在额定负载条件下校准 WTI。 光纤传感器的实际测量基本上纠正了在临界温度下的 WTI 测量，其中变压器的冷却是关键的，变压器的负载需要密切管理。

Benefit: Recognized by Insurance Companies
福利：保险公司认可

The installation of fiber-optic temperature probes can result in a higher confidence level for the newly energized transformer. As a bonus, the sensors then provide the ability to monitor in future years to safely manage the loading and thus the life of the transformer. A multi-national property insurer, covering over 100,000 power transformers worldwide, lists the fiber-optic direct hot-spot monitor as part of their ideal transformer.
Now that the immediate benefits are more clearly understood, the conversation inevitably turns to cost of implementation.
光纤温度探头的安装可以提高新通电变压器的可信度。 作为回报，传感器了提供了在未来几年的监测能力，以安全地管理负载，从而使变压器的寿命延长。 一家覆盖全球 10 万多台电力变压器的跨国财产保险公司将光纤直接热点监测系统列为其理想变压器的一部分。
现在对眼前的好处有了更清楚的了解，不可避免地转向了实施成本。

Associated Costs
相关费用

Pricing of systems can vary depending on the transformer, mainly due to the number of channels, length of cables, and monitor communications required. A rule of thumb is that the external monitoring components (external cables and monitor) are 50-60% of the total cost of the system. Therefore, asset owners can achieve the benefits of the fiber-optic sensor installation at less than half the cost they initially would have imagined. Table 3 compares the relative costs associated with each adoption strategy.
光纤温度监测系统的定价可以根据变压器的不同而变化，主要是由于通道的数量、电缆的长度和监视所需的通信。 根据经验，外部监控组件（外部电缆和监视器）占系统总成本的 50-60%。 因此，设备拥有者可以以不到他们最初想象的一半的成本实现光纤传感器安装的好处。 表 3 比较了各种策略的相对成本。

Table 3. Cost of adoption
成本预算

Strategy/ Parameter	Type Test	100% quality check during FAT	Monitoring pilot project	Continuous monitoring
Sensors installed?	12-30 on one transformer	All transformers	All transformers	All transformers
Monitor needed?	No	No	One transformer per site	All
Investment	10-15%	40-50%	60-70%	100%

The concept of installing sensors without monitoring at the energized transformer site we refer to as “Dark Sensor” installations. Dark Sensors are one of the least guarded secrets of our industry, however many end users and asset owners are unaware of this strategy which is available at just 10-50% the material costs related to continuous on-line monitoring. Since fiber-optic sensors need to be installed in the windings at the time of manufacture, investing in the immediate benefits also comes with the ability to reap the long-term benefits later. Consider the installed sensors as an “Insurance policy” which can be cashed in later enabling those long-term benefits.
安装传感器，而不监测在现场通电监测变压器，我们称为"黑暗传感器"安装。 黑暗传感器是我们行业最不保守的秘密之一，然而许多最终用户和资产所有者不知道这种策略，这种策略只有 10%-50%的材料成本，且与持续在线监测有关。
由于光纤传感器在制造时需要安装在绕组中，投资于眼前的利益也伴随着以后获得长期利益的能力。把安装的传感器看作是一份“保险单”，可以在以后兑现，从而获得这些长期利益。

The Insurance Policy
保险策略

Consider the following cases which are likely to occur in the future, and which the existing fiber-optic sensors would then be utilized. As Figure 3 [11] helps illustrate, managing the temperatures of the hot spots through dynamic loading and efficient cooling in order to avoid rapid loss of life is critical. Having real-time, accurate temperature data from fiber-optic sensors would be invaluable. Where on the dotted line of Figure 3 are your transformers?
考虑以下可能在未来发生的情况，以及现有的光纤传感器将被使用的情况。 如图 3 所示，通过动态加载和有效冷却来管理热点的温度，以避免快速的缩短寿命是至关重要的。 从光纤传感器获得实时、准确的温度数据将是非常宝贵的。 清看图 3.

Figure 3. A Transformer's life expectancy is dependent on winding hot-spot temperature
变压器的寿命取决于绕组热点温度

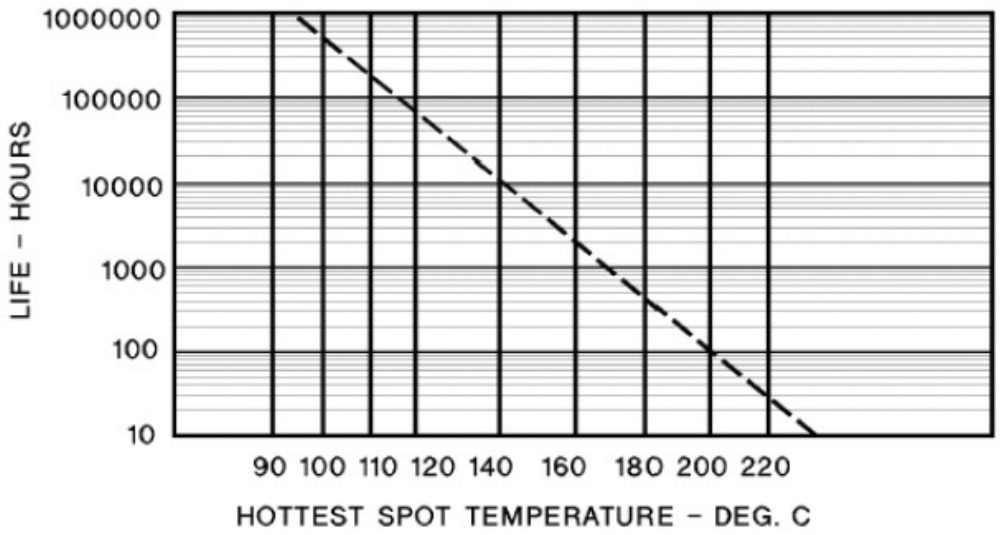


Figure 3 - Minimum life expectancy curve for liquid-immersed distribution, power, and regulating transformers rated in accordance with Clause 5 IEEE Std C57.12.00-2015, at 65°C average winding rise, 80°C hottest-spot rise

New Regulations and Laws
新的条例和法律

As national energy policies evolve, new requirements can be introduced which require the understanding of how the transformer will fare under emergency loading conditions. What happens when one transformer fails and others have to carry a higher load? The transformer previously running at 60% may now need to run above 100% rated load. Ten, twenty, thirty years after first being energized, can it do so safely?
随着国家能源政策的发展，可以提出新的要求，要求了解变压器在紧急装载条件下的情况。当一个变压器故障，而另一个变压器必须承载更高的负载时，会发生什么？ 以前运行在 60%的变压器现在可能需要运行在 100%额定负载以上。 十年，二十年，三十年后，它能安全地这样做吗？

Increasing Demand
增长的需求

Most transformers when put into service are not heavily loaded, perhaps only loaded to 40-60% of the nameplate value. This may last for 5 years or 15 years, but eventually the transformer can become heavily loaded and subject to stresses from overload or dynamic loading situations. As populations increase, space constraints occur, and/or economic realities change the situation can quickly become even more severe. In some countries today the electrical T&D networks run close or at maximum capacity. There are times when transformers in the network will be over rated load and the owner will want to efficiently cool, or reduce

loading when the transformer temperature gets too hot. Catastrophic failures also need to be avoided. India is one country where managing overload conditions is the main driver for adoption.
大多数变压器投入使用时没有重载，可能只加载到铭牌值的 40-60%。这可能持续 5 年或 15 年，但最终变压器可以成为重负荷和承受压力的过载或动态加载情况。 随着人口的增加，经济现实的变化，情况可能很快变得更加严重。 在今天的一些国家，电力网络运行密切或更大的容量需求。 有时，变压器将超过额定负荷，业主将希望有效冷却，或减少负荷时，变压器温度变得太热。 灾难性的失败也需要避免。 印度是一个管理超载条件的国家，是采取监测系统的主要驱动力。

Revenue Opportunity from Overcapacity
产能过剩带来的收入机会

The economic benefit for owners to run their transformers over rated load for short periods of time to capture additional revenues can be calculated directly using only a few variables. Net yearly benefits of several hundreds of thousands of dollars can be realized with on-line monitoring, adding typically less than 1% to the cost of the transformer. In places like Australia and the United States this is one reason why direct measurements and comprehensive monitoring systems are employed. Utilities can make better informed decisions with the accurate data the real-time, direct temperature measurements provide.
业主在短时间内运行他们的变压器超过额定负荷以获得额外收入的经济效益可以直接使用几个变量来计算。 通过在线监测，每年可获得数十万美元的净收益，变压器的成本通常不到 1% 。在像澳大利亚和美国这样的地方，这是使用直接测量和全面监测系统的原因之一。实用程序可以通过实时、直接的温度测量提供的准确数据做出更好的知情决策。

The Age of Dark Sensors
黑暗传感器时代

The complexity of on-line condition monitoring coupled with the rigors of asset maintenance can paralyze an organization when evaluating new technologies for incorporation into their future planning. Long term benefits do need to be understood, but in the case of direct real-time hot-spot monitoring the immediate benefits provided during factory acceptance testing make their specification and installation into new power transformers a smart decision by owners of these assets.
在线状态监测的复杂性加上资产维护的严格性可能会使一个组织在评估新技术以纳入其未来规划时陷入瘫痪。 长期的利益确实需要考虑，但在直接实时热点监测的情况下，在工厂验收测试期间提供的即时效益，光纤温度监测安装到新的电力变压器是这些设备拥有者的明智决定。

The immediate benefits include:

- Identify design flaws and root out material and workmanship issues before acceptance from manufacturer
- Used as a basis on which to receive a pre-negotiated discount, or even reject entirely
- Used to correct the existing hot-spot indicators (WTI) which may still be used to control

cooling

- Provide beginning-of-life performance “fingerprint” against which to compare energized transformers on-site before their warranty expires

当前的好处包括:

- 在制造商交货之前，找出设计缺陷并找出材料和工艺问题
- 用作验收预先协商的折扣，甚至完全拒绝的条件限制
- 用于校正现有的热点指示器(WTI)，这些指示器仍可用于控制冷却系统
- 提供变压器寿命的性能的“特征参数”，以在现场通电测试比较。

Further, the medium and long-term benefits experienced from efficiently managing load on a transformer due to increasing demand, economic benefit, or in order to comply with new regulations are non-debatable. Transformers with fiber-optic sensors providing real-time accurate hot-spot temperature measurements will operate safer and last longer.
此外，由于需求增加、经济效益增加或为了遵守新的条例而有效地管理变压器上的负荷所带来的中长期利益是不可争辩的。 带有光纤传感器的变压器提供实时准确的热点温度测量，将运行更安全和更长时间。

Take a step back from the concept of condition-based asset maintenance for a moment and focus on the immediate benefits to your transformer fleet. The short-term benefits and the corresponding insurance policy for the future that direct hot-spot monitoring provides are clear. The installation of fiber-optic sensors into your power transformers for direct winding hot-spot temperature measurement could be your next bright idea [12].
专注于对您的变压器的直接好处。直接热点监测提供的短期利益和未来相应的保险单是明确的。安装光纤传感器到你的电力变压器直接绕组热点温度测量可能是你的下一个明智的想法。

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