Availability trends observed at operational wind farms
从运营风电场观察风电场可利用率趋势

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Abstract *Over the past decade Garrad Hassan (GH) has assessed the performance of more than 15,000 MW of operating wind farms; approximately 15 % of the total worldwide installed capacity. Based on this experience, GH has compiled a database consisting of over 850 wind farm years of availability statistics. High level distributions of average wind farm availability figures are presented, along with trends and plots showing how wind farm availability changes over time. The tendency of wind farm availability to 'ramps-up' over time as teething issues are resolved is highlighted. An insight is given on how wind farms perform as they reach maturity. Commentary is provided on how the presented results can be used to understand the risks associated with availability at all stages of wind farm development from conception to financing and into operation.*
Keywords *Availability, Operational Wind Farms, Performance*

摘要： *在过去的十年中，Garrad Hassan (GH)已经对超过 15,000 兆瓦，占全球大约 15 %装机容量的运营风电场进行了性能评估。在此经验基础上，GH 编制了一个包含超过 850 个风电场年的可利用率统计数据的数据库。风电场的平均可利用率分布图已给出，趋势和图表也显示风电场可利用率随时间的改变。由此可以看到，在运行磨合期之后，风电场可利用率是逐步增加的。风场达到成熟期后运行性能的情况也被给出。所提供的结果可用来了解同风电场开发各个阶段（概念、融资和运营）可利用率相关的风险。*
关键词 *可利用率，运营风电场，性能*

Background
背景

Over the past decade Garrad Hassan (GH) has assessed the performance of more than 15,000 MW of operating wind farms; approximately 15 % of the total worldwide installed capacity. Based on this experience GH has conducted a high level investigation into how operational wind farms have performed in terms of availability amongst many other factors.

在过去的十年中，Garrad Hassan (GH)已经对超过 15,000 兆瓦，占全球大约 15 %装机容量的运营风电场进行了性能评估。在此经验基础上，针对运营风电场在诸多因素影响下可利用率的表现，GH 进行了一次系统的调查。

In addition to information available from the turbine manufacturers on the availability of their turbines GH has gathered together further information on the performance of wind farms in the course of analysis work on behalf of owners and lenders.

除了风机制造商提供的风机可利用率信息之外，GH 在代表业主和贷方的分析工作过程中进一步收集风电场性能的资料。

The information presented in this paper is for more than 250 wind farms across Europe, US and Asia with duration of operation ranging from 1 year up to 12 years. The resulting database consists of over 850 wind farm years of availability statistics. All of the major European and US manufacturers are represented in the database. The availability data is wind farm 'system availability' and includes downtime associated with the electrical connection system and the grid. Therefore, this availability measure will always result in availability levels less than turbine availability alone.

此论文中提供的信息来自欧洲、美国和亚洲的 250 多个风力发电场，运行时间从 1 年至 12 年不等。由此产生的数据库包括了超过 850 个风电场年的可利用率统计数据。所有主要的欧洲和美国的制造商都在

数据库中列出。可利用率数据为风电场的系统可利用率，包括与电气系统和电网相关故障造成的停机。因此，这个可利用率往往会低于风机单独的可利用率。

Results
结果

The database of availability statistics is presented from two different perspectives in Figure 1.1 and Figure 1.2.

Figure 1.1 presents the distribution of average annual wind farm availability figures. The average annual availability is shown on the x-axis and the percentage of wind farm years in the database is shown on the y-axis. It is clear that the majority of wind farms operate at an annual availability level of between 97% and 99%. Very few wind farms operate at less than 95% availability. There are some outliers but generally the data confirms that most projects operate with availability levels similar to that assumed for a typical wind farm in GH energy assessment work and generally used in financial modelling.

图 1.1 及图 1.2 从两种不同的角度展现可利用率统计数据库。图 1.1 呈现了风电场年平均可利用率的数字分布。X 轴表示年平均可利用率，Y 轴表示占数据库中的风电场年数的百分比。由此可以清楚地看出绝大多数风电场的运行年可利用率在 97%到 99%之间。极少数的风电场运行可利用率不到 95%。虽然有一些异常数据的存在，但一般来说，这些数据证实绝大多数项目运行可利用率水平与 GH 在风电场发电量预测和财务建模中使用的假设值相近。

Figure 1.2 presents the availability versus the years of wind farm operation. The individual solid points show the average availability for all wind farms in the database for each month since commissioning. The open points show the number of wind farms in the database that make up the individual monthly availability figures. Also shown, as solid lines, are the quarterly and annual moving average availability. It can clearly be seen that the availability of the wind farms 'ramps up' over time as teething issues are resolved. On average the wind farms show availability of approximately 93% in the first quarter of operation rising to close to 97% from the end of the second year. Beyond the end of the second year the availability remains broadly constant at between 97% and 98% as far as the end of year 10. The increased volatility between year 8 and 10 is due to the reducing number of wind farms in the database.

图 1.2 呈现出可利用率相对风电场运行年限的变化。 每个独立的实心点表示在资料库中所有风电场自从运行开始每个月的平均可利用率。空心点表示在数据库中构成独立月可利用率的风电场的数量。同时，实线表示的是季度和年度的可利用率。从图上可以看出，在运行磨合期之后，风电场可利用率是逐步增加的。总体上看，风电场的可利用率从运行第一季度的大约 93%上升到第二年末的接近 97%。从第二年末开始到运行 10 年，可利用率大致保持不变，稳定在 97%到 98%之间。由于数据库中适用的风电场的数量减少，8 到 10 年之间的数据的不稳定性增加。

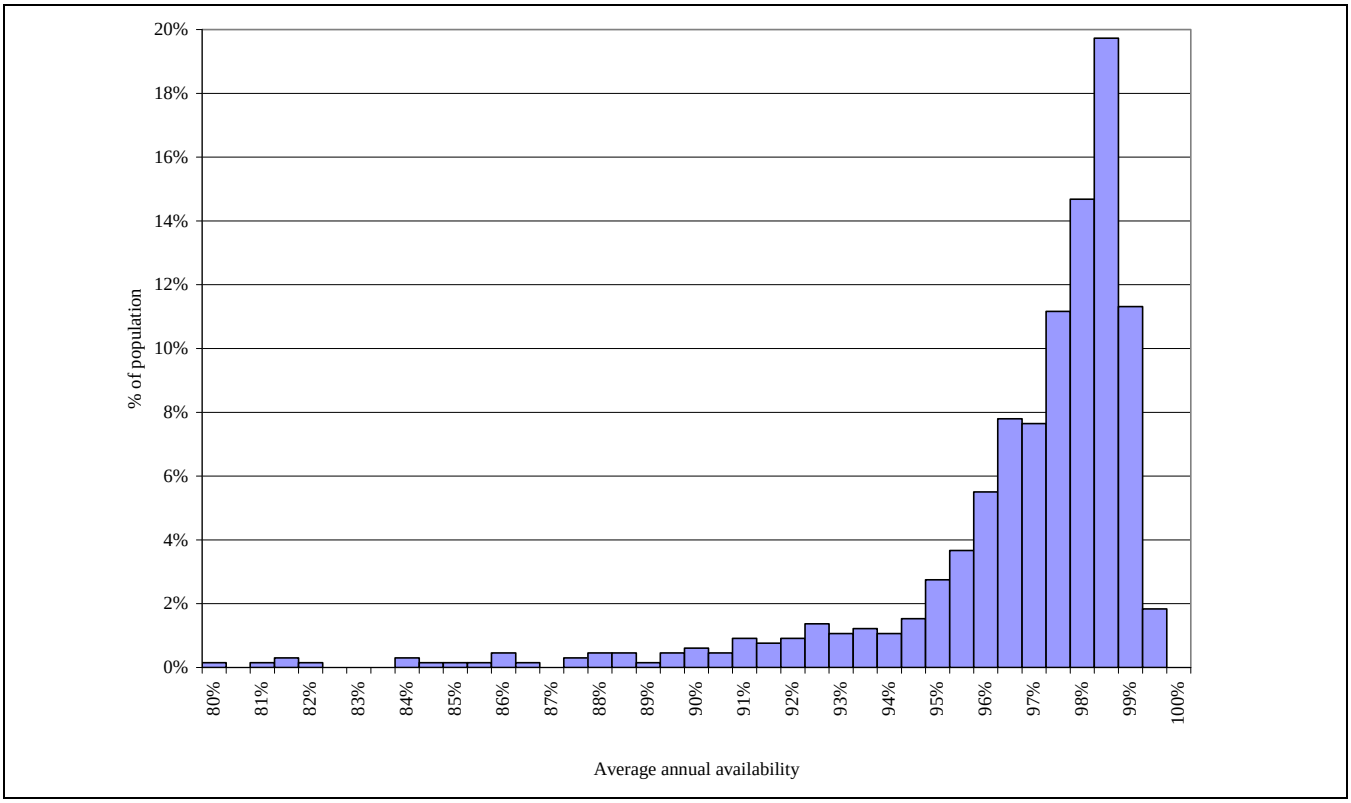

Figure 1.1 Distribution of average annual availability

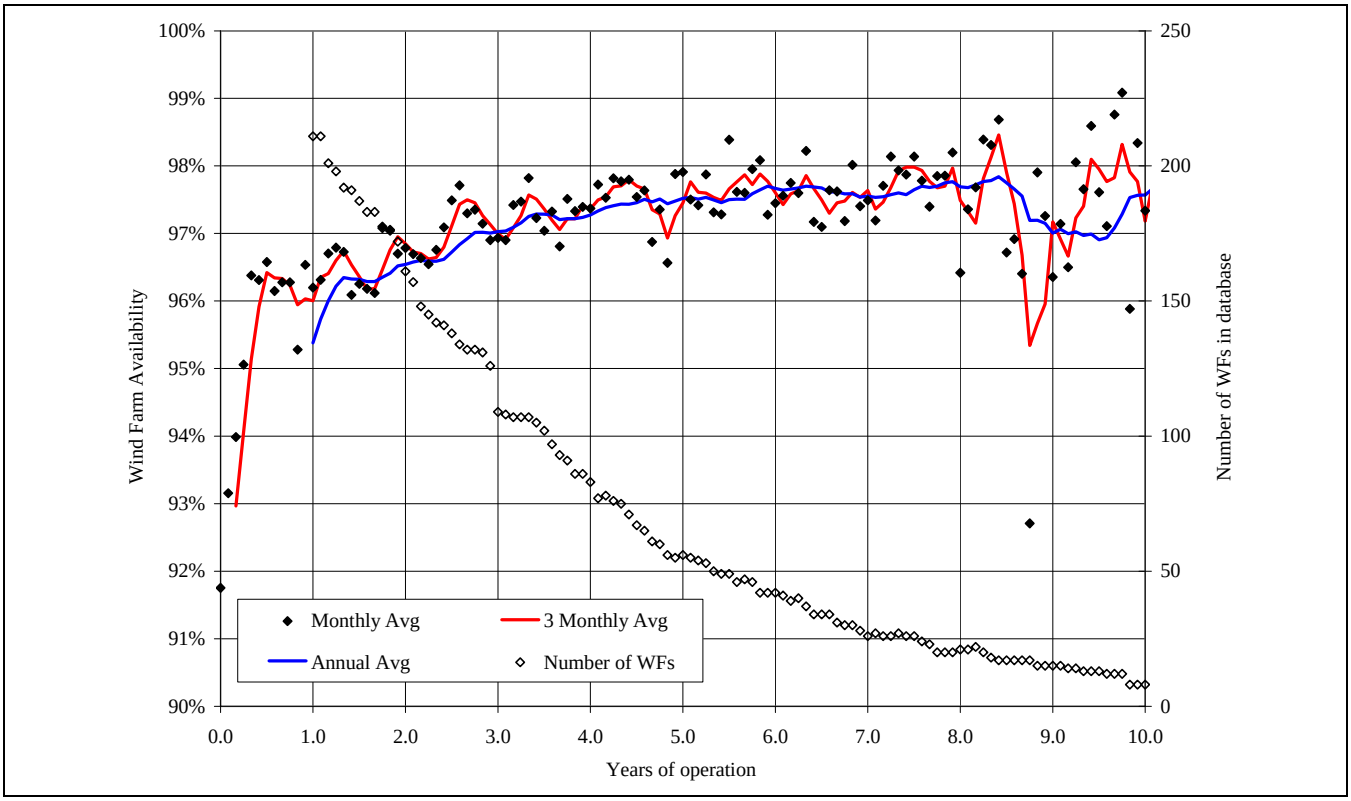

Figure 1.2 Availability versus time trend – shown monthly, quarterly and annual

Conclusion and discussion
结论及讨论

When investing in a modern wind farm development it is generally considered appropriate to expect 97 % availability averaged over the life-time of the project, typically 20 years. The results of this study provide confidence that, as wind farms reach maturity and teething issues are resolved, it is reasonable to expect on average 97 % availability.

投资一个现代风电场，普遍认为在项目平均寿命期内（通常为 20 年）可利用率期望值为 97%。这个研究结果证实，在风电场已达到成熟期并且磨合问题已得到解决之后，平均可利用率为 97%是一个合理的期望值。

It can be expected that from year to year availability will vary above and below 97 %. The distribution of annual availability demonstrates that the number of occurrences of annual availability levels less than 80% on a modern wind farm is relatively low. Such low system availability may be caused by external factors for instance utility enforced downtime as well as turbine issues such as large component serial defects including gearboxes and blades.

可以预计每一年的可利用率会在 97%上下波动。这个年可利用率分布表明，一个现代风电场出现年可利用率低于 80%的几率是比较低的。这样低的系统可利用率可能由于外部因素造成，如设备强迫停机或风机问题（如齿轮箱和叶片的连续故障）。

Minimising the risk of low grid availability may be possible through the signing of a ‘take or pay’ grid connection agreement. This is where the utility company pays compensation when the grid is not available to export production.

降低电网可利用率的风险可通过签署一项“照付不议”条款实现。当电网无法传送电能时，电网公司需要对此造成的损失做出补偿。

Minimising the turbine availability risk is possible through procurement of a turbine availability warranty associated with an operation and maintenance agreement. This is typical in the first years of operation of the project. Some manufacturers will provide longer term agreements, up to 12 years.

可通过取得一个与风机运行和维护条款相关的可利用率担保减少风机可利用率风险。这样的协议在项目运营前几年特别典型。有些制造商提供更远可长达 12 年的可利用率担保协议。

Availability risks associated with environmental conditions should also be considered on a regional or individual wind farm basis. For instance icing can impact the ability of the turbines to operate efficiently as well as causing accessibility problems. At high wind speed sites, repairs to components such as blades can be delayed causing turbine downtime to be high. It is very important to establish the impact of environmental conditions as this type of down-time is often a risk taken by the wind farm owner.

对一个地区或者单独的风电场，与环境条件相关的可利用率风险也应当进行考虑。比如结冰会影响风机的有效运行，同时也给及时的现场维修带来不便。在高风速地区，部件如叶片的修护，可能被延迟并造成风机停机时间过长。确定环境条件的影响也非常重要，这种因素造成的停机往往是风电场所有者需要承担的风险。

Increasingly it is industry practice for the turbine manufacturer to negotiate an allowance of between 48 and 90 hours a year for ‘routine maintenance’ of the turbines. This includes such activities as oil changes, greasing and bolt tightening. Time taken carrying out these activities up to the allowance limit does not count against availability. The impact of this allowance on the availability should be fully understood.

愈来愈多的风机制造商按照行业惯例商议一年大概 48-90 小时的风机“常规保养”。这包括类似换油，润滑和拧紧螺栓等事项。“常规保养”期内所花费的时间不计算在可利用率以内。这个措施对可利用率的影响应得到充分的理解。

The risk of lost production and hence lost revenue as a result of low availability should be clearly understood. In Europe and North America this is typically done through an independent technical due diligence assessment prior to investment or purchase.
由低可利用率造成的生产损失进而造成利润损失的风险应当清楚地被了解。在欧洲和北美，通常在投资或购买前需要通过一个独立的技术尽职调查评估风险。

There are few modern wind farms that have operated in excess of 10 years and therefore no strong conclusions are drawn for availability beyond this. However, it is considered prudent to allocate increased operation and maintenance budgets after operational year 10 and again after operational year 15 to minimise the impact of increased probability of component failure as the end of the turbine design life is approached.
只有极少数的现代风电场运营期超过十年，因此关于运行超过 10 年风电场的可利用率并无有力的结论。然而，在风机的设计寿命的末期，在运行 10 年和 15 年之后，增加运营和维护预算，以减少设备故障的风险是谨慎的考虑。

With respect to the relatively young but fast growing Chinese wind energy market, Garrad Hassan is aware that there have been issues with respect to low availability levels achieved at some wind farms in China. However, it is reasonable to assume that if operation and maintenance practices are adopted in a similar manner as implemented in the mature markets of Europe, then similar levels of availability as presented in this paper can be achieved.
对于相对年轻但是高速增长的中国风电市场，GH 了解到在一些风电场的可利用率相对较低。然而有理由相信，如果采用欧洲成熟市场执行的运营和维护惯例，可以达到这份报道里所提到相同级别的可利用率。

The conclusions drawn from reviewing the trends presented in this paper are to be taken in the context of the wind farm data included in the database. The following points are to be considered:

上述的结论是通过研究资料库中的风电场的数据，研究风场的运行趋势得到的。需要考虑以下因素：

- The statistics are collected from a geographically diverse population of wind farms and therefore the equivalent trends may vary from region to region.
  这些统计数字是从各地区不同数量的风电场收集而来，因此相对不同的地区而言趋势可能有差异。

- The database contains statistics from all turbine manufacturers and turbine types for which data were obtained. Some turbine types may be considered ‘unproven’.
  该数据库包含从各风机制造商得到的统计资料和风机类型数据。一些风机类型可能被视为“尚未检验的”。

- The database has a high proportion of availability statistics for the previous generation of sub-1MW turbines. Indeed the majority of wind farms included that have operated for over 5 years are sub-1MW turbines.
  该数据库中前一代低于一兆瓦级风机的可利用率统计数字的比例较高。事实上，绝大多数运营了 5 年以上的风电场皆使用低于一兆瓦的风机。

- The smallest turbine size represented in the database is rated at 300 kW, the largest is rated at 3MW. No weighting is applied for turbine size.
  数据库中列出的最小的风机额定功率为 300 千瓦，最大的风机额定功率为 3 兆瓦。风机大小没有加权。

- The wind farm sizes vary from only a few turbines to wind farms consisting of over 100 turbines. No weighting is applied for wind farm size.
  风电场的大小不尽相同，从几台风机到由 100 多台风机组成的风电场。风电场的规模没有加权。

- A significant proportion of the availability figures are reported directly from the manufacturers' or owners' operational reports. Some manufacturers' availability figures may have allowances included for maintenance time in which case the 'real' availability figures, that reflect the real periods of turbine down-time may actually be slightly lower.
  可利用率的数字很大比例直接来自于制造商或业主的运行报告。一些制造商的可利用率数字可能包括常规维护时间，在这种情况下，“真正”反映风机停机时间的可利用率数字，实际上可能略低。

- For wind farms where only turbine availability has been provided a further adjustment factor of 99.5% has been applied to convert the manufacturer's availability to estimated wind farm 'system' availability. Actually be slightly lower.
  对于只提供了风机可利用率的风电场，使用一个 99.5%的调整系数用于转换制造商的可利用率，从而估测风电场“系统”的可利用率。风电场系统可利用率的实际值可能略低。