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TMEIC
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VARIABLE FREQUENCY DRIVE RELIABILITY

Comparing reliability of Medium Voltage Variable Frequency Drives (VFDs) can be confusing. This paper defines the key terms used in reliability comparisons and compares two reliability assessment methods commonly in use by VFD manufacturers. The goal will be to provide a clear way for users to compare VFD products from a reliability standpoint.

Introduction

Product reliability is a familiar topic in many areas of life. We purchase a new car in hope and expectation that it will start without fail and then continue to operate properly as we drive. The same requirements and expectations apply to many products that we rely on daily: cell phones, washing machines, copiers, and services like electric power. And when our expectations are not met we consider those products or services unreliable.

We may have feelings of general or extreme dissatisfaction with a particular product or service, but the people responsible for their consistent performance have developed statistical ways to measure reliability. One of the most common methods is Mean Time Between Failure (MTBF). MTBF is the statistical average time between instances when the product failed or the service was unavailable. For example, if over a five-year period a car refuses to start or fails to run five times, the average time between failures (MTBF) is 5 years / 5 failures = 1 year MTBF.

Reliability applied to VFD systems

The same general measures for reliability apply to VFDs. MTBF for a VFD is the measure, on average, of how frequently a user might expect to have his operation interrupted due to an internal problem with the VFD. In addition to knowing the price and suitability for the desired application, potential VFD users should certainly want to compare the manufacturers' published MTBF figures before finalizing their purchase. How are these statistical measures calculated? Are some MTBF calculation methods inherently more practical than others? And how are VFD products designed to make them reliable? Let's look at these areas one at a time.

Initial calculations

When new designs are created, but no operating experience is available, how do designers estimate the product's reliability? They rely on statistical measures of each of the components and subassemblies included in their design. Manufacturers of components and subassemblies publish these numbers for just this purpose. The entire assembly will have a MTBF resulting from the sum of the effect of each of the components. For example, for a system consisting of 10 parts, each with an average of one failure for every 10,000 hours of operation, the final assembly would have a failure rate of 10 x 1 = 10 failures per 10,000 hours. The MTBF would be the inverse of this, or
10,000 hours / 10 failures = 1,000 hours.

Components typically included in a VFD have failure rates measured in failures per billion hours. For example, a power diode usually has a statistical failure rate of 80 failures per billion hours, or 80×10^{-9} hours. This measurement is called FIT (Failures In Time) rate, and each component or assembly is assigned such a number by its manufacturer. For a new VFD design, engineers list all the components and their quantities, multiply them by their FIT rates, and add them up to get a total expected system FIT rate. The expected system MTBF is then calculated as the inverse of this FIT rate.

$$\textbf{MTBF} = 1 / \Sigma \textit{ component FIT Rates}$$

For simplicity, the composite failure rates of subassemblies like power supplies are used rather than the sum of their individual component FIT rates. Such control power supplies may have a FIT rate of $1{,}000 \times 10^{-9}$ hours.

Example. FIT rate calculations for a hypothetical medium voltage drive using a thyristor converter and an SGCT inverter with two series power semiconductors per leg:

Current Source INV w/Active 18-Pulse SCR Converter			
	FIT*	Quantity	IGCT INV
Switching Device (SCR)	80	18	1,440
Switching Device (SGCT)	13	12	960
Gate Driver (SGCT)	3,115	12	37,380
Gate PS (SGCT)	1,000	12	12,000
Gate Drive (SCR) EST	200	18	3,600
Gate PS (SCR)	1,000	11	000
		Total	**56,380**

**Failures/Billion Hours*

The MTBF of the whole system would calculate as

$$\textbf{MTBF} = 1 / (56{,}380 \times 10^{-9}) = 17{,}737 \text{ hours,}$$

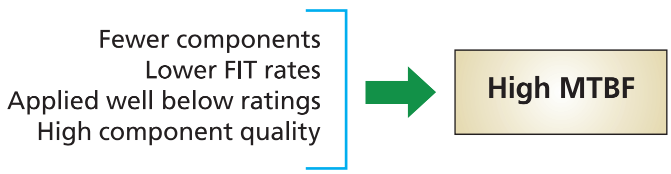
or just over 2 years. Not particularly good, so a careful designer would take steps to improve that.

Key factors

Several important factors affect the calculated MTBF (and the actual fleet MTBF experience) once the product is released, including:

- total number of components
- the FIT rate of each component
- the quality of the components
- how conservatively the components are used

One would expect a VFD with fewer components, each with excellent FIT rate, (designed and used well under their published ratings) to have a much higher MTBF than a VFD designed and constructed less conservatively, with cheaper components.



After a product is released

A manufacturer may continue to use the calculated MTBF in their advertisements for part or all of the life of the product. The manufacturer may apply a factor of conservatism or optimism to this calculated number based on their previous experience with similar designs. In the hypothetical VFD example on the previous page, in which we calculated MTBF of just over 2 years, the manufacturer may look to its fleet experience and double that to 4 years for their advertising. Later, predicted MTBF can be based on fleet experience.

Availability vs. Reliability

It is important here to distinguish between **availability** and inherent **reliability.** Some manufacturers have added additional components (such as bypass switches to cut out failed power cells) so that their VFD can continue to operate at a lower power level after one of the cells fails to operate. In order to have this bypass system work, the detection system, the power switches, and other related components all have to be functional. Although some increased operating availability may be gained, it requires more components. It may even cover up inherent unreliability issues. This is one reason why TMEIC chooses **not** to add such components that will decrease reliability in order to gain possible higher availability.

Fleet reliability

Another method of calculating MTBF uses carefully kept equipment failure records of the operating fleet of VFDs. This method requires the accumulation of VFD fleet operating hours. MTBF is calculated by dividing this figure by the number of failures in the same period.

$$\text{MTBF} = \frac{\text{Operating Hours}}{\text{Failures During Period}}$$

Option for record keeping

The operating hours and failures can be tracked from day one, when the first system began operating. Alternately, running averages of failures over periods of 12 or 24 months may be kept. Tracking lifetime failures and operating hours is more accurate, because it includes early troubles experienced when a new VFD is first released. Running totals are quite valid, however. They reflect the most recent experience and likely include experience from corrections applied to fleet problems. Additionally, running averages for MTBF calculations can quickly show product changes, for better or worse. A true product improvement could raise the MTBF. Or, a bad batch of components from a vendor that causes drive problems would lower calculated MTBF. When the bad parts are replaced, the MTBF improvement results rise quickly.

After all the careful design work is done and the VFD's inherent **design reliability** has been calculated, it is the **fleet reliability** that really matters. For this reason, TMEIC's policy is to publish only fleet reliability once a relatively few months of VFD field experience is gained.

Example. Here are some fleet MTBF calculations based on recent TMEIC experience for one of its drives:

Item	Raw Value	Conservative Value
Days per Month	30	30
Daily Operating Percent Time (Conservative factor)	100%	80%
Running Hours Per Month	720	576
Fleet of Running Drives	620	620
Monthly Fleet Hours	446,400 (B)	357,120 (B)
12-Month Average of Significant Events/ Month	2.58 (A)	2.58 (A)
Drive Hours Between Failures	172,800 (C)	138,240 (C)
Hours/Year	8,760	8,760
MTBF Years Between Significant Events	19.7 (D)	15.8 (D)

In the above example, **446,400** monthly fleet hours **(B) / 2.58** failures per month **(A) = 172,800** average hours per failure **(C)**. Dividing by **8,760** hours per year yields an MTBF of **19.7 years**. A conservative factor of **80%** reduces this to **15.8 years (D)**. This factor takes into account that not all drives may be operating in a particular month and that some events may not have been reported. Using the more conservative 15.8 year **(D)** value easily allows truthful advertising that states "drive reliability is greater than 15 years."

Basic ground rules

Some basic ground rules and definitions have been established for gathering such information. These include the following:

What are significant events?

In general, they are events that are the result of TMEIC hardware or system failures that stop operation of the drive. These include:

- Events such as non-resettable trips that require hardware replacement or repair, replacement of blown fuses, and so forth.
- Events that result from failure or misoperation of internal drive components supplied and included by TMEIC, such as breakers, inductors, power supplies, and so forth.

What events are excluded from MTBF?

- Events that happen before commissioning is complete (even during commissioning) are not counted, but they are analyzed for improvement.
- Events occurring from a problem after a solution has been identified (like firmware changes) while the solution is being applied to the fleet.
- Events that are the result of customer equipment or site conditions (wiring and cable or connections, dust, over-temperature in control room, poor maintenance, and so forth).
- Events that, after individual engineering and/or factory review, result in no failure being found (example – power module returned to factory and found OK – possibly was a loose or contaminated fiber optic connector).
- Events that result from normal wear – such as fans, capacitor age, power supplies, and so forth, which are past their recommended replacement period.

Back to the beginning

As we showed earlier, using fewer, higher-quality components applied at well below their published ratings will produce superior results. Additionally, factory testing, factory assembly, and basic construction of the VFD equipment lends itself to reliable operation and practical service. Here are some examples of TMEIC practices.

- **Stainless steel fittings and hardware** are the rule for water-cooled drives. Plus, the insulated tubes connecting to the power heatsinks are carefully selected and tested to eliminate leaks, a prime source of unreliability in water-cooled VFDs.
- **Dry, film-type capacitors** are used instead of electrolytic capacitors in multilevel drives (TMdrive-MVG2, MVe2) to eliminate problems with aging, high-maintenance, and shortened equipment life.
- **Long-life variable-speed cooling fans** (TM-MVe2) provide more than double the expected operating lifetime versus traditional fixed-speed fans.
- **Factory assembly** – Careful procedures are followed in important areas, including meticulous power and control wiring, and properly torqued fasteners for mechanical and electrical joints.
- **Factory testing** – These include extremes of the intended operational, electrical, and mechanical environment. Critical components such as the microprocessor boards are thermally cycled for several hours to ensure proper operation.

Other key reliability factors

Other not-so-obvious factors can greatly affect the VFDs in service reliability. These include, but are not limited to, critical items such as the following:

- Experienced-based VFD application engineering.
- Selecting and matching the VFD to the required user or OEM environment, process loads, and electrical system.
- VFD installation guidance and commissioning services ensure proper equipment setup and interconnection with user equipment and processes.
- Regular preventive maintenance after equipment is in service maximizes equipment life.

TMEIC Drive Fleet MTBF

December 2016 fleet records for TMEIC drives' MTBF are summarized below:

TMEIC Family	Fleet MTBF Years	Notes
TM-XL55, 75, 80, 85	44	Since 1st shipment
TM-MV / MVG / MVG2	13	Since 1st shipment
TM-MVe2	15	Since 1st shipment
Dura-Bilt5i MV	15	1-year rolling average
TM30 / 50 / 70 / 70e2	22	Since 1st shipment

Summary

We have discussed basic understandings of VFD reliability, including what it means, how it is calculated, and how good design and manufacturing maximize reliability. We have also shown how keeping accurate records of fleet operating time and reported operational problems allows the use of the actual fleet MTBF statistics. We have shown how this is the superior method to continuing the use of calculated MTBF after the equipment is in service. All users would be well advised to use fleet MTBF as their criteria in comparing various medium voltage VFD offerings.

For specifications not mentioned here, contact TMEIC

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