



# ROBICON CORPORATION

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**Reliability Document for**  
**Perfect Harmony Variable**  
**Frequency Drive (VFD)**  
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## INTRODUCTION

This document applies to the Perfect Harmony Variable Frequency AC Motor Drives (VFD) configured from three through six power cells. The development of this document was intended as a source of reference for the overall Reliability, Availability, and Maintainability of the Perfect Harmony VFD.

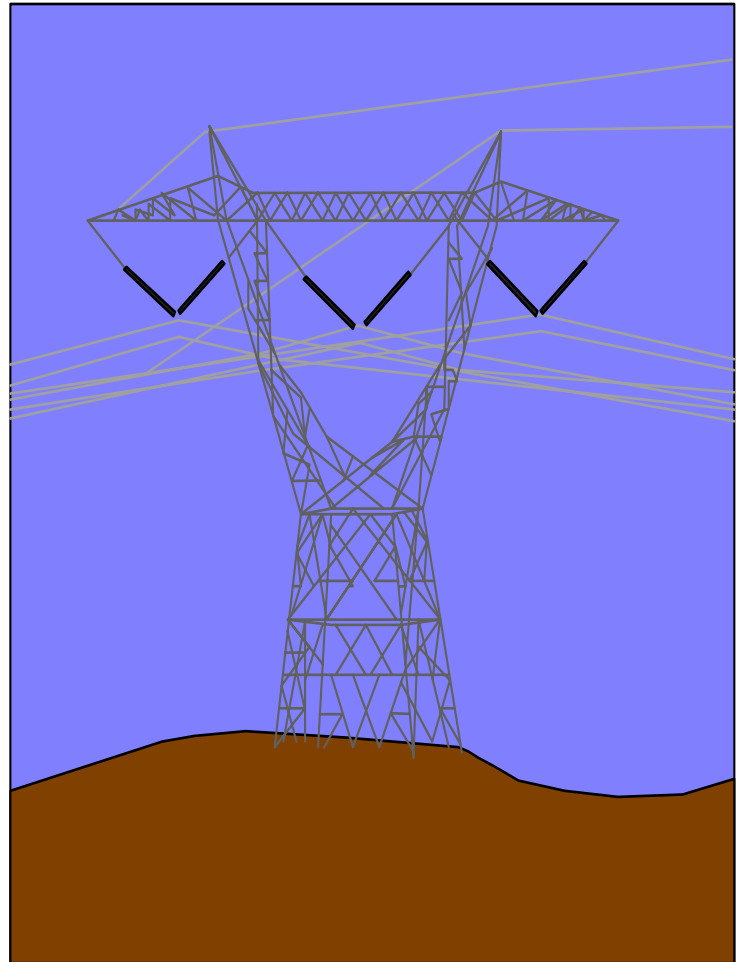
### **Reliability;**

The Probability that an item can perform it's intended function for a specific interval under stated conditions.

### **Availability;**

A measure of the degree to which an item is operable and committed at an unknown point in time.

## THE VISION



**to be number one in the world in  
high power conversion solutions.**

### **Maintainability;**

The measure of the ability of an item to be restored to a specific condition when maintenance is performed by personnel having specific skill levels, using approved procedures.

### **Measures of Reliability;**

The MTBF is a basic measure of reliability for repairable items: The mean life during which all parts perform within their specified limits, during a point measurement period under stated conditions.

### Measures of Availability:

The three common measures are Inherent, Achieved, and Operational Availability.

Inherent (potential) availability only considers the Mean Time Between Failure MTBF and Mean Time To Repair MTTR. Inherent availability,  $A_i$  is calculated by:

$$A_i = MTBF / (MTBF + MTTR)$$

Achieved (final) availability is more realistic because preventive maintenance is taken in account along with corrective maintenance. Achieved availability,  $A_a$  is calculated by:

$$A_a = MTBMA / (MTBMA + MMT)$$

MTBMA is Mean Time Between Maintenance Action.

MMT is Mean Maintenance Time.

Operation (actual) availability is what typically occurs in practice and takes in account maintenance that is non instantaneous due to logistics or replacement parts not in stock. Operational availability,  $A_o$  is calculated by:

$$A_o = MTBMA / (MTBMA + MDT)$$

MDT is Mean Down Time.

### Failure Modes and Mechanisms:

When failure occurs, it is not adequate to simply note the time of the failure along with mode and calculate a rate of failure. The mechanism of the failure must be investigated and understood.

The failure types are categorized in three periods, Infant Mortality, Constant Failure Rate, and Wearout or fatigue.

The infant mortality period contains failures that are related to workmanship and components not to standard. These are typically not design related issues. As the defects are repaired the failure rate decreases for a given time period.

The Constant Failure Rate is attributed to random failures. By random it is only predictable in that, the probability of a failure in a time will occur, but a specific component is not. This failure rate period is the best time period for the reliability prediction.

The wearout (fatigue) period is observed with an increased failure rate. The time to failure ratio indicates that the item is no longer efficient and useful life period is ending.

The "Bathtub" curve illustrates the three periods of failure. They each have their own distributions and associated calculations for failure rates. Throughout this document exponential calculations are utilized to determine the reliability of the Robicon VFD.

### Reliability Functions:

$\lambda_c$  Failure Rate of Components  
FIT(10 • E - 9)

$\lambda_d$  Failure Rate of Drive  
FIT (10 • E - 9)

R Reliability,  $R = e - \lambda t$ ,  $t = 8760$   
hrs

MTBF Mean Time Between Failure

$MTBF_c = 1 / \lambda_c$

$MTBF_d = 1 / \lambda_d$

MTTR Mean Time To Repair

$A_c$  Availability for Component

*Ad* Availability for Drive  
Analyses of series and parallel system reliability calculations are as follows:

$$R_{\text{series}} = R_1 \cdot R_2 \cdot R_n$$

$$R_{\text{parallel}} = 1 - (1 - R_1) + (1 - R_2) + (1 - R_n)$$

**Reliability Prediction:**

The reliability prediction of a Harmony VFD requires the consideration of the failure rates for each subsystem. The Harmony VFD is made up of a complex series/parallel system with redundancy options.

IEEE Standard 500 contains failure rates for three phase transformers of  $\lambda_c = 540 \cdot 10 \cdot E - 9$ . Therefore the Reliability,  $R = e - \lambda t = 0.995$ .

Similar reports display failure rates for cooling systems of  $\lambda_c = 1,000 \cdot 10 \cdot E - 9$ . Therefore the Reliability,  $R = e - \lambda t = 0.9912$ .

Through actual field data the control circuitry has a failure rate of  $\lambda_c = 11,143 \cdot 10 \cdot E - 9$ . Therefore the Reliability,  $R = e - \lambda t = 0.907$ .

The power device section of the drive has a calculated failure of  $\lambda_c = 570 \cdot 10 \cdot E - 9$  per cell. Therefore, the Reliability,  $R = e - \lambda t = 0.995$  per cell.

The power section can be examined as three, four, five and six cell VFD.

To determine the Reliability of the series-parallel cell network plug into the equation for series network

$$R_s = R_1 \cdot R_2 \cdot R_n = (0.995) \cdot (0.995) \cdot (0.995) = 0.985.$$

The value is used for all three phases and is plugged into the  $R_{\text{parallel}}$  equation

$$1 - (1 - R_1) + (1 - R_2) + (1 - R_n).$$

$$R_p = 1 - (1 - 0.985) + (1 - 0.985) + (1 - 0.985) = 0.955$$

Include the Reliability of each component for the total VFD Reliability,  $R$  is:

$$0.995 \cdot 0.9912 \cdot 0.907 \cdot 0.955 = 0.854.$$

The MTBFd is equal to  $-t / \ln R = -8760 / \ln 0.854 = 55,513$  hours.

The four cell VFD Reliability,  $R$  is equal to 0.840, with an MTBFd of 50,258 hours.

The five cell VFD Reliability,  $R = 0.827$ , with an MTBFd of 46,129 hours.

The six cell VFD Reliability,  $R = 0.814$ , with an MTBFd of 42,565 hours.

However, due to the by-pass feature available on each of these VFDs. The MTBFd is actually reaching the plus 70,000 hour range. Because a VFD is considered still functional with zero or one cell defective.

Example for the four cell system; The four cell system has twelve cells and for a VFD to be considered operational eleven cells must be functional.

Therefore the probability of completing

the operation is:  $\sum_{i=0}^r \binom{n}{r} (p)^r (1 - p)^{n-r}$

plugging in the data;  
0 failures

$$\sum_{i=0}^r (12! / 0!(12 - 0)!(0.005)^0 (0.995)^{12} = (1)(1)(0.9416) = 0.9416,$$

1 failure

$$\sum_{i=0}^r (12! / i!(12-i)!(0.005)^i(0.995)^{11} =$$
$$(12)(0.005)(0.9463) = 0.05677,$$

The probability of 1 or less cell failures is:  $0.941 + 0.05677 = 0.997$ .

Plug this value in to the Rseries equation along with all other components and the Reliability of the VFD is:  
 $0.995 \bullet 0.9912 \bullet 0.907 \bullet 0.997 = 0.892$ .

The MTBFd is equal to  $-t / \ln R = -8760 / \ln 0.892 = 76,647$  hours. This is an estimated increase of 26,000 hours.

#### **Availability:**

The three types of Availability are calculated as:

Three cell VFD equals

Inherent (potential) availability

$$A_i = MTBF / MTBF + MTTR$$

$$A_i = 55,513 / 55,513 + 100 = 0.998$$

One hundred hours is worst case given no parts or qualified repair person on site at time of failure.

Achieved (final) availability

$$A_a = MTBMA / MTBMA + MMT$$

$$A_a = 4380 / 4380 + 10 = 0.997$$

4380 equals six month interval as recommended in the Harmaony User's Manual. Ten hours is used for time to maintenance.

Operation (actual) availability

$$A_o = MTBMA / MTBMA + MDT$$

$$A_o = 4380 / 4380 + 48 = 0.989$$

The forty eight hour down time could be expected if spare parts are not available at the time of trouble.

#### **Maintainability:**

In the Perfect Harmony user Manual, page 7-1 reviews the maintenance procedure. It will require approximately eight to twelve hours the first couple of times because of connections coming loose. The drive requires a settling time, after which loose hardware connections will decrease. The time to maintenance the drive should decrease sharply at this point.

In the Inherent availability calculation 100 hours mean time to repair This takes into account the time for travel, analysis, logistics, and replacement of defective components. This value can be reduced by training personnel on site to troubleshoot and repair the VFD. Additionally, with spare parts on site an availability of 0.9999 can be achieved.

The mean maintenance time of ten, for Achieved availability is chosen simple because it is considered average maintenance time for a VFD less than one year old.

Operation availability of forty eight hour is reasonable given no spare parts, but a trained repair person on site.