The Reliability of Neutral Point Clamped vs. Cascaded H-Bridge Inverters

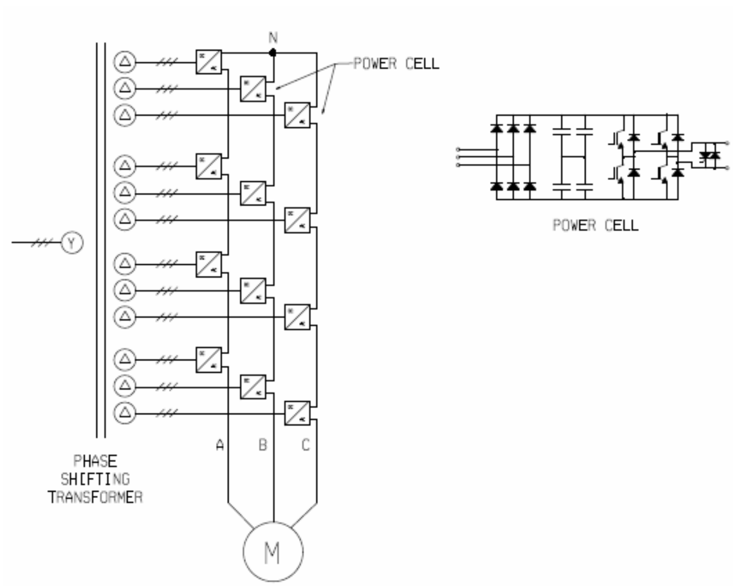

Figure 1. Cascaded H-Bridge (Paice) Topology.

This paper discusses reliability of Medium Voltage Adjustable Frequency Drive designs utilizing standards of measurement of reliability. We will justify the design criteria of MV AFD design with respect to long life and long service by better utilizing reliability analysis to compare the two different designs of medium voltage adjustable frequency drives.

The drive technologies to be compared are both voltage source inverter technologies, which provide better efficiency and reliability over older current source inverter technologies. The two technologies discussed in this paper are Neutral Point Clamped (NPC) inverters and Cascaded H-Bridge inverters. The two technologies differ in that the NPC inverter designed with MV IGBTs and the H-Bridge inverter low-voltage (LV) IGBTs in a series connected output to produce an MV level from an LV DC bus.

Before the advent of medium voltage IGBT devices, two engineers, Derek A. Paice and Charles Edwards from Westinghouse's Distribution and Control Business Unit (acquired by Eaton Corporation in 1994) came up with a novel arrangement of LV drives connected in series to construct MV waveforms for motor control. This is the H-Bridge or Paice Inverter shown in Figure 1.

The advent of true medium voltage IGBT has changed the role of the MV AFD. Just as the IGBT changed the LV drive designs in the 1990's, the MV IGBT is quickly becoming the semi-conductor of choice in MV AFD technology.

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This paper will examine for comparison of reliability the three-level NPC inverter design (Figure 2).

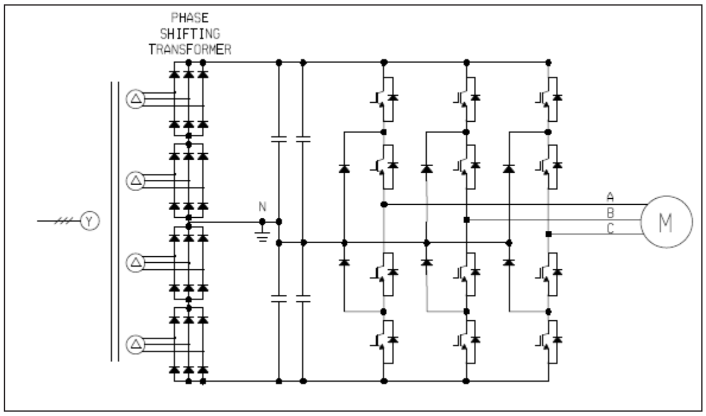

Figure 2. NPC Three-phase Drive.

The main difference between multi-level inverter design topologies, seen in Figures 1 & 2, is that the NPC design utilizes medium voltage (MV) components and cascaded H-Bridge utilizes low voltage (LV) components.

Failure In Time (FIT) analysis of components within a multi-level inverter system

The main power components within a multi-level inverter system are, but not limited to:

- Diode rectifiers
- DC link capacitors
- IGBT switching devices

This analysis will investigate the reliability of each topology with respect to the main power components. The standard method of analyzing reliability is using FIT. FIT is defined as the number of failures per one billion hours of operating time.

$$\lambda = \frac{failures}{10^9\,hours}$$

Mean Time To Fail (MTTF) is related to the inverse of the FIT rate if component failure follows an exponential distribution:

$$MTTF = \frac{1}{\lambda} * 10^9\,hours$$

$$\lambda = \frac{1}{MTTF}$$

The MTTF is obtained for a system by using the sum of all component FIT rates. All FIT rates are based on manufacturers specified cycle time, voltage, current and temperature ratings. Any deviation from these tests will significantly alter FIT rates. Our component count is based on a 4160 V, 1000 HP drive.

HV IGBT: λ = 400 FIT [i]

HV capacitor: λ = 300 FIT (EPCOS) [ii]

LV IGBT: λ = 100 FIT

LV SCR: λ = 100 FIT [iii]

LV capacitor: λ = 400 FIT (BHC) [iv]

Diode: λ = 100 FIT

The sum of all FIT rate assumes this is a non-fault tolerant system, meaning any single component failure would stop the system output.

Table 1. NPC Topology.

Component	Quantity	FIT	Total FIT
Diodes	30	100	3000
DC capacitors	4	300	1200
IGBT	12	400	4800
Total			**9000**

Table 2. H-Bridge Topology.

Component	Quantity	FIT	Total FIT
Diodes	72	100	7200
DC capacitors	72	400	28800
IGBT	48	100	4800
Total			**40800**

From the total FIT rate of the system, the MTTF is calculated:

$$MTTF = \frac{1}{\lambda} = \frac{1}{9000} * 10^9\,hours = 111{,}111 \text{ hours (NPC)}$$

$$MTTF = \frac{1}{\lambda} = \frac{1}{40800} * 10^9\,hours = 24{,}510 \text{ hours (H-Bridge)}$$

Cell Bypass

One of the concerns with the cascaded H-Bridge is that the component count increases the probability of a component failure as reflected by the MTTF numbers. In order to increase drive availability a fault tolerant system can be designed. This system has the option for a bypass switch on all of the power cells. A single component failure of a diode, capacitor or IGBT can initiate closing the bypass switch, effectively removing that power cell from that phase allowing continued albeit reduced power output. This allows the process to continue until personnel can shutdown and repair the damaged components. One cell could fail due to the following issues: failure on the secondary of the transformer, low voltage secondary fuse, the low voltage rectifier, one of the many electrolytic capacitors a control circuit or the low voltage IGBT's. The motor will not receive power for about ½ second while the failed cell is identified and bypassed. When a cell is bypassed, the drive can run the motor to 87.5% voltage thus limiting the drive to 67% power and 76.6% torque maximum. If more than one cell failed such as in a cascaded or catastrophic failure, the drive would shutdown and operation would not be possible.

Figure 3 shows a visual of how the bypass allows continued operation with a failure of any single component.

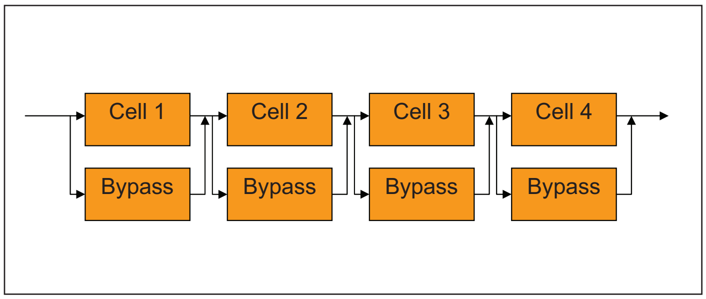

Figure 3. Bypass Operation.

The bypass does not increase MTTF, since a failure has occurred but instead allows continued operation. The question is what the next MTTF or Mean Time Between Failure (MTBF) is under a bypassed system.

Conclusion

Even with the ability to utilize the cell bypass feature of the Paice Inverter, the reliability of today's modern multi-level inverter for medium voltage applications greatly exceeds the reliability of the older Paice design. When economics are considered, the NPC inverter provides 4.5x the reliability for roughly the same installed cost, truly making it the only solution for today's MV AFD applications.

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