PERFORMANCE AND RELIABILITY EVALUATION OF INDUCTION MACHINES: AN OVERVIEW

Lokesh Varshney*[1], J. S. Shakya[2] & R. K. Saket[1]

[1]Department of Electrical Engineering
Institute of Technology, Banaras Hindu University
Varanasi – 221 005 (Uttar Pradesh), India
E-mail: lokesh_varshney@rediffmail.com , rksaket.eee@itbhu.ac.in

[2]Department of Electrical Engineering
Samrat Ashok Technological Institute, Vidisha (Madhya Pradesh), India
E-mail: jitnet_2004@yahoo.co.in

ABSTRACT
This paper presents an overview on performance and reliability evaluation of induction machines. Induction Machine has been found to be very suitable for electrical to mechanical energy conversion vice versa. Induction machines have been subjected to increased demand for low cost and size, simple construction, absence of separate dc source for excitation, least maintenance, operational simplicity, brush less construction with cage rotor, easy parallel operation, no hunting, higher horsepower per frame size, higher operating temperatures, more demanding duty cycles, higher starting currents, frequent voltage transients, severe environmental exposure, long life and reliable performance. The fault modes of induction machine are very complex, so that many people are plagued to establish the fault evidences for reliability verification. The classification of the various faults of the induction machines have been discussed in this paper. The major failure modes of the machines are classified as class A, Class B and Class C modes. Reliability evaluation technique, Refusable Fault Rate (REFR), Acceptable Fault Rate (ACFR), and an overview on various types of reliability methods have been described considering various fault modes.

Keywords: *Induction machine, fault modes, reliability evaluation, ACFR, REFR.*

1. INTRODUCTION
In recent years of the 21st century, the increasing concern of green house gas emission, the crises of draining fossil fuel, environmental degradation and depletion of conventional energy have motivated the world towards increase the use of electrical energy. Induction machine has many advantages over other machines. Induction machines are widely used in many industrial applications and required reliability evaluation for continuous operation considering occurrence the industrial fault [1]. Reliability is the probability of a device or system performing its function adequately, for the period of time intended, under the operating conditions intended. Reliability theory as an extension of probability theory was first applied in electronics, nuclear and space industries after world war-II, where, high reliability was a requirement from these increasingly complex systems. A high degree of reliability is also absolutely essential for some industrial customers. For this reason reliability has been one of the major factor in the planning, design, operation and maintenance of electric machines [2]-[4].

2. FAILURE MODES OF INDUCTION MACHINES.
2.1. Failure cause: A partial list of such failure causes would include as follows [5]
- Misuse
- Misapplication/unsuitable for environment
- Unbalanced or incorrect voltage
- Poor maintenance practices
- Misalignment/vibration.
- Improper connection

2.2. Major fault modes
The major fault modes of induction generator are very complex to establish the fault evidences for reliability verify. In order to analyze the major failure modes and their effects the faults of motor are classified [6]:

Class A: The critical faults caused by the inherent weakness failures of the electric insulation system or the main structural part.

- Failure of Electrical insulation system
- Rotor touch on stator
- Failure frame or end cover
- Failure of rotor cage
- Shaft broken
- Failure of excitation

Class B: The major faults, which will cause a minor failure or cause less damage to the operation of the motors and can be repaired by replacing some pairs. For repairing these faults, less time and less cost required.

- Failure of terminal box
- Failure of wiring box
- Failure of fan
- Failure of bearing
- Loss of rotor's balance pieces.

Class C: The other faults, such as misuse faults and secondary faults.

3. RELIABILITY EVALUATION OF THE INDUCTION MACHINE

3.1. Hazard model of the Electrical Machines

The curve of motor's fault rate vs. time is drawn as shown in fig.1. In this curve, the motor's life can be separated into three periods. Early failure period, constant failure period and wear-out failure period have been described in the curve. Over many years, and across a wide variety of mechanical and electrical component systems, people have calculated empirical population failure rates as unit's age over time and repeatedly obtained a graph as shown in fig.1. Because of the shape of this failure rate curve, it has become widely known as the "Bathtub" curve. The initial region that begins at time zero when a customer first begins to use the product is characterized by a high but rapidly decreasing failure rate. This region is known as the Early Failure Period (EFP). Next, the failure rate level off and remains roughly constant for (hopefully) the majority of the useful life of the product. This long period of a level failure rate is known as the Intrinsic Failure Period (IFP) and the constant failure rate level is called the Intrinsic Failure Rate (IFR). Finally, if units from the population remain in use long enough, the failure rate begins to increase as materials wear out and degradation failures occur at an ever increasing rate. This is the Wear-Out Failure Period (WOF) of the component. Hazard rate and failure chance of the mechanical component, electrical component and machines have been described using different curves as shown in the following curve [5].

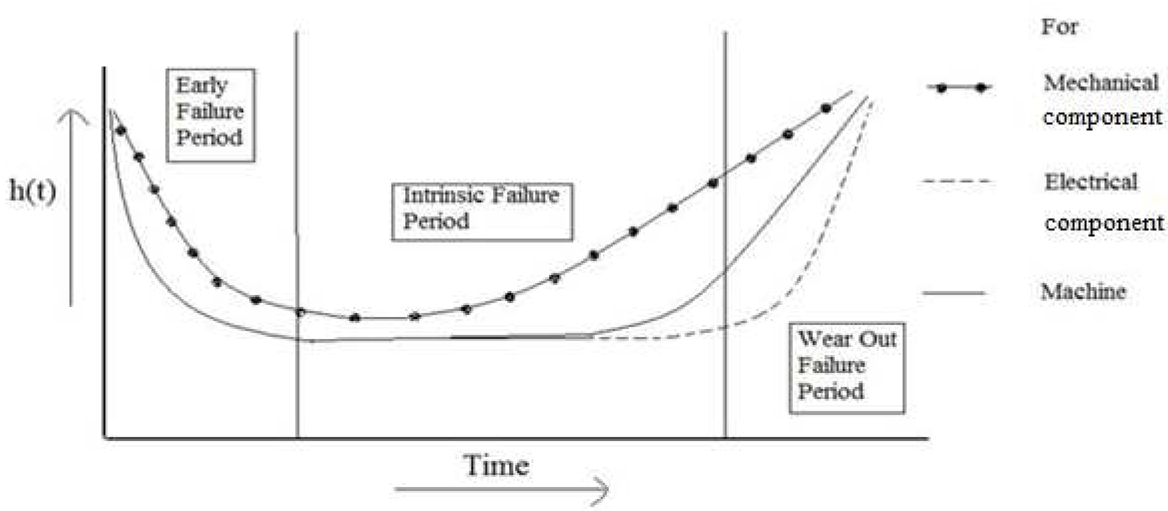

Fig. 1 Hazard model of the Electrical Machines

3.2. Reliability indices [5].

- The expected number of failures that will occur in a specified period of time
- The average time between failures
- The average duration or down time of a system or a device.
- The expected loss in revenue due to failure.
- The expected loss of output due to failure

3.3. Reliability Evaluation Techniques: Reliability evaluation technique steps involved are as follows [5]:

- Understand the way the system operates;
- Identify the ways in which it can fail;
- Deduce the consequence of the failures;
- Derive models to represent these characteristics;
- Select the reliability evaluation technique.

3.4. Methods of Determining Motor Reliability

The following methods have been employed over the years to determine the MTBF [7]:

1) Conduct life testing in a controlled laboratory environment over an extended period of time
2) Field-test a large population of motors over an extended period of time in a number of different environments
3) Use empirical data from a sufficient field sample size to conduct a statistical analysis
4) Conduct a failure mode affects analysis (FMEA) on a new design and compare with existing designs that have proven field performance that can be used as a benchmark
5) analyse field failures and warranty data after units have been in operation long enough to return meaningful data.

3.5. Algorithm

- **Step 1:** Calculate the Machine Parameters, Source Voltage and Current, p.f. of load, Synchronous speed test data etc.
- **Step 2:** Solve the circuit model of Induction motor by using Nodal Admittance Method or Loop Impedance Method
- **Step 3:** Determine the Torque - speed curve.
- **Step 4:** By using the Torque - speed curve (T v/s w), determine T.
- **Step 5:** Store the relevant data in data file.
- **Step 6:** By using the values of the above calculated parameters, various characteristics that yield to the machine performance are obtained.
- **Step 7:** Find the reliability of the performance of Induction machine using following method.
- **Step 8:** Stop.

4. THE METHODS FOR THE RELIABILITY COMPLIANCE TEST OF INDUCTION MACHINES [6]

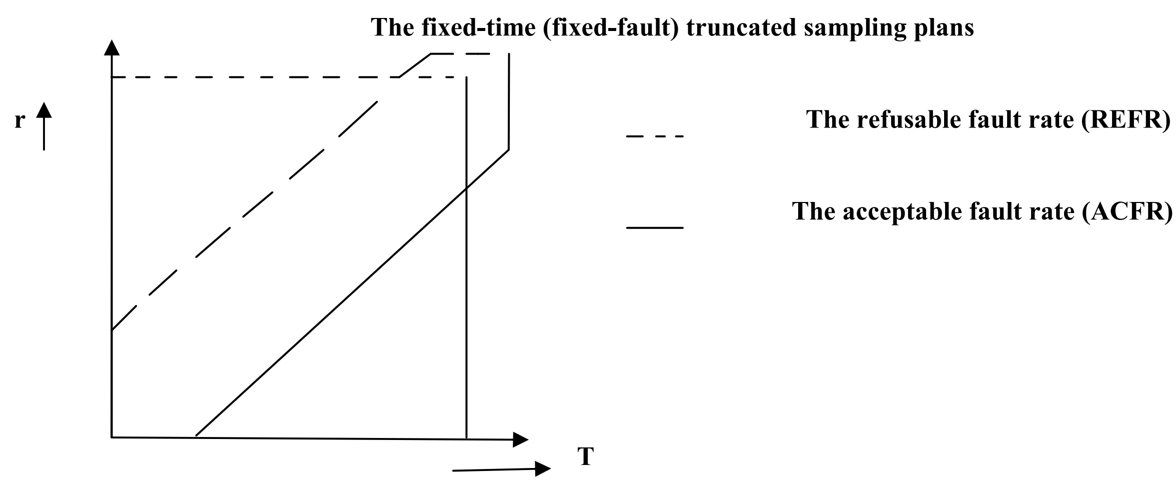

Fig. 2 Comparison of the two methods for reliability compliance test of Induction machine

4.1. The refusable fault rate (REFR) and the acceptable fault rate (ACFR)

Find the reliability of the motor has been described in the section as follows, whether the motor is conformity or nonconformity [6].

Observed the accumulated operation time between two faults

- If the time is long (>>ACFR), Then the motor is conformity; (ACFR)
- If the time is short (<<REFR), Then the motor is nonconformity; (REFR)
- If the time is situated between ACFR and REFR, the test must be continuing.

The ACFR and REFR for an Induction Machines as follow:

Let

The producer's risk = α,

Consumer's risk = β,

Acceptable MTBF = μ_0,

Refusable MTBF = μ_1

The operation time = *t*

The nonconformity rate = p

Choosing *n* samples from *N* products randomly, then the probability of the faults number will be

$$Pr = \frac{e^{-np}(np)^r}{r!} \tag{1}$$

Summing that the sample's life obeys Single-Parameter Exponential Distribution (SPED), and letting the fault rate be λ, the accumulated operation time be *T*, then

$$\mathrm{Pr} = \frac{e^{-n\lambda t}(n\lambda t)^r}{r!} = \frac{e^{-\lambda t}(\lambda t)^r}{r!} = \frac{e^{-\frac{T}{\mu}}\left(\frac{T}{\mu}\right)^r}{r!} \tag{2}$$

$$\frac{P_{r1}}{P_{r0}} = e^{-\left(\mu_1^{-1}-\mu_0^{-1}\right)T}\left(\frac{\mu_0}{\mu_1}\right)^r \tag{3}$$

Let $A = (1-\beta)/\alpha$, $B = \beta/(1-\alpha)$ then, if $Pr_1/Pr_0 \geq A$, it will be refused; if $Pr_1/Pr_0 \leq B$, It will be accepted;

And if $A > Pr_1/Pr_0 > B$, the test will be continued. Thus, the condition of continuing test is

$$B < (\mu_0/\mu_1)^r e^{-\left(\mu_1^{-1}-\mu_0^{-1}\right)T} < A,$$

$$lnB < rln(\mu_0/\mu_1)^r - \left(\mu_1^{-1} - \mu_0^{-1}\right)T < A$$

$$\frac{-lnA + rln(\mu_0/\mu_1)}{\mu_1^{-1}-\mu_0^{-1}} < T < \frac{-lnB + rln(\mu_0/\mu_1)}{\mu_1^{-1}-\mu_0^{-1}}$$

Let

$$h_0 = \frac{-lnB}{\mu_1^{-1} - \mu_0^{-1}},\ h_1 = \frac{-lnA}{\mu_1^{-1} - \mu_0^{-1}},\ \text{and } S = \frac{ln(\mu_0/\mu_1)}{\mu_1^{-1} - \mu_0^{-1}}$$

Then,

$$-h_{1+sr} < T < h_{0+sr} \tag{4}$$

It means that, up to the number *r* fault happening, if $T \geq (h_0 + sr)$, the products will be accepted, and if $T \leq (-h_1 + sr)$, the products will be refused. To avoid too long test time, we define a fixed-fault number r_0, stipulate that if the time up to number r_0 fault happen is shorter than $(h_0 + sr_0)$, the test will be stop and the products will be refused.

5. CONCLUSION

The hazard models of the mechanical component, electrical component and machine have been described to solve the different methods of the reliability. Various steps involved in the reliability evaluation of the induction machines have been illustrated successfully in this paper. The fault modes and effects are critically analysised with fault evidence establishment. The reliability of the motor has been discussed, whether the motor is conformity (ACFR) or nonconformity (REFR). Future work is proposed to evaluate the reliability of the Self Excited Induction Generator with various comparisons of the practical results to achieve the desired reliability.

6. ACKNOWLEDGEMENTS

Authors are grateful to Electrical Engineering Department, Institute of Technology, Banaras Hindu University, Varanasi (India) for providing necessary facilities and peaceful environment to complete this research work. Author's presents humble thanks to Khushi and Siddhant for providing emotional happiness and encouragement to complete this manuscript in its present shape.

7. REFERENCES

[1]. R. K. Saket (2011); "Reliability Evaluation of Defence Support Systems", Book Title: Innovations in Defence Support Systems: 2, ISBN: 978-3-642-17763-7, Socio-Technical Systems Series: Studies in Computational Intelligence, Vol. 338, pp: 239-284, First edition, Edited by: Dr. Lakhmi C. Jain; Aidman, Eugene; Abeynayake, Canicious; University of South Australia, Australia, Springer-Verlag, Berlin (Germany) and Heidelberg GmbH & Co. K, Publication date: February 09, 2011. Web site: http://www.springer.com/engineering/books

[2]. Saket, R. K. and Anand Kumar, K. S. (2006), "Hybrid Micro Hydro Power Generation using Municipal Waste Water and its Reliability Evaluation", In proceeding of the Greater Mekong Sub region Academic and Research Network (GMSARN) International Conference-6-7 December 2006 on Sustainable Development: Issues and Prospects for the Greater Mekong Sub region, Asian Institute of Technology, Bangkok, Thailand, pp: 13-20, http://www.gmsarn.ait.ac.th

[3]. Dr. Saket, R.K.; Dr. Bansal, R.C. and Anand Kumar, K.S. (2007); "Reliability Evaluation of Micro Hydro Photo Voltaic Hybrid Power Generation using municipal waste water", GMSARN International Journal on sustainable Development: Issues and prospects for the Greater Mekong Sub-region, Klong Luang, Pathumthani, Thailand, First issue of the Biannual journal, June 2007, vol.1, No:1, pp:13-20, http://www.gmsarn.ait.ac.th

[4]. R. K. Saket (2008); "Design, Development and Reliability Evaluation of Micro Hydro Power Generation System Based on Municipal Waste Water", In proceedings of the IEEE Electrical Power and Energy International Conference: 2008 (EPEC 2008), IEEE Canada and IEEE Vancouver Section, The University of British Columbia, Vancouver, BC Canada, V6T1Z4, British Columbia, 6 - 7 October, 2008, pp: 01-08, DOI: 10.1109 / EPC. 2008. 4763355, Web-Site: http://www.ieeexplore.ieee.org .

[5]. R. Billinton and Ronald N. Allan, "Reliability Evaluation of Engineering Systems: Concepts and Techniques", Second Edition, Springer-verlag, Berlin (Germany).

[6]. Fang Youtong, Fan Chengzhi and Ye Yunyuel Zhu Ziqiang (2003), "The Reliability Compliance Test of Induction Machines" In proceedings of the Electric Machines and Drives Conference, IEEE International , 2003, vol.3,pp.1629-1632, http://www.ieeexplore.ieee.org

[7]. Austin H. Bonnett and Chuck yung (2008), "Increased Efficiency versus Increased Reliability A comparison of pre-EPAct, EPAct, and premium-efficient motors", IEEE Industry Applications Magazine, Jan 2008, pp.29-36.