A Risk Reduction Worth Index for Sensitivity Analysis of Motor Protection System Components

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Abstract: Adequate operations of motor protection system plays a key role in judging the performance of the electric motor. The system components were connected both in series and in parallel. The two components connected in series were available for correct system operation. In this paper, the availability, unavailability, failure rates and risk reduction worth index (RRWI) of four different protection system components: circuit breaker, differential relays, RTD and DC were computed using appropriate mathematical notations. Results of the work showed that by increasing the unavailability of the breaker from 0.931387 to 0.946326, the annual down-time increased from 13.38hr/yr to 16.76hr/yr. In addition, by increasing the failure rate from 0.0031036 to 0.0031347, the RRWI increased from 1.109312 to 1.116328.By decreasing the unavailability of the differential relay from 6.00×10^{-4} to 4.00×10^{4}, the annual down-time increased from 16.12hr/yr to 14.31hr/yr while increasing the failure rate from 0.0042133 to 0.00451314 leads to a corresponding increase in RRWI from 1.0429416 to 1.0631061.For the RTD, increasing the unavailability from 0.00007 to0.000028 , lead to an increase in the annual down-time from 13.1hr/yr to 17.3hr/yr with a corresponding increase in RRWI from 1.031421 to 1.1723104 when the failure rate of the RTD was increased from 0.003181 to 0.003317.The annual down-time of the DC increased from 16.38sec to 17.62sec when the DC unavailability increased from 2.0×10^{-5} to 8.0×10^{5} even though as the failure rate of the DC increased from 0.0046318 to 0.0048163, the RRWI increased sharply from 1.0268713 to 1.03810934. The RRWI, annual down-time and failure rate of motor protection system increase by increasing protection components unavailability. Circuit breaker is the most effective component among motor protection system components. The RRWI will form a sound basis for judging the sensitivity of motor protection system which will help to prolong their lifespan.

Keywords: Risk Reduction Worth Index, Availability, Unavailability, Failure Rate, Circuit Breakers, Differential Relay

I. INTRODUCTION

Maintaining reliability of electrical motors on desirable level will improve the optimal performance of the plant. Appropriate operation of protection system can significantly reduce electrical motor failures (Nituca 2013, Fot 2010, Hong *et al* 2006). Maintenance and routine tests are necessary to maximize the protection system availability and minimize the protection system unavailability (Gleichman 2012, Kumm *et al* 2010, Illinton *et al* 2013).

Motor Protection

Electrical motors are usually associated with operating limits. Overshooting these limits will eventually destroy it and the systems it drives, the immediate effect being operation shutdown and losses (Chiriac 2012, Weak and Molinski 2004, Zhi and Habetler 2005,Nadgi *et al* 2011, Schweitzer *et al* 2007).

Electrical: This includes power surges, voltage drops, unbalance and phase losses causing vibrations in the absorbed current; shot circuits where the current can reach levels that can destroy the receiver (Zocholl 2006, Zhi and Golby 2008, Vico and Allcock 2011, Khederzadeh 2006, Sanaye-Pasand *et al* 2013).

Mechanical: This includes rotor stalling momentary or prolonged overloads, increasing the current absorbed by the motor and dangerously heating its windings (Tsun-Yu and Chan-Nan 2013, Robinson *et al* 2004, Crossleg and Pugh 2013).

The loss of these incidents can be high. It includes production loss, loss of new materials, and repair of the production equipment, non-quality production and delivery delays (Schweitzer and Zochull 2013). The economic necessity for businesses to be more competitive implies reducing the cost and hence, reducing the cost of discontinuous output and non-quality (Pinjia and Yi 2014, Cantemir and Nituan 2011, Mittra and Chattenjee 2010, Abous-El-Ela and Megahed 2006).

These incidents can also have a serious impact on the safety of people in direct or indirect contact with the motor. Protection is necessary to overcome these incidents or at least mitigate their impact and prevent them from causing damage to equipment and disturbing the power supply. It isolates the equipment from the mains power by means of a breaking device which detects and measures electrical waveforms, voltage, current e.t.c. (Zocholl and Schweitler 2004, Whatey and Lauter 2008, Khederzadeh 2007).

Every starter motor unit should include protection against short circuits, to detect and break abnormal currents usually ten times greater than the rated current and includes protection against overloads to detect current increase up to about 10 RC and open the power circuit before the motor heat up, damaging the insulation..

These protections are ensured by special devices such as fuses, circuit breakers and overload relays or by integral devices with a range of protectors (Kawase and Ichihashi 2009, Valenzuela and Regel 2010, Seyedi *et al* 2006).

II. MATERIALS AND METHODS

Mathematical Modelling of Protection System Components

Four protection system components- Circuit breakers, Differential relays, RTD and DC were modelled mathematically to establish their sensitivities on the risk reduction worth index.

Consider a system component arranged in series or parallel mode. For a system with two components connected in series, both of them must be available for correct system operation.

The system availability

$$A_{System} = 1 - A_B \times A_C \quad (1)$$

The system Unavailability

$$U_{System} = 1 - A_{System} = U_B + U_C - U_B \times U_C \quad (2)$$

$$U_{System} = U_B \times U_C$$

$$A_{System} = 1 - U_{System} = A_B + A_C - A_B \times A_C \quad (3)$$

The annual Downtime is

$$A_d = U_{System} \times 8760\ (hr/yr) \quad (4)$$

$$U_{System} = \frac{1+e^{(-\lambda T_1)}-1}{\lambda T_1} \quad (5)$$

$$\lambda = F(U_{System}, T_1) \quad (6)$$

The Risk Reduction Worth Index (RRWI) is given by

$$I_i^{RRW} = \frac{U_S[U_{base}]}{U_S[U_{base}/U_i=0]} \quad (7)$$

Thus, $U_S[U_{base}]$ and $U_S[U_{base}/U_i = 0]$ show the system unavailability when component 'i' is not perfect reliable.

III. DISCUSSION OF RESULTS

The availability and unavailability of the breaker system increased and decreased from 0.931387 and 0.068613 to 0.946326 and 0.053674 respectively with a corresponding increase in the annual downtime from 13.38hr/yr to 16.76hr/yr justifying the breaker unavailability that was on increase at this period. Even though, the breaker failure rate has appreciably increased from 0.0031036 to 0.0031347, the risk reduction worth index followed similar trend by increasing from 1.109312 to 1.116328 as shown in Figure 1.

For the differential relay, the unavailability changed appreciably from 0.0006 to 0.0004, thus representing a 30% decrease of these parameters. In this case, the availability also changed from 0.9994 to 0.9996, thus representing 30% increase. The annual downtimes of the relay decreased sharply from 16.12hr/yr to 14.31hr/yr indicating a prompt maintenance action on the relay in order to prolong their lifespan. The RRWI for the differential relay increased from 1.0429416 to 1.0631061 as a result of the failure rate of the relay that also increased from 0.0042133 to 0.00451314 as illustrated in Figure 2.

Figure 3 shows the relationship between the indices and the RTD.

The unavailability of RTD changed from 0.00007 to 0.000028 respectively while the availability appreciably changed from 0.99993 to 0.999972. The failure rate increased from 0.003181 to 0.003317 with an appreciable increase in the RRWI from 1.031421 to 1.1723104.

The correlation between the sensitivity and indices protection system component is shown in Figure 4.

The unavailability of the DC protection system component increased from 0.00002 to 0.00008 while the availability changed as well from 0.99998 to 0.99992 representing a 300% increase and 0.0006% decrease respectively with the DC protection system component failure at the rate of 0.0046318 to 0.0048163 representing a 3.97% increase in the failure rate with 2.17% increase in the RRWI. The RRWI is about 1.31times the lowest one. That means this component is the most effective components in the failure of motor protection in the manufacturing of circuit breakers. Effect of redundancy consideration in the protection of system components is necessary. If time delay over-current relay is considered as a back-up protection for instantaneous over-current relay, RRWI of over-current relay decreased by 5.3% more than the RRWI of the relay in motor protection system that do not have back-up protection.

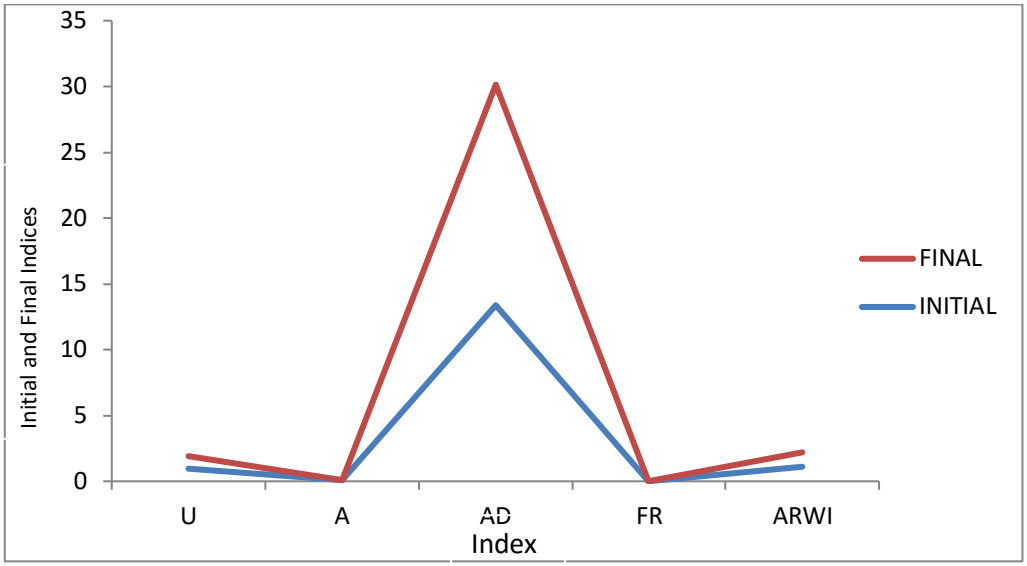

Figure 1: Initial and Final Breaker indices versus index

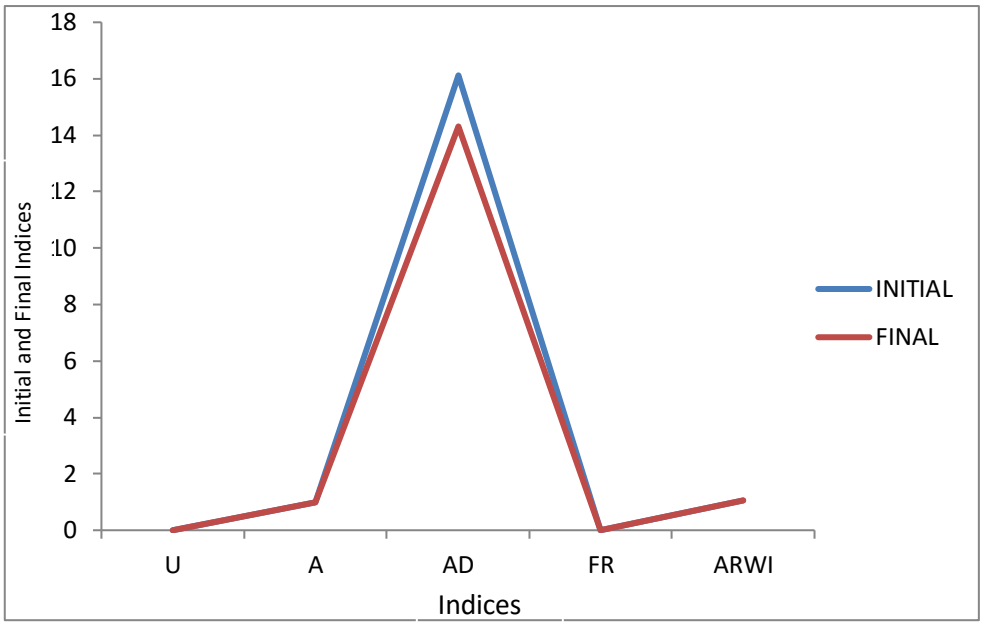

Figure 2: Initial and Final indices versus indices for Differential Relay

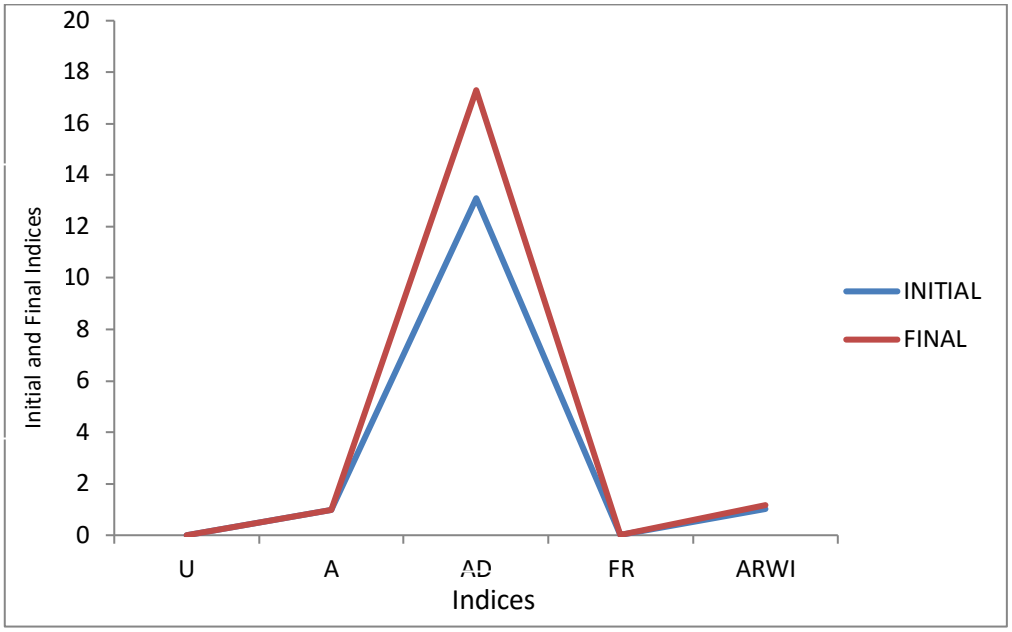

Figure 3: Initial and Final indices versus indices for RTD

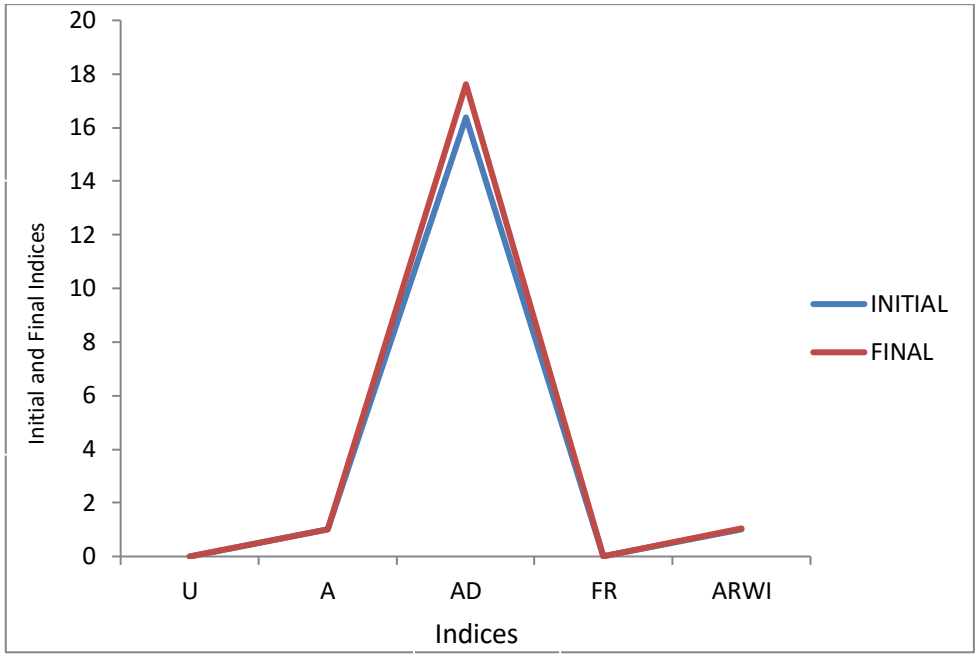

Figure 4: Initial and Final indices versus indices for DC

IV. CONCLUSION

Four selected protection system components – circuit breakers, differential relays, RTD and DC have used in the risk reduction worth index for the sensitivity analysis of electric motors while the effect of protecting system components have been investigated. By increasing the availability of the breaker from 0.931387 to 0.946326 the motor protection system failure rate and risk reduction worth index increased from 0.0031036 to 0.00031347 and 1.109312 to 1.116328 respectively while the annual downtimes also increased from 13.38hr/yr to 16.76hr/yr representing a 23.1% increase.

The results of the paper showed that the circuit breaker is the most effective component among motor protection system components.

Conflict of Interest: The authors declare that they have no conflict of interest.

Ethical Statement: The authors declare that they have followed ethical responsibilities.

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