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Improving Industrial Three Phase Induction Motors Availability Using Protection Devices.

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ABSTRACT: Industries all over the world are established to produce items and make profits. One of the most common machines in industrial milieu is the AC induction motor which convert electrical energy into mechanical type. This has earned it an appellation of an Industrial workhorse. To make profits, there must be increase in production machines' availability. Electric motors impart rotating motions on production machineries and their breakdowns result to downtimes with resultant production loss. The paper highlights their constructional features and pinpoints their common problems. It was reiterated that voltage imbalance, overvoltage, under voltage, Shaft Overload, short circuit, phase failure and high winding temperatures are common pitfalls to avoid. Protective devices were suggested to counteract all impending faults. A simple Direct-on-line starter was included in order to demonstrate their selections.

Keywords — Availability, Motors, Protection, Starter, Overcurrent, Overload, Overheating.

I. INTRODUCTION

Some industrial processes are achieved through rotating machines; hence their availability or uptimes can never be waived aside by any industrial management. These machines impart rotating motions on the coupled machineries. Those machineries could be water pumps, chemical pumps, fuel pumps, blowing or extraction fans, boiler firing systems, heat exchangers, agitation systems and compressors. AC Induction motors are the most common electric motors being used in the industrial milieu. Apart from industrial usages, they also find their use in home appliances. Induction motors are simple, rugged, parade low cost of maintenance. All the aforementioned desirable characteristics allow industrial stakeholders to call them industrial workhorse [1]. There are various types available in the market; a single phase induction motor has two stator windings namely main windings and starting windings or auxiliary windings [2] and is powered by single phase supply while three phase unit is powered with three phase supply and comprises three stator windings hence allowing it to produce rotating magnetic field hence making it self-starting. By considering the foregoing, investment on their protections can never be overemphasized. The windings must be protected from Overvoltage, Overcurrent, Single phasing and windings' overheat [3].

II. CONSTRUCTIONAL FEATURES OF INDUCTION MOTORS

The two major components of an electric motor are stator and rotor, the former is the stationary or static part while the latter is the rotating component. The stator is made of slotted laminations produced from high grade steel sheets [4].Thus stator windings are embedded in the slots. On the other hand, rotor is made of slotted laminations made from ferromagnetic material; it can be wound rotor or squirrel cage type. In cage type, the rotor comprises series of conducting bars inserted into slots on its periphery and shorted by large shorting rings. It is the most common type due to its ruggedness and simplicity; it is said that about ninety percent of induction motors are the cage type [5]. A three phase wound rotor type has its rotor windings usually connected in star and their terminals connected to the slip rings on the motor shaft.

Figure 1: Three Phase Induction Motor

The rotor shaft are shorted through brushes riding on the slip rings [6]. The latter information makes them to require much maintenance and they are more expensive than the cage type. In three phase motor, three wires are

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connected to the stator windings, the phases are displaced from one another by 120^0 phase shift, they reach their maximum in sequence hence produces a anticlockwise rotating vectors. The ampere-turn or magnetomotive force generated produces proportional rotating magnetic field. This field induces electromotive force in the rotor winding; an act that causes current to flow in them with its commensurate field. Now we have two fields in the air gap between the stator and rotor. The interactions between the two results to a twisting force, the rotor of the motor rotates in the direction of the resultant torque.

III. SPECIFICATIONS OF INDUCTION MOTORS

They are procured using specifications based on the applications for which they are being acquired. A typical AC induction motor has a nameplate riveted on its enclosure. The information will enable engineers and technicians alike to select the correct motor for a particular task. They are helpful for preventive maintenance works. The information includes the rated terminal voltage, number of phases; three phase or single phase, the rated full load supply current, rated supply frequency, the output power in kW of Hp, power factor, speed in rpm, duty cycle: whether the motor drives its load for short time or continuous, efficiency, IP Rating,, the manufacturer's name, address of Manufacturer, date of manufacture and class of Insulation. For example a class F motor means the windings temperature should not exceed 155^0C [7]. Some motors have built-in thermal overload protection to avoid damage and breakdown of motors; hence, it has to be indicated on the nameplate.

IV. PROTECTION OF INDUCTION MOTORS

In industries, reduction in production targets is caused by breakdowns of machines. Generally, the acts of restoring the machines to their operative state, that is, corrective maintenance, depletes all resources and negatively impact on the corporate profit margins. All workers will be fed for coming to work doing nothing, water resources are used up with zero production, and electricity will be consumed for lightings and other office systems. The list of losses is endless. Induction motors are protected against over-current due to short circuits and ground faults, overload arising from mechanical or rotor overload, low terminal voltage, phase reversals and Phase failure or single phasing [3].

4.1 Over-current Protection

Over-current protection is put in place to protect electric motors, personnel, conductors and control circuits from excessive current. Stator windings conductors are enamelled coated so as to insulate them from adjacent conductors, any failure of the insulation will results to short circuit with its concomitant over-current. A short circuit protection system senses the current and disconnects the motor circuits from the power supply. Such devices can be fuses and circuit breakers. They are normally set to interrupt excess current in a shortest possible time by matching the rating with the current envisaged or adjust the setting devices on the casings.

Motors are started with higher starting current; hence fuses should not blow when switching ON. They are rated by current, voltage and time delay characteristics.

4.2 Overload Protection

Overload protection is deployed in order to protect the motor from being damaged as a result of mechanical overload while motor is running. Whenever there is overload on its shaft, an electrical overload comes; since the machine works in order to overcome the anomaly that usually come with a lull in the speed, more current is drawn from the mains which tends to increase the temperature of the windings due to I^2R losses. If this persists, the motor windings get burnt. Main causes of rotor overload are worn out bearings, poor alignment of the motor-and its driven machine, entanglement from foreign object and when the load carrying ability of the motor is exceeded. Some machines that have short duty cycle are operated continuously; this will result to an overload. Motors are protected by inserting overload relays in their main circuits, any deviation from their settings trigger their normally closed contact sets open. Since the latter are connected in control circuits, the main contactors de-energize thus disconnecting the motor from the mains supply. The relay has test, stop and Hand/Auto rest buttons.

Electric Motor windings get burnt if there is no overload protection, or incorrect overload relay is installed; likewise when the overload relay is set incorrectly [8].

4.3 Phase Failure Protection

This type of protection prevents the motor from being damaged as result of sudden loss of a phase while the motor is running. During single phasing, that is, when a phase is thrown off [3], remaining two windings works to sustain the

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rotation and compensate for the loss phase, the occurrence causes more current to flow in them with an attendant overheating in the motor windings. Fuses and overload relays are not usually enough to protect the circuits; hence a phase failure relay senses the loss of phase and disconnect the motor from the main supply since its controls circuits is wired through a contact set energized by an output relay.

Some of these relays also include protection for under-voltage, overvoltage, voltage unbalance, phase sequence failure and PTC protection. For a wrong phase sequence, the output relay in the device switches off thus opening the closed contact set wired in the control circuit and vice versa. A PTC protection incorporates thermistor that senses winding temperature, in the event winding temperature exceeds the limit temperature T_c of PTC, the output relay switches off instantly, thereby disabling main power to the electric motor.

V. STARTING INDUCTION MOTORS

Another name for three phase Induction motor is Asynchronous motor because its shaft rotates at a speed N_r other than synchronous speed N_s. Starters are used to start motors, they ensure that they continue to run, disconnect motors and provide means of protection against faults that may damage them. There are different methods of starting namely: Direct on line starting, Star-Delta starting, Auto transformer starting and Inductive reactor/resistor starting. The last three are reduced voltage starters; the most common of them is the Star Delta starter in which stator windings are initially connected star thereby reducing the initial starting inrush current, as the speed attain is working speed, the motor winding is removed from star and engaged in delta connection. At star, the voltage is reduced by a factor of $\sqrt{3}$ and current drawn is $\frac{1}{3}$ of the one to be drawn when connected in delta. A reduced current comes with lower start up torque which is $\frac{1}{3}$ of the delta. Engineers engage Star-Delta starters for motors in the range of 15kW to 355kW [9].

5.1 Example using Direct-on-Line (DOL) Motor Starting

A Direct-On-Line starter is normally engaged for small and medium power motor since they attain their full working speed in a short period. It consists three main lines (L_1, L_2, and L_3) directly to the motor terminals when the start button is pressed. The drawing of DOL starter comprises two separate stages. They are referred to as Main and Control circuits. Direct-On-Line starter method is the simplest and most commonly used method. [8] It does nothing to limit the starting current of the motor. However, it provides means of protecting the induction motor connected to its terminals. When the isolator is switched ON, the power is delivered to the 1-3-5 terminals of the contactor. Figure 2. The unit has 3-poles and one normally opened contact with 380V operating coil. As the start button is depressed, the contactor operating coil receives 380V across it through pin 5, stop button, overload normally closed contact set, and phase failure relay contact normally closed contact set. This energizes the contactor and closes its poles contacts.

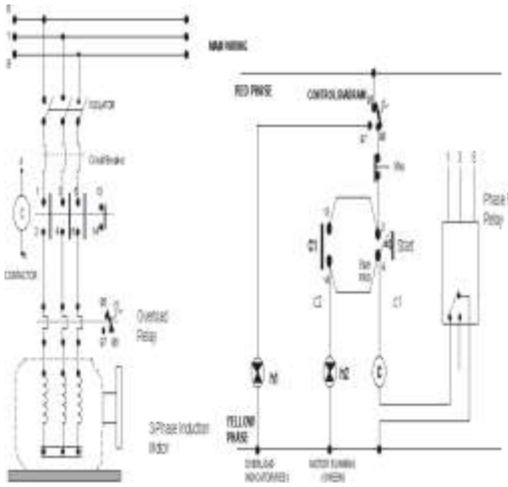

Figure 2: A Direct-On-Line Starter with Protection Devices

In the event of excess current due to shorts circuit or earth fault, the fuse elements rupture, also if there is any shaft overload, overload currents flows which opens overload relay's normally close contact set, any phase reversal, low voltage or imbalance and loss of phase will be tackled by the phase failure relay. All the aforementioned removes power from the operating coil thereby de-energizing it, an act that removes power from the motor's terminals.
The action delivers power to the induction motors terminals thus causing its rotors rotating.

5.2 Selection of Contactor

The International Electro-technical Commission IEC standard IEC60947-4-1 defines a contactor as mechanical switching device having only one position of rest, operated otherwise than by hand, capable of making carrying and breaking currents under normal circuit conditions including operating overload conditions. A simple guide for its selection:

.$P_{motor} = \sqrt{3}\ V_L I_L \cos\varphi$ = 5kW, Power factor = Cos φ = 0.85. V_L = 380V

$$I_L = \frac{P_{motor}}{\sqrt{3}\ V_L \cos\varphi} = \frac{5kW}{\sqrt{3} \times 380 \times 0.85} = 8.94A,$$

Contactor current rating, $I_{Contactor} \geq 9A$

5.3 Selection of an Overload Relay and Circuit Breaker

Generally Induction motors can cater for a 110 to 120% overload [8]. A suitable overload relay with current range of 7-10A is recommended. Staring current of motors are higher than the running current because motor shaft is expected to overcome a state of rest . Sometimes it can be as high as 500% of their running value. Engineers are expected to set the current threshold to a value that will not allow undesired cut off as a result of peak in current and at the same time think about quick operation of the device in case of fault. In all, it is expedient to have a compromise between the two reasons; however, , the response level has to be set a little above the maximum starting current while a tripping must be delayed by 50mS. [10]. By procuring circuit breakers with setting positions on them, one can practically set the tripping thresholds at installation. Using fixed set types like Miniature Circuit Breakers, one with a factor of four of the running current can be selected. $I_{setting} \cong 4 \times I_L = 4 \times 9A = 36$ A. Any 3 poles, 40A Miniature Circuit Breaker will serve.

5.4 Selection of Phase Failure Relay

Those available in the market are microcontroller controlled which offers phase failure protection, voltage unbalance, phase sequence, Auto/Manual reset, adjustable unbalance setting and two change- over output relay with working voltage ranging from 380V-440VAC

The knowledge of its change over contact sets and inclusion of Auto/Manual reset are watchwords when selecting them.

VI. CONCLUSION

In addition to the foregoing, the importance of preventive maintenance can never be waived aside, it should be understood that good maintenance system will help to prevent breakdowns and also predicts an impending trouble. Deployment of 5S concepts which are Japanese words starting with S (Seiri- sort out, Seiton-tidy up, Seiso-cleaning, seiketsu-standardize and shitsuke-self discipline)[11] along with Total Productive Maintenance (TPM) methodology that involve production workers in maintenance of their machines; also, being a proactive system that corrects anomalies at symptoms level can be helpful in preventing critical breakdowns thus allowing improvement in the production machines availability [12] Any fault trip should be investigated before reset of the particular protection device.

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