

# ***PROTECTIVE DEVICE FOR PUMPS / MOTORS***

Every year, more than 20% of electric motors installed burnout around the world. This is in spite of protection systems being provided. This proves inadequacy of selected protection systems. In most cases, the reasons for pumping system failure are other than the pumping system itself. These include improper selection of pump, improper handling of the system, and improper selection of protective devices. This paper deals with the selection of protective devices.

The protective device for the pump is the heart of the total system. Great care is needed while making an appropriate selection of the same.

Different kinds of protective relays are available to perform different functions. It is important that a proper protective device is selected for desired function. Incorrect selection of protective devices can lead to the notion that these are not fulfilling their intended functions.

## **Need for Pump Protection :**

The need for protective devices cannot be emphasized enough. It is difficult to imagine a pumping system without providing for proper protection against various hazards.

Pumps employing 3-phase motors as prime movers are required to be protected from burning. The major causes of motor burn-outs are :

- a) Phase Failure (Single Phasing) or loss of one phase.
- b) Unbalanced supply.
- c) Dry running
- d) Overloading
- e) Over heating of windings.
- f) Under / Over Voltage.

Specialized protections like against moisture, earth leakage, bearing failure etc. may also be required for some pumps.

PHASE FAILURE causes burning of motors. Due to fuse failure, loose connections or loss of phase supply, one of the supply lines to the motor becomes dead. However, the motors continue to run on two phases, drawing heavy currents, and burnout.

REVERSE RUNNING of pumps and certain machines due to wrong connections or reverse phase sequence endangers the motor and consequently the machine.

UNBALANCED SUPPLY generates double frequency currents in the motor windings causing overheating. Unbalanced supply voltage produces heavy negative sequence currents. These are double frequency components of supply. They increase rotor resistance due to skin effect. Overheating of motor winding due to this, is unevenly distributed over the rotor. This leads to insulation breakdown.

\*UNDER VOLTAGE overloads the motors in continuous running and is particularly dangerous while starting. Motor draws more currents at reduced voltages, RPM, Torque and Power reduce due to under voltage.

\* DRY RUNNING is equally dangerous for submersible pumps. Motors of submersible pumps are designed for running under water. They use water as a heat-transfer medium. In case the water level goes down and the pump runs dry, the motor gets overheated and burns out. Due to such dry running the bearing temperature also increases, damaging the bearing and the surrounding portion of the pump.

\*OVER LOADING is also one major cause of motor burning. It may occur due to phase failure condition, dry running condition or direct overloading condition of the pump. Overloading causes increase in currents, this in turn results in insulation failure.

Any pump used for transfer of water should stop working if it is running empty. This may happen if the water level is lower than the inlet valve; the suction pipe is leaking and has picked up air; or the pump is started without priming (in case of pumps requiring priming) etc. In such conditions the pump should stop immediately even though continued running may not be hazardous to the pump.

In majority cases, however, a bimetal (thermal) overload relay is relied upon for pump protection. When electronic phase failure relay is used for protection, it again generally is a voltage sensing relay. It is mostly preferred as it is suitable for motors of any HP rating and hence inventory or stocking is not a problem. However, these relays suffer from many disadvantages and limitations as compared to current sensing relays.

### PROTECTION BY THERMAL OVERLOAD RELAY

Thermal overload relays with built-in phase failure protection offer protection only if the phase failure occurs at 100% loading of the motor. Moreover, the trip delay is over 10-15 seconds. When the motor is partially loaded the trip time delay increases further and if the motor is loaded below 60% the overload relay will not trip on phase failure. Following will illustrate limitations of thermal (bimetal) overload relay for protection against single phasing.

Under the circumstances, during single phasing when supply is available only in L1 & L3 (ref. Fig. No. 1) the currents taken by the windings A, B & C of a delta connected motor and the behavior of the bimetallic relay are approximately as follows :

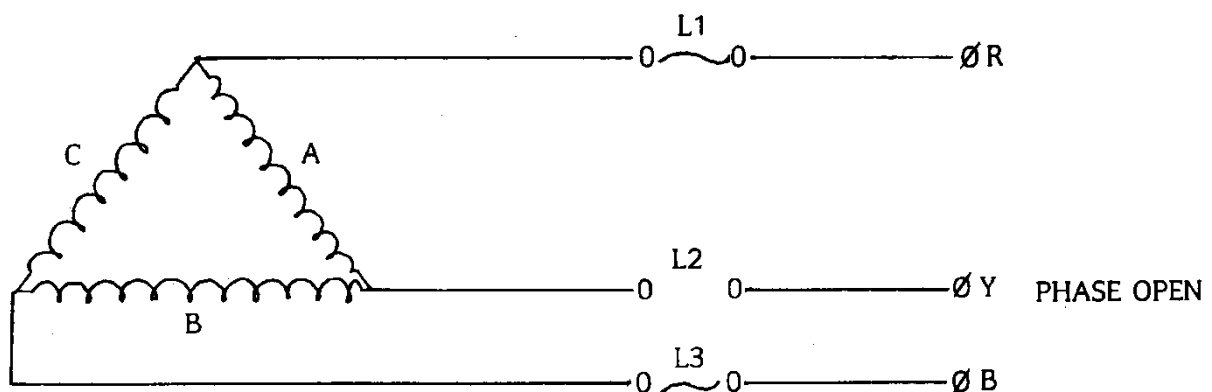


Fig. No. - 1

% of Rated Full Load on the Motor	Line Current in sound Phases L1 & L3	Phase Current in series Windings A & B	Phase Current in winding C	Remarks
<b>EXPRESSED AS % OF RATED FULL LOAD CURRENT</b>				
50%	80%	50%	110%	Bimetallic relay doesn't operate. However, motor may not burn
57%	95%	58%	120%	Line current is less than rated current. Winding C is overload. Bi-metal relay doesn't trip. Motor may burn.
75%	150%	85%	180%	Line current exceeds rated value. Winding C highly overloaded. Bi-metal relay may operate. But not in time to prevent damage to motor.
100%	240%	130%	280%	Extent of overload being very high Bi-metal should operate quickly and save the motor.

It will be seen that the bi-metal relay connected to the line and set for the rated load of the motor doesn't offer any protection during single phasing if the "actual load" on the motor is below about 75% to 80% of the rated load. At the same time to ensure reliable operation on load, the setting of the relay cannot be made lower than that the load permits under normal conditions. Thus reliance for protection during single phasing cannot always be placed on bimetallic relays.

Further, the overload relay cannot operate efficiently under phase failure conditions. During unbalanced conditions as well as during phase failure, the negative sequence components in the supply increase abnormally. These are double frequency components and are the root cause of winding overheating. Thermal overload relays cannot detect the presence or increase in the value of negative sequence components. These negative components will rise abnormally during unbalanced conditions as well as during phase failure conditions, even if they occur at NO LOAD condition of the motor.

## OVERLOADING PROTECTION

Due to the variable thermal-withstanding characteristics of different motors, overload protection for the motor must necessarily match its thermal – withstanding characteristics. In case of thermal overload it is not possible to select a particular characteristic, since only one fixed characteristic is provided. Because of a single operating characteristic of thermal overload relay, it will fail to protect motors requiring precise and quicker overload protection (like Hermetically Sealed / Semi

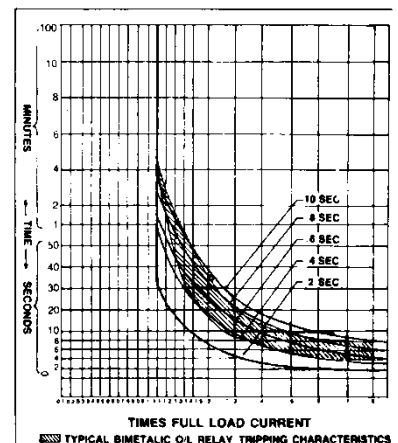


Fig No. 2

Sealed Compressor motors). It will also trip some motors unnecessarily much early, even though they can sustain even larger overloading conditions for longer times. By using an electronic overload relay, it is possible to match the motor's characteristics perfectly to ensure its optimum utilization.

## **LIMITATIONS OF VOLTAGE SENSING PHASE FAILURE RELAYS**

First, they offer protection against phase failure faults occurring from the incoming side up to sensing points only. Normally these devices are used alongwith the starter and hence sensing to these relays is normally taken from the outgoing terminals of the starter. From these points up to the motor terminals, a cable of variable length is used. From the submersible pump this cable is a minimum of 100 meters in length. If any fault develops along this cable length or at the motor terminals of the cable, the voltage sensing phase failure relay will not trip the starter and the motor will remain unprotected.

In case of phase failure faults, every motor generates back e.m.f. on phase failure condition. This happens even if the phase failure occurs during the running of the motor, the motor continues to run on the two remaining phases and acts as a generator rather than a motor and generates voltage which is fed back to the 3<sup>rd</sup> phase. Sometimes, this back e.m.f. is almost equivalent to the incoming supply voltage. Under such conditions, where very high e.m.f. is generated by the motors, the voltage sensing phase failure relay cannot offer any protection.

Similarly, when power factor correction capacitors are used, voltage sensing phase failure relay does not offer adequate protection. These capacitors are connected across the motor windings and are fully charged to the supply voltage. In case of phase failure the capacitor has to discharge sufficiently to create unbalanced condition to ensure the operation of the phase failure relay, and under such conditions, delayed tripping of phase failure relays is observed.

Because of the above limitations, voltage sensing phase failure relays cannot be considered as perfect protection devices for the motor. As against this, current sensing phase failure relays have no such limitations, and they offer full proof protection during all the above conditions. Since all other switch gear items like cable, terminal strip contactor, overload relay, fuses etc. are selected according to the HP rating of the motor, it is very easy to select the proper current sensing phase failure relay.

## **CONCLUSIONS**

A relay combining both current sensing and voltage sensing operating principle can satisfactorily cover the basic protection requirements, by doing away with limitations.

Microprocessor based protection relays may have such better protection level compared to solid state relays. This is because of facilities available for parameter settings as per site conditions. In addition, it may be programmable to take sensing from additional inputs like winding temperature, pressure, vibration, condition monitoring etc.

## **UNDER/ OVER VOLTAGE PROTECTION**

Low Voltage compels electric motor to draw more current in order to deliver required power. This creates overloading condition. Moreover, power output, RPM and torque of the motor also drop considerable at low voltage ( $T \propto V^2$ ; a change of 5% in supply voltage will cause about 10% change in rotor torque, if V decreases, then T also decreases. Hence, for maintaining same torque, slip increases and speed falls). To a limited extent torque can be improved by improving power factor, by adding external resistance in rotor circuit. This could be effective during starting of AC induction motor, but is ineffective during running. Beyond the max. limit of torque, torque and speed continue to decrease as slip increases which eventually leads to zero speed i.e. "locked rotor condition".

In case of high voltage, there is a field effect on the motor windings. Higher value of voltage will cause rupturing of insulation and leading to burnout. Dielectric strength of the insulating material reduces with temperature rise.

It is therefore essential that under/over voltage protection should have inverse time characteristics, so that there will be definite tripping at all varying voltage values. A protection relay with flat characteristics will not be able to protect motor perfectly.

## DRY RUNNING PROTECTION

For protection against dry running a sensing prod is used. It is positioned inside the bore, slightly above the level of the pump. When the water level on the bore drops lower than then the sensing prod, it is expected to trip the starter. However, this does not happen because of many problems like :

- 1) Corrosion of the prod after a certain period due to moist atmosphere leading to loss of sensitivity.
- 2) Incorrect dry-run signal due to formation of water film around the prod.
- 3) Incorrect continuity signal resulting from a humid and moist atmosphere around the prod, due to water yield from the top even if the water level is very low.
- 4) Failure of water level guard due to the absence of proper earthing on the control panel.
- 5) Difficulty in taking out the pump for servicing due to –
  - a) Loosening of the prod from the terminals of breaking of the cable.
  - b) Prod getting stuck in the lining.
- 6) Installation of a water level guard is not possible without removing the pump set completely. In short this prod fails to function as a water level guard in most installations. Hence, it is not advisable to depend upon a device which employs a prod for its dry running protection.

Because of these limitations, normally the water level guard is by – passed immediately after commissioning of the pump and the pump is virtually denied dry running protection.

It is possible to offer protection against dry running by sensing the motor current which changes during dry running conditions or by sensing the motor current which changes during dry running conditions or by sensing the RPM of the motor and the water pressure which also change during dry running conditions. If suitable devices are used to sense the motor current or the motor RPM and water pressure, then it is possible to provide reliable protection against dry running. Sensing the water level in the borewell is also possible with capacitance based water level guards or an ultrasonic level detector.

## WINDING OVER – TEMPERATURE

It is a common practice to sense the winding temperature by PTC type thermistors which are embedded in the windings during motor manufacturing or re-winding process. The output leads of PTCs are connected to an electronic switching device. The PTC sensors are available for different temperature ratings from 60 Degree Centigrade to 180 degree Centigrade.

Appropriate temperature value of PTC is to be selected as per class of insulation of motors. PTC wire leads have standard colour codes to indicate its temperature (Ref. table)

PTC. TEMP (DEG. C.)	WINDING CLASS OF INSULATION	COLOUR CODE FOR SINGLE	COLOUR CODE FOR TRIPPLE PTC
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70	-	WHITE – BROWN	-
80	-	WHITE – WHITE	WHITE-WHITE-BLACK-WHITE
90	-	GREEN-GREEN	GREEN-GREEN-BLACK-GREEN
100	A	RED-RED	RED-RED-BLACK-RED
110	-	BROWN-BROWN	BROWN-BROWN-BLACK-BROWN
120	E	GREY-GREY	GREY-GREY-BLACK-GREY
130	B	BLUE-BLUE	BLUE-BLUE-BLACK-BLUE
140	-	WHITE-BLUE	WHITE-BLUE-BLUE-BLUE
150	F	BLACK-BLACK	BLACK-BLACK-WHITE-BLACK
160	-	BLUE-RED	BLUE-RED-RED-RED
170	H	WHITE-GREEN	WHITE-GREEN-GREEN-GREEN
180	C	WHITE-RED	-

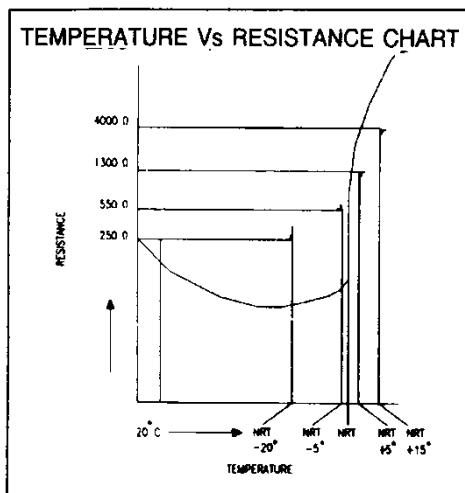


Fig No. 3

Normally for a 3 Phase motor, 3 PTC thermistors are used – one per phase. However, it is better to use two or 3 PTC thermistors per phase, so that they are placed at different locations inside the winding to detect temp. rise and hot spots.

When the motor temperature exceeds the PTC value (see Fig. No. 3) the resistance of the PTC changes drastically at the normal response temperature of the PTC and this change is sensed by the electronic switching device, causing tripping of the starter.

Oil-cooled pumps also need protection against excessive moisture. This protection can be offered by a moisture sensor which gives signals to the switching unit. However, this practice is not very widely used.

## STAR – TO – DELTA CHANGEOVER

It is a common practice to use Star delta starters for motors normally between 7.5 / 10 H. P. to 30/40 H. P. ratings, to reduce starting in-rush currents by applying reduced voltage to the motor windings during star connections. After certain time delay the configuration is expected to change over to delta connection in normal running.

This changeover from Star-to-delta is required to take place when the starting current of the motor has reduced to approx. 120% of the full load value or when the motor has attained around 80% of its speed. A thermal, pneumatic or electronic time delay relay is used to affect this changeover after a certain time delay from starting. For many applications of motors, particularly when motor is started at varying loading conditions, changeover with a fixed time delay is disastrous. The most appropriate way of changeover should be based on either sensing the current of the motor or sensing the speed of the motor since these parameters will vary at varying loads. Star-to-delta changeover is basically a current function and not a time function. Therefore, it is ideal to use a current sensing device to actuate star-to-delta changeover.

Following graph will illustrate the disadvantages of star to delta changeover by fixed time delay device; at the same time it would explain that a current dependent changeover device will always give the star delta changeover at an appropriate time when the current has reached the safe level.

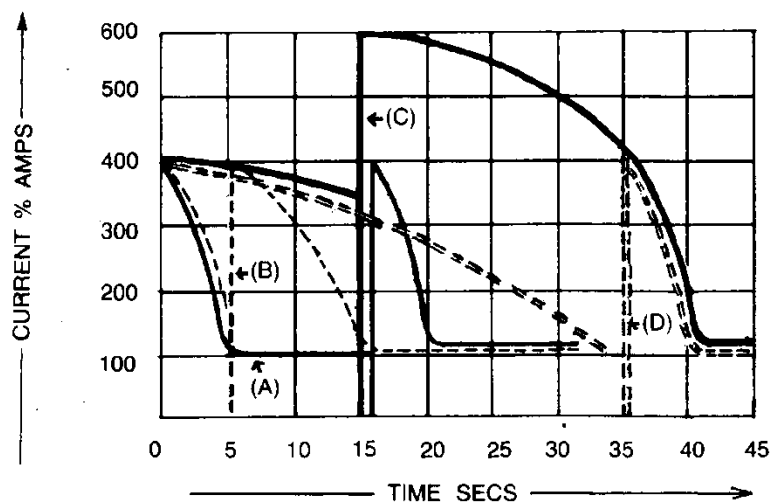


Fig. No. 3 (A)

In the above figure No. 3 (A) Graph 'C' is the curve of current when the star delta changeover has occurred prematurely (motor at full load) due to fixed time delay. A heavy current spike can be experienced because of this phenomenon. Graph 'B' and Graph 'D' explain how a current dependent changeover device will ensure the star-to-delta changeover at an appropriate current level thereby not allowing current to rise abnormally during changeover. Curve 'A' again explains the limitation of fixed timer for changeover, since motor is forced to run in star connection unnecessarily for some time.

### TYPE 'C' CO-ORDINATION

Normally in any switchboard or control panel board various switching and protecting devices like fuses, circuit breakers, contactors, overload relays, Earth Fault Relays, Voltage and Current relays are used. All these devices should be selected in such a fashion that their functions are collectively co-ordinated to achieve an optimum level of function from each of them. These devices should not trip the motor while running on rated load, drawing heavy starting currents for the permissible time or operating for permissible short time overload capacity and should continue to remain in safe operating limits without exceeding the temperature limits as well as getting damaged themselves. There is a decided sequence of tripping of each of these devices at a set amount of time for respective different faults.

Operation of a particular protective device is expected at the most appropriate time to ensure that not only the motor is protected from danger but also the other protective devices in the circuit are also not damaged. IEC 292 defines various requirements of co-ordination between the different protective devices when used in circuit. Out of these, Type 'C' co-ordination should be most preferred since it ensures that no damage occurs to the devices.

The selection of protective device should offer an appropriate protection so that the operating characteristics of different devices not only match but are properly co-ordinated. For example, in case of sustained overloads, the overload relay should operate to ensure that it does not damage itself in the process. Similarly, in case of short circuit the short circuit protection device should disconnect the supply before the overload protection device is damaged. Similar is true for other devices in the Circuit.

### PROTECTION MATRIX

The level of protection offered by different devices is shown in Figure No. 4. This can serve as a guideline while selecting an appropriate protection scheme for your applications.

**A COMPARATIVE CHART OF  
LEVEL OF PROTECTIONS OFFERED  
BY VARIOUS PROTECTION RELAYS  
V/S ABNORMAL OPERATING  
CONDITIONS.**

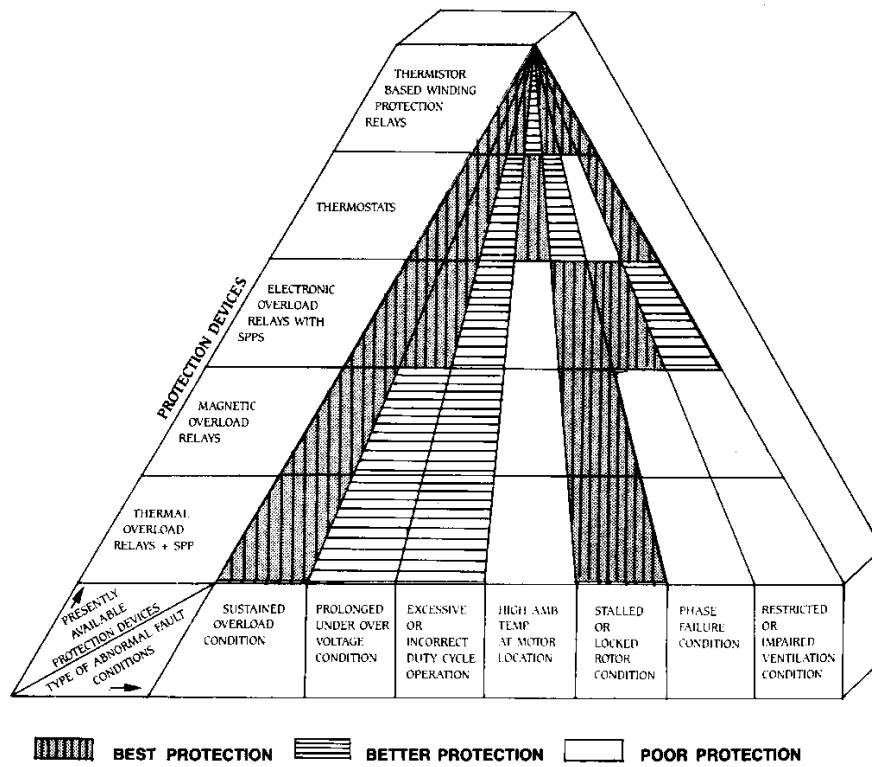


Fig No. 4

## CONCLUSION

The above discussion emphasizes that the selection of appropriate devices should bear the following points.

- a) It operates on the current sensing principle, for phase failure faults.
- b) It senses the negative sequence components of the supply.
- c) If under / over voltage protection is desired, it should have inverse time characteristic.
- d) It offers positive protection against phase failure even at NO – load condition.
- e) It offers protection against overloading according to the thermal – withstanding characteristics of the motor.
- f) Dry running protection is not based on sensing the water level directly by a sensor, but by means of indirect methods like sensing current, RPM of water pressure.
- g) If winding temperature protection is required, it should be through sufficient no. of PTC thermistors embedded in motor windings.

Protective device with the above characteristics will certainly lead to longer pump / motor life.

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