UPG
Technical Services

APPLICATION ENGINEERING
BULLETIN Number # AE-003-05

TOPIC: Three-Phase Voltage Imbalance[1]

SCOPE & PURPOSE:

- Three-Phase loads, blower motors and compressor motors in particular are prone to premature failure due to voltage and current imbalances. Many failed motors are replaced without determining the cause of the failure. Often the cause is due to voltage imbalance on the three-phase power. Imbalance may be located on the line (power system), in the wiring, at the contactor or starter or in the motor itself. This bulletin will explain 1) How to measure and calculate voltage imbalance. 2) The result of imbalance. 3) Steps to determining the exact cause of imbalance. 4) Solutions to imbalance.

CONTENT:

- What Imbalance Is:
  1. Three-phase power consists of three hot wires each having full line voltage with respect to the other two. These three voltages should be nearly if not exactly equal in voltage to each other. The voltages are measured and the imbalance is calculated in percent of voltage deviation from the average of the three measured voltages. It is generally accepted that any imbalance exceeding 3% is unacceptable and needs to be corrected.

- Results Of Voltage Imbalance:
  1. A voltage imbalance usually causes a corresponding current imbalance on the three power legs serving the motor. The major result of a voltage imbalance is motor overheating. This overheating may or may not be enough to cause

[1] Voltage imbalance cannot take place on single phase wiring systems. By definition imbalance refers to widely varying voltage measurement between each of the three legs of a three-phase power system.

motor protection devices to trip depending upon the location, quality and trip points of the protection devices.[2]

2. Motors operating with an imbalance may continue to operate at elevated motor winding temperatures. This in turn will reduce the life of the motor. In some cases the lifespan of the motor will be reduced to hours, in other cases to weeks or months or perhaps a few years when the motor could have served its intended purpose for many, many trouble free years.
3. Voltage imbalance can raise the motor winding temperature significantly. The winding temperature increases by 2 times the square of the percent imbalance as is illustrated in the following table.

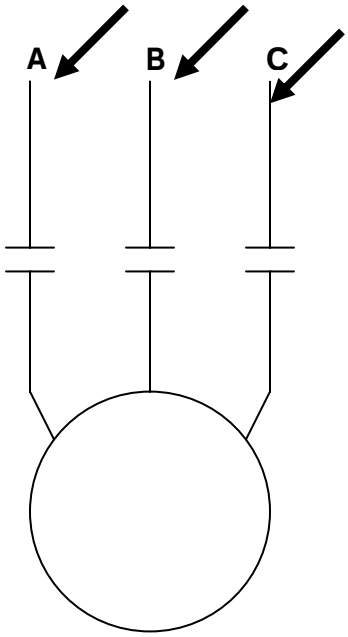
% Voltage Imbalance	% Motor Winding Temperature Increase
2%	8%
3%	18%
4%	32%
5%	50%
6%	72%
7%	98%
8%	128%

As the table shows, a small voltage imbalance will cause the motor windings to operate at highly elevated temperatures over normal thus reducing the motor life. Many motors and compressors have failed unnecessarily from this preventable condition. Checking voltage imbalance should be a regular part of service on three-phase motors.

- Voltage Measurements:
  1. Actual voltage measurements must be taken using a quality multimeter. Measure the actual voltage between each of the three-phase power legs. We will call each of the legs A, B & C for this illustration. You may mark the three legs with these letters or use colors. In any event, it will be necessary to be able to identify each of the three phases as they may need to be moved (rotated) later during the process of troubleshooting.
  2. Voltage measurements will be taken across legs A, B & C at several locations to determine if the imbalance exists only at the motor, below the motor contactor or starter, at the disconnect and at the service entrance.
  3. For example, if the imbalance exists at the motor (load) side of the starter but is not present on the line side of the starter the source of the imbalance is the starter.
  4. Additionally, a voltage drop across the contacts of the contactor or starter, as measured on a given leg from the line side of the contact to the load side of

[2] Standard motor overload protection commonly used in motor starters may not be sufficient protection against current and/or voltage imbalance. Solid state protection devices are available to protect against a number of concerns including voltage imbalance, phase reversal, over and undervoltage, single phasing as well as other unwanted conditions.

the contact indicates poor contact connections. Note that the contacts with a voltage drop across them when closed are definitely deficient however, contacts may still be in need of replacement even if a voltage across the contacts is not detected.



Measure the voltage from
A to B =
A to C =
B to C =

Add the three voltages and divide by three to determine the average voltage

To determine the percent of voltage imbalance use the following equation:[3]

% Voltage Imbalance = Maximum Deviation from the Average/Average X 100

As an example, a series of voltage readings are taken on the load side of a motor contactor with the following values.

A to B = 230
A to C = 232
B to C = 238

Adding these values and dividing by 3 gives the average voltage. Therefore, the sum of these values equals 700, divided by 3 yields **233.3 ave volts**.

The maximum deviation from the ave is the measured value furthest from the 233.3. The difference between 230 and 233.3 is 3.3 volts. The difference between 238 and 233.3 is 4.7 volts. Therefore, the **4.7** volt value is used in the equation as the value with the greatest deviation from the average.

% Voltage Imbalance = 4.7/233.3 X 100

The percent winding temperature rise due to voltage imbalance is calculated as follows;

% Temp Rise = $Imbal^2$ X 2

% Temp Rise = 2.01^2 X 2

% Temp Rise = 4.04 X 2

[3] Checking for voltage imbalance both under load (with the motor operating) and with no load (motor off) may also provide useful information as to the caus of the imbalance.

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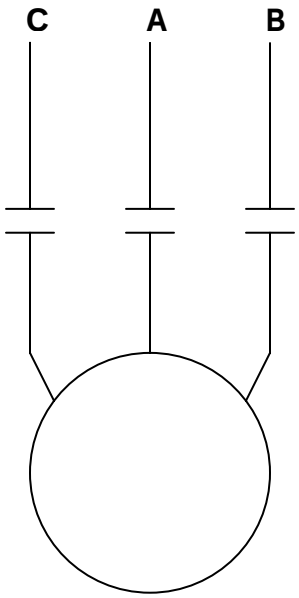
% Voltage Imbalance = .0201 X 100
% Voltage Imbalance = **2.01**

(A voltage imbalance of 2.01 means the motor windings will operate more than 8% hotter than normal and the motor's lifespan will be reduced accordingly)

- Causes Of Imbalance
  1. Poor wiring connections
     - Such connections could be at the power transformer serving the building, at the service entrance, at the disconnect, at the line side of the contactor or starter, at the motor or any other connection point on the three-phase system.
  2. Deteriorated starter or contactor contacts
     - Poor contacts are a point of electrical resistance and cause a voltage drop. A voltage imbalance that exists on the load (motor) side of the contactor but not on the line side of the contactor is most likely a connection or contact problem in the contactor.
  3. Mixed wire sizes
     - Wire runs, especially longer runs, drop voltage. When the three-phase power wiring sizes are not the same wire gauge, the smaller wire will drop more voltage thus creating an imbalance. Never allow a load to be connected via mixed wire sizes.
  4. Winding problem internal to the motor
     - It is possible that the cause of the imbalance is internal to the motor windings such as a partial winding to winding short. When detected, the only solution is to replace the motor. However, how does one determine the cause of the problem is actually the motor and not something else? The solution is simple.

- Follow this troubleshooting procedure
  1. Measure and record the imbalanced amperages on each leg A, B & C.
  2. Disconnect the power to the motor
  3. Remove each of the power wires A, B & C and rotate them so A is where B was connected, B is where C was connected and move C to where A was connected. What was A, B & C is now C, A, B. (Rotating all three legs will not cause the motor to run in reverse)
  4. Now measure and record the imbalanced amperages on each leg A, B & C. Remember that A, B & C keep their letter identifications but have been moved to new positions.
     - If the measured imbalanced currents did not rotate with the wires, then they remained with the motor windings and therefore the problem in internal to the motor.

- If the imbalanced currents rotated (remained with their rotated wires A, B & C) then the problem currents rotated with the wires so the problem is external to the motor (A wiring connection, starter contacts, power transformer problem, etc…)
- If the imbalance is no longer present then the problem was at one or more of the connections that were changed when rotating the wires.



Rotate the 3-phase power wires A, B & C to spell CAB

Re-measure and record the currents and compare

Current values that do not rotate with the wires indicate a problem with the motor

Current values that rotate with the wires indicate a problem external to the motor

Solutions

1. If the problem is in the motor itself as indicated by the previous rotation test, the motor must be replaced.
2. If the problem is at one or more of the wiring connections, remake the connection(s).
3. If unequal wiring sizes are used to supply power to the motor, replace the wires with three equally sized wires of the correct gauge for the application following the national and local electrical codes.[4]
4. If the problem is due to voltage differences across the line to load side of the contactor or starter replace the contactor or starter or replace the contacts if they are of the replaceable type.[5]

[4] Sizing and replacing power wiring usually requires the services of a licensed electrician and may involve obtaining an electrical permit and inspection. Consult your local electrical inspection office if there is any doubt as to the state and local requirements in your area.

[5] When replacing contacts always use replacement contacts manufactured for that particular brand and model starter or contactor. In addition, check to see that the contacts are properly rated for the application. It may be that the contacts deteriorated due to improper sizing or application.

Cleaning contacts as opposed to replacing them is not recommended. Improper cleaning technique can do more harm and exacerbate the problem often resulting in the loss of the motor during an attempt to save it.

5. If it has been determined that the problem is not with the motor, is not a contactor or starter problem, is not a voltage drop in the power wiring and is not a poor connection an HVAC technician can legally service, the problem must be dealt with by a licensed electrician or the local power company. When dealing with the electrician or power company be ready to share the measurements, calculations and troubleshooting procedure used in determining that the problem does not exist in the wiring and equipment you are authorized to service.

SUMMARY/CONCLUSION:

- Three-Phase voltage imbalance can cause current imbalance and high motor winding operating temperatures which greatly reduce the life of the motor. Measuring voltage and current imbalance should be a regular practice during system start-up, service and troubleshooting. This is especially important when determining the cause of a motor or compressor failure.
- Motor winding operating temperature rises exponentially as voltage imbalance increases.
- Many motor and compressor failures result from imbalance which if detected early could have been prevented. Most compressor failures are due to system problems or external electrical problems, not the compressor itself.
- Proper troubleshooting technique can determine if the cause of the problem is in the motor or external to the motor. Additional checks can determine if the problem is a contact, connection or wiring problem or if the problem needs to addressed by the power company.
- Rotating the three-phase power legs can be used to determine if the problem is with the motor or external to the motor.
- Another indication that the cause of the imbalance may be the motor or the starter rather than the building power system is when taking the imbalance at the line side of the starter is only in an imbalanced condition when the motor is operating.
- Always replace the motor contactor or starter anytime a failed motor is replaced.

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KEY WORDS (For searches)

- Voltage imbalance
- Current imbalance
- Phase imbalance
- Overheating motor windings
- Motor calculations