EFFECTS OF LOW VOLTAGE ON INDUSTRIAL FORKLIFTS

Abstract

To explain the correlation between voltage drop and heat as it specifically applies to modern industrial forklift technology and the resulting component failure. It is also within the scope of this report to discuss the effects of the voltage drop on the power supply; specifically industrial motive batteries.

Introduction

When discussing the effects of voltage drop on industrial forklift circuits it is important to realize that changes in technology have changed the way this anomaly has manifested itself while at the same time has had no effect on the resulting condition. Voltage drop affects the different components in different ways requiring separate analysis in order to understand the overall resulting condition. The following conditions will be discussed.

1. Low Voltage affect on power supply.
2. Thermal transfer.
3. Low voltage affect on control systems.
4. Low voltage affects on power components.
5. Low voltage effects on motors.

LOW VOLTAGE AFFECT ON POWER SUPPLY:

The power supply for most modern forklifts is electrochemical, specifically the Industrial Motive or Traction Battery. Many technologies are incorporated within this grouping including flooded batteries and VRLA such as GEL and AGM. It is not within the scope of this report to discuss the differences in these technologies however it is important to realize that the effects of voltage drop are consistent among all of these with the only real difference as a manifestation of time.

Battery capacity is not linear. According to Peukert's Law we express a batteries capacity in terms of the rate at which it is discharged.

$Cp=IkT$

Where Cp = Capacity expressed in Amp Hours
I = Discharge Current expressed in Amps
K= Peukert Constant
T = Time of Discharge expressed in Hours

The Peukert constant, expressed as K, is a dimensionless quantity that would ideally be 1 which would result in a battery with a capacity that was independent of the current draw. This, however, is not the case. We would typically see the Peukert Constant starting at 1.1 and going up from there. The Peukert Constant will elevate when the battery is exposed to temperature rise, suffers from sulfation, increases in age, or any anomaly that increases the internal resistance. Peukert's Law is reinforced and a product of the non linear rate at which the chemical reaction occurs inside a battery during high current demands

Through simple algebraic manipulation of Peukert's Law we can conclude that voltage drop across the power supply and the resulting increase in current demand will affect capacity in a non linear manner. The importance of this will become clearer as the compounding problem of voltage drop, decreased capacity, high current demands and the related heat generation is further explored.

THERMAL TRANSFER:

Another source of heat originating from the power supply is Thermal Transfer. As voltage drops and current demands increase, compounded by non linear decrease in capacity, the internal components of a battery will rise in temperature. Once a temperature difference is developed between the battery and the forklift the Peltier Effect will allow thermal transfer through the conductors to the forklift components. This thermal transfer, for all practical purposes, converts the forklift components into heat sinks in order to dissipate the heat from the battery.

LOW VOLTAGE AFFECT ON CONTROL SYSTEMS:

Control systems are affected by the stresses of thermal transfer that we would expect from the Peltier Effect and continually operating at the outer boundaries of design limitations. Control systems; protect themselves through internal low voltage alarms and response systems along with relatively low Bus Voltage requirements.

LOW VOLTAGE AFFECT ON POWER COMPONENTS:

The power components of a modern industrial forklift are tasked with the distribution and low speed switching of the power supply. The effects of low voltage on the individual components are not unique but do however manifest in different ways as described below.

- POWER CABLES: electrical cabling provides the distribution from the power source to the individual components. Current capacity of these cables change drastically as temperatures rise and the reduction in capacity begins to generate heat on its own while dropping voltage.

  EXAMPLE: A free air 2/0 cable designed to carry a 225A load at 77°F will only be able to
  carry 130A at 122°F

This reduction in current carrying capacity is dissipated as heat throughout the entire electrical system along with a proportional voltage loss.

- CONTACTOR COILS: Contactor coils are voltage specific but will compensate for low voltage, within the operational parameters, through higher current demands. Joule's Law;

$$P=IV$$

Describes this effect of Wattage (P) being a result of Current (I) multiplied by Voltage (V). The contactor coils will continue to function, substituting current for voltage in order to meet overall power requirements, within operation limits. Operating on the fringes of operational limits results in excessive wear on these electrical components and increase heat generation. At this point coils are both subject to the thermal strains of the Peltier Effect as well as contributing to it.

- CONTACTORS: Contactors are used to switch high current circuits. They are of course subject to the Peltier Effect but to a lesser degree. Joule's Law has a severe effect on contactors especially as it relates to the contact points. Contactors are a mechanical means of switching and are prone to arching when current carrying demands exceed that of design limitations. According to Joule's Law, as voltage drops across a circuit current will rise thus exceeding the design limitations of the contactors point of contact. The result of this increase in current will be pitting of the contactor tips or clamping in some extreme cases.

- RELAYS, FUSES, COILS, SELENOIDS, ETC: All of these components, among others, are subject to the same laws as the previous components.

LOW VOLTAGE EFFECTS ON MOTORS:

Generally speaking motor speed is a product of voltage while torque is a product of current. Upon energizing a motor we apply low voltage and high current in order to generate the torque required for starting. As RPM's increase, current drops and voltage increases. While increasing in speed the motor produces a counter-EMF that opposes the applied current until some equilibrium is reached. Most torque is produced when the RPM's are low and current is high.

Controllers in most modern forklifts prevent amperage from exceeding operational limits therefore reducing the direct effect of Joule's Law on the motor itself. The motor is still subject to stress from thermal transfer.

As rotation begins voltage and current are sent to the motor and efficiency is found somewhere within the combination of voltage, counter-EMF and current. This efficiency is further realized as current drops. In a low voltage situation the current is unable to drop into an efficient state while it still maintains its operational limits imposed by the motor controller. It is therefore possible to operate the motor inefficiently while still complying with the current limiting demands of the motor controller. At this point we are current starving the motor and we begin approaching stall speed. Truck performance at this point is not severely affected because maximum torque with a DC motor is achieved just prior to stall therefore all operational requirements are met while under these adverse conditions. Operation of the motor under these conditions is extremely inefficient and results in heat generation. This heat drastically increases the resistance in the field windings and damages brushes, armatures, etc.

CONCLUSION:

While individual component failure due to low voltage exposure has been discussed it is important to see the compounding problem that is created in this situation. As current demands increase among individual components we create a situation where total battery capacity drops at a non linear rate, according to Peukert's Law, thus creating a voltage starved circuit. For example, if we have a 1000 AH battery we can pull approximately 167 amps per hour out of this battery for 6-hours. However, if low voltage scenarios are applied and our demand is 280 amps per hour we can only operate in acceptable voltage limitations for 3 hours. As a result we have exchanged a 1000 AH battery for an 840 AH for a net loss of 16% capacity. If we are already dealing with a low voltage situation and we give up 16% more capacity we have compounded the problem drastically.