Electric traction and Protection of Pantograph using modern technique - PCDS (Pantograph Collision Detecting System)

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Abstract— This paper present the events that bring about the today's electric traction system and pantograph protection technique. Electric traction system of any country reflects the development of it. Basically, an electric traction system is a system which causes the propulsion of vehicles in which tractive or driving force is obtained from various devices such as diesel engine drives, steam engine drives, electric motors, etc. Nowadays , electric traction system has become more and more popular due to its number of advantages such as the electric traction system is the most efficient than all other traction system as compared to steam and internal combustion, including quick start and stop, pollution free, easy to handle and easy speed control. The main parts of electric traction system are locomotive pantograph, circuit breaker, transformer, rectifier, DC link, main inverter, auxiliary inverter, axle brush, battery, compressor, cooling fans. Electric locomotive pantograph is the backbone of any traction system thus, it's protection is must for the betterment of the whole system.

Key words: electric traction system, pantograph, Catenary, PCDS (Pantograph Collision Detecting System)

I. INTRODUCTION

There is a wide variety of electric traction systems around the world, which have been built according to the type of railway, its location and the technology available at the time of the installation. Many installations seen today were first built up to 100 years ago, some when electric traction was barely out its diapers, so to speak, and this has had a great influence on what is seen today. In the last 20 years there has been a gigantic acceleration in railway traction development. This has run in parallel with the development of power electronics and microprocessors. What have been the accepted norms for the industry for, sometimes, 80 years, have suddenly been thrown out and replaced by fundamental changes in design, manufacture and operation.

II. PARTS OF TRACTION SYSTEM

A. Power Supply:

To begin with, the electric railway needs a power supply that the trains can access at all times. It must be safe, economical and user friendly. It can use either DC (direct current) or AC (alternating current), the former being, for many years, simpler for railway traction purposes, the latter being better over long distances and cheaper to install but, until recently, more complicated to control at train level [1][2].Transmission of power is always along the track by means of an overhead wire or at ground level, using an extra, third rail laid close to the running rails. AC systems always use overhead wires, DC can use either an overhead wire or a third rail; both are common. Both overhead systems require at least one collector attached to the train so it can always be in contact with the power. Overhead current collectors use a "pantograph", so called because that was the shape of most of them until about 30 years ago. The return circuit is via the running rails back to the substation. The running rails are at earth potential and are connected to the substation.

B. Third Rail:

This diagram shows a DC 3-Rail Traction System with the location of the current rail in relation to the running rails. The third rail system uses a "shoe" to collect the current on the train, perhaps because it was first called a "slipper" by the pioneers of the industry (it slipped along the rail, OK?) but it was not very pretty to look at, so perhaps someone thought shoe was a better description. Whatever the origin, shoe has stuck to this day.

C. Shoes and Shoe gear:

Third rail current collection comes in a variety of designs. The simplest is what is called "top contact" because that's the part of the rail upon which the pick-up shoe slides. Being the simplest, it has drawbacks, not the least of which is that it is exposed to anyone or anything which might come into contact with it. It also suffers during bad weather, the smallest amount of ice or snow rendering top contact third rail systems almost unworkable unless expensive remedies are carried out. Side contact is not much better but at least it is less exposed. Bottom contact is best - you can cover effectively most of the rail and it is protected from the worst of the cold weather. This DC 3rd rail Top Contact Collector Shoe (London Underground - Central Line) has remote lifting facilities. All shoes need some way of being moved clear of the current rail, usually for emergency purposes. The most common reason is when a shoe breaks off and its connecting lead to the electrical equipment on the train has to be secured safely. The other shoes on the same circuit must be isolated while this is done, unless the current is switched off from the whole section - perhaps disabling several other trains. Isolation used to involve inserting a wooden "paddle" between the shoe and the current rail and then tying the shoe up with a strap or rope. More recently, mechanical or pneumatic systems have been devised to make it possible to lift shoes from inside the train remotely from the driving cab. Most types of top contact shoes simply hang from a beam suspended between the axle boxes of the bogie. The suspension method was originally just a couple of slotted links to compensate for movement which allowed gravity to provide the necessary pressure. Later systems had radially mounted shoes to provide more stable contact through lever action. Top contact systems with protective covers over them, like the New York Subway, needed radially mounted shoes anyway to allow them to fit under the cover. Side and bottom contact shoes are spring loaded to provide the necessary contact force. An example of a bottom contact shoe as used on a German metro line. Some top contact systems have also used spring loading but they are mechanically more difficult to control because of the hunting action of the bogie and the risk that the shoes will get trapped under the head of the rail and turn it over.

D. Gaps:

You will often see trains with only one pantograph but, on trains which use shoes, there are always several shoes. The contact with the overhead wire is not normally broken but the third rail must be broken at junctions to allow for the continuity of running rails. These third rail breaks, or "gaps", as they are called, can lead to loss of power on the train. The power losses can be reduced by locating shoes along the train and connecting them together by a cable known as a bus line. In spite of this, there can be problems. Woes betide the driver who stops his train with all the shoes "off juice" or "gapped". Yes, it happens more often than you think and yes, before you ask, it's happened to me. It is an embarrassing nuisance only solved by being pushed onto the third rail by another train or by obtaining special long leads with a plug at one end for the train and shoes at the other end for the third rail. Of course, it does cause a long delay. Current rail gaps are also provided where the substations feed the line . Normally, each track is fed in each direction towards the next substation. This allows for some over supply and provides for continuity if one substation fails. These substation gaps are usually marked by a sign or a light which indicates if the current is on in the section ahead. A train must stop before entering the dead section. Since the current may have been switched off to stop an arc or because of a short circuit, it is important that the train does not connect the dead section to the live section by passing over the gap and allowing its bus line to bridge the gap. Some of the more sophisticated systems in use today now link the traction current status to the signaling so that a train will not be allowed to proceed onto a dead section. At various points along the line, there will be places where trains can be temporarily isolated electrically from the supply system. At such places, like terminal stations, "section switches" are provided. When opened, they prevent part of the line for being fed by the substation. They are used when it is necessary to isolate a train with an electrical fault in its current collection system.

E. 3rd Rail Uses:

Although 3rd rail is considered a suburban or metro railway system, 750 volt DC third rail supply has been used extensively over southern England and trains using it run regularly up to 145 km/h. This is about its limit for speed and has only spread over such a large area for historical reasons.

F. Return:

What about the electrical return? There has to be a complete circuit, from the source of the energy out to the consuming item (light bulb, cooking stove or train) and back to the source, so a return conductor is needed for our railway. Simple – use the steel rails the wheels run on. Provided precautions are taken to prevent the voltage getting too high above the zero of the ground, it works very well and has done so for the last century. Of course, as many railways use the running rails for signaling circuits as well, special precautions have to be taken to protect them from interference. The power circuit on the train is completed by connecting the return to brushes rubbing on the axle ends. The wheels, being steel, take it to the running rails. These are wired into the substation supplying the power and that does the job. The same technique is used for DC or AC overhead line supplies.

G. AC or DC traction:

It doesn't really matter whether you have AC or DC motors, nowadays either can work with an AC or DC supply. You just need to put the right sort of control system between the supply and the motor and it will work. However, the choice of AC or DC power transmission system along the line is important. Generally, it's a question of what sort of railway you have. It can be summarized simply as AC for long distance and DC for short distance. Of course there are exceptions and we will see some of them later. It is easier to boost the voltage of AC than that of DC, so it is easier to send more power over transmission lines with AC. This is why national electrical supplies are distributed at up to 765,000 volts AC. As AC is easier to transmit over long distances, it is an ideal medium for electric railways. Only the problems of converting it on the train to run DC motors restricted its widespread adoption until the 1960s.DC, on the other hand was the preferred option for shorter lines, urban systems and tramways. However, it was also used on a number of main line railway systems, and still is in some parts of continental Europe, for example. Apart from only requiring a simple control system for the motors, the smaller size of urban operations meant that trains were usually lighter and needed less power. Of course, it needed a heavier transmission medium, a third rail or a thick wire, to carry the power and it lost a fair amount of voltage as the distance between supplies connections increased. This was overcome by placing substations at close intervals – every three or four kilometers at first, nowadays two or three on a 750 volt system – compared with every 20 kilometers or so for a 25 kV AC line. It should be mentioned at this point that corrosion is always a factor to be considered in electric supply systems, particularly DC systems. The tendency of return currents to wander away from the running rails into the ground can set up electrolysis with water pipes and similar metallics. This was well understood in the late 19th Century and was one of the reasons why London's Underground railways adopted a fully insulated DC system with a separate negative return rail as well as a positive rail - the four-rail system. Nevertheless, some embarrassing incidents in Asia with disintegrating manhole covers near a metro line as recently as the early 1980s means that the problem still exists and isn't always properly understood. Careful preparation of earthing protection in structures and tunnels is an essential part of the railway design process and is neglected at one's peril.

H. Overhead Line (Catenary):

The mechanics of power supply wiring is not as simple as it is. Hanging a wire over the track, providing it with current and running trains under it is not that easy if it is to do the job properly and last long enough to justify the expense of installing it. The wire must be able to carry the current (several thousand amps), remain in line with the route, withstand wind (in Hong Kong typhoon winds can reach 200 km/h), extreme cold and heat and other hostile weather conditions. Overhead Catenary systems, called "Catenary" from the curve formed by the supporting cable, have a complex geometry, nowadays usually designed by computer. The contact wire has to be held in tension horizontally and pulled laterally to negotiate curves in the track. The contact wire tension will be in the region of 2 tones. The wire length is usually between 1000 and 1500 meters long, depending on the temperature ranges. The wire is zigzagged relative to the centre line of the track to even the wear on the train's pantograph as it runs underneath. The contact wire is grooved to allow a clip to be fixed on the top side. The clip is used to attach the dropper wire. The tension of the wire is maintained by weights suspended at each end of its length. Each length is overlapped by its neighbor to ensure a smooth passage for the "pan". Incorrect tension, combined with the wrong speed of a train, will cause the pantograph head to start bouncing. An electric arc occurs with each bounce and a pan and wire will soon both become worn through under such conditions.

More than one pantograph on a train can cause a similar problem when the leading pantograph head sets up a wave in the wire and the rear head can't stay in contact. High speeds worsen the problem. The French TGV (High Speed Train) formation has a power car at each end of the train but only runs with one pantograph raised under the high speed 25 kV AC lines. The rear car is supplied through a 25 kV cable running the length of the train. This would be prohibited in Britain due to the inflexible safety approach there. A waving wire will cause another problem. It can cause the dropper wires, from which the contact wire is hung, to "kink" and form little loops. The contact wire then becomes too high and aggravates the poor contact. Overhead lines are normally fed in sections like 3rd rail systems, but AC overhead sections are usually much longer. Each subsection is isolated from its neighbor by a section insulator in the overhead contact as shown in this picture below. The subsections can be joined through special high speed section switches. To reduce the arcing at a neutral section in the overhead Catenary, some systems use track magnets to automatically switch off the power on the train on the approach to the neutral section. A second set of magnets restores the power immediately after the neutral section has been passed. The next photo shows a set of track magnets.

I. Catenary Suspension Systems:

Various forms of Catenary suspension are used, depending on the system, its age, its location and the speed of trains using it. Broadly speaking, the higher speeds, the more complex the "stitching", although a simple Catenary will usually suffice if the support posts are close enough together on a high speed route. Modern installations often use the simple Catenary, slightly sagged to provide a good contact. It has been found to perform well at speeds up to 125 m/hr (200 km/hr).At the other end of the scale, a tram depot may have just a single wire hung directly from insulated supports. As a pantograph passes along it, the wire can be seen to rise and fall. This is all that is necessary in a slow speed depot environment. I haven't yet mentioned trolley poles as a method of current collection. These were used for current collection on low speed overhead systems and were common on trams or streetcars but they are now obsolete. DC overhead wires are usually thicker and, in extreme load cases, double wires are used, as in Hong Kong Mass Transit's 1500 v DC supply system. Up to 3000 volts overhead is used by DC main line systems (e.g. parts of France, Belgium and Italy) but below 1500 volts, a third rail can be used. In operating terms, the third rail is awkward because of the greater risk of it being touched at ground level. It also means that, if trains are stopped and have to be evacuated, the current has to be turned off before passengers can be allowed to wander the track. Third rail routes need special protection to be completely safe. On the other hand, some people consider the overhead Catenary system a visual intrusion. Singapore, for example, has banned its use outside of tunnels.

J. Booster Transformers:

On lines equipped with AC overhead wires, special precautions are taken to reduce interference in communications cables. If a communications cable is laid alongside rails carrying the return current of the overhead line supply, it can have unequal voltages induced in it. Over long distances the unequal voltages can represent a safety hazard. To overcome this problem, booster transformers are provided. These are positioned on masts at intervals along the route. They are connected to the feeder station by a return conductor cable hung from the masts so that it is roughly the same distance from the track as the overhead line. The return conductor is connected to the running rail at intervals to parallel the return cable and rails. The effect of this arrangement is to reduce the noise levels in the communications cable and ensure the voltages remain at a safe level.

K. Dual Voltage:

Some train services operate over lines using more than one type of current. In cities such as London, New York City and Boston, the same trains run under overhead wires for part of the journey and use third rail for the remainder. In Europe, some locomotives are equipped to operate under four voltages - 25 kV AC, 15kV AC, 3,000 V DC and 1,500 V DC. Modern electronics makes this possible with relative ease and cross voltage travel is now possible without changing locomotives.

L. Pantographs:

Current is collected from overhead lines by pantographs. Pantographs are easy in terms of isolation - you just lower the pan to lose the power supply to the vehicle. However, they do provide some complications in different ways. Since the pantograph is usually the single point power contact for the locomotive or power car, it must maintain good contact under all running conditions. The higher the speed, the more difficult the maintenance of good contact . We have already mentioned the problem (above) of a wave being formed in the wire by a pantograph moving at high speed. Pantograph contact is maintained either by spring or air pressure. Compressed air pressure is preferred for high speed operation. The pantograph is connected to a piston in a cylinder and air pressure in the cylinder maintains the pantograph in the raised condition. Originally, pantographs were just that, a diamond-shaped "pantograph" with the contact head at the top. Two contact faces are normally provided. More modern systems use a single arm pantograph - really just half of the original shape - a neater looking design.

The contact strips of the pantograph are supported by a lightweight transverse frame which has "horns" at each end. These are turned downwards to reduce the risk of the pantograph being hooked over the top of the contact wire as the train moves along. This is one of the most common causes of wires "being down". A train moving at speed with its pantograph hooked over the wire can bring down several kilometers of line before it is detected and the train stopped. The most sophisticated pantographs have horns which are designed to break off when struck hard, for example, by a dropper or Catenary support arm. These special horns have a small air pressure tube attached which, if the pressure is lost, will cause the pan to lower automatically and so reduce the possible wire damage[4].

III. PANTOGRAPH AND ITS PROTECTION TECHNIQUES

A. History:

The pantograph was invented in 1879 by Walter Reichel, chief engineer at Siemens & Halske in Germany. A flat slide-pantograph was invented in 1895 at the Baltimore and Ohio Railroad .The familiar diamond-shaped roller pantograph was invented by John Q. Brown of the Key System shops for their commuter trains which ran between San Francisco and the East Bay section of the San Francisco Bay Area in California. They appear in photographs of the first day of service, 26 October 1903. For many decades thereafter, the same diamond shape was used by electric-rail systems around the world and remains in use by some today [5].

B. Facts:

The pantograph was an improvement on the simple trolley pole, which prevailed up to that time, primarily because the pantograph allows an electric-rail vehicle to travel at much higher speeds without losing contact with the overhead lines. The most common type of pantograph today is the so-called half-pantograph (sometimes 'Z'-shaped), which has evolved to provide a more compact and responsive single-arm design at high speeds as trains get faster. Louis Faiveley invented this type of pantograph in 1955. The half-pantograph can be seen in use on everything from very fast trains (such as the TGV) to low-speed urban tram systems. The design operates with equal efficiency in either direction of motion, as demonstrated by the Swiss and Austrian railways whose newest high performance locomotives, the Re 460 and Taurus, operate with them set in the opposite direction [4].

C. Construction and working:

The electric transmission system for modern electric rail systems consists of an upper, weight-carrying wire (known as a catenary) from which is suspended a contact wire. The pantograph is spring-loaded and pushes a contact shoe up against the underside of the contact wire to draw the current needed to run the train. The steel rails of the tracks act as the electrical return. As the train moves, the contact shoe slides along the wire and can set upstanding waves in the wires which break the contact and degrade current collection. This means that on some systems adjacent pantographs are not permitted. Pantographs are the successor technology to trolley poles, which were widely used on early streetcar systems. Trolley poles are still used by trolleybuses, whose freedom of movement and need for a two-wire circuit makes pantographs impractical, and some streetcar networks, such as the Toronto streetcar system, which have frequent turns sharp enough to require additional freedom of movement in their current collection to ensure unbroken contact. However, many of these networks, including Toronto's, are undergoing upgrades to accommodate pantograph operation. Pantographs with overhead wires are now the dominant form of current collection for modern electric trains because Pantographs are typically operated by compressed air from the vehicle's braking system, either to raise the unit and hold it against the conductor or, when springs are used to effect the extension, to lower it. As a precaution against loss of pressure in the second case, the arm is held in the down position by a catch. For high-voltage systems, the same air supply is used to "blow out" the electric arc when roof-mounted circuit breakers are used.

D. Types of pantograph:

Pantographs may have either a single or a double arm. Double-arm pantographs are usually heavier, requiring more power to raise and lower, but may also be more fault-tolerant. On railways of the former USSR, the most widely used pantographs are those with a double arm ("made of two rhombs"), but since the late 1990s there have been some single-arm pantographs on Russian railways. Some streetcars use double-arm pantographs, among them the Russian KTM-5, KTM-8, LVS-86 and many other Russian-made trams, as well as some Euro-PCC trams in Belgium. American streetcars use either trolley poles or single-arm pantographs.

E. Limitations:

Contact between pantograph and overhead Catenary wire is usually assured through a block of graphite. This material conducts electricity while working as a lubricants. As graphite is brittle, pieces can break off during operation. Bad pantographs can seize the overhead wire and tear it down. So there is a two way influence where bad wires can damage the pantograph and bad pantographs can damage the wires. To prevent this, a pantograph monitoring station can be used. In the UK, in older vehicles the pantographs are raised by air pressure, and the graphite contact strips cover some vents in the pantograph head which release the air if a graphite strip is lost, automatically lowering the pantograph to prevent damage. Newer electric traction units may use more sophisticated methods involving microprocessors which detect the disturbances caused by arcing at the point of contact if the graphite strips are damaged. There are always at least two pantographs so the other one can be used if one is damaged.

IV. CASE-STUDY

The PCDS (Pantograph Collision Detection system) monitors the interface between the overhead centenary and the pantograph and provides real time warnings for unusual contacts or strikes. In regular use a Pantograph may be struck by an overhead support component that is loose or/defective and hanging low. Identification of the loose or/defective part can be time consuming and difficult, causing unnecessary network downtime. When an abnormal impact is detected the location and time of the impact is sent via SMS to the operator[2][3].

A. Overview of making of PCDS:

1) Mechanical:

- 3805-1000 Impact Processing Module
  435 x 300 x 75mm (excluding mounting brackets), 8.2kg
- 3805-1001 Power Supply Module
  435 x 300 x 75mm (excluding mounting brackets), 8.5kg
- 3805-1011 Impact Detector Modules
  50 x 50 x 20mm (excluding cables and mounting brackets), > 100grams

B. Technical Information:

1) General

- System data available includes: Vehicle ID, Speed, Location, Time/Date, Status, Impact levels
- System adjustable parameters include: Impact Thresholds, System sleep/wake parameters, Admin and Status User phone numbers for SMS data

2) Shock and Vibration

- IEC61373, Category 1, Class B.

3) GPS

- Concurrent Global Navigation Satellite System (GNSS).
- Can receive and track multiple GNSS systems
- Receiver Types GPS, QZSS, GLONASS, BeiDou, Galilieo (when available)

4) Wireless Technology

- Technology; 3G UMTS/HSDPA/HSUPA
- UMTS/HSPA Bands I, II, IV, V, VI, VIII
- Standard size SIM Card required in the Impact Processing Module

5) Impact Detectors

- High performance 3-axis linear accelerometer
- 16bit resolution
- 10,000 g shock survivability

6) System Power

- 2 x in built solar panels
- High performance LiFePO4 batteries
- Maintains power for 7 days without solar input (assumes 12hr/day active)

7) On-Board Memory

- 64Mbit Flash memory

V. CONCLUSION

In this fast going life, it is of utmost importance that a man should travel and carry goods at the fastest possible speed in a safe and economical way , which is only possible by means of electric traction. After studying the whole system we can see how efficient, reliable, accessible and safe is it. In modern global era, the pantograph protection technique (such as PCDS) will prove to be worthy with advanced micro- controlling system and it will minimize the life- smacking accidents .

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