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THE LONDON UNDERGROUND & ITS ELECTRIFICATION

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The first underground railway in the World was installed in London by the Metropolitan Railway Company in 1862 between Paddington and Farringdon Street, being commissioned on 10th January 1863. It was a joint venture between the GWR and LNER to connect their surface railway termini of Paddington and Kings Cross and was 3 ¾ mile long. The first rolling stock came from the GWR pulled by steam locomotives for 7 months, after which LNER rolling stock was used due to a disagreement with GWR.

The company also had aspirations that this line would eventually be extended to connect to the London, Chatham and Dover Railway, later achieved through a connection from Farringdon through to Blackfriars (this section of track is currently used by Thameslink train services from Bedford to South London and the Brighton line). There were even thoughts of extending further, through a channel tunnel, to France! In addition and under the chairmanship of the Victorian tycoon Sir Edward Watkin, appointed in 1872 to breathe new life into the company, the Metropolitan Railway embarked on grand plans for a main line railway to break the stranglehold of the GWR and other companies with routes into London from the north and west. Slowly but steadily a line was built out from the Baker Street terminus, through the sparse north-west suburbs then existing, for many miles through the countryside of Middlesex, Hertfordshire and Buckinghamshire. The line reached Willesden Green in 1879, Harrow-on-the-Hill (1880), Rickmansworth (1887), Chesham (1889), Aylesbury (1892), and finally Verney Junction, over 50 miles from London in 1894. Apart from the first 3 miles from Baker Street, which was in cut-and-cover tunnel, the line was above ground and very different in nature to the remainder of the railway system developing in London. The Metropolitan was establishing a commuter railway, but initially without the commuters! Unlike any other railway company the Metropolitan had rights not only to build a railway but also to acquire land and issue licenses for house building, which it did in later years to great advantage, creating what is affectionately known to-day as 'Metroland'. As a successful and profitable steam operated railway it stood aloof from the other underground lines and was slow to make the change to electric traction (more of which later), in part because its suburban steam operation was very successful and profitable.

Although travelling on the Metropolitan Railway Company's first line was a rather dirty and smelly experience due to the use of steam engines below ground it was not long before the residents of West London wanted their own line. This second line was installed by the Metropolitan District Railway Company, opening between High Street Kensington and Westminster by the end of 1869 and on to Blackfriars by May 1870. This soon became known as the District Line and for the first couple of years used steam engines borrowed from the Metropolitan Railway Company. Many other shallow lines were installed as extensions of the above two between 1871 and 1889, including sections of the so-called "Circle Completion".

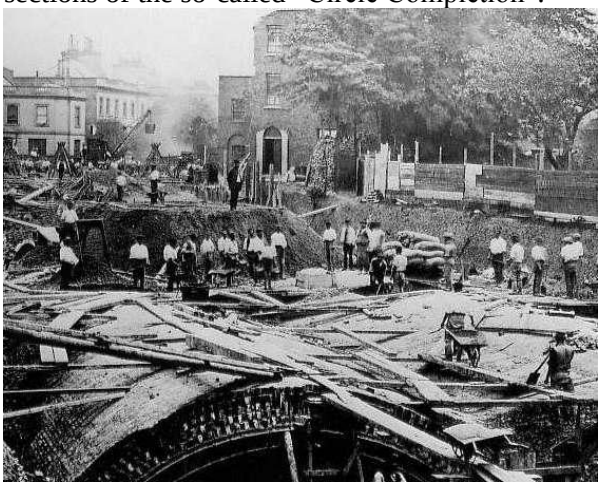

Fig.1 The chaos of the cut-and-cover method

These first lines were hand-dug following the existing road structure and were very shallow, described as the "cut-and-cover" method. One can only imagine the disruption that ensued with this!

Considerable problems were encountered with ventilation due to the use of steam engines, but additional ventilation eventually managed to make the system workable. There is much evidence still existing to-day relating to this early steam operation. At Baker Street the Circle Line platforms (5 & 6) were restored some years ago, highlighting the original smoke holes in the platform back walls to make an attractive feature. The Circle line between Edgware Road and Paddington has several tunnel openings, again for smoke ventilation; likewise on the District line where it passes under the Embankment Gardens near the IET building at Savoy Place.

The first deep level 'tube', known as the East London Railway, was installed from Wapping to Old Kent Road and was commissioned in 1869, still using steam engines for haulage. This tube line had been constructed with the knowledge gained from Marc Brunel's method of tunnelling using his invention of a shield protection enabling tunnelling to proceed more safely. With the development of the deep tubes, the use of steam powered locomotives made it almost impossible to create adequate ventilation. So the next deep tube by the Waterloo & Charing Cross Electric Railway Company, started out with electric traction in mind as befits their title. Their Chief Electrical Advisor was Dr. C W Siemens, due to the Siemens Company having expertise of the first electric railway system in Germany.

Fig.2 Stockwell Generating Station

A generating station was built at Stockwell and the system adopted was 500 V d.c., with the traction supply provided from a third rail set between the two running rails. The first electric locomotives (14), designed by Dr Edward Hopkinson, were ordered from Mather & Platt from their Salford Iron Works. Power was provided by two 50 HP 2-pole Edison-Hopkinson motors (thus providing a total power output of 100 HP), the armatures of which were wound directly onto the axles. Line current was fed through manually operated rheostats and series/parallel control was also used. These locos were quite small, being only 14 ft in length and 6 ft 10 ins in width.

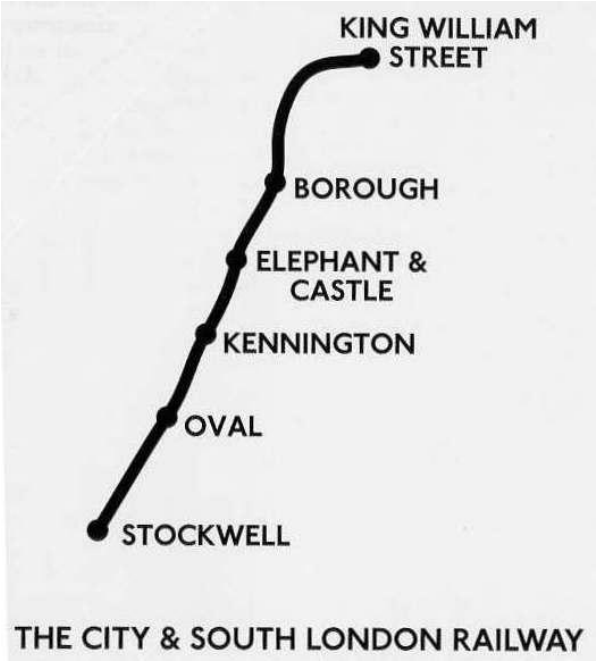

Fig.3 The First Electrified Tube Diagram

Later additions, built by the Crompton Company, were fitted with 80 HP motors. The new line from Stockwell to King William Street in the City, was 3 miles long and was called the City & South London Railway, opening to the public on the 4th November 1890. The traction engines only pulled 3 cars initially and the cars had no windows! It was so successful that plans were immediately laid to extend both north and south and opened from Clapham Common to Moorgate in 1900 (which now forms a part of the central section of the current Northern line). Garcke's Manual for 1904 gives a summary of the generating plant installed at the Stockwell Power Station, its capacity at that time being 3,000 kW.

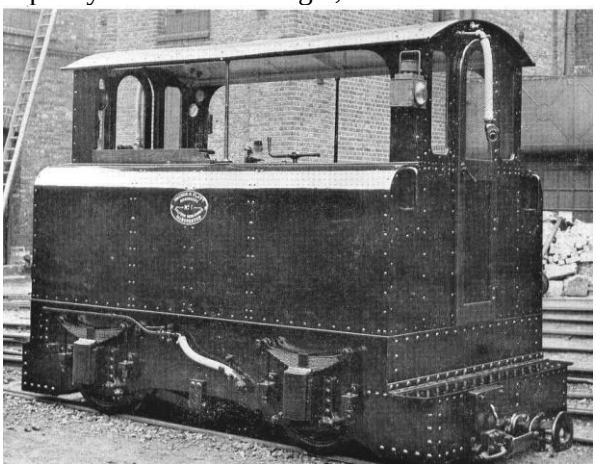

Fig.4 First Electric Locomotive by Mather & Platt

The next deep tube, the second, was installed from Waterloo to the Mansion House and was known as the Waterloo & City Railway Company, although being promoted by the London and South West Railway Company. It was opened on 8th August 1898. A small generating station had been built at Waterloo, with generating plant installed totalling 1,350 kW. Electricity was conveyed to the traction engines by a centrally situated third rail (again 500 V d.c.). The rolling stock, using motor cars instead of locomotives, was purchased from the USA being made by Jackson & Sharpe with electrical equipment by Siemens and assembled at Eastleigh Works in the UK. There were initially five trains, each with a seating capacity of 208 persons and the average train speed was stated as 18 mph. This line was taken over by the London & South Western Railway Company in 1907.

The third tube line was the Central London Railway from Shepherd's Bush to Cornhill (The Bank), a considerable length of 5 ½ miles. A generating station was built at Wood Lane, in the district now known as White City, generating at 5,000 V a.c., being one of the first traction generating stations to generate at a.c. instead of d.c. By 1904 the generating plant installed was 5,100 kW. However, it was decided to set the converter substations at a deep level to change from a.c. to 550 V d.c., in order to supply the track direct at d.c., which caused problems with rotary machinery being relatively inaccessible. This was also a third rail system with the traction current return path being facilitated through the bonded running rails.

Again the traction engines were made in America, by General Electric, with the train cars made by Ashbury and Brush. These engines also had armatures built directly into the axles, with 4 motors giving a total output of 800hp. The line opened to the public in 30th July 1900 but by 1903 all the stock had been replaced with motor units combined into the car design due to extreme problems of vibration. This arose because it had been considered unnecessary to fit springs into the locomotive frames as it was thought that the rigid track bed would damp out the vibrations; instead it magnified them, to the annoyance of property owners above who threatened legal action! In consequence this sounded the death knell for any further use of locomotives to haul trains in the deep level tubes.

The fourth tube was the Great Northern and City Railway from Finsbury Park (a main line station) to Moorgate. Agreement was reached with the City and South London Railway for a joint station at Old Street. The multiple units with motors in the train cars opened in February 1904 with the rolling stock made in UK by the Brush Electrical Engineering Company at Loughborough. A generating station was constructed at Poole Street with an output of around 5,000 kW. When the company was taken over by the Metropolitan Railway Company in 1913 it was closed down, transferring the supply source to the other company's generating station at Neasden, of which more about later.

Reverting in timescale back to around 1900, the shallow lines run by the two Metropolitan Railway Companies had become considerably out of date with their steam driven locos, since the deeper tubes were by then operated by electricity. The two companies embarked on an experiment, electrifying the line between High Street Kensington and Earls Court with conductor rails laid each side of the running rails and operating at a voltage of 600V d.c. One trial train was built and operated for a year, proving the case for low voltage d.c. operation. However, when tenders were received for the electrification of the two lines, a system submitted by Ganz of Budapest was the one that most impressed the adjudicators. This was a 3,000 V three-phase a.c. system utilising a pair of overhead copper conductors for two of the phases and the running rails for the third! However, around that time an American entrepreneur C T Yerkes bought the rights to a proposed railway, the Charing Cross to Hampstead Line and, with the help of an Englishman Robert Helps, in 1901 purchased the by now ailing Metropolitan District Railway. He immediately set about electrifying that railway, establishing a new company called the Metropolitan District Electric Traction Company, with American expertise of the 600 V d.c. system, for this purpose. This left the Metropolitan Railway Company on its own, still favouring and fighting a rear-guard action for the Ganz system. This went to arbitration, with the Board of Trade finally deciding on the British Thomson-Houston 600V d.c. system for use throughout the London Underground. One reason given for not pursuing the Ganz system was the perceived danger from the much higher voltage – at that time the highest traction voltage in use was 750 V. From then on, with an agreed standardised system, electrification proceeded apace, but the Metropolitan still maintained its dogged independence by providing its own power supplies!

The first electrification of the original shallow lines occurred when part of the District line had been converted to electric operation on 28th June 1903, being wholly converted by 1905. This line initially used electric locomotives built by the Metropolitan Railway Carriage and Wagon Company and fitted with General Electric motors. They were also employed on through workings to/from locations outside London. One popular journey of that era was the double-headed corridor express from Ealing Broadway to Southend-on-Sea. Some GWR suburban passenger trains were also locomotive hauled from Paddington through to the City (who said Crossrail was new?), although goods trains serving places such as Smithfield market continued to be steam hauled.

Another main tube line, on which work had commenced way back in June 1898, the Baker Street and Waterloo Railway, failed by 1900 due to the collapse of the financial backers. This gave Yerkes the opportunity he was looking for and he stepped in and acquired the B and WR and immediately set about electrifying it in 1902 in the American manner, which was completed by 1906.

Yerkes then set about acquiring the other companies and electrifying them accordingly using a 3rd and 4th rail system. Because of the lack of adequate public electricity supplies a new generating station was built at Lots Road between Chelsea and Fulham on the banks of the River Thames. The station was commissioned in 1905 generating at 11,000 V a.c. and then the power being transmitted across London to substations where the electricity was changed to 600 V d.c. using rotary convertors, which were later replaced with mercury arc rectifiers. At the time of its opening the Lots Road Power Station was the largest in Europe! It contained 64 Babcock and Wilcox boilers with chain-grate stokers, the coal handling plant having a capacity of 240 tons/hour. The generating plant comprised 8 Westinghouse turbines directly coupled to 3-phase alternators ($33^1/_3$ Hz), each with an output of 5,500 kW, i.e. an initial total output of 44 MW. Provision was made for future extension to a total of 80 boilers and additional generating capacity to 57.7 MW.

It is sad that with all Yerkes' energetic activity to consolidate and unify the London Underground systems he did not live to see the fruits of his endeavours since he died in 1905. Amalgamations occurred with a composite company being established by 1910 called the London Electric Railway. Yerkes had been Chairman of the Underground Electric Group, but with his death in 1905 at the age of 68, his place was taken by another American, Edgar Speyer. His firm, Speyer Brothers, had acquired London United Tramways (LUT), so he was in a pivotal position. The multiple unit rolling stock was therefore built in the USA by the American Car & Foundry Company and assembled in this country. The initial order included 36 motorised cars with 72 trailer cars, which were formed into 3 car sets.

The next major tube to open was the Great Northern Piccadilly and Brompton Railway, which had been authorised in 1894, but did not commence business until November 1907. This was later extended from Earls Court to Holborn and in a northerly direction to Finsbury Park (now a part of the current Piccadilly line). The last major tube line to be constructed was the Charing Cross, Euston & Hampstead (a further part of the current Northern line), which is surprising, when one considers that this was the first company to be acquired by Yerkes in 1900. Work commenced in 1902 and opened for business in 1907.

The year 1907 was quite an important one in the underground calendar of events, because a new leading player arrived on the scene. His name was Albert Stanley, an Englishman, but with a strong pedigree in American railways. He was General Manager of the New Jersey Street Railway Department. He had been invited to be General Manager of the Underground Group and within three years had become Managing Director. From this commanding position he was responsible for shaping the network under his control into a unified form, and for his considerable efforts was knighted in 1914 and two years later entered the Government of the time as President of the Board of Trade. He returned as Chairman of the Underground Group in 1919 and was created Lord Ashfield of Southwell in 1920.

After 1911, only two underground railways remained outside the control of the Underground Group. These were the Waterloo & City Line and the Metropolitan Railway. However many extensions were made in the 1920's. The Central London line was extended 4 ¼ miles from Wood Lane to Ealing Broadway. The City & South London Railway had been taken over by the Underground Group and they set about enlarging the tunnels to 11ft 8ins diameter and reopened it to traffic on 20th April 1924.. The Hampstead to Edgware and Clapham to Morden extensions were opened on 13th September 1926 as also were the extensions from Kennington to Hampstead,

Charing Cross to Waterloo and Edgware Road to Putney Bridge, a busy building time indeed.

Returning to the Metropolitan Railway Company, once the traction system had been decided by the Board of Trade, it also embarked on electrification, but because of the nature of its extensive system this was only undertaken in stages over a time span of many years, only finally being completed in 1961. In connection with the opening of a branch from its main line, at Harrow-on-the-Hill, to Uxbridge in 1905, the main line to Harrow and this new branch were the first sections to be electrified. The Company turned down the offer of power supplies from the London Underground Group's Lots Road power station and being fiercely independent.

Fig.5 Neasden Power Station

They therefore built their own power station at Neasden, on land adjacent to the Company's main depot and workshops. Like Lots Road, this was a chain grate coal-fired station with Babcock and Wilcox boilers fitted with super-heaters and had an initial output of 14 MW. Station output was at 11 kV, $33^{1}/_{3}$ Hz, fed to substations along the line route where it was transformed down in voltage and rectified to 600 V d.c. Coal supplies naturally arrived by rail and cooling water supplies were provided from a newly constructed reservoir and artesian wells on site, in conjunction with wooden cooling towers for steam condensing. To meet increasing demand in the 1930s with the opening of the Stanmore branch of the Bakerloo Line (now Jubilee) its original capacity was increased.

With the start of electrification on the Met a mixture of traction came into use, electric multiple units, electric locomotives and the continuation of steam. The new Baker Street – Uxbridge service (electrified from the start) was operated with variations of slam-door electric multiple units whilst the main line trains were locomotive hauled as far as Harrow (where the power ended!) and onwards by steam. The first Met locomotives (1905 stock) were fitted with BTH motors producing 868 HP. There was also a special locomotive hauled Pullman service, known as the 'Aylesbury Pullman' for the city gent commuters. Further electrification of the main line north of Harrow was not commenced until after the First World War. By 1925 the main line had been electrified as far as Rickmansworth as well as the short branch to Watford. Beyond Rickmansworth all trains continued to be steam hauled, this state of affairs existing until 1961.

Fig.6 Neasden Station Plant

Following unification with the creation of the London Passenger Transport Board (LPTB) in 1933, the Uxbridge line stock was replaced by more conventional guard-operated electric door trains transferred from other lines. However, slam-door electric multiple units continued to operate on the Watford services until the next major change for the Met in 1961. These were six coach electric multiple units, comprising four trailers with a motor coach at each end – the acceleration was not wonderful! The services running beyond Rickmansworth were made up from rakes of compartment carriages hauled by Metropolitan-Vickers electric locomotives as far as Rickmansworth where this locomotive was replaced by a steam engine for the onward journey to Aylesbury (by then the line beyond Aylesbury to Verney Junction had been transferred to the Great Central Railway). The locomotive change was reputed to be the fastest of anywhere on the railway system, around three to

four minutes being typical. This quick changeover was achieved in part through a good track layout in the Rickmansworth station confines.

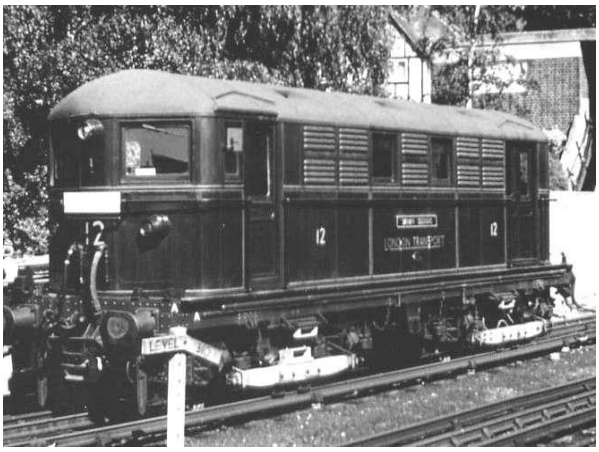

Fig.7 The Met-Vick Loco Sarah Siddons

The Metro-Vick locomotives were built between 1921 and 1923. Originally the intention had been to re-build on the frames of the 1905 stock but, apart from one prototype, they were all built from scratch because that was found to be the cheaper option. There were twenty of these, named after people connected with places served by the railway. Number 8 was Sherlock Holmes and number 18 was Michael Faraday, the nameplate of which was presented to the IEE (now the IET) on its withdrawal from service. Number 5, John Hampden, is preserved in the London Transport museum at Covent Garden. Each locomotive weighed in at around 56 tons and had a total power output of 1,200 HP (895 kW electrical equivalent) from four axle-hung motors with electro-magnetic control. The design top speed was 65 mph. The control system permitted two or even three locos to be coupled together and operated by the driver in the leading loco but normal running was with just one loco on a train. One problem with the Metro-Vick electric locomotives, arising from the short spacing between the current collector shoes at the two ends of the loco, was the risk of gapping whereby if such a loco stopped when passing over points it might lose its power supply because of the necessary gaps in the conductor rail at such locations. To prevent this from happening, each guard's van coach was fitted with additional collector shoes, coupled by a heavy duty cable back to the locomotive at the front of the train.

Because of the slam-door compartment stock used on the Aylesbury and Watford services the guards on those trains had a traditional role to perform in using a green flag and whistle to give the 'right away' signal to the train driver for starting. In addition a pair of bare signalling wires ran along the length of the platform (at the surface stations, secured on porcelain insulators fixed to the station lamp posts). The end of the pole carrying the guard's flag had a brass sheath and this end was shorted across the open wires to sound a bell at the driver's end of the platform.

As far as the rest of the system was concerned, by the 1930's extensions were going at a great pace due mainly to the new Act of Parliament of 1929 providing loans, guarantees and grants to be made available from the Government and enabling roughly 16 ½ miles of tube lines to be constructed.

On 1st July 1933 the then existing five London Underground railway companies, together with numerous bus, coach and tramway companies operating in a newly designated London Traffic Area, were absorbed under the umbrella of one operating organisation – the London Passenger Transport Board (LPTB). It was no surprise when it was announced that the first Chairman would be Lord Ashfield, remaining in the post until 1947 nationalisation. The new London Traffic Area, established by the London Passenger Transport Act of 1933, covered a vast area of approximately 2,000 square miles. It extended from Baldock (Hertfordshire) in the north to Horsham (Sussex) in the south and from High Wycombe (Bucks) in the west to Gravesend (Kent) in the east. It is not surprising to learn that the Metropolitan Railway Company was not at all happy about losing its individuality and suffering what amounted to a take-over! In fact the great length of the Metropolitan line meant that it extended even beyond the extensive boundary of this new LPTB area.

The 1934/5 Garcke's Manual contains a detailed account of the new LPTB, which took over responsibility for the five underground railway undertakings – the Metropolitan, District, London Electric, City and South London and Central London. The combined route mileage was 227, serving 238 stations, of which 186 were owned by the Board. The list of assets acquired from the Metropolitan Railway Company reflects the nature of their operations at that time – 56 locos (20 electric and 36 steam!) and 544 goods vehicles in addition to 719 passenger vehicles. Coal was still very important goods traffic for the Metropolitan, with sidings and coal yards located at many stations from whence coal deliveries were made by local suppliers to keep the home fires burning.

Three power stations were also taken into ownership by the LPTB, Lots Road, Chelsea (the former station of the 'Underground Group', the capacity of which by then had reached 150MW), Neasden (the former station of the Metropolitan Railway Company, the capacity of which by then had reached 97 MW) and Greenwich (a former London County Council Tramways station with a capacity at that time of 92 MW). All three power stations generated at 11 kV, Lots Road and Neasden at $33^1/_3$ Hz and Greenwich at 25 Hz. In later years, with the move to take more power from the national grid, Neasden was closed and demolished in the late 1960s.

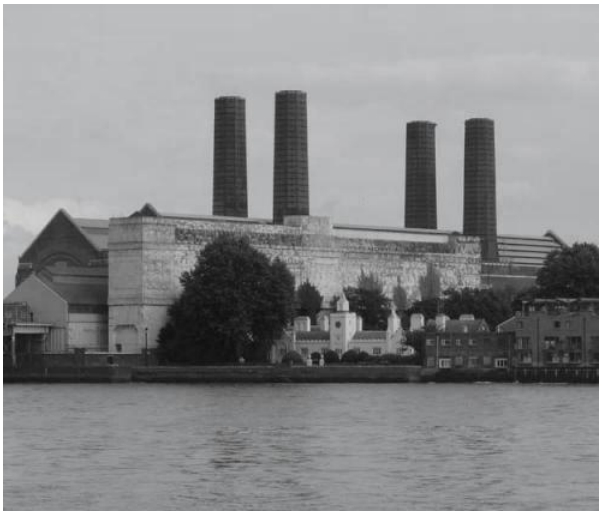

Fig.8 Lots Road Power Station

Lots Road continued generating until closure in Oct 2002, thereafter all power being taken from the national grid. Greenwich is now a gas turbine station operated by EDF Energy Powerlink. It is equipped with seven Rolls Royce Avon jet engines, each coupled to a 14 MW generator set and is retained to provide emergency supplies at 15 minutes notice for station lighting, lifts and escalators (but not for traction) in the event of a major grid failure.

The creation of the LPTB brought about a more financially secure future and provided the opportunity for some long term planning. It had long been recognised that some of the London suburbs were not served by the system then existing, which a 1935-40 new works programme sought to remedy. Work started on extending the Central line both eastwards and westwards from its central section. However, this was interrupted by the outbreak of war in 1939. The newly constructed tunnels of the eastern extension were taken into use as underground factories for war production. Following the end of hostilities, work started again and within a few years the western extension had been completed to West Ruislip and the eastern extension to Hainault and Epping.

The final electrification scheme for the Metropolitan Railway came to fruition in 1961 which also involved further line rationalisation. It was decided that London Underground services would extend only as far as Amersham, leaving British Railways alone to service the stations beyond (i.e. to Aylesbury) by the suburban line (formerly part of the Great Central) from Marylebone. Since these trains shared the same pair of tracks with the Metropolitan from Harrow onwards this severely limited service capacity. As a result the rationalisation plan involved quadrupling the line from Harrow through to the junction for the Watford branch as well as electrification of the existing tracks onwards from Rickmansworth to Amersham. 10th September 1961 finally brought an end to steam hauled passenger services on the Metropolitan and therefore on the London Underground, although steam hauled service trains continued until 6th June 1971. In more recent times, the occasional 'steam on the Met' days have been run with specials operating non-stop from Harrow to Amersham.

With the Amersham electrification the opportunity was taken to introduce new eight coach multiple unit trains (known as "A stock"). These are different in several respects to other London Underground surface and tube stock. In line with its suburban role all seats are transverse and as a sop to the 'city gent' commuters small luggage racks are provided for brief cases and umbrellas! The trains are also equipped with more powerful motors rated for 60mph running, recognising the long non-stop runs that occur on the line, i.e. Finchley Road – Harrow – Moor Park for the Amersham/Chesham services. As well as the passing of steam, the introduction of new trains also made the Met-Vick locos redundant and most were scrapped. However several were retained mainly for depot duties or for hauling special excursion trains (there is a photo record of No 12 Sarah Siddons heading a special to Portsmouth in July 1984!)

The standard traction supply arrangement for all London Underground lines is now 630 V d.c. compared to 750 V d.c. on the Network Rail lines in Southern England (former Southern Region territory). As well as a difference in voltage the two systems employ different traction supply arrangements. The LU system has the positive rail at +420 V and the negative rail at -210 V with

reference to the earthed running rails. The two motors on each axle operate initially in series and then in parallel as speed increases, in both configurations with variable in-line resistance. The Network Rail system has one conductor rail (positive) with current return through the running rails (unearthed). The negative return voltage floats and depends on the distance from the substation, where earthed. However, there are several sections of line used by both London Underground and the main line train companies, viz Gunnersbury – Richmond, Queen's Park – Harrow and Wealdstone and empty stock movements on a part of the Wimbledon branch of the District Line. On these sections of line the negative conductor rail is still provided for the benefit of LU trains but is bonded to the running rails and the LU train motors are understood to operate in series mode only.

Interestingly the schematic diagram of the underground lines as we know it today only came into being in 1933 designed by Mr Harry Beck – what a legacy! In many respects this diagram and the line names reflect the history of the London Underground. The sub-surface Circle line of early cut-and-cover construction with the two former Metropolitan Railways routed along the north (Metropolitan) and south (District) sides, the deep level tubes and the isolated City and Waterloo line. It will also be noted that the Underground is mainly confined to north of the river Thames. Again, this has come about because of history since during the early years many surface suburban steam operated lines were built out through the south London suburbs to towns in the South East. Many of these were subsequently electrified between the two world wars on the 750 V third rail system already mentioned.

Time has moved on and further changes are currently planned for the 'sub-surface lines' (Metropolitan, Hammersmith and City, District and Circle Lines). The current Metropolitan line stock is now approaching 50 years of age. New trains are on order (to be known as S stock) and expected to be introduced into service next year. Again they will be 8 car sets (S8s) as opposed to the 6/7 cars on the other lines. There will also be several other new innovations for the London Underground. These will be the first underground trains to be air conditioned and will have walk-through inter-car connections. London Underground also has plans to convert from 630 V d.c. to 750 V d.c. for traction supplies on the sub-surface lines, which will increase train power relative to weight, therefore resulting in potential energy savings (as well as bringing about voltage compatibility with the Network Rail Southern system, previously mentioned). In line with this, the new S stock will be fitted with traction equipment designed for the higher voltage. Following on from the replacement of the Metropolitan line stock similar new trains will be provided for the other sub-surface lines but these will be 7-car sets (S7s) because of platform length limitations. It is also planned to re-jig running arrangements on the Circle line so that trains will not run round and round the circle. Instead trains will start from Hammersmith, pass through Edgware Road and around the circle clockwise back to Edgware Road, where they will reverse for the return journey.

Finally, a good quiz question: Where are London Underground tube trains to be found in operation other than the London environs? Answer: On the Isle of Wight between Ryde Pierhead and Shanklin, but that's another story!

Acknowledgements:
The authors gratefully acknowledge material provided by John Perkin and Roger Hennessey. Copies of the relevant Garcke's manuals are held in our Bristol (Cairns Road) Archives.

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