DC POWER SYSTEM STUDIES FOR JUBILEE LINE

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1. Introduction

The Jubilee Line Extension Project is one of the largest ongoing transit construction project in the world. It comprises two sub projects: upgrading of the existing line and a new extension. This paper describes the system studies carried out for the d.c. power supply system for this prestigious project.

1.1 Upgrade

At present the Jubilee Line runs from Stanmore in the north of the city to Charing Cross in the centre of London. It serves 17 passenger stations with a route length of 22 km [ref. 1]. Peak hour service is at 3 minutes interval (20 trains per hour). Normal service is at 5 to 7 minutes interval.

Power supply is via 3rd and 4th rails, at d.c. 630 V nominal voltage, which is converted from 11 kV supplies. The line is powered by 9 traction substations, one of which is dedicated to the sidings at Stanmore. The Jubilee Line tracks run in parallel with the Metropolitan Line tracks for 11 km between Wembley Park and Baker Street. Subsequently 4 traction substations supply both lines with common d.c. buses.

Existing trains are 6 cars with camshaft controlled d.c. traction motors. No regeneration braking is available. New trains are inverter controlled induction motors, with regenerative braking. The initial train consist is 6 cars and ultimately 7 cars.

When the new signalling system is installed, the train service capacity will increase to 36 trains per hour. Due to the increase in power demand, 3 new traction substations (TSS) and two new track paralleling huts (TPH) are to be constructed. Additionally sections of steel conductor rails between Finchley Road and St John's Wood are replaced by low resistance aluminium composite rails. The existing TSS at Stanmore is reconfigured to supply the mainline as well as the sidings.

The 4 existing traction substations supplying both Jubilee and Metropolitan lines are reconfigured so that the two lines become electrically segregated on the d.c. side.

1.2 Extension

The extension runs from Green Park to Stratford, with a route length of 16 km. 11 passenger stations will be served, with power supply from 5 new TSS and 1 TPH. A new depot is also being constructed at the Stratford end.

Throughout the extension, aluminium composite conductor rails are used. Maximum train service capacity will be 36 trains per hour.

2. Scope of Work

The C203 contract's scope of work is for power, cabling and conductor rails. It includes but is not limited to the following:

Primary A.C. Distribution (11 kV and 22 kV) - including switchgear and cabling

A.C./D.C. Conversion - Rectifier transformers and rectifiers

For the upgrade:	11 kV a.c. / 630 V d.c., 1.5 MW
For the extension:	22 kV a.c. / 630 V d.c., 2.25 MW

Each rectifier is a 12 pulse unit with series bridge connection. Each new substation has two rectifier units. The two units are phase shifted on the primary of transformers by +/-7.5 degrees to make up an overall phase shift of 15 degrees, so that 24 pulse operation can be achieved.

D.C. Distribution

D.C. Switchgears
D.C. Feeder Cables and Continuity Cables
D.C. Conductor rails
Section Switches

Secondary A.C. Distribution

Auxiliary transformers for the upgrade:	11 kV a.c. / 415 V a.c.
Auxiliary transformers for the extension:	22 kV a.c. / 415 V a.c.
Batteries and chargers	

Interfaces with other contractors

3. Specifications

The main requirement for the d.c. power supply system concerns the voltages delivered to the trains. For example, during normal operation and under the condition of a single plant outage (except track feeder outage),

the average motoring voltage for an inter-station run should be greater than 575 V;
the minimum voltage delivered to the train should be greater than 450 V.

Rectifier load is selected as BS4417 class F. On the a.c. side, total harmonic voltage distortion at point of common coupling should conform to Engineering Recommendation G5/3, which determines the requirement for 24 pulse operation of rectifiers.

4. Simulation Software

Simulation studies are carried out to determine the plant ratings and the performance of the overall power supply system.

The Cegelec Multi-Train Simulator (MTS) is a suite of software developed over the last two decades. It has proven to be a very useful tool to support d.c. power supply system design [ref.2,3]. The following table gives a comparison between simulated and measured loads for a previous transit power supply project.

Substation i.d.	Installed Capacity (kW)	Simulated Load (kW)	Metered Load (kW)	Error (%)
TSS 1	600	470	486	-3
TSS 2	600	460	450	2
TSS 3	600	440	394	12
TSS 4	600	350	356	-2
TSS 5	600	250	104	140
TSS 6	600	400	366	9
TSS 7	600	260	240	8

These figures show excellent correlation between simulated and metered loads, except TSS 5. TSS 5 is an end-of-line substation where the simulated load was increased to cater for future extension.

Within the MTS, numerical summaries of the simulated results are output in numerical forms, including:

Overall summary of train voltages
Rectifier loadings
Track feeder loadings (for ratings) and current grading (for protection coordination),
Inter-station run results (run time, train speed, voltage, etc),
Conductor rail current,
Harmonic current and voltage distortion,
etc.

The numerical summaries are also supplemented by graphical output. The original MTS version was for d.c. traction motors only [ref. 4]. Due to the adoption of a.c. traction motors on the Jubilee Line Extension, the MTS was further developed to model the characteristics of a.c. traction motors [ref. 5,6].

5. Execution of Studies

The MTS studies have been carried out for a number of conditions, including

- Normal Operation

- Outage Conditions

  Single rectifier outage
  A.C. bus outage
  D.C. feeder outage (single end feeding)

- Substation Outages due to Upgrade Works

  This is required to assess the effects of complete substation outages on the normal operation of train services during the implementation of the works.

6. D.C. System Protection

Three schemes are installed for d.c. track feeder protection. These are

1. Direct Acting Overload Protection

2. Whipp & Bourne MITRE Relay, including 4 elements

   - Instantaneous overcurrent
   - Rate of rise with ΔI
   - Inverse time overcurrent
   - Thermal modelling

3. Under Voltage with Multiplexed Inter Tripping System (MITS)

Coordination studies have been carried out to determine the settings of the schemes. Proofing of settings are carried out in two aspects:

. Drop short tests - the rate of rise element reaches the end of a feeding section
. Online tests - no spurious trips by any of the protection scheme.

7. Further Information

For further information, interested readers are referred to the following web sites on the internet:

Jubilee Line Extension Project Home Page:- http://www.jle.lul.co.uk/

Cegelec Projects Limited Home Page:- http://www.cegelecproj.co.uk/

8. Acknowledgement

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9. References

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