D. W. LEES

THE INSTITUTION OF ENGINEERS, AUSTRALIA
VICTORIA DIVISION

ELECTRICAL AND COMMUNICATIONS ENGINEERING BRANCH
AND
THE INSTITUTION OF ELECTRICAL ENGINEERS

SYMPOSIUM

"ELECTRIC TRACTION SYSTEMS"

TUESDAY, 6th MAY, 1975

At Clunies Ross House, 191 Royal Parade, Parkville

3.45 p.m. to 9.00 p.m.

PAPERS

PROGRAMME

3.45 p.m. - 4.00 p.m.	Registration.
4.00 p.m. - 4.10 p.m.	Introduction by Chairman of the Electrical and Communications Engineering Branch - Mr. A.N. Bird, M.I.E.Aust.
4.10 p.m. - 4.55 p.m.	Paper No. 1 - Electricity for Transportation - Mr. R.G. Chapman, F.I.E.Aust., Assistant General Manager (Marketing and Distribution), State Electricity Commission of Victoria.
4.55 p.m. - 5.40 p.m.	Paper No. 2 - Electric Vehicles for Street Public Transport - Mr. F.D. Snell, M.I.E.Aust., Deputy Chairman, Melbourne and Metropolitan Tramways Board.
5.40 p.m. - 6.25 p.m.	Paper No. 3 - Electric Railways - Mr. A. Firth, M.I.E.Aust., Chief Electrical Engineer, Victorian Railways.
6.30 p.m. - 7.45 p.m.	DINNER.
7.45 p.m. - 9.00 p.m.	Panel Discussion, involving the three speakers and led by the Moderator, Mr. C.W. Freeland, M.I.E.Aust., Acting First Assistant Secretary, Land Transport Policy Division, Department of Transport, Canberra.

ELECTRIC VEHICLES FOR STREET PUBLIC TRANSPORT

F.D. SNELL

DEPUTY CHAIRMAN

MELBOURNE AND METROPOLITAN TRAMWAYS BOARD.

6TH MAY, 1975.

ELECTRIC VEHICLES FOR STREET PUBLIC TRANSPORT.

Organised street public transport commenced in Melbourne in 1869 when horse buses began to operate between Bourke Street and the Birmingham Hotel at the corner of Smith and Johnston Streets, Fitzroy. The buses were very successful. By 1882 there were 178 buses in operation on 15 routes, carrying some 10 million passengers in that year.

In 1885 the first tramway was opened - a cable tramway along Flinders Street and Bridge Road between Spencer Street and the Yarra in Richmond. By 1891 there were 70 kilometres of cable tramways in service.

Electric trams made a brief appearance between 1889 and 1896 when a service was operated in Tram Road between Whitehorse Road and Doncaster Road. The equipment had been brought to Melbourne for the 1888 Centenial International Exposition and was purchased by land developers who wanted to attract purchasers to land at Doncaster. It failed when the land boom collapsed.

As the suburbs developed it became obvious that longer distance travel by cable tram was not practicable and electric tramways were built to extend the routes. These electric tramways were generally built by Trusts formed by Municipal Councils.

In 1919 the cable and electric tramways were combined under the control of the Tramways Board. The disadvantages of this mixed system included the need for modal interchange between the two systems and the Board commenced the conversion of the cable tramways leading to the present system with its 217 kilometres of electric tramways.

A fascinating collection of electric trams were operated by the various Tramway Trusts who built the separate electric tramways and one of the first tasks of the Board was the building of a standard fleet.

Between 1920 and 1933 it built some 400 trams in the class now known as W2 trams. It built well because 338 of these trams are still included in the Board's fleet. The combined distance travelled by the remaining trams is now more than 750 million kilometres with all vehicles exceeding 1.6 million and some exceeding 2.5 million kilometres.

They have substantial steel channel underframes and wooden framed bodies with light, non load bearing steel panels. The roof is canvas covered planked oregon. The bogies are of riveted construction with hornstay guides and equalizer beams and have primary coil springs with secondary leaf springs supporting the bolster.

Each tram has four 600 volt DC, self ventilated, axle suspended motors which drive their axles through a double helical gear and pinion. The motors are controlled through full current controllers which switch the appropriate resistors during acceleration, with the motors connected first with two pairs in series and then with two pairs in parallel.

About 1935 the design changed and the remainder of the trams in the fleet have riveted steel frame sides with load carrying 16 and 14 gauge steel panels. Many have sliding doors in place of the blinds on earlier trams. The roof is still oregon but ceilings are lined. The bogies have semi-elliptical laminated primary springs and secondary springing is provided by coil springs in the bolster.

The motors are still axle suspended and of similar design to those in the earlier trams. The controller still operates at 600 volts but in these trams the controller handles the coil current of contactors which carry out the switching.

In all these trams the braking is by brake shoes (originally cast iron but now non-metallic) applied to the wheel tread by compressed air. The hand wheel operated parking brake mechanically applies the brake shoes. Emergency electrical braking is provided by switching interconnected motors into a motor-generator configuration.

The design is crude by modern standards and yet very reliable. Its very reliability inhibited development because it was difficult to justify replacement of equipment which continued to operate effectively, particularly in an era when popular opinion predicted the eclipse of trams and there appeared to be more urgent projects for the investment of capital by the State.

The Board imported equipment for a modern PCC tram from America in 1949 and operated this tram in service for some time but decided that it would retain its 1935 tram design for the 62 trams that it built in 1955 and 1956. In retrospect this was probably the wrong decision but the Board was building a tramway in Bourke Street to replace a bus service and was moving against the tide because all other major cities in Australia were replacing trams with buses. The modern vehicles were more expensive than the older design and the Board's funds were limited.

It is worth pausing to consider the PCC tram; it is the basis of all modern trams in the world. The tram was developed by the major street car operators in America who formed a Presidents' Car Committee to design a modern tram which they hoped would halt the loss of patronage from older trams.

The specification produced by the Committee was arranged so that any of a number of manufacturers could produce a standard vehicle.

The vehicle specified offered passengers a ride on comfortable seats in an enclosed vehicle with heating in winter. The hand controller was replaced by foot pedal controls which permitted the driver to select acceleration and braking rates so that the pilot motor driven drum controller inserted or removed resistance in the motor circuits at the appropriate rate to give smooth and constant acceleration or braking.

In the version of the equipment purchased by the Board the four 300 volt motors were arranged with two motors permanently in series and with each pair of motors permanently in parallel. The motors were high speed light weight units mounted on the bogie frame at right angles to the axles.

Service braking was rheostatic, supported by spring applied electrically actuated drum brakes which provided low speed braking and also acted as parking brakes. Four electromagnetic track brakes were used for emergency braking. Because all braking was removed from the wheel treads there was less difficulty in the use of resilient wheels with rubber sandwiches.

In 1972, when the need to upgrade public transport was accepted by the Victorian Government, the Board was able to demonstrate the economic advantages of replacing 113 of its existing trams, with their labour intensive maintenance requirements (including daily brake adjustment and weekly servicing) by 100 modern all-electric trams.

While tenders were being called and examined the Board built a prototype tram, generally complying with its new tram specification, to test public reaction to the new body and to evaluate ventilation and other features.

Because early completion of the prototype was essential it was decided to retain the PCC bogies, import the latest version of the PCC type control equipment from Belgium and manufacture the body at Preston. The vehicle was operational in less than 12 months.

The new control equipment provided anti-skid and anti-slip protection and the pairs of 300 volt motors were connected first in series and then in parallel to give smoother acceleration and better low speed control than the original PCC equipment.

The contract for the supply of 100 trams was let to Commonwealth Engineering (Vic.) Pty. Ltd. who designed the body and auxiliary equipment and are building and equipping the bodies at Dandenong. The main electrical and mechanical equipment was designed by ASEA in Sweden. That company is providing all of the motors and traction control equipment, manufacturing the majority of the motors in Australia and assembling the imported control equipment. Bogie frames are being manufactured by Commonwealth Engineering and the bogies are being assembled by the Board.

The tram is 16.46 metres long, 2.67 metres wide and weighs approximately 19 tonnes. The body is fabricated from pressed and roll formed steel sections with an interior stressed skin.

The two bogies have a stress relieved electrically welded tubular frame. The roller bearing axle boxes support chevron rubber primary suspension units and rubber is also used for the suspension of the bogie bolster.

Tractive effort is provided by four 300 volt forced air ventilated high speed DC motors each rated at 52 kW. They have Class F insulation in both rotor and stator. The motors are mounted on the bogie frame parallel to the axle and are coupled to the gear box through a short rubber bushed cardan shaft. The double reduction gear box has a ratio of 7.27 to 1.

The acceleration and braking of the tram is controlled by the driver through three pedals. The left foot is used to operate a safety pedal. The vehicle cannot be started until pressure is applied to this pedal and braking is automatically applied if the pedal is depressed beyond a set position or released while the vehicle is in motion.

The accelerator and brake pedals are operated by the right foot and the position of these pedals determines the value of inputs to an electronic control unit (tramiac). The tramiac also receives information from tachometers attached to each motor shaft and from shunts in the motor circuits. It uses this information to determine the appropriate rate for contactor switching of the resistor in the motor circuits. If wheel slip or skid is detected the rate of acceleration or deceleration is adjusted to eliminate the condition.

The block diagram in Attachment "A" illustrates the operation of the control system, while Attachment "B" gives details of the vehicle.

Braking is normally electrodynamic down to approximately 2 kilometres per hour when the spring applied, hydraulically removed disc brake is applied to bring the tram to rest but the disc brake is capable of stopping the tram from the maximum speed of 72 kilometres per hour should dynamic braking fail. Emergency braking is provided by electromagnetic track brakes.

The control system is designed to provide a smooth comfortable ride for passengers under all conditions and to provide all possible assistance to the driver in obtaining maximum performance.

The vehicle is totally enclosed and doors are interlocked so that the vehicle cannot start until the doors are closed and the doors cannot be opened until the speed falls below 2 kilometres per hour.

Because the doors are normally closed, forced ventilation of the tram interior is provided through 6 AC motor driven fans in the ceiling. Supply for the fans is provided by an alternator driven by a 4.7 kW 600 volt DC motor. The three phase alternator has an output of 2 kVA at 20 volts, 50 to 60 HZ and its main function is to provide a 24 volt supply to the tram control circuits via a bank of 165 ampere-hour (5 hour rate) lead acid batteries.

Two fans are mounted, one at each end of the motor alternator shaft. One fan is used to provide forced ventilation for the traction motors and the other fan is used to cool the starting and braking resistor bank. Air for this fan is drawn from within the tram and the air leaving the resistor cubicle is either recirculated for interior heating or dumped to atmosphere as required.

Trams have survived in Melbourne for a number of reasons. The wide streets - particularly in the area surveyed by Hoddle, who had more faith in the development of Melbourne as a major city than many of his successors - have received much credit but a high standard of track construction and maintenance has also contributed. One provision of the Board's Act - originally inserted to protect the municipalities from the Board - has also had a significant effect. This provision requires the Board to build a roadway at least equivalent to the adjacent roadway if it removes its tracks from any street. The cost of the rails is the major difference in cost between reconstructing a tramway and abandoning it.

While trams survived in Melbourne they continued to develop in Europe so that it is not surprising that most of the tenders submitted to the Board were based on European designs. Some seventy combinations of mechanical and electrical equipment were offered.

Trams also survived in the United States, principally in Boston and San Francisco and these two cities have now combined to place an order for 230 articulated trams with Boeing-Vertol. These trams are 21.8 metres long and are powered by two 600 volt 230 h.p. motors, each driving two axles. Many of the mechanical and electrical features are similar to European articulated trams.

The energy crisis and the growing awareness of the problems of pollution have combined to awaken interest in electric traction throughout the world. Trams are being re-considered by many major cities.

There is also a renewed interest in the trolley bus which has a number of attractive features. It does not require tracks, is quiet and pollution free and its freedom from engine vibration results in a long body life and low maintenance costs. The high tractive effort means that it is better suited for hilly routes than diesel buses.

However, the operator has little control over the quality of the surface of the route operated by the trolley bus, the overhead is more complex than for trams and feeder costs are higher because there is no rail for return current. As with trams its diversion from routes is difficult because it must remain in contact with its overhead supply.

This aspect of trolley bus operation is now under review and two methods of improving its flexibility are being investigated.

Lockheed are experimenting with a large flywheel - raised to a speed of 30,000 rpm in two minutes by a combination of electronic controls and a variable frequency motor generator set - which stores some 9 kWhr of useful energy. When auxiliary power is required the energy is released through a variable frequency alternator and rectifier to provide 600 volts DC. The equipment must be capable of delivering peak power of the order 150 to 200 kW during acceleration of the vehicle. The additional equipment necessary will weigh some 1200 kilograms and is expected to provide 3-6 kilometres of travel away from the trolley wires. It has not yet reached the practical operating stage because of unsolved bearing and metallurgical problems. The power requirements for raising the flywheel to speed may provide some problems for the supply authority.

The alternative under investigation is the provision of a 72 volt battery on the trolley bus and the use of a DC/DC converter to charge the battery and also to drive the vehicle through low voltage motors. When supply is lost the battery drives the vehicle until external supply is restored. The design under investigation would give the vehicle a range of 24 to 40 kilometres without external supply.

A great deal has been written and a lot of work has been carried out to produce a battery bus for urban public transport. Many of these buses are small units - about 20 seats - designed for very special service in or around city centres.

In Japan there have been two developments in the design of a full scale battery operated urban bus. A hybrid bus has been used in Tokyo. This bus is 10 metres long and has a load capacity of 80 passengers (29 seated). Its tare weight is 10 tonnes and gross weight is 14.5 tonnes. The drive is by means of a conventional differential and rear axle but the main drive motor is a 400 volt DC series motor with a continuous rating of 67 kW developing 158 kW at 2370 rpm with maximum torque of 65 kgm. The motor is thyristor controlled and is driven by a 420 volt lead acid battery with a capacity of 135 ampere-hour at the 5 hour rate.

The vehicle also carries a 40 horsepower diesel engine arranged to operate on a fixed throttle and to drive an alternator with a continuous rating of 27 kVA. In operation in Tokyo the vehicle is claimed to be capable of a normal days urban service without the need to recharge the batteries. The diesel engine is switched off while the bus is in the centre of the city.

The cost of a production vehicle is estimated to be three times that of a diesel bus and the Tokyo Transport Authority did not appear to have much interest in its further development. Maintenance and operating costs are high. The noise level inside the vehicle appeared to be higher than in a normal diesel bus.

An all electric bus being tested in Osaka is 9.25 metres long, has a tare weight of 9.8 tonnes (including 3.4 tonnes for the battery) and with its load of 72 passengers has a gross weight of 13.8 tonnes. The 360 volt main drive motor has a continuous rating of 70 kW at 3000 rpm and a maximum output of 126 kW.

The controller is a thyristor chopper and the bus has regenerative brakes. The battery is a pasted type 384 volt (6 volt monoblock x 64) unit with 350 ampere-hour capacity at the 5 hour rate. The range on a single charge is 190 kilometres at a constant speed of 45 km/h and 65 kilometres on typical city bus operation.

The bus is operated between Osaka City and Osaka Port on a reasonably flat route in heavy traffic. It is necessary to change the battery at least once in a normal tour of duty and the bus, with its passengers, is driven into the depot and on to a ramp. The driver plugs a lead into the side of the bus and presses a button. A complex automatic battery exchange system replaces the battery in 2.5 minutes and the driver removes the lead and returns the bus to service. The battery is transferred to an automatic charger for rapid recharging.

The bus is at present very expensive - at least three times the cost of a diesel bus, partly because all aluminium construction has been used in an attempt to overcome the battery weight - and operating costs were stated to be 1.3 times that of a diesel bus. However the Municipality intends to continue the development of the vehicle, being prepared to pay the premium to overcome objections to noisy bus operation in narrow streets. The ride is harsh by our standards but the vehicle operates quietly, apart from some fan noise from the battery ventilation system.

Another approach to the battery bus is to carry the battery on a single axle trailer. This allows the bus to retain its full passenger capacity but increases the total length by some 3 metres. An experiment - sponsored by the electricity authority - is being conducted in Moenchen-Gladbach in West Germany. Thirteen M.A.N. buses designed for battery operation are being operated on a 24 km test route over an extended period to evaluate the effectiveness of the system.

Most of this paper is devoted to discussion of conventional electric public transport vehicles but mention should be made of the Personal Rapid Transit systems which have been developed in recent years.

Most of the more successful installations have been designed for specific purposes and the most successful must be the very specially designed moon buggy. While the buggy operated very successfully in a harsh environment its development was not inhibited by a tight budget and it did not require many of the features of a public transport vehicle. Aero space designers have had difficulty in translating some of their concepts to passenger transport.

Public transport operators in major cities have yet to accept the new concepts and many pilot schemes appear to be foundering for want of a large scale market. There are serious environmental problems in introducing the systems into existing cities and there are also fears in America for the safety of passengers in unattended vehicles.

However the cost of labour for the crews of vehicles is a significant part of the total operating cost of public transport and automatic operation is an obvious answer to the provision of low cost public transport so the search for a viable system must continue.

Communication has always been important in the operation of street public transport. A feasibility study is in progress in Melbourne to determine the economic advantage of equipping all trams and buses with modern communication equipment.

A number of overseas operators have installed equipment to provide rapid attention to faults and delays and protection for crews. A typical example is Gothenburg Tram Company which operates 320 trams and 285 buses and has a modern communications installation.

It is based on a computer coupled radio network operating on five semi-duplex channels in the 450 MHZ UHF/FM band. Each vehicle is allocated a distinct selective calling identification and as it leaves the depot the despatcher advises the control computer by teletype of the duty allocated to the vehicle for the day. The information is held in core so that if a call is received from the vehicle the computer can display to the operator at the control desk the route and approximate location of the vehicle at the time of the call.

The equipment on the vehicle continually scans the five channels and when control wishes to pass a message to one vehicle a stop tone is transmitted on one channel. All receivers stop scanning at that channel until the vehicle identification signal is transmitted and resume scanning unless the signal is for that receiver.

Signals are transmitted from the vehicles on a randomly selected free channel. The computer acknowledges the call which may be a request to speak to the controller or one of a set of pre-coded messages - e.g. "collision", "power failure", "behind schedule" or "call police".

The calls are all displayed on a video screen at each controller's desk. The priority of the call determines its position in the display. As a controller completes a task he calls for the next job which is transferred to the centre of his screen and deleted from the screens at other desks.

Control centre facilities include radio communication with emergency vehicles and direct lines to other public utilities. The controller can talk to any or all drivers of vehicles on a route or to the passengers in the vehicles through the on board public address system.

It is claimed that significant improvements have been achieved in handling faults and accidents and in restoring normal services after delays.

Whatever form of vehicle is used for street public transport there are certain factors which contribute to its successful operation.

1. A system with well designed routes having stops strategically placed along each route so that economic operation is possible without requiring passengers to walk too far.

2. Ready access to the stops with protection for the passengers when approaching or leaving the vehicle. This includes effective passenger interchanges between modes, adequate passenger shelters at stops and protection from road traffic. The public transport operator is, and must be, actively interested in the welfare of the pedestrian.

3. Separate or protected right of way for the public transport vehicle. This includes reservations, the use of concrete kerbs, safety zones and priority at traffic signals. A vehicle carrying fifty times the load of the average car in three to four times its area deserves this protection.

4. Modern, comfortable and clean vehicles - capable of rapid, smooth acceleration and deceleration - providing regular services with short headways.

All of these features combine to provide an efficient service.

Regardless of the technological advances made in the design of vehicles and systems, no public transport operation can be successful if it is not designed to meet the needs of its passengers.

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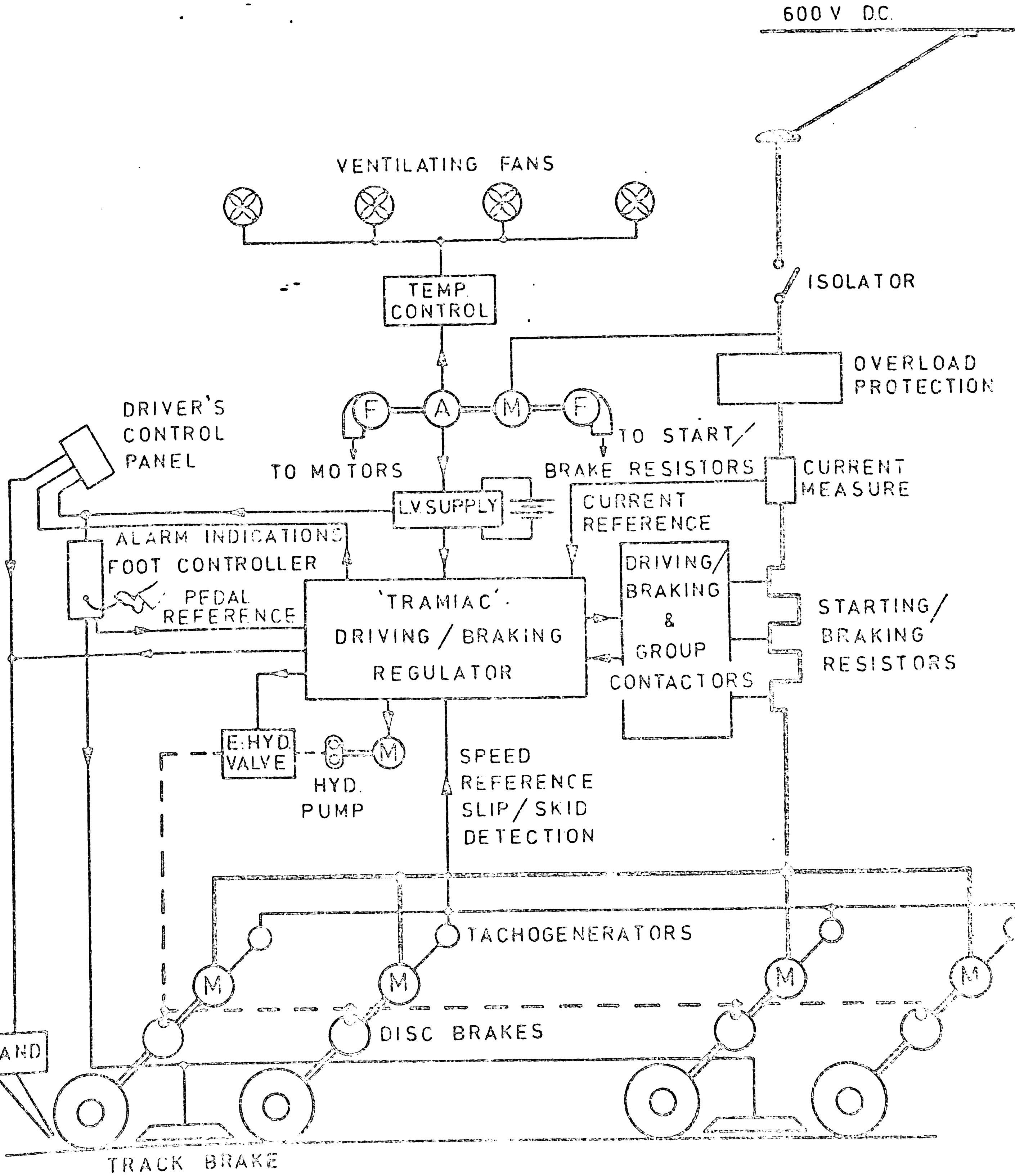
ATTACHMENT "A"



BLOCK DIAGRAM OF CONTROL SYSTEM

ALL-ELECTRIC TRAMS FOR MELBOURNE.

ATTACHMENT "B"

NEW ALL-ELECTRIC TRAMS FOR MELBOURNE.

PERFORMANCE.

Maximum speed	72 km/h
Service acceleration	1.75 m/s^2
Service deceleration	1.5 m/s^2
Emergency deceleration	3.7 m/s^2
Maximum jerk	2.1 m/s^3
Design capacity	48 seated, 77 standing
Empty weight	19 tonnes
Weight with design capacity	27 tonnes

DIMENSIONS.

Length	16560 mm
Width	2667 mm
Height	3550 mm
Interior width	2540 mm
Interior headroom (flat ceiling)	2105 mm
Centre aisle width	690 mm
Floor height	850 mm
First step height	285 mm

MECHANICAL AND ELECTRICAL EQUIPMENT.

Truck centres	8500 mm
Wheel base	1796 mm
Wheel diameter	680 mm
Track gauge	1435 mm
Number of motors	4 (one per axle)
Motor type	Series
Motor voltage	300 V
Gear ratio	1 : 7.24
Drive type	Resilient coupling to 2 stage gear box
Service brakes	Electro dynamic rheostatic with motor shaft disc brake
Emergency brakes	Motor shaft disc brake and electro-magnetic track brake

ELECTRICAL CONTROL SYSTEM.

Line voltage	600 vdc
Control voltage	24 vdc
Control type	Electronic (tramiac)
Starting steps	41
Braking steps	17
Driving controls	3 pedals

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