

solely due to tires running on the road surface, by instrumenting and engaging only to the negative trolley line (one pole up) and coasting the coach down a hill. Again this was solved by adding resistance between the negative line and the coach body to make sure we could bleed off a static buildup. We unsuccessfully tried a ground strap to the road surface.

Another problem in the hot coach category is AC voltage coupled onto the coach body through capacitance of the motor windings to the motor frame and inductor windings to inductor frames. What this amounts to is very narrow pulses of fairly high voltage. This was solved by providing capacitance between the negative line and the coach body. This was also instrumental in reducing radio frequency interference (RFI).

Another problem occurred when driving on streets in Seattle that have overhanging trees with wet leaves. Because the coach body was referenced to the negative line, the hot coach detector would go off if the negative line was 25 to 30 V above earth ground and the detector was set at a too-sensitive position.

Radio frequency interference has been a nagging problem and I believe it plagues all trolley systems. The Randtronics system found effective ways to reduce interference to a level that is not too detrimental. The RFI problem is difficult because in the Randtronics system the coach body is part of the RFI shield. Because of 600-V isolation, creep, and strike for voltage isolation, much of the system is built in a fiberglass cradle and with fiberglass insulation components that do not shield RFI. So the coach body becomes part of the RFI shield.

In addition the overhead lines are an effective antenna system that distributes RFI and amplifies it. The overhead line actually has some of the characteristics of an antenna system. RFI exists in standing waves on the overhead lines and couples directly into automotive AM radio antennas. This has been a difficult problem; it is difficult to even measure the broadband RFI from the trolleys. We started out by using a spectrum analyzer; however, it was found that a spectrum analyzer is the wrong kind of equipment to use for measuring low-level broadband interference. We found that a car radio is the best monitor for interference, which has been confirmed by the experts in the RFI field.

In addition, we experienced noise and radio frequency susceptibility in Seattle. Under the TV towers on Queen Anne Hill our converter and our dynamic brakes would quit; these problems have been solved simply. People riding in the bus have operated CB radios and ham 2-m transceivers in the back seat, near the propulsion system. This is a design problem that has to be considered; in the presence of high-level radio frequency it must be at least fail-safe. If the propulsion system has been well shielded with, for example, a zinc metal spray on the outside of the fiberglass cradle or a completely metal-enclosed propulsion package, operations would not have been affected.

We experienced arcing on aluminum heat sinks, in spite of the fact that they are milled flat, and we used Penetrox and correct clamping pressure on pressure-pack-type devices. I have concluded that the most reliable heat sink material, at least at the interface to SCRs and diodes, is nickel-plated copper.

We have had problems at crosswalks with plastic stripes; as the bus accelerated across them, the rear axle would break traction, speed up to a high speed, come across the crosswalk, and then grab hold of the pavement. We had initial problems with the speed loop in getting stability.

In conclusion, I would like to emphasize that no matter what system is being considered or installed, there will most likely be problems; I believe patience is the key to solving them.

## Advanced Technology for Trolley Bus Systems

Thomas C. Matty

During the 1960s Westinghouse began a program to advance the state of the art of technology used in the transportation industry. This effort successfully bore fruit when the contract of the BART System in San Francisco was awarded to Westinghouse in 1969, which resulted in development of a completely new form and generation of automatic train signaling equipment. This same technology was later applied to the Sao Paulo Metro as well as to a number of people mover systems throughout the United States and Great Britain.

Also during this period, Westinghouse had prototype choppers in operation at BART, New York, and Chicago. The first production contracts for Westinghouse chopper propulsion were BART and Sao Paulo. Since then, Westinghouse has more than 1,700 units of advanced chopper propulsion in revenue service and on order for both heavy and light rail applications, including 250 sets for the new trolley buses in Vancouver. Now that the last lingering question of the technical applicability of choppers, i.e., electromagnetic interference, has been successfully resolved at the Washington Metro, it appears that chopper technology has finally come of age in the transit industry.

Through the 1970s, Westinghouse continued to advance transit technology state of the art. In 1976 Westinghouse started a new technology development to allow the use of convection cooled semiconductor equipment for propulsion systems. Another program developed solid-state motor control circuits, which were applied in a prototype trolley bus in operation in Mexico City. Its power circuit is completely convection cooled and uses all solid-state devices to perform the mode switching and circuit configurations for a trolley bus. This circuit resulted from the development of two- and four-motor circuits for heavier transit equipment.

### WESTINGHOUSE CHOPPER PROPULSION FOR VANCOUVER TROLLEY BUSES

The new trolley buses for Vancouver represent another developmental step in the state of the art for traction equipment (Figure 1).

The propulsion systems are fully solid-state, controlled by a microprocessor with only a minimum number of mechanical switches to assure high reliability and minimum maintenance cost. Although the Vancouver bus propulsion may appear to be complex, it is, in fact, simpler and easier to maintain than previous trolley bus equipment designs (Figure 2). All components are mounted in a single-layer, sealed package so that only the components that need to be changed are removed. Because the semiconductor package is sealed, heat is transferred through a cold plate. Cooling occurs by natural convection assisted by motor inlet cooling air, thus eliminating the need for an expensive fan and high-maintenance filters.



Figure 1. New bus for Vancouver trolley fleet.

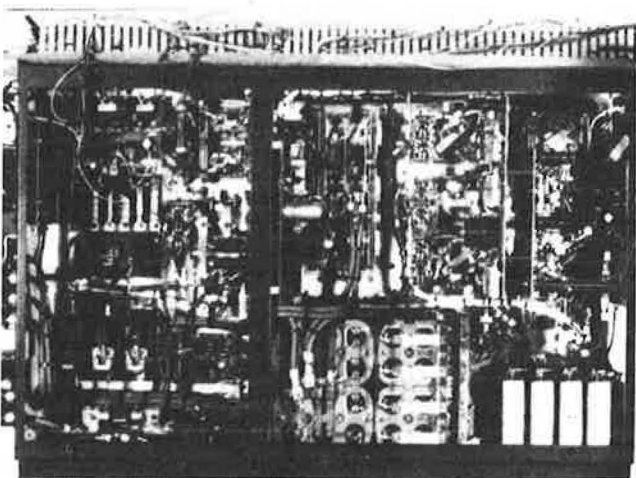


Figure 2. Propulsion system in Vancouver vehicles.

Before any device is removed, the unit can be fully tested using a three-mode test automatically controlled by the microprocessor. Each mode performs a complete series of tests to verify every component in the propulsion system, including semiconductor devices, fuses, and capacitors.

The bus carries an auxiliary propulsion battery, maintained by a dual output converter, which allows for off-wire capability to change routes and avoid obstacles. It also has electric dynamic and regenerative braking capability from top speed down to 3 km/h. This provides for smooth but efficient operation at minimum energy costs.

#### MICROPROCESSOR DEVELOPMENTS

The Vancouver bus microprocessor is the Westinghouse standard unit used on heavy and light rail transit systems, including the Rio de Janeiro Metro, SEPTA, WMATA, and the Baltimore and Miami Metros. It is maintained using a "black box" replacement concept. After the unit is removed from the bus, it is checked by using a programmable simulator unit that checks and verifies all functions of the microprocessor package. A test unit is also provided for the converter package that automatically tests all converter functions.

But the development of even more efficient and reliable transit propulsion technology must and will continue. Once again, Westinghouse is developing a new advanced cooling concept for semiconductors used in chopper propulsion gear to eliminate many maintenance problems now associated with previous applications of semiconductor technology. This new cooling concept will be completely solid-state in nature, without the application and maintenance problems of coolants such as freon. The operator's maintenance personnel will be able to maintain and service the solid-state drives easily by using conventional tools and equipment (Figure 3).

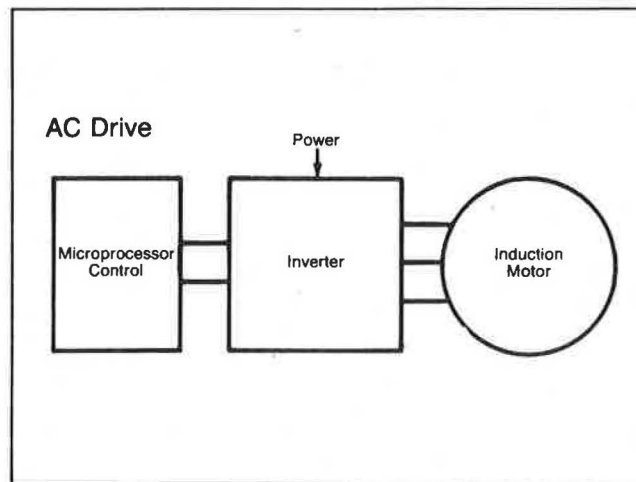


Figure 3. Systems to be maintained.

#### AC DRIVE PROPULSION

Another key propulsion technology development area for Westinghouse is the AC drive. Propulsion technology developments at Westinghouse are not confined to the power circuit, although that is the most costly component and one of the most critical maintenance items in the total propulsion system. Westinghouse is also working on a new electronics control to enable much more simplified maintenance philosophies for system operators. The new control incorporates both on-board diagnostics and sophisticated external diagnostics, which Westinghouse calls prognostic capability. Prognostics is similar to diagnostics except that the former has additional intelligence to predict impending failures before they cause service disruption.

For example, determination that a semiconductor device in the power circuit is exceeding certain temperature limits under certain operating conditions may signal that another problem exists somewhere in the equipment, which is causing the overtemperature condition. The importance of prognostics is the ability to recognize an impending failure so that the operator can take corrective action. This may involve removing the equipment from service or some other kind of strategic action to minimize or avoid disruption of normal operating service.

#### OTHER NEW TECHNOLOGY OPPORTUNITIES

Westinghouse is also investigating other new technologies that could prove applicable and beneficial to trolley bus use. Automatic rewiring capability should offer significant benefits on new systems by

eliminating much of the special work associated with street intersections and by increasing the operating flexibility of the system. With the development of limited off-wire capability at Vancouver, the next step in trolley bus system technology advancement is automatic rewiring capability to enable a bus operator to drive through an intersection or divert around an obstacle without ever having to leave his position to reconnect the trolley poles with the catenary.

There are also a number of other strategies using off-wire alternative energy that could be employed to improve trolley bus operation. However, implementation of these strategies requires additional development in the application of existing microprocessor capabilities. For example, if battery off-wire capability exists onboard the bus, it would be useful to maintain the charge on that battery so that maximum regenerative energy recovery could always be obtained. With the microprocessor today, it is possible that each trolley bus operation can be adjusted to the normal route followed in service, including the complete grade profile. This would allow the bus propulsion system to use part of its energy from the battery and less energy from the line when climbing grades. Energy can then be returned to the battery on downgrades instead of burning it either in brake shoes or resistor heat.

#### MAINTENANCE IMPLICATIONS

Arguments continue today about the trade-offs associated with advanced technology and the increased labor and technical skills required to maintain more sophisticated equipment. In the 1940s and 1950s electrical engineers were basically power circuit specialists. Starting in the 1960s they became more electronics oriented. Today, it is difficult to hire a DC motor designer or a power circuit engineer or a power systems engineer. Young engineers now believe that electrical engineering should be focused on developing applications for microprocessors.

What is the base of knowledge that new maintenance and service people will bring to transit operators in the future? The answer is microprocessors, solid-state devices, and some of the new concepts that have been presented here.

Westinghouse believes in advancing technology for all forms of electrified transit, and has seized the opportunity to do so again for a reemerging transit mode--the trolley bus. The necessary maintenance and technical support capability will be there, from operators and suppliers like Westinghouse, so that the significant benefits of advanced technology can be realized by current and future trolley bus system operators in North America and around the world.

## Off-Wire Operation

Tom E. Parkinson

Off-wire propulsion can fill several needs, including the short-term need to avoid delays when stuck on an insulator or to get around a defective switch or broken wire. These minor problems occur every day but do not always appear in the records. They need little stored energy capacity. This small capacity would also permit running through an intersection with a wire down, detouring over a block to avoid a fire, or short turning where there is no wire. This is the biggest need for off-wire capa-

bility. To run around the block, about 0.5 mile of off-wire capability is needed.

Another need involves a branch where wiring cannot be justified. Ideally, it is level and there are no air conditioning or heating requirements because auxiliaries put a severe constraint on off-wire operation. This is the type of service of which many European buses, equipped with small diesel or gasoline engines, are capable. It is also a need that can be met with current battery technology.

There is also a need to have a full-service capability off-wire; that is, the full performance of 200 or more hp. This is not currently available; however, when available it will probably produce disadvantages for both the diesel bus and the trolley bus. It is difficult to see any economic viability in this area.

In all off-wire needs the poles have to be taken off the wires. To do this automatically is not a problem, even while moving. However, putting the poles back up without having the driver get out of the bus is much more difficult. There are different ways to accomplish this by using quite sophisticated electronic servomechanisms, but lack of reliability in all types of weather and the rigors of transit operation strongly suggest that the procedure is not realistic. The idea that it is possible to avoid all the overhead and intersections and get rid of the switches and the visual pollution by having to pull down the poles and cross the intersection and put them up again is, in my opinion, absurd--now or in the future. To pull down the poles to run over an unused branch, or for an emergency short turn, once or twice every round trip, is realistic. In a short-term emergency the driver can rewire by getting out and using the ropes to put the poles back up. In a regular, off-wire operation to service a branch, there are various competing means to reliably put the poles back up on the wires at a predetermined location when the coach is stopped.

Off-wire requirements can be achieved with batteries, with reciprocating engines, and with flywheels. These all have limitations, which are related to weight, cost, and reliability. The short-distance need is met easily, cheaply, and reliably by batteries. The medium-distance reduced-performance need can be met by all three. Only the reciprocating engine is here at the present time. Batteries that provide the capability to run 2 miles off the wire (and 2 miles back) are available, but the weight or the cost of some of the new, high-energy-density batteries is high. The flywheel has not yet been developed to an acceptable cost or weight.

My view, knowing the packaging and the weight problems and that off-wire trolley buses will always be a small production item, is that it is difficult to see the cost of these units going down. I doubt that flywheels on buses will become economically viable.

I also do not believe in using reciprocating engines on trolley buses. The advantage of a trolley bus is that it is an all-electric vehicle. It is stored out of doors in the coldest weather; it does not have to be filled with fluids; oil does not drip out nor do vibrations reduce its life. The use of a reciprocating engine on the trolley bus provides the equivalent of the diesel bus. A diesel or gasoline engine on a bus also reduces reliability, despite figures to the contrary from European properties where there is a considerably higher maintenance standard. The capability of a property to maintain new designs of vehicles must always be considered. Some properties are not capable of operating standard trolley buses because despite their