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 capability. 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

many advantages they need more management and more street supervision. The operation of trolley buses requires extra effort in order to get the benefits; a property that is not able to or is not prepared to put in that extra effort is well advised to keep to diesels. Dual-mode vehicles compound this situation. Vancouver chose the limited-range battery because most delay incidents are minor, relating to broken insulators, stalls on insulators, short sections of wire down, or defective switches.

The original specification called for an option of a reciprocating engine; the cost ($10,000 to $20,000) appeared quite reasonable. The weight was something else. The current designs of trolley buses are converted diesel buses and are too heavy. In the future as we move to better coaches and better propulsion systems, particularly AC motors with inverters, it should become possible to include the added weight of batteries or flywheels.

The limited-range battery cannot power the compressor. Consequently, the travel of the bus off-wire is limited not only to the capability of the battery, but also to the amount of air that can be stored. Assuming that the air system would be fully charged before the poles are pulled, the bus can make eight full stops. An additional air tank could be fitted if necessary to expand this capability. There is no danger of losing braking capability as the buses have the maxi-brake system, which applies an emergency brake from a separate air reservoir when the main air pressure has reached a preset level. The driver has no control over this application but can release the emergency brake to make one move of the bus and then reapply it.

The new trolley buses in Vancouver are currently being equipped with standard bus batteries for limited off-wire use. These batteries are not optimized for traction applications and add some 400 kg to the vehicle weight. Such batteries typically deliver about 20 kWh/kg. When experience has been accumulated on the actual duties of these off-wire batteries, state-of-the-art lead acid batteries could be used to deliver some 35 kWh/kg, provided that these more expensive batteries are cost effective. Development in lead acid batteries is still continuing; it is expected that the battery capability could be extended to 50 kWh/kg. Advances in battery technology have been slow in moving from the laboratory to the production stage. Several new battery technologies offer the opportunity of 100 or more kWh/kg, which within the space and weight capabilities of full-sized buses would permit substantial off-wire operation in the range of 5 to 10 km of wire that would correspond to a branch of 5 km with the batteries recharging under wire on the main trunk or downtown section of a route. Among the advanced batteries, sodium sulfur has been under extensive development, but it has the liability of requiring an operating temperature of 300°C.

Nickel iron batteries are now being used extensively in railway applications in Europe and have the potential for development into higher energy-density levels. Nickel zinc and the more expensive silver zinc batteries also offer high energy densities and are being developed in robust configurations for traction service. The latest development with longer-term potential is the application of semiconductor physics to battery technologies in the form of the polyacetylene battery. Organic polymer batteries, although at an early stage of development, appear to have particular attraction for electric vehicle applications.

Apart from certain specific applications, reciprocating engines and flywheels are not a desirable addition to the trolley coach. However, traction batteries now capable of providing limited off-wire operation will be the way to provide more extensive off-wire operations in the medium-term future.