A Look at Chopper Systems

George Swartz

I started with Randtronics Transit in 1977. I designed the two-phase armature chopper, which is used on the trolley fleets in Seattle and in Philadelphia. Some 109 trolleys were delivered to Seattle in 1979 and 1980, and 110 were delivered to Philadelphia in 1980. I followed the trolleys to Seattle and took over the warranty maintenance there; over the last 3 years we have gained quite a bit of experience. The Seattle system is running well at this point, and we are approaching 10 million miles of chopper operation in the two trolley fleets.

The energy saving of a chopper system of 15 to 20 percent compared with a cam controller is justification alone for using a chopper system, despite expectations of some maintenance headaches or extra effort required for an electronic or solid-state system. The extra maintenance has not materialized; the system in Seattle is running well at a low maintenance cost. The smooth control of a chopper system improves ride and reduces stress on the drive train.

The Randtronics system uses the GE 1213 compound motor at 165 hp. The AMG trolley in Seattle will go up the 18 percent Queen Anne hill at between 15 and 20 miles/hr. The current limit on the chopper is 475 amps and the chopper will work as low as 200 V line voltage and as high as 750 V; the Seattle system is 700 V nominal.

Because the 1213 is a compound motor, there is also a field chopper in the system rated at 5 amps. In the propulsion package Randtronics also provided a static converter for battery charging, which is rated at 350 amps and 13.7 V.

The system uses a two-phase chopper, essentially two single-phase choppers operating in parallel like a two-cylinder gasoline engine; this has the advantage that if one side of the system fails, the bus can continue to run on the remaining chopper. When one of the two phases fails, the current limit is reduced, so the bus cannot negotiate the hills in Seattle with a crush load. In Philadelphia, when one side of the chopper historically has failed, the bus has continued to run for weeks or months until the chopper is repaired. In addition, the two-phase chopper reduces ripple current in the motor and is a convenient way to share current between two main SCRs.

The chopper is configured with an H-type commutator and a pulse commutation so that the voltage across each device in the chopper is approximately one time the line voltage. Thus, if the line voltage is 700 V, the devices typically see about 800 to 900 V with transients on top of the line. The advantage of this configuration is that only one device has to be used in each position in the chopper rather than using several SCRs in series.

The next feature is the full-on or bypass mode of the chopper. When the vehicle reaches the base speed of the motor, the main chopper turns on fully and the commutator turns off. The advantage to running in this mode is reduced electromagnetic interference (EMI); there is also reduced noise and heat generation. Because of this full-on mode the only time the chopper is operating is during initial acceleration. The duty cycle on chopper operation is probably 10 to 15 percent of the operating time of the bus.

We also designed the logic with discrete integrated circuit CMOS logic. We had a choice to make: we could have gone to microprocessor logic. The only reason we stayed with discrete logic was that we felt that it would be easier for the properties to maintain in the field. In fact, microprocessor logic would have been cheaper for the manufacturer.

Much of the expense of the Randtronics system is related to the modular design. The chopper, the convertor, and all other modules can be pulled out in a matter of minutes and replaced with new modules to get a bus back on the road. In Seattle there is a 97-bus signout. With 109 buses in the fleet and a portion of buses scheduled for routine preventive maintenance, we were allowed a maximum of four buses down for propulsion-related problems. In the last 3 years we have never missed a signout in Seattle. In fact, typically, there is either none or one bus down at any given time.

The modular design allowed us to work in the bus yard and not in the barn. For example, we could pull out a chopper or a logic rack or some other module that had a problem. Without bringing the bus into the barn we could replace the most difficult module in 1 hour at the most.

In addition, Randtronics built in diagnostic test channels and status indicators, which proved invaluable in the maintenance program. Something that any property should consider in procurement is a fault memory in the logic, i.e., circuits built into the logic that will diagnose what happened after an event, because the most difficult problems in chopper propulsion are intermittent--those that stop a bus, but disappear by the time the technicians arrive. Thermal problems especially are of this nature; by the time somebody arrives to look at the bus, things have cooled off. This is a factor that should be written into specifications.

The propulsion systems have to be viewed in a systems approach. A propulsion system is not a unit apart from the bus. Both EMI or "hot coach" problems, the trolley bus, the chassis, the overhead lines, the substations--i.e., the complete system--must be considered.

We solved problems with hot coach bodies that were caused by diodes in the hot coach detector and, to some degree, by the overall design of the coach. Randtronics did not build the hot coach detector; it was built by a firm in Canada. The hot coach detector connected the shell of the coach to the negative line through resistance and a diode network. The negative line in the Seattle and Philadelphia systems is a quasiearth ground and the coach body typically runs 20 to 25 V from earth ground, which is considered safe. The hot coach detector diodes interacted with the noise or spikes in the negative line; the diodes rectified the spikes and caused the coach body to go 75 to 100 V negative with respect to earth ground and presented a shock hazard. This is a lethal shock hazard, but because the bus chassis has capacitance to earth ground one could contact the bus, get a shock, and maybe jump back into a hazard. This was solved by adding resistance without diode networks between the coach body and the negative line.

In Philadelphia we found that static buildup due to the tires running on the road surface alone would cause the coach body to go negative 5,000 V with respect to the propulsion system. Again, the diodes in the hot coach detector were in a blocking direction and as soon as we got up to 4,000 to 5,000 V, there would be an arc in the propulsion system and our logic would fault. We determined that this was 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.