Most late model vehicles today use the Powertrain Control Module (PCM) to control or oversee the output of the charging system. The PCM may do this directly by varying the current to the alternator's rotor, or by monitoring and controlling the voltage regulator.

The basic reasons for using the PCM to regulate charging voltage include:

- **Improving fuel economy** — Reducing charging output when it isn’t absolutely necessary means the belt-driven alternator uses less power (the higher the charging output, the more power it takes to turn the alternator). Reducing power consumption reduces fuel consumption for better mileage.

- **Improved drivability** — The PCM can ramp up charging output more gradually when electrical demand goes up, eliminating sudden loads on the alternator that can cause noticeable idle roughness or loss of power (especially in small displacement four cylinder engines). The PCM can also increase idle speed as needed to increase charging output under certain conditions.

- **Longer Battery Life** — Smart charging can better control charging output for optimum battery life. Smart charging does a better job of keeping the battery at or near full charge under a wider range of operating conditions.

How Charging Output is Regulated

The output voltage and current of the charging system is not fixed or constant because electrical loads are continually changing as the vehicle is being driven. Cranking the engine to start pulls amps from the battery, which have to be replaced so the battery doesn’t run down. The ignition system, fuel pump, PCM and other control modules also require power while the engine is running, which the charging system must also provide. Turning on the lights or other electrical accessories further increases the demand on the electrical system, so charging output has to increase to match these requirements as well.

If there’s no charging output, or not enough output to keep up with demand, the power has to come from the battery. If there are no amps going back into the battery to replace those being pulled out, the battery will eventually run down and go dead.

Most alternators on late model vehicles are capable of producing up to 70 amps or more at idle, and up to 160 to 180 or more amps at 2,000 to 2,500 RPM. Current output increases with engine speed and the supply current
that is being fed into the alternator through its "FLD" (Field) terminal.

NOTE: Amperage (amps) is the amount of current flowing through a circuit, while voltage (volts) is the electromotive force pushing that current through the circuit. Automotive electrical systems are all 12 volts, but some modules and sensors operate at lower voltages (5 volts). Current flow depends on the circuit and usage, and can range from milliamps (1/1000th of an amp) in a sensor circuit up to a hundred amps or more in the starter or charging system circuits.

The rotor inside an alternator is nothing more than a rotating electromagnet. The more current supplied to the rotor through the Field terminal and brushes, the stronger the rotor’s magnetic field. And the stronger the magnetic field (and the faster the rotor spins), the more current it induces in the copper windings in the stator coils surrounding the rotor. Consequently, if more charging output is needed, more current is fed to the rotor. If less charging output is needed, the rotor current is reduced.

Charging Theory
The main difference between “smart” charging and older methods of regulating voltage (electronic and mechanical) is that smart charging can change charging output as needed independent of the battery’s state of charge or the electrical load on the system. The PCM determines charging output based on programmed algorithms and inputs from various sensors that monitor battery load, voltage, engine RPM and temperature. The PCM decides the charging output based on operating conditions and other variables rather than simply reacting to changes in battery voltage or electrical load.

On many applications where the PCM controls the alternator, charging out is controlled by varying the “duty cycle” (on-off time) of the voltage regulator with a Pulse Width Modulation (PWM) signal. The PWM signal can be varied from 5 percent duty cycle (for minimal voltage and amperage output) up to 100 percent (for maximum charging output).

On certain GM smart charging applications (Cadillac CTS, for example), the Body Control Module (BCM) rather than the PCM monitors battery voltage, temperature and charging output. A battery current sensor on the battery ground cable provides input to the BCM to sense battery load. This information is relayed to the PCM which decides the charging output and duty cycle for the voltage regulator. The BCM estimates battery temperature based on ambient temperature, battery voltage and charging output, and sends an idle boost request to the PCM if increased charging is needed.

Ford uses a different approach, as does Chrysler. On a 2012 Ford Fusion, the PCM has two communication lines to the alternator. Both use pulse width modulation signals to communicate. One line carries the duty cycle signal for the voltage regulator, and the other provides a return signal that indicates the load on the alternator. A third circuit, connected to the "A" terminal on the regulator, senses battery voltage.

Not So Smart Charging
With ordinary “dumb” voltage regulation, the regulator senses battery voltage and balances charging output with electrical demand. When the system voltage is low, the regulator increases the supply current to the alternator’s rotor to increase charging output. The process isn’t entirely dumb because electronic regulators also alter the charging rate to compensate for temperature. It will increase the charging rate when the battery is cold, and reduce the charging rate when the battery is warm.

Most alternators have an “internal” voltage regulator (mounted inside or on the alternator housing), while others use an “external” regulator (mounted elsewhere in the engine compartment) to control the field current to the rotor.

The charging output voltage will vary somewhat from one vehicle to another, and may range from 13.5 up to 14.8 volts. Most systems typically operate in the 13.8 to 14.3 volt range at room temperature, but may jump to 15 volts briefly when ambient temperatures are below freezing. As the engine and battery warm up, the charging voltage ramps back down to a more normal range.

A fully charged automotive lead-acid wet cell battery should measure 12.66 volts (or 12.8 to 13.0 volts for an AGM, Absorbent Glass Mat, battery). To charge the battery, the alternator’s output voltage must be at least half a volt higher than base battery voltage. The higher the charging voltage and amperage, the faster the battery will charge — up to a point. If the charging voltage is too high (over 14.8 volts), the liquid electrolyte inside the battery...
can breakdown, releasing hydrogen and oxygen gas. Excessive gassing can lead to loss of electrolyte and battery failure.

**Charging Tests**

On older vehicles, maximum charging output could be tested by bypassing the regulator or full fielding the alternator and measuring voltage at the battery with a digital or analog voltmeter. A digital voltmeter is preferred because the display is easier to read and shows the voltage to the nearest tenth or hundredth of a volt depending on the range selected.

Full fielding test procedures vary depending on the application. On some older alternators, depressing a tab inside a hole in the back of the alternator full fields its output. On others, a jumper wire is used to momentarily connect the alternator’s “BAT” (battery) and “FLD” (Field) terminals to route full battery voltage to the rotor. Either method should make the alternator go to maximum output.

On some vehicles, the alternator’s output can be controlled with a scan tool. This requires a scan tool with bidirectional capability to command the charging system. A simple DIY scan tool that lacks bidirectional communication capability cannot be used for this type of test (although it can be used to read system voltage and to check for battery or charging system related fault codes). Alternators can also be bench tested using an alternator test stand that spins the alternator and measures output voltage and current. The bench tester (and some charging system testers) will also check for fluctuations (“ripple current”) in the alternator’s output voltage which would indicate bad diodes. Diodes on the back of the alternator transform the alternator’s Alternating Current (AC) output into Direct Current (DC). If one or more of these diodes has failed, it will cause an uneven output and AC “noise” in the electrical system (which may have an adverse effect on some control modules). Diode leakage can also allow current to leak from the battery back through the alternator, causing the battery to slowly discharge when the engine is not running.

**Smart Diagnostics**

If an alternator produces its rated voltage and amperage when tested, it should be a good unit. There should be no need to replace it. Consequently, if the vehicle has a charging problem and the alternator tests good, the cause is something else such as a bad voltage regulator, PCM or wiring harness.

Loose, corroded or damaged wiring terminals at the back of the alternator are common causes of charging problems. Wiring connectors and terminals may appear to be okay on the outside, but have loose, corroded or broken wires inside. The only way you can find these kinds of problems is to do a voltage drop test across each of the connections.

A high amperage connection should have less than a 0.5 voltage drop, and less than 0.1 volts on a low amperage connection.

Other sources of trouble include loose, corroded or damaged battery cables and ground straps, blown fuses in the power center, or a blown fusible link in the wiring (refer to the vehicle service literature to determine the fusible link’s location, if used).

Another source of trouble can be miscommunication or lack of communication between the PCM and alternator or regulator. A good alternator that is capable of producing the required charging voltage and current may not work properly if it doesn’t communicate properly with the PCM. Some remanufactured alternators sold in discount stores may be listed for applications for which they are not totally compatible. They may fit the application physically, but if they don’t speak the same electronic language as the PCM, they may not work properly or may not charge at all.

On some applications, the charging system will go into a fail-safe mode if communication between the PCM and alternator or regulator is lost. The alternator will continue to produce voltage and current, but at a much lower fixed rate.

**Battery State Of Charge**

Because car batteries are so sensitive to their state of charge, it’s important to make sure a replacement battery is fully charged BEFORE it is installed. This will assure proper charging operation as well as reduce the initial load on the alternator when the vehicle is first started with a new battery installed. An alternator is designed to maintain battery charge, not recharge a dead battery. Overloading the alternator may result in heat damage to the diodes, rectifier assembly and/or internal voltage regulator, which can cause the alternator to fail.

**Why Battery Charging Is So Important**

The average service life of a typical wet-cell lead-acid car battery is only about four to five years, and can be as little as three years in a hot climate. For a battery to realize its maximum service life, it must be maintained at or near full charge most of its service life. If the battery is allowed to run down (deep discharge), sulfate will form on the surface of the cell plates. The crystals form a barrier that interferes with the recharging process. If the sulfate remains on the plates for more than a few days, it can damage or ruin the battery.

Marine and RV batteries use a slightly different chemistry in their cell plates that is more resistant to sulfation so they can handle repeated deep discharge cycles without damage. The
Maintain the battery at full charge. Then apply a "float" charge of around 13.0 to 13.8 volts to avoid overcharging (which could damage the battery). Some smart chargers will have different charging rates for conventional wet-cell, gel cell and AGM batteries. Most smart chargers also have the ability to detect battery polarity, and will prevent charging if the positive and negative clamps are accidentally connected to the wrong battery terminals. Reversing the connections with an ordinary charger may damage the charger, battery or vehicle electronics.

Some battery chargers have a special charging mode that can help sulfated batteries recover from a deep discharge. The charger applies a higher than normal initial voltage and/or pulses the charging voltage until the sulfate is dislodged and the battery starts to accept a charge. It then reverts back to a normal charging mode until the battery comes back up to full charge.

### Review Questions

1. The advantages of smart charging control are all of the following EXCEPT:
   a. Eliminates need for voltage regulation
   b. Better fuel economy
   c. Longer battery life
   d. Smoother idle

2. Charging output is increased by:
   a. Increasing the speed of the alternator
   b. Increasing the duty cycle of the regulator
   c. Increasing the field current to the rotor
   d. Any of the above

3. If an alternator tests "good" but is not charging, the fault may be:
   a. Loose, corroded or damaged wiring harness or connectors
   b. Loss of communication between the PCM and alternator/ regulator
   c. PCM internal problem
   d. Any of the above

Answers: 1. a, 2. d, 3. d