

# Alternator Secrets

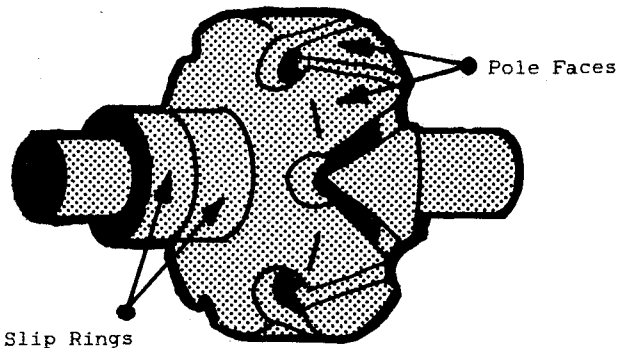
## INTRODUCTION

In the last two decades alternators have replaced generators in motor vehicles. The reasons are many: output current can be produced at lower rpm, voltage can be more accurately controlled with solid state regulators, alternators need less maintenance, and they cost less to manufacture.

When modified, auto alternators can provide variable direct current at 0 to 120 volts for battery charging, hot charging, light arc welding, or for running AC-DC appliances and lights. Another simple modification provides AC power to run some transformer-operated appliances. If you know the secrets of its operation and the modifications possible, the small low-cost alternator can become a versatile power plant.

## BASIC CONSTRUCTION

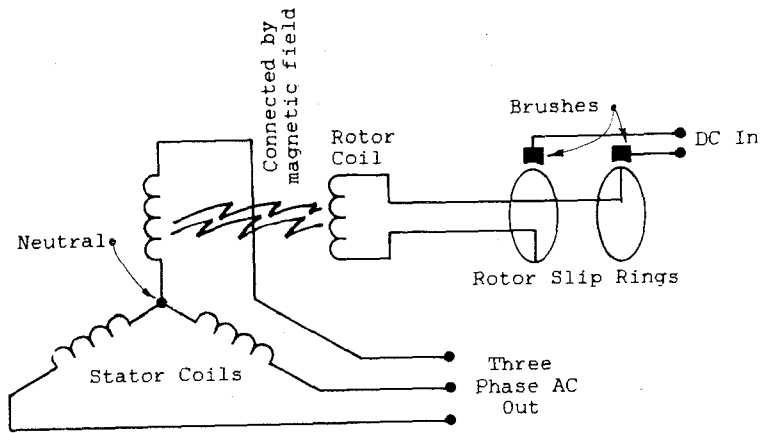
The old-fashioned generator contains a wound stator which produces a constant magnetic field in which a revolving coil of wire, called an armature, turns. A commutator on one end of the armature made up of many individual brass segments passes the generated current to the outside world through carbon brushes.



TYPICAL ALTERNATOR ROTOR

Because commutator segments must be electrically insulated from one another, they can not be fabricated from a single block of metal. Each commutator segment must be individually attached to the armature shaft. This is a source of mechanical weakness. When the armature is rotated at high RPM, centrifugal force can cause the commutator to explode, throwing segments in all directions.

To prevent explosions, the generator is usually driven at less than engine speed. An auto engine may turn 5000 RPM, but the generator must be geared to a maximum 2500 rpm for safety's



ELECTRICAL SCHEMATIC OF  
A TYPICAL ALTERNATOR

sake. As a result, the generator turns so slowly at low engine rpm that it produces little or no current.

A modern alternator, like the generator, contains both moving and stationary coils of wire. In the alternator, however, the moving coil, called the rotor, uses current supplied through slip rings to generate a moving field. Power is extracted from the stationary field coils.

Slip rings replace the weak generator commutator. The rotor coils themselves are encased in a strong soft iron shell making the whole assembly much stronger than the generator armature. The net result is that alternators can be driven to much higher speeds without danger of explosion. In fact, alternators are usually driven at up to twice engine speed some running at 8000 rpm or more. At low engine rpm the geared up alternator turns much faster than a comparable geared down generator. The net result is that the alternator can begin producing useful charging current at lower engine rpm than can the generator.



SOLID STATE DIODE

A coil of wire rotating in a magnetic field produces an alternating current with a frequency dependent on how fast the coil turns, one cycle being produced per revolution. A generator armature uses a commutator to mechanically switch rotating windings in and out of automobile's electrical system to produce direct current.

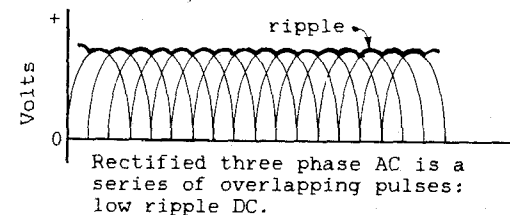
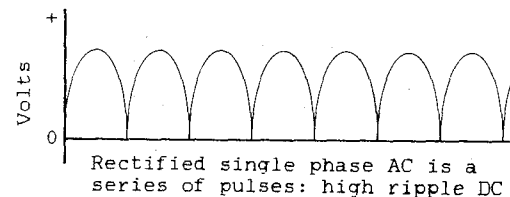
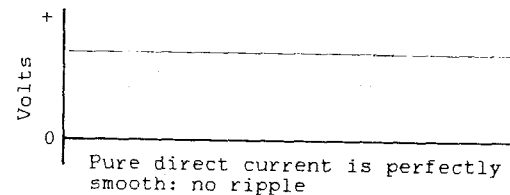
The three separate stationary windings of the typical auto alternator produce three-phase alternating current. Rather than use a commutator to mechanically convert AC to DC, the alternator uses six diodes in a full-wave bridge rectifier circuit. In essence the diodes are solid state switches with no moving parts, making them maintenance-free and explosion proof.

The alternator output voltage can be controlled or regulated by varying the rotor current. Regulators sample the output voltage and automatically change the intensity of the rotating magnetic field by adjusting the current fed to the rotor through the slip rings. The adjustments are made in such a way so as to bring the output voltage to the desired level.

### THREE-PHASE POWER

Surprisingly, alternators are constructed with three sets of field windings positioned evenly at 120 degree intervals inside the frame. Such construction produces three-phase AC. But why three-phase?

If we look at the effect of diodes on a single-phase AC current, we see that the output is a series of DC pulses. True direct current is completely smooth. The output of the diodes (rectified AC) is bumpy, and is said to possess ripple.



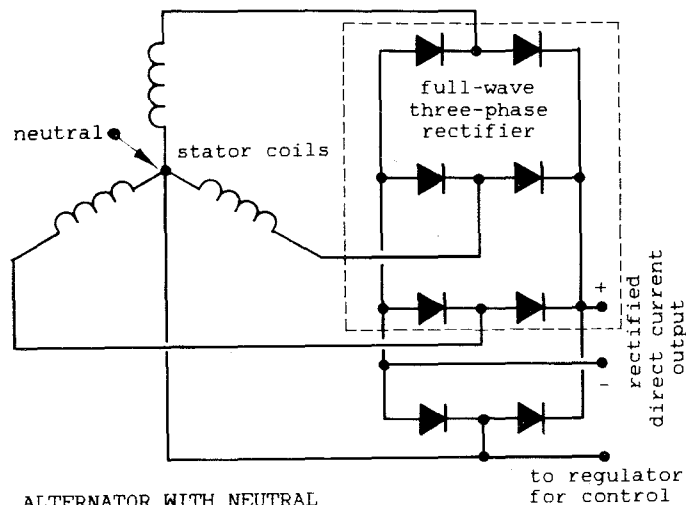
When the rectified DC from each of the three-phase windings is added together or superimposed, the peaks overlap to produce a much cleaner DC with much less ripple. Lead-acid auto batteries last longer when charged with pure DC than high ripple rectified DC. Generators may be a mechanical and electrical nightmare, but they put out very clean DC. Three-phase windings were designed into alternators to produce DC of great purity.

Many alternators connect one lead of winding to a common point called a neutral. The other lead of each winding is connected to a pair of diodes. Three windings each using two diodes accounts for the six diodes found on most alternators.

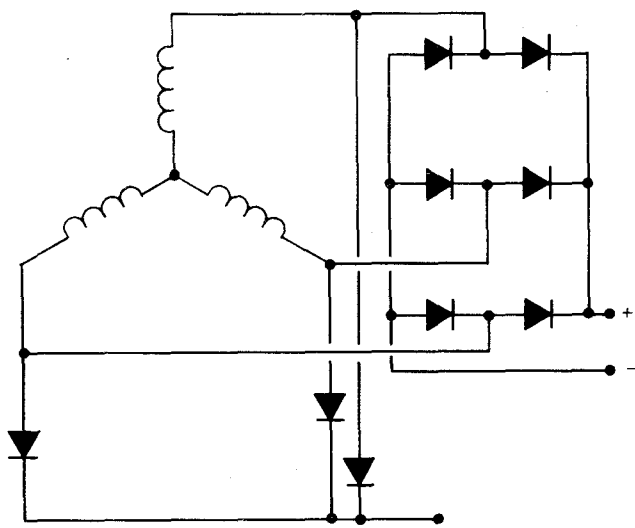
Newer alternators particularly high current models, use two additional diodes on the neutral connection to sample alternator output voltage for use by the regulator.

In the future internal mechanical construction, electrical circuits, regulator operation and physical location will probably change somewhat. But basic alternator theory will not change. The exact details for the alternator you have can usually be found in a standard auto repair manual such as Motor's or Chilton's. Often you'll get instructions on dismantling and repairing alternators as well.

The diagrams in this booklet are general and should



ALTERNATOR WITH NEUTRAL SAMPLING CIRCUIT



ALTERNATOR WITH STATOR COIL SAMPLING CIRCUIT

apply to all alternators. Again, refer to a recent auto manual for details on your particular alternator should you have problems.

#### REGULATORS

Early alternators used relays to regulate their output voltage much like those used on generators. When lower cost, more reliable solid state devices became available, electronic regulators became standard.

Although most regulators are factory set to force an alternator to produce 12 to 14 volts, they can be modified or new regulators custom built to provide almost any voltage up to 130 volts once their operation is understood.

If we were to run an alternator at some fixed rpm, we would find that changing the intensity of the rotating magnetic field would change the output voltage of the alternator. We can change that magnetic field by changing the amount of current flowing through the slip rings into the rotor. Since the resistance of the rotor windings is constant, merely changing the input voltage to the rotor will change the current flowing into the rotor by a proportionate amount.

Suppose we have alternator spinning at 2000 rpm. We have it attached to some electrical load drawing say 10 amps at 12 volts. Let's assume that the rotor is using 1 amp at 4 volts. Suppose we increase the electrical load so that we now need 15 amps. Due to internal electrical resistance of the whole system, the voltage falls to 11 volts. To get the output voltage back up to 12 volts we must increase the rotor magnetic field intensity. So we adjust the rotor voltage up to 6 volts, and in doing so, we find the rotor now drawing 1.5 amps of current. This increased current results in increase magnetic field which at 2000 rpm gives us an output of 15 amps at 12 volts. It is the job of the regulator to make these adjustments, quickly and automatically.

Let's suppose that we set the rotor current at its maximum value, say 3 amps at 12 volts, and varying the rpm. At low rpm, the output voltage might be only five volts. As the rpm comes up, the output voltage would hit 12 volts then 25, then 50, and at top end, over 100 volts. Alternators can sometimes put out 140 volts when driven at top rpm.

As you can imagine, when the alternator is running at low rpm, the alternator is putting maximum voltage and current into the rotor so that the alternator output voltage will come up to 12 volts. When the rpm starts to pick up so that the voltage starts to climb above 12, the regulator starts cutting back the voltage and current into the rotor. At very high rpm, the regulator is supplying the rotor with very little current, so that the output voltage remains at a constant 12 volts.

An electronic regulator provides continuous and instantaneous adjustment of rotor current by sampling the alternator output voltage and by comparing it against an internal standard reference. When output falls, a small current is sent to transistor B which amplifies it and sends it to transistor A which acts as a valve in controlling the heavy current flow from the battery to the rotor.

Input voltage to the regulator is usually a steady 12 volts whereas output to the rotor varies from zero to 12 volts to control rotor current. Many rotors have a winding resistance of about 3 or 4 ohms, which causes a current of 3 to 4 amps to flow at 12 volts (calculated with Ohm's law).

Suppose that to get 12 volts out of an alternator we need to pump 2 amps of direct current into the alternator's rotor which has an internal resistance of 3 ohms. What would the rotor voltage have to be? We can calculate it with Ohm's law:

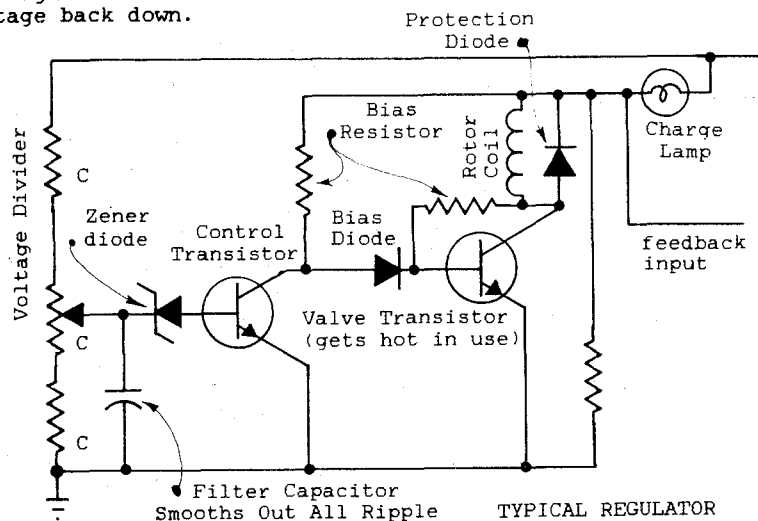
$$\begin{aligned} \text{volts} &= \text{amps} \times \text{ohms} \\ &= 2 \quad \times 3 \\ &= 6 \end{aligned}$$

The regulator passes 2 amps but has to eat up the difference between supply voltage, 12 volts, and rotor voltage, 6 volts or 6 volts. How much power is this? We can do another simple calculation:

$$\begin{aligned} \text{watts} &= \text{amps} \times \text{volts} \\ &= 2 \text{ amps rotor current} \times 6 \text{ volts difference} \\ &= 12 \end{aligned}$$

This 12 watts of power is turned into heat, and if the regulator is to be kept cool and working properly, it must have heat-dissipating fins or should be mounted to a large heat sink such as a fender or firewall where destructive heat can be carried away.

Regulators use Zener diodes to provide a stable reference voltage. A voltage divider - the three resistors labeled C - extracts a preset fraction of the voltage for comparison against the Zener. For example, a regulator might have a 6 volt Zener in its circuit. To provide a regulated 12 volts, the resistive voltage divider is set to extract 1/2 of the sample voltage. When 12 volts is produced, half of 12, or six, is compared against the 6 volt Zener. They are equal; no change is made in rotor current. If output voltage falls to 8, the Zener is compared to 1/2 of 8, or 4 volts, and the regulator output current is increased to compensate. If output rises above 12, the regulator transistor is shut down enough to bring the output voltage back down.

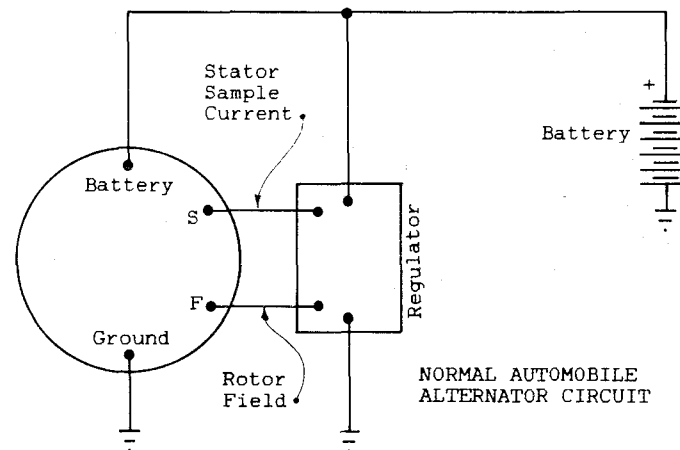


Electronic regulators are superior to the old triple relay regulators used on generators. Obviously, there are no contacts to burn. While the older regulators would click in and out at the rate needed to hold output fairly steady, the solid-state regulators provides smooth quiet service, providing small continuous changes in rotor current. As long as the electronic unit kept cool, it should never need any service.

Alternator rotors are usually very rugged. Specially shaped poles create multiple magnetic poles from a single rotor winding. For instance, some Delco alternator have 8 alternating pairs of poles folded back from either end. With a single revolution of the rotor, the stator windings are hit with eight magnetic fields, producing eight cycles of alternating current. This is probably done to increase alternator output at very low rpm with limited rotor current. At normal running speeds the frequency of the alternating current fed to the diodes is usually several hundred cycles per second in frequency ---

HUNDREDS --- anything but the 60 cycles you get from a wall outlet.

Again, alternators are exceptionally strong allowing them to be overdriven at high rpm. They will produce usable current at lower rpm, and high voltage at high rpm if the rotor current is turned to maximum. High frequency three-phase AC is fed to solid state diodes to produce low ripple DC.



#### MODIFICATIONS

You'll see ads in many magazines promoting a simple device which when added to an auto alternator will allow you to get 3000 watts of DC to run AC-DC type appliances such as power drills, saws, and lights. This so-called wonder has been sold at prices from a few dollars to more than \$25. You can build one for a couple dollars.

The secret of this magical little box is extremely simple. A switch puts bypasses the regulator putting 12 volts into the alternator rotor while transferring the alternator output from the auto circuit to an outlet installed in the box. When the auto engine rpm is increased, the voltage comes up to 120 volts. The device, therefore is nothing more than a switch and an outlet.

As we just discussed, alternator output voltage increases as the rpm goes up. It is the job of the regulator to cut back rotor current as rpm increases so that alternator output voltage stays at a constant 12 to 14 volts. The switch in the wonder box prevents the regulator from doing its job. As rpm increases so does the alternator output voltage. Some of the more expensive boxes have a volt meter to monitor voltage.

The diodes, also called rectifiers, are solid state devices which have low internal resistance --- that is, they eat up very little of the current flowing through them. These days solid state diodes are easy to build and therefore, low cost.

Diodes have two ratings: PIV and amperage. Amperage rating tells you how much current the diode can handle continuously. All diodes have some resistance, and at high current levels some power is converted to heat by this resistance. The ability to get rid of the waste heat determines how much current the diodes can handle. Remember, waste heat is determined by the current flowing. It has nothing to do whatsoever with voltage.

PIV, peak inverse volts, tells you how much voltage the diode can withstand before its internal insulation breaks down.



RPM must be geared to run the alternator at 5200 RPM; We need to gear the alternator up by

5200  
 ---- = 2  
 2600

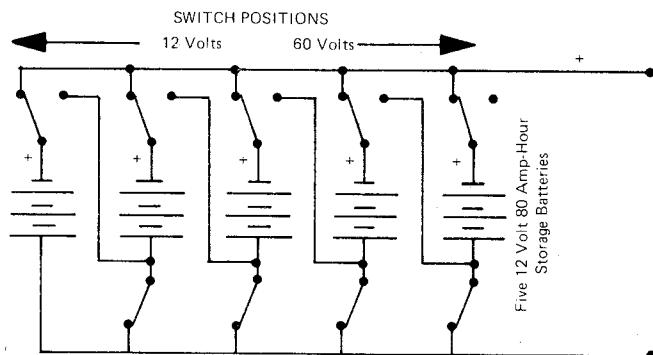
a factor of 2. Therefore, the pulley on the engine should be twice the diameter as the pulley on the alternator.

The whole powerplant can be built on a plywood base, and if a motorcycle battery is used to save weight, the unit can be quite small and easily portable. When the unit is producing the higher voltages, the battery provides the necessary rotor current. After a few hours of operation, it is advisable to throw the regulator back into the circuit and recharge the battery.

With simple modifications it is possible to use an alternator to charge 12 volt batteries, hot charge batteries at 30 to 40 volts and high current, arc-weld at 50 to 60 volts, and run AC-DC appliances at 120 volts.

#### SPECIAL REGULATORS

You may be interested in using an alternator to convert wind or water power to electricity. In such systems it is common practice to charge a bank of storage batteries, so that power is available even when the wind isn't blowing, or water levels are low.



This arrangement allows five storage batteries to be charged as a single 60 volt 80 amp-hour battery, but provides 12 volt 400 Amp-hour to drive inverters or appliances. Knife switches should be used to switch the bank. All switches should be brought to the open position, and then all switches should be moved to their new position. Most toggle switches will not work because they have no neutral position, and cannot handle heavy currents.

Most of these systems use a standard 12 volt system which works well for average service, but seldom allows conversion of large amounts of available rotational energy.

Suppose, for example, our windmill, waterwheel, or treadmill provides one horsepower of mechanical power to our 60 amp alternator. At 12 volts and 60 amps we get 720 watts out -- almost one horsepower.

Now suppose that more energy is available because of high winds or higher water head. The mill or wheel can now provide two horsepower, but because we cannot exceed 60 amps out without overheating windings or popping diodes, we can only

provide the maximum 720 watts at 12 volts. The additional horsepower is available, but not convertible.

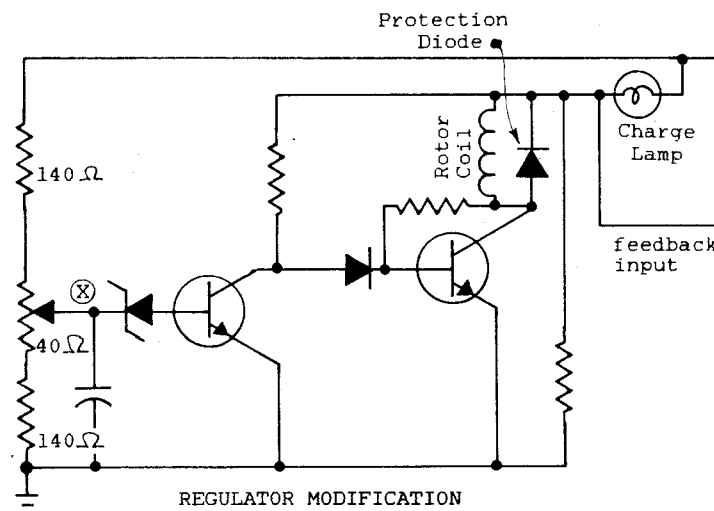
Most storage banks are built from many batteries in parallel to provide 12 volts with at least 200 amp-hour capacity. Suppose that for those periods of high wind or water, that the batteries are connected into a 36 volt battery pack and that the alternator is regulated by a special 36 volt regulator. Suppose, too, that we run the current all the way up to 60 amps output. Now we are converting 36 volts X 60 amps, or 2160 watts -- almost 3 horsepower. If the voltage could be run up to 120 volts, total watts at 60 amps would be 7200, ten times that available at 12 volts from the very same alternator.

At first impression you might think that the alternator could never handle it, but it can. Voltage is limited by the thickness of insulation on the windings and breakdown (PIV--peak inverse volts) voltage of the diodes. Current through the windings and diodes produces heat. As long as the manufacturer's rated maximum current is not exceeded, the windings and diodes will not overheat and melt. If you can provide the mechanical power at an excess of 5000 shaft RPM, you can extract the 7200 watts without electrical damage. REMEMBER! The waste heat generated in both the diodes and windings is proportional to the current being produced whether it be at 12 or 120 volts.

Mechanical damage is another consideration. Since 7200 watts is almost 10 horsepower, we must question the ability of the alternator bearings to handle this much power.

At this power level, V-belt drive will not work for two reasons. First, the usual auto fanbelt is too small to handle the strain of 10 horsepower. It would snap under the tension. Second, V-belts require much friction on the sides of the pulley to transfer power, and this means the bearings are heavily loaded with a pull to one side. At 10 horsepower, they would probably wear out in a hurry. For these high power levels you'll have to consider chain and sprocket drive which can handle the higher power levels more efficiently with much less bearing loading.

High voltage regulators can be built with little difficulty. If it were not for the fact that most auto regulators are sealed, they could be simply modified. Nevertheless, the regulator circuits used on low-voltage hobbyist power supplies will do the job. Schematics can be found in the electronics



magazines, Radio Amateur's Handbook, and books on electronic power supplies. The basic design has been around for years.

In the typical regulator circuit shown, the resistors A, B and C make up a circuit called a voltage divider. Its is function to extract a fraction of the alternator output voltage and compare it against an internal voltage reference.

From ground to the high side in the diagram we have 140 + 40 + 140 ohms or 320 ohms total. If we assume that variable resistor B is set to 20 ohms, we see that from ground to line X we have 140 + 20 ohms or 160 ohms. Therefore, on line X we will see 160/320 or 1/2 of the high side voltage. In other words, if the high side had 12 volts on it, measured from ground, we would see 6 volts on line X measured from ground. Moving the variable resistor arm closer to ground would lower the voltage on line X. The variable resistor selects the exact fraction or percentage of voltage that is to be compared with the internal reference.

Lets suppose the Zener diode, our internal reference, produces 6 volts. And let's assume that our voltage divider is set at 50%. When the high side is at 12 volts, the divider takes 50% or half, 6 volts and compares with the Zener. Since the Zener is at 6 volts, there is no difference, and the regulator takes no action.

If high side drops to, say, 10 volts, the divider takes half or 5 volts. Now we have a one volt difference when compared to the unchanging 6 volt Zener voltage. This one volt drop causes the the transistors in the rest of the circuit which act as valves to open a little more and let more current into the rotor to increase the revolving magnetic field and bring output voltage back up. This continues until the high side voltage comes back up to 12.

If output voltage goes up, much the same thing happens. The difference between the voltage sample and the Zener is of opposite polarity, so the transistors shut off to the degree necessary to force alternator voltage back down.

In practice these actions take place smoothly and continuously. Our explanation is simplified, but fairly accurate.

If you change the percentage setting of voltage divider resistors, you can change the alternator voltage. Suppose you change the divider setting so that 20% of voltage is extracted. What would the output of the alternator be? To find out divide the Zener reference voltage by the percentage:

$$\begin{aligned} \text{output volts} &= \text{zener} / \text{percentage} \\ &= 6 \text{ volts} / .20 \\ &= 30 \end{aligned}$$

The regulator will take 30 volts, extract 20% with the voltage divider which comes to 6 volts. Compared with the Zener 6 volts, no corrective action will be taken. Any change from 30 volts will create a correction voltage that cause the transistors to open or close as necessary until voltage comes back to 30.

Suppose we set the voltage divider at 80%. What output voltage would we get from the alternator?

$$\begin{aligned} \text{output volts} &= \text{zener} / \text{percentage} \\ &= 6 \text{ volts} / .80 \\ &= 7.5 \end{aligned}$$

In this case we've dropped from 12 to 7 1/2 volts.

The practical percentage ranges of voltage dividers usually run from 40% to 60%. This might translate into settings of 10 to 15 alternator output volts.

To get beyond this range we need to change the Zener and perhaps the divider range as well. Consider for a minute if we installed a 50 volt Zener diode. At 50% divider setting output voltage would be:

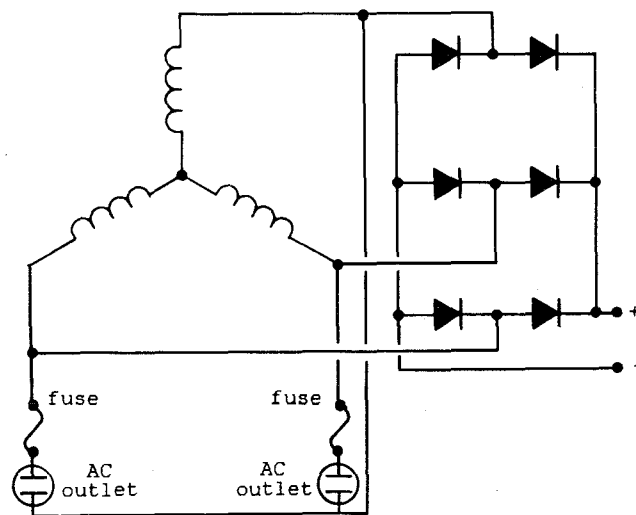
$$\begin{aligned} \text{output volts} &= \text{zener} / \text{percentage} \\ &= 50 / .50 \\ &= 100 \end{aligned}$$

And if we again consider a practical 40% to 60% range, the alternator could be regulated to produce a constant voltage in the 83 to 125 volt range.

The same resistors used for the 12 volt regulator could not be used in a high voltage regulator. At 120 volts, you'd be putting 10 times as much voltage across them, causing 10 times as much current to flow. Since power through a resistor is equal to the square of the current times ohms of resistance, you'd be putting 100 times more power into the resistors. In other words, they'd smoke and burn! In practice you'd probably want to increase the resistance 100 times. That would limit the current flow and power into resistors to its original value when run at 12 volts.

It is not the purpose of this manual to be a course in electronics design. The principles involved in designing and building a basic electronic regulator can be found in a great many books on electronics and power supply design. You should read up on the subject before designing a regulator.

One good book worth consulting is Regulated Power Supplies by Irving M Gottlieb, published by Howard W Sams, Indianapolis IN. There are many others.



MODIFICATION TO GET AC OUTPUT

## MODIFICATION FOR 110 VOLT AC

Alternators produce rectified DC power. If we tap the leads attached to the diodes, we can obtain 120 volt AC power. Some, but not all transformer operated appliances such as TV's, radio's, flourescent lights might be possibly be run on this AC.

AC coming from the alternator is very high frequency and a great many transformers will overheat at the high frequency. The only way to tell is to plug the device in for a few seconds, unplug it, and then feel the transformer or ballast to see if it is overheating. Even this is risky. Unless you're willing to take the chances involved, you might be better off converting an induction motor to provide pure 60 cycle AC, described later on.

If you'd still like to give it a try, conversion is a simple matter of removing diodes, and connecting leads. In most alternators two wires are soldered to each of the diodes. Remove both from the diode and attach it to one of three leads. When wired as shown, two outlets with a common ground can be powered.

Forget about running motor-driven appliances unless they use universal AC-DC brush type motors. Ordinary induction motors are designed for 60 cycles AC. At different frequencies they will run at different rpm if at all, and will quite possibly overheat or be destroyed.

## REWINDING THE WINDMILL USE...

Alternators usually loaf along at low RPM, and do not usually begin to produce a lot of power until they exceed about 1000 RPM. This lower RPM limit can be dropped by rewinding the alternator's stationary coils. An alternator modified in this way used on a windmill, for instance, can begin producing power at a lower windspeed, realizing greater total power output over a period of time.

For example, a 45 amp Chrysler alternator can be modified by removing each of the 16 turn coils, and by replacing them with a smaller diameter wire so that each coil is made up of more turns. Number 20 plastic coated wire (such as Belden polythermaleze) obtained from a motor shop can be used to wind coils of 25 to 26 turns before all available slot space is used. Coils are set by dipping in motor varnish and baking with low heat until hardened. Small diameter wire reduces maximum current available. Here, No. 20 will handle only about 25 amps with good cooling, but the extra windings allow the alternator to begin charging at a much lower RPM.

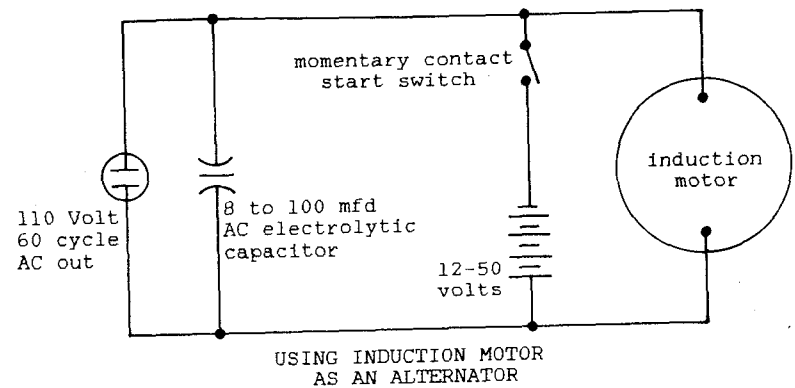
One good reference on motor and generator rewinding is Armature Winding and Motor Repair by Daniel Breymer available from Lindsay Publications.

## BUILDING A 60 CYCLE ALTERNATOR

Theory says that any generator can be used as a motor and vice-versa. If this is so, could we take a common 1/3 hp induction washing machine motor and use it to produce 120 volts 60 cycle power? The answer is yes!

But we have two problems to solve. First, we must drive the motor faster than its nameplate rpm to get 60 cycle. Second, when we start the unit, we may have to hit the coils with a DC pulse to start it generating.

Induction motors have no physical connection between the stationary winding and the squirrel cage rotor. The electricity flowing in the rotor is created by transformer action because the magnetic field in the stator winding is revolving at 1800 rpm while the rotor is revolving at 1725 rpm. The 75 rpm



difference (4 to 5%) causes a current to be induced into the rotor.

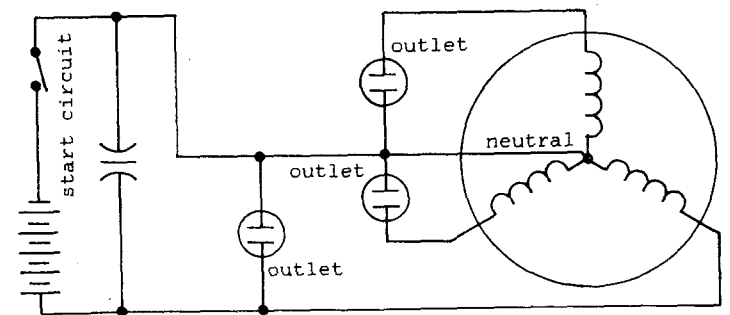
When used as an alternator, the motor must be driven 4-5% faster than the 1800 rpm synchronous speed. This comes to about 1880 rpm, faster or slower depending on alternator loading. When the driving speed is exactly right, the alternator will be producing exactly 60 cycle power.

Some motors will begin generating power as soon as they're driven because there's a small amount of residual magnetism remaining in the rotor and windings. If generation doesn't begin by itself, you'll probably have to hit the windings with a pulse of DC current to get it started. A switch connected to a 12 volt battery will probably be adequate, although in some cases you may need as much as 60 volts to do the job.

A split-phase capacitor-run motor can be used as is. But other motors will probably need a capacitor in the 8 to 100 mfd range. Trial and error will determine the exact size. Make sure the capacitors are rated at 250 to 300 volts AC.

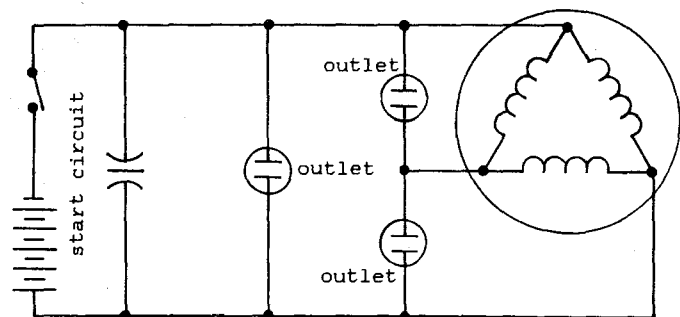
Not all motors will work properly, and we don't really know why. Fortunately, most do.

You won't be able to get as much power out of the motor as the nameplate indicates. To find exactly how much power you can get, connect ordinary light bulbs to your new alternator one after another. At some point the alternator will suddenly



THREE PHASE STAR MOTOR WITH NEUTRAL  
each outlet delivers 220 VAC at 60 Htz





THREE PHASE DELTA MOTOR  
 each outlet delivers  
 208 or 220 VAC at 60 Htz

stop working, indicating that it is overloaded. This response can sometimes be a hassle, but it makes the alternator burn-out proof.

To get large amount of AC out, you will need a large motor --- over a horsepower. You may be able to find a large single phase motor on a table saw or on farm machinery. But you may have to use a three-phase motor. With a three-phase machine you'll need a capacitor across one of the legs, but not on all three. Remember though! Three-phase motors will generate power from 208 volts on up. To get 110 volts you'll have to use a large transformer to step the 208 down to 110, and that's not very practical.

The frequency of the AC out will vary as the engine rpm varies. How are you going to know when you have 60 cycle? One easy way is to use a motor driven clock. Plug it into the circuit and leave it there. It only draws a few watts. Compare the second hand with the seconds counter on a quartz wrist watch. If the motor clock is running slow, the AC is less than 60 cycle. Adjust engine rpm until the clock is keeping accurate time.

In conclusion, you can generate small amounts of 120 volt 60 cycle that will drive anything from your TV to your refrigerator using an induction motor as an alternator. It will take experimentation. When it works (which is most of the time), it works very well. It's certainly worth trying.