Instruction Book

19-602A

ACCURCON II FIXED-FREQUENCY
STATIC INVERTER SYSTEM

"Basic Theory and Principles
of Operation"

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Westinghouse Electric Corporation

BASIC THEORY AND PRINCIPLES OF OPERATION

INTRODUCTION

"AccurCon" is the Westinghouse tradename for a multi-stage, harmonic neutralized static inverter. The inverter's primary function is for use in uninterruptible power supply systems, where along with a regulated power supply and a bank of batteries, it supplies uninterruptible, high-quality, transient-free AC power.

The static inverter is designed to operate over the wide voltage range of a standard battery. The regulated power supply is sized large enough to supply power to the inverter and charge the batteries at the same time.

A. INVERTER PRINCIPLES - GENERAL

The basic function of an inverter is to produce alternating current output power from a direct current input source. In this capacity, the inverter may be thought of as a synchronous switch. Its purpose is to switch the load alternately to the positive and negative DC bus, in synchronism with special synchronizing signals from a master oscillator which sets the operating frequency with the desired degree of precision. It is helpful to the understanding of the AccurCon to begin a discussion of the switching action to develop the concepts involved.

1. Switching Analogy

In a single phase bridge arrangement as shown in Figure 1, contactors A, B, C, and D are used to produce an AC output as follows. With contactors A and D closed, the bus voltage causes current to flow: from positive, through A, through the load, through D, and back to the negative bus. Current through the load (shown in solid line) is in the positive direction. Next with contactors A and D open, but B and C closed, the following condition results: - from positive, through B, through the load in the opposite direction, through C, and back to the negative bus. The resultant load voltage would be as shown.

The use of mechanical contactors is unsuited to a practical circuit because of the switching rate and the resultant short life. Solid-state contactors can be used, however, to overcome both objections. Thus, in Figure 2, the contactors have been directly replaced with silicon controlled rectifiers, thyristors, to act as switches. An examination of this sketch will show one basic problem associated with inverter thyristors. The voltage across any thyristor is always applied in the same direction, since a DC source is used. Thus, if any thyristor is switched ON, there is no mechanism shown for turning it back OFF at the desired time. Contrast this with the use of a thyristor as a controlled rectifier on an alternating current supply. In that case, the current conveniently goes through zero twice every cycle, thereby permitting the thyristor to switch OFF automatically. This is a basic difference in the way a thyristor is used between rectifier operation and inverter operation.

2. Turn-Off Mechanism Of Inverter Thyristor Devices

It is characteristic of thyristors that while they may be made conducting by application of a gate pulse, the same gate is not effective in turning off the device. Turn-off may be accomplished only by reducing the anode-to-cathode load current to zero for a given length of time. (Actually, the load current must be reduced below the "holding" current for a time in excess of the device "turn-off" time.) Most inverter circuits utilize a similar method of turn-off, or "commutation." Namely, the energy stored in a capacitor, is discharged at the appropriate instant in such a way as to drive the load current through the thyristor to zero.

This basic idea is illustrated in Figure 3, which shows how "commutation" is achieved. With the 300 volt DC supply connected as shown in "a", thyristor A and D are conducting current through the load. Capacitors B and C are charged up to the 300 volt line potential with the polarity marked. The other capacitors, are in effect, shorted by the conducting thyristors.

At the desired moment of commutation, thyristors B and C are gated ON. The immediate effect is to connect the capacitor voltage to the midpoint of the center-tapped reactor. By transformer action, the upper end of reactor AC rises to a potential of +600 volts; the line side of thyristor A is at a potential of +300 volts. The result is that there is a net voltage of 300 volts across thyristor A in the "backward" direction to drive its current to zero and turn it OFF. (A similar action is, of course, taking place at thyristor D.)

After commutation, both thyristor A and D have recovered their blocking state, and thyristor B and C are now carrying the load current. The other capacitors (A and B) have now charged up to line potential in preparation for the next "commutation". To summarize, any thyristor is turned OFF by firing its mate. It is important to note that if proper commutation does not occur, then both the thyristor and its mate will be in the ON state, resulting in a short circuit directly across the DC Bus. This is termed a "mis-fire"and will cause the protective fuses to blow."Mis-fires" are usually a result of overloading the inverter beyond the value of current which can be commutated safely. A mis-fire can also result from improper gating signals or electrical "noise".

3. Voltage Control

The following sketches and discussion will omit the commutation circuitry for the sake of clarity. While the circuit of Figure 2 showed the basic switching function necessary to produce an AC output, the thyristors need to be switched in pairs as was shown. In fact, for most purposes, they are not switched in pairs, but are controlled independently to give control of voltage output. Consider Figure 4, which shows the same circuit as Figure 2, but observe the effect of individual thyristor control. With thyristors A and D switched ON, current flows through the load in the positive direction. Next, switch on thyristor B, which turns thyristor D OFF, now both ends of the load are connected to the same potential, and no current flows. As thyristor C is next fired, load current flows in the reverse direction. Lastly, firing thyristor A will turn OFF thyristor C, again connecting both ends of the load to the same potential, producing zero current flow. The cycle is completed by firing thyristor D, which sets up the original condition.

The load voltage which results is shown in Figure 4e. It is seen that by proper control of the thyristor firing instant, the width of the positive and negative pulses can be controlled also. This will be seen later to be of special importance since the inverter output voltage must be varied with frequency to accommodate motor loads properly.

4. Inductive Load Effects

Previous circuits discussed could possibly be used on pure resistance loads, where current instantly falls to zero with load voltage. For loads which are inductive, such as AC motor loads, the current does not go to zero with voltage zero, but continues to flow in the same direction for a time. Because of this, the basic circuit must be modified to accommodate this inductive current flow.

Figure 5 shows the addition of four diodes, in a direction necessary to block the main DC voltage but also to permit the flow of "free-wheeling" current. For example, consider that thyristors A and D have been carrying current through an inductive load. As thyristor B is fired, turning OFF thyristor D, the voltage across the load goes to zero because both ends of the load are connected to the same bus potential. The current, however, does not go to zero because of the load inductance, but will instead circulate through the path formed by thyristor A and diode B until falling to zero according to circuit parameters.

This point is basic to inverters which must supply inductive loads, and all such inverters will show some form of "reactive" diode circuitry. These same diodes also form a path which is capable of accommodating regenerative power from the load. Since motors will try to regenerate power to the source when the speed is decreased, it is important that the inverter be able to handle such regeneration. The motor power is rectified by the "reactive" diodes, converted to DC power, and passed back to the DC bus to help carry other loads fed from the same DC bus.

B. INVERTER PRINCIPLES - ACCURCON II

With the foregoing principles understood, the AccurCon inverter may now better be described. In Figure 6, a simple block diagram shows a static frequency changer consisting of constant potential DC source, three-phase inverter, pulse generator for synchronizing the inverter frequency, and a load. Since the inverter has already been described as a synchronous switch, it follows that if the pulse generator frequency can be adjusted, the inverter's output frequency will also be adjusted accordingly. With the addition of battery banks to maintain the DC bus voltage, (as shown in Figure 7.) such inverter systems can provide an uninterruptible power supply at the desired frequency and voltage output.

1. Inverter Stage Operation

The key to the AccurCon inverter is that it is basically made up of single-phase inverter stages. Six stages are used for many ratings, but more stages may be used to achieve higher power ratings for given application requirements. The present discussion will be confined to a description of a six stage AccurCon inverter.

Figure 8 presents a block diagram of a six stage inverter, along with typical waveforms produced by each stage. Each of the six stages is a single phase inverter feeding its own single phase transformer. The voltage waveshape produced by each stage is shown, and it is seen that each stage produces the same output. The only difference is that each output voltage is delayed by 30 degrees from its neighboring stage. This is achieved by the wired in logic signals fed to each stage. It is important to recognize that all stages are electrically and mechanically interchangeable with one another, which is significant in reducing the number of spare parts required, and also in simplifying troubleshooting procedures.

2. Harmonic Neutralization

Next, observe that each stage feeds its own transformer, and that this transformer has three secondary windings. IT IS THE INTERCONNECTION OF THE TRANSFORMER SECONDARIES WHICH GIVES RISE TO THE UNIQUE AND PATENTED HARMONIC NEUTRALIZATION FEATURES. This connection does several things:

1. It sums the contribution of all six stages to produce the total power required.

2. It produces three phase output power from single-phase inverter stages.

3. It cancels out unwanted harmonic voltages, leaving only the 11th and some higher harmonics.

4. It provides the unique ability to continue inverter operation, even in the event of certain component failures.

The operation of the harmonic neutralizing transformers is seen in Figure 9. Since each stage produces the same output voltage, but displaced by 30 degrees in time from its neighbor, the set of six vectors shown can be used to represent the six stages. The three secondaries of each transformer have been arranged graphically in phase with each vector, to represent their contribution to the total operation. For example, the three windings parallel to the vector of the stage marked "0" degrees, are seen to be located in phase A, phase B, and phase C. Likewise, the three windings parallel to the vector of the stage marked 60 degrees are also connected in series in phase A, phase B, and phase C. The windings associated with the other stages are likewise connected in series, with the net result shown by the set of three balanced output voltages, displaced by 120 degrees, which is the requirement of a three phase system.

Summarizing, the series addition of voltages totalizes the KVA contribution of all six stages. Secondly, three phase output has been achieved from single phase stage inverters. Thirdly, by virtue of the series connections, certain harmonic voltages are cancelled out completely, leaving an output waveshape much more nearly sinusoidal than most inverters.

Lastly, the failure of certain components can be confined to one stage, whose loss does not interrupt operation of the three phase output. For example, the loss of stage A means loss of that contribution in phases A, B, and C, but the three phase output is still produced, although reduced in output momentarily. The system voltage regulator quickly restores the output voltage, although perfect harmonic cancellation no longer results and some voltage unbalance may be present.

The practical result, however, is that the load can continue to operate until such time as may be convenient to shut down, or to transfer the load to a spare supply. In critical load applications, this can be a very valuable capability. It is unique to the Westinghouse AccurCon inverter system, since other types of inverters will cause single phasing and immediate shut down. (For practical purposes, this will only apply to inverters employing six stages or more. On four stage units, the voltage unbalance and harmonic content may not be suitable for continued operation with most loads.

It is important to note that harmonic neutralization can be achieved with other transformer interconnections, and the schematic diagram of a particular AccurCon system will show the connections actually used. For practical reasons of transformer design, number of stages used, total number of windings, etc., different configurations are employed. In all cases, however, the same harmonic cancellation takes place as indicated above. It can be shown that the different configurations are mathematically and electrically identical.

3. Voltage Regulator Operation

It has previously been shown how the voltage output of an individual stage can be controlled by varying the firing signals to the thyristor switches. It is the function of the voltage regulator to measure the actual inverter output voltage, compare this value to the desired set point of voltage, and to make any necessary correction in stage ON-time. The correction is made to all stages simultaneously by a signal from the voltage regulator logic board.

4. Logic Section

The logic section of the AccurCon II inverter system is discussed in detail in the service manual. It is important, however, to recognize the basic functions provided by this section, and the main component blocks utilized.

a. Logic Power Supply

This assembly is located in a removable drawer, which also houses the individual logic boards. It is a DC to DC converter supplied directly from the DC bus to produce regulated output voltages of +40, +20, and -20, in addition to a square-wave gate carrier supply for all the required control voltages.

b. Pulse Generator

A pulse-generator logic board provides the master timing signals for the inverter. This sets a stable timing base for the entire inverter. The timing rate can be trimmed slightly to adjust output frequency for purposes of line synchronizing to an external source. For those cases, an auxiliary logic board is used (line synchronizing board.)

c. Counter/Driver

This logic board combines two functions, namely, a ring counter section and a driver section. The counter section operates in conjunction with like sections on the other counter driver boards, and with them, forms a ring counter to receive properly shaped pulses from the pulse generator, and to distribute them to the several inverter stages in the correct sequence and at the proper intervals. Specifically, the counter output signals are applied to the driver sections of this same board which in turn, amplify and shape the signals to be sent to the inverter stages. Secondary control functions are also effected here.

d. Voltage Regulator

Voltage control, either by manual operation or by automatic operation, is effected by means of a DC signal from the voltage regulator board, which feeds its signal to all individual stages. Secondary control functions are also effected here.

e. Gate Modulators

These units are located on the individual power stages, providing direct application of the gate signal to the thyristor with necessary isolation. They also apply the proper biasing of the thyristors.

5. Magnetic Section

The magnetic section of the AccurCon comprises all necessary apparatus for input and output disconnections, sequencing and interlocking controls, instrumentation used for both input and output measurement, ventilation controls and motors, alarm circuitry, and so forth. The harmonic neutralizing transformers are physically located in this section.

Commonly supplied also is circuitry for safely charging the large amounts of capacitance associated with inverters. Reference to the schematic diagram for a specific order will show the magnetic functions provided.

6. Output Power and Filter Section (see Figure 10)

In any practical inverters, the number of stages used is not high enough to satisfy requirements for total harmonic or individual harmonic distortion. Second, it is better to build a 3-wire output inverter, and convert to 4-wire where required. Therefore, fixed-frequency inverters have a filter network including an autotransformer in the output circuit.

Typically, the network consists of a three-phase series reactor, a shunt capacitor, and autotransformer. Most filters are designed to hold distortion within tolerance at the worst condition, which is usually high input line and no load. (Refer to service manual for additional information.)

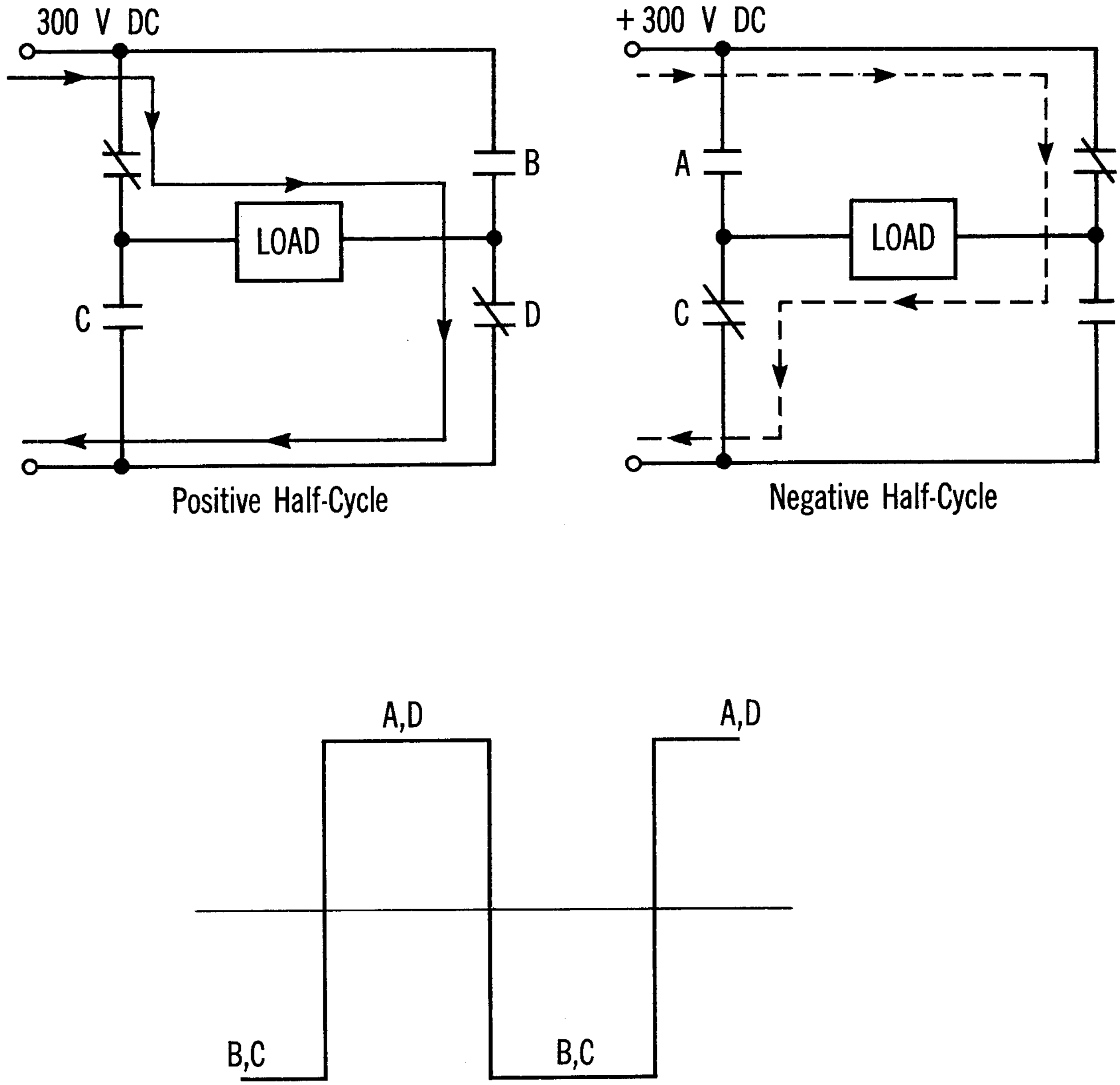


FIGURE 1 - SWITCHING ANALOGY FOR SINGLE-PHASE INVERTER MODULE

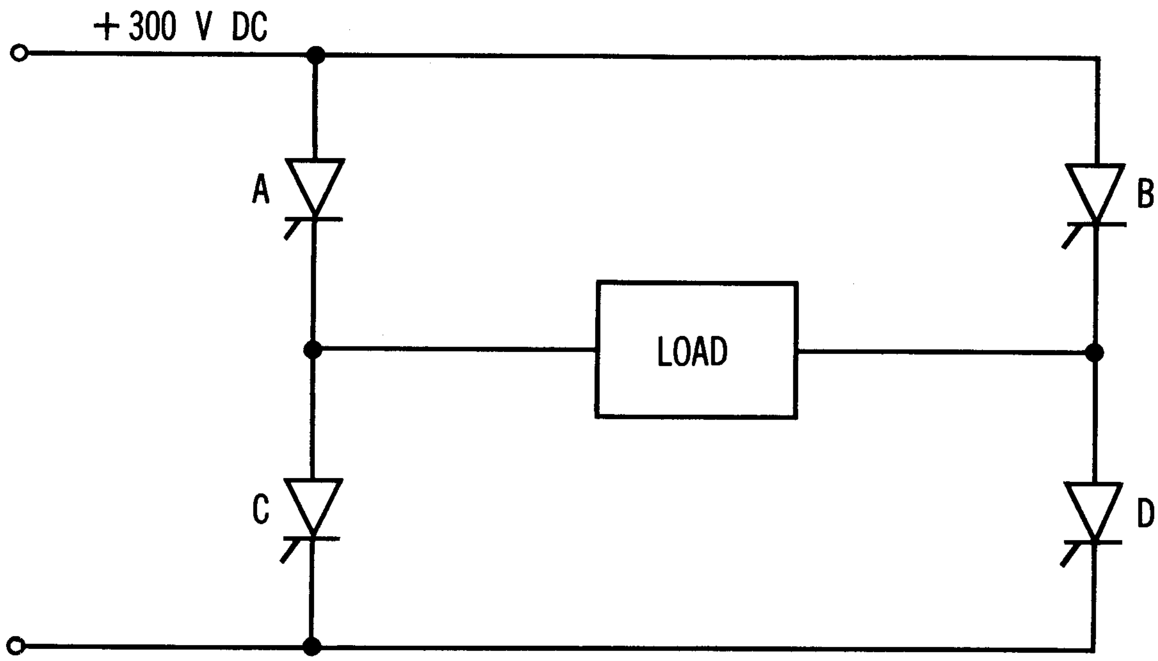
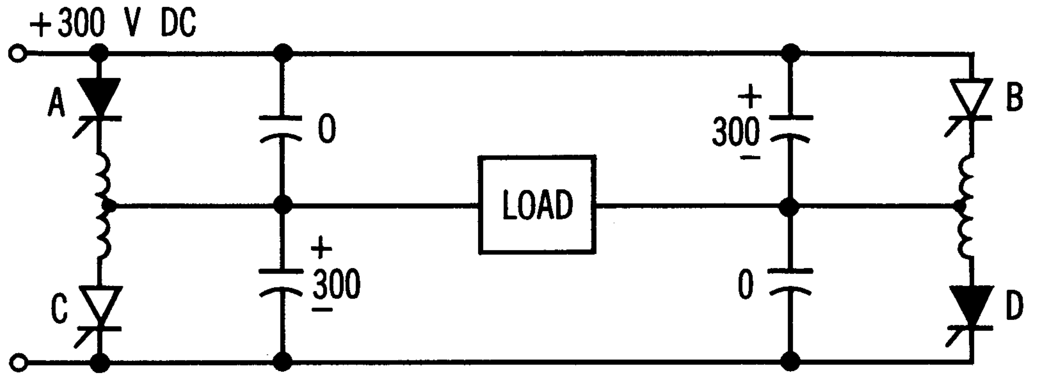
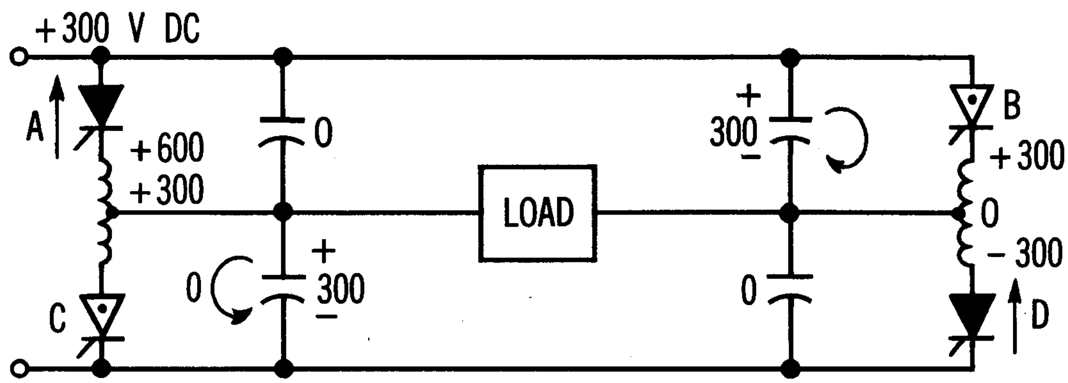


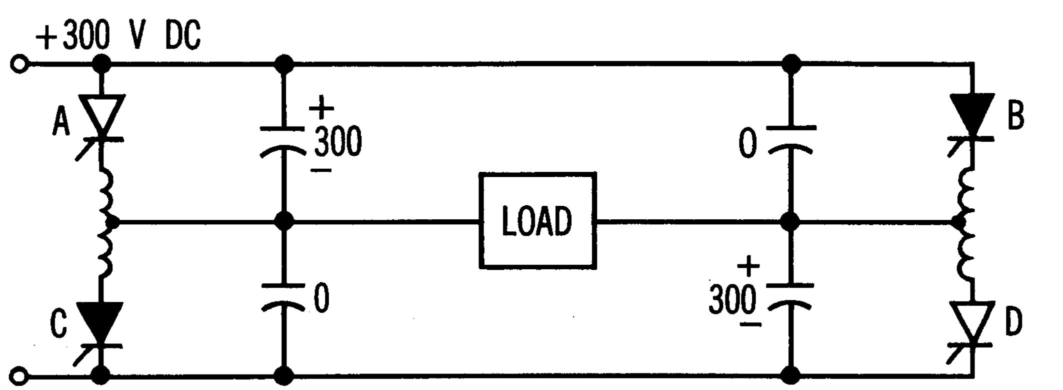
FIGURE 2 - SIMPLIFIED SCHEMATIC SHOWING REPLACEMENT OF CONTACTORS BY THYRISTORS



(a) Condition Prior to Turnoff



(b) Condition at Turnoff



(c) Condition after Turnoff

FIGURE 3 - SIMPLIFIED INVERTER BRIDGE SHOWING THYRISTOR TURNOFF ACTION

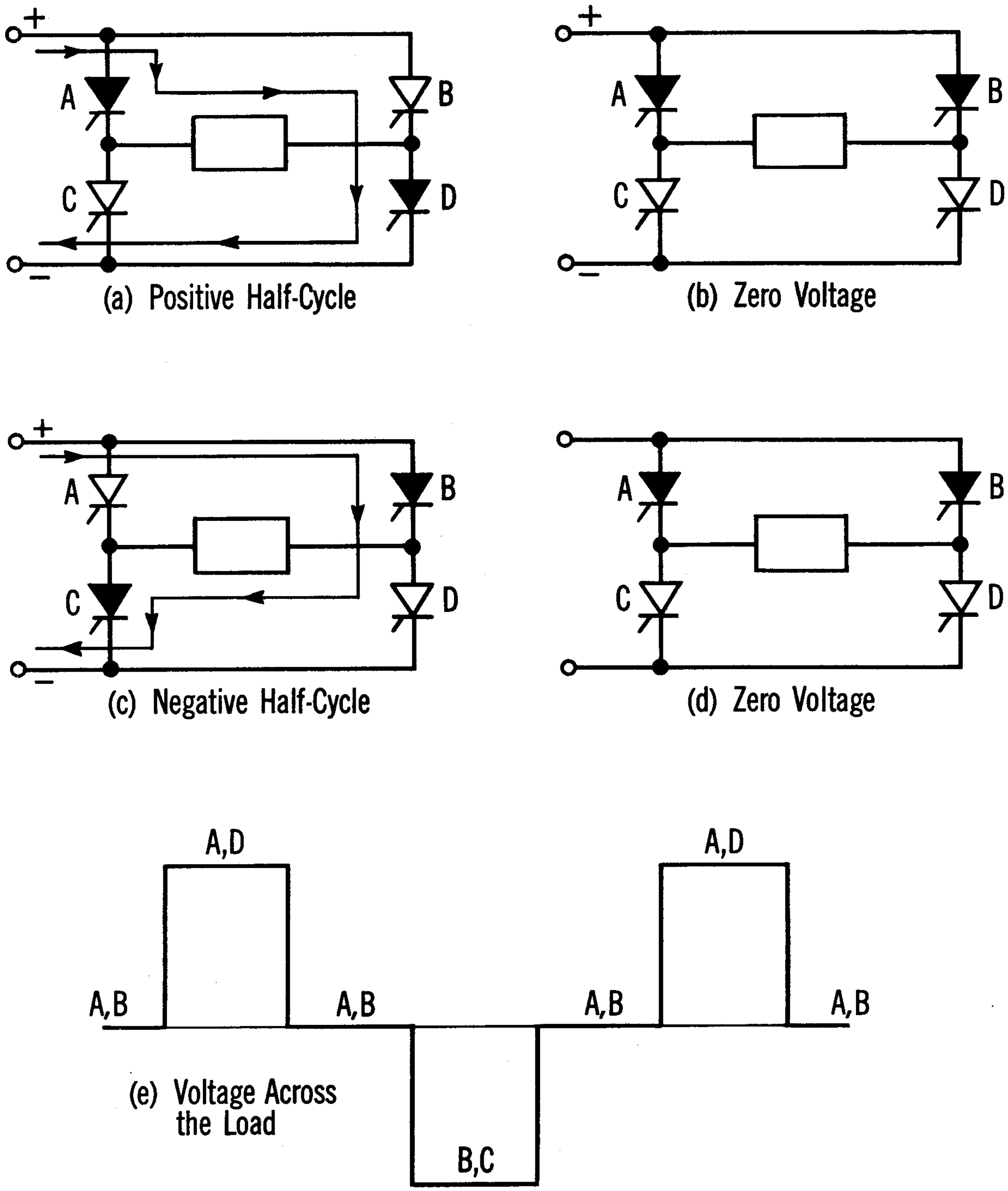


FIGURE 4 - SKETCHES SHOWING
VOLTAGE CONTROL
BY ADJUSTING PULSE WIDTH

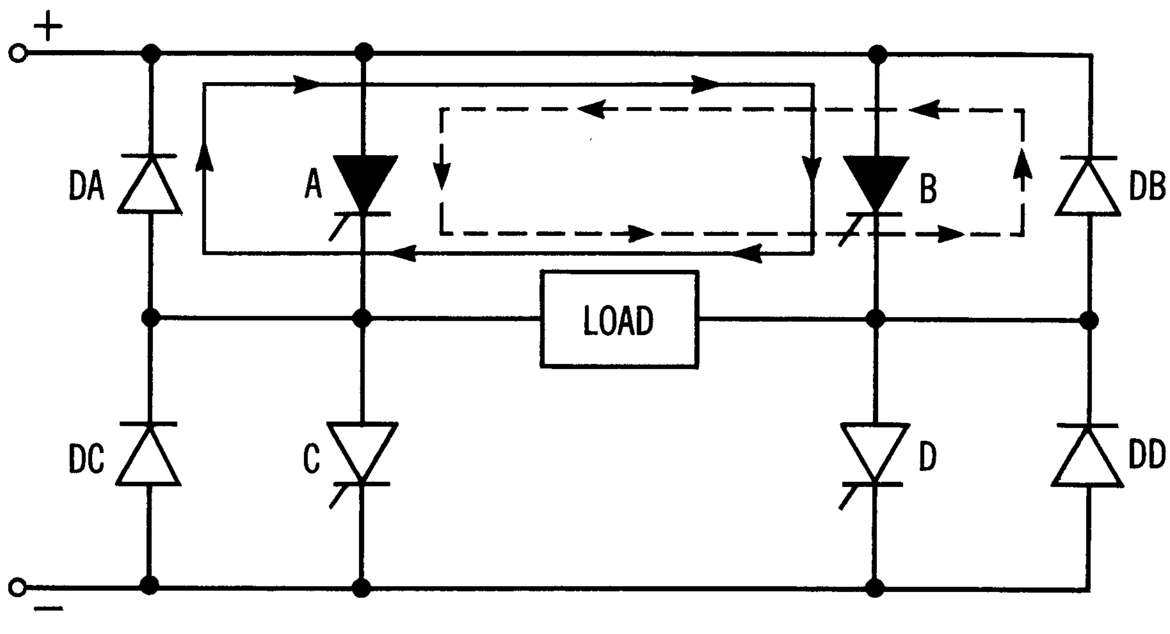


FIGURE 5 - SIMPLIFIED INVERTER BRIDGE
SHOWING ADDITION OF FREE WHEELING DIODES
TO ACCOMMODATE INDUCTIVE LOAD CURRENT

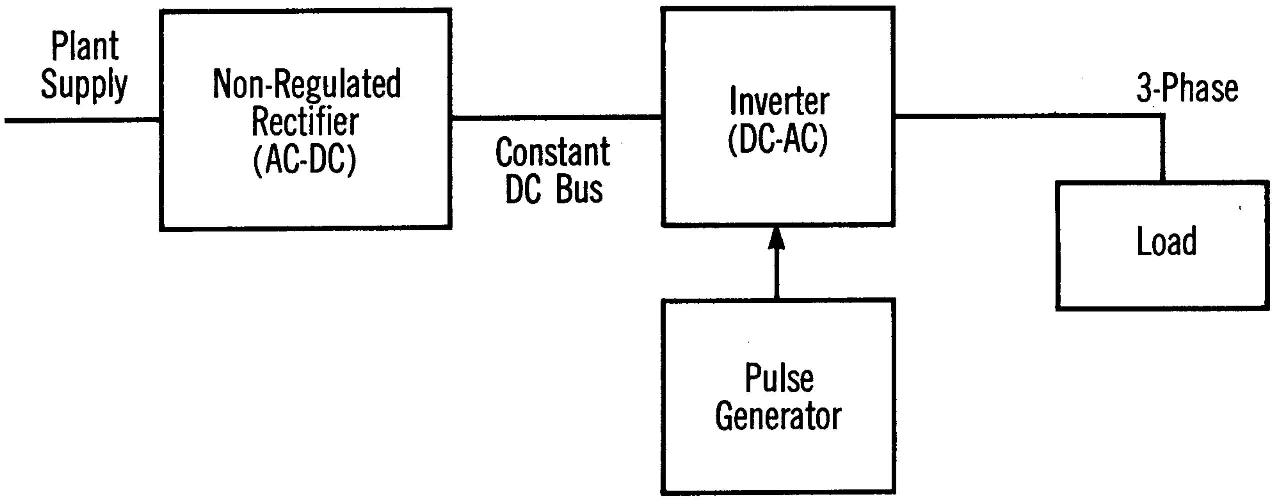


FIGURE 6 - BLOCK DIAGRAM OF STATIC FREQUENCY CHANGER OR POWER CONDITIONER (NO BATTERY REQUIRED)

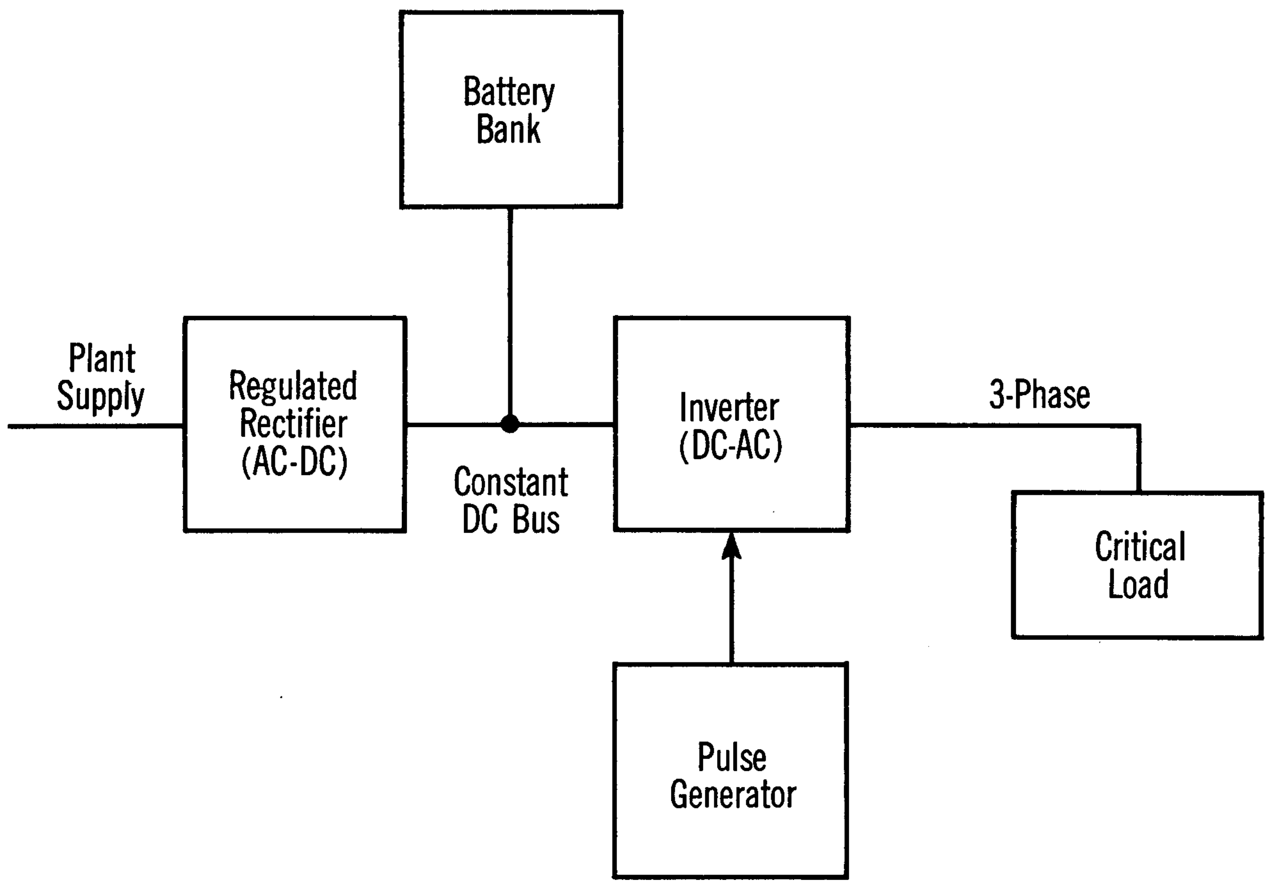
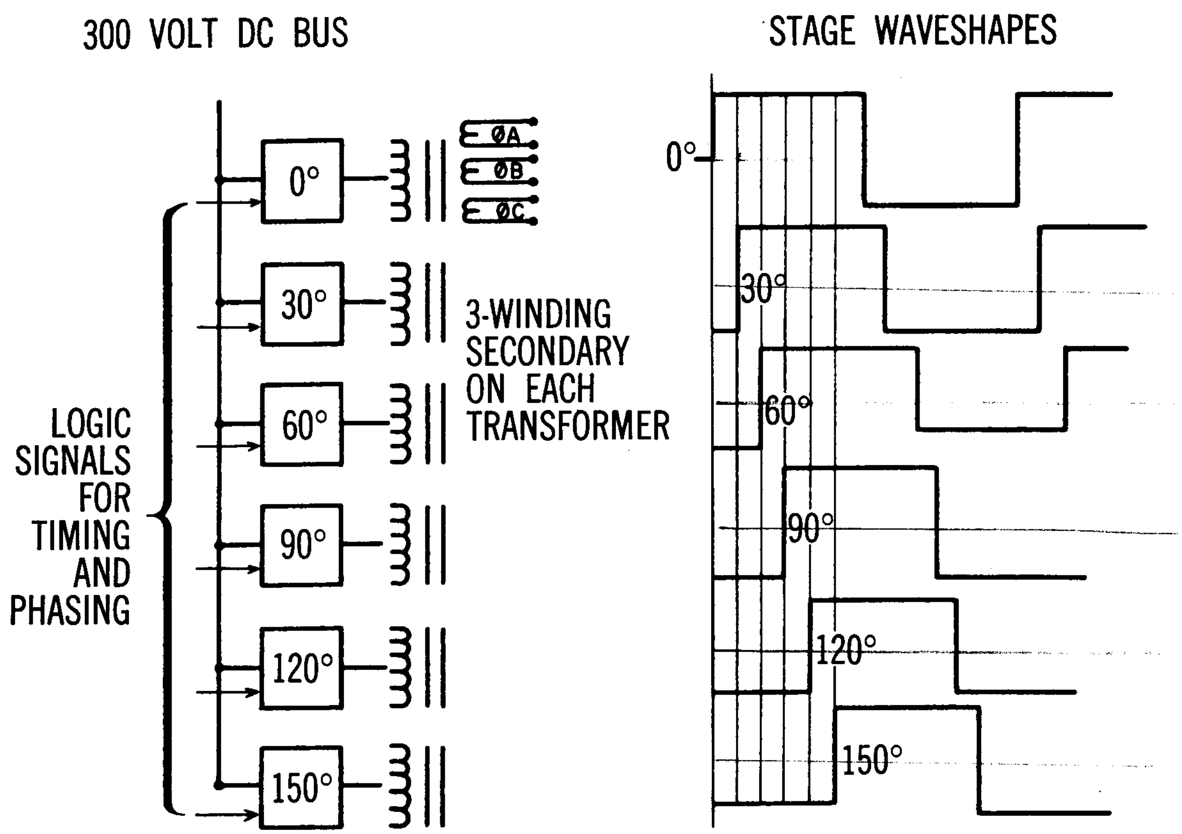


FIGURE 7 - BLOCK DIAGRAM OF FIXED FREQUENCY SINGLE INVERTER SYSTEM UNINTERRUPTIBLE POWER SUPPLY (UPS)

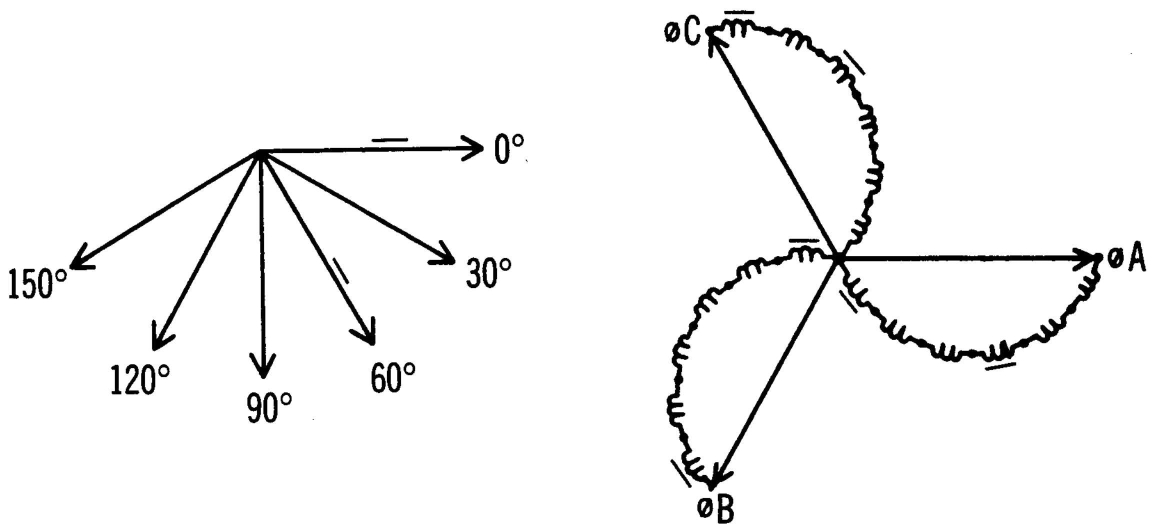
The Inverter cell consists of six
(or more) identical Single-phase stages



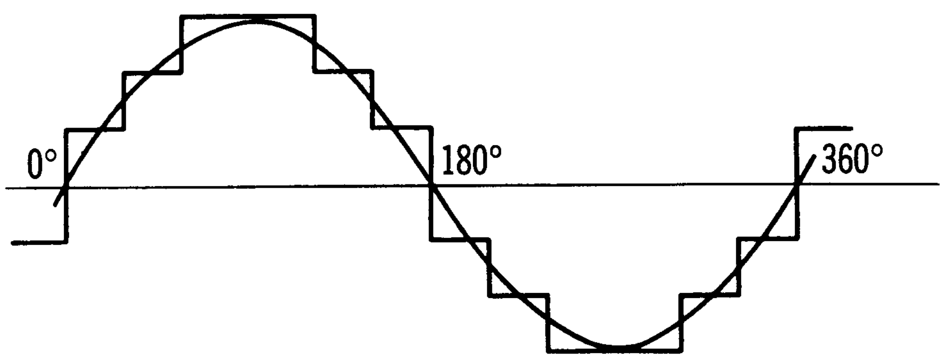
Wiring of transformer secondaries in patented
harmonic neutralization scheme produces
balanced three-phase output voltage. Minimum
harmonic distortion results from cancellation effect.

FIGURE 8 - TYPICAL SIX-STAGE INVERTER
OPERATING PRINCIPLE

Three-phase wave is achieved by vector addition of transformer secondaries . . .



. . . producing a multi-stepped output wave for each phase . . .



. . . with major harmonic components neutralized by the transformer connections, giving close to sine-wave operation.

FIGURE 9 - SKETCH SHOWING OPERATION OF HARMONIC NEUTRALIZATION

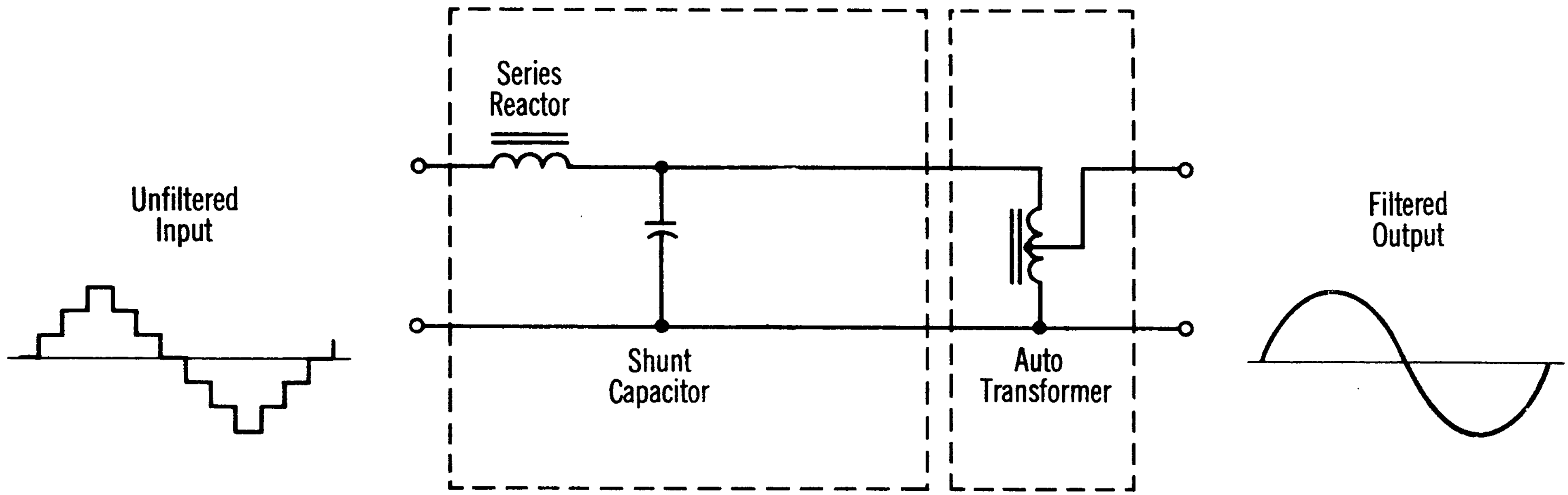


FIGURE 10 - POWER FILTER AND AUTOTRANSFORMER SECTION