

A Multistandard AC/DC Converter

The present invention concerns a circuit for converting an AC input voltage lying within a predetermined range of frequencies and which varies on either side of a base level into a DC output voltage at or above a predetermined minimum level.

5 There exists, throughout the world, a wide variety of mains AC voltages. Broadly, there are two groups: those of the low voltage range (88V-132V) and those of the high voltage range (176V-264V). It is desirable to design electrically powered equipment which can be used throughout the world, thereby simplifying design and production and allowing equipment to be portable between countries other than
10 where originally purchased. This requires that the equipment must be adaptable for use on both low and high voltage ranges. AC electrical power is distributed at frequencies of nominally 50 to 60 Hz, with a tolerance of 3Hz typically allowed.

The requirement for a circuit to provide a substantially constant DC voltage when supplied with a range of AC input voltages is popularly fulfilled by the use
15 of a doubler/bridge switch in association with an AC to DC converter circuit. Such a switch operates so as to select voltage doubling and rectification for AC inputs of the low voltage range and to select full wave bridge rectification for AC inputs of the high voltage range. Both manual and automatic types are known.

Figure 1 shows a typical doubler/bridge arrangement for rectification and
20 smoothing of input AC voltage V_{AC} , diodes D_1 to D_4 forming a full-wave bridge rectifier, with AC input voltage V_{AC} being applied between nodes 2, 3 and the rectified output available between nodes 4, 5. Capacitors C_1 and C_2 act to smooth the rectified output to a constant DC level, and switching element T permits the switching between full wave bridge rectification when in a non-conducting state, and
25 voltage doubling rectification when in a conducting state. A load L may be connected between nodes 4, 5. When this circuit is used in voltage doubling rectifier mode, capacitor C_1 is the positive half cycle smoothing capacitor, and capacitor C_2

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is the negative half cycle smoothing capacitor. In a manually controlled circuit, the switching element is a mechanical switch. In an automatic doubler/bridge circuit, the switching element T may be a relay, a triac or another equivalent device.

Once a triac is turned on by applying a bias voltage to its control terminal, it will then remain conductive until the current through it falls below the minimum holding current value, irrespective of the voltage applied to its control terminal. Hence, only a short pulse of bias voltage is required to turn on a triac, provided that the potential difference between its main terminals is greater than that required to cause the minimum holding current to flow.

Missing cycles are temporary blockages of the AC power, and are produced, for example, during changeover of the power supply between substations and feeder lines of the electricity supply company. As missing cycles represent periods of no mains supply, the voltage output of an AC/DC converter will drop as a result of the load draining charge from its output smoothing capacitors until resumption of AC supply.

Manually controlled doubler/bridge circuits require the operator of the electrical equipment to set the switch in the correct position before applying the AC mains supply.

The manually controlled doubler/bridge circuit has a major drawback in that the operator may forget to check the position or choose the wrong position of the switch, which could cause doubling of a high voltage, leading to damage to the equipment. Alternatively, the equipment could be designed to withstand such damage, leading to extra cost of the equipment.

Several types of automatic doubler/bridge switches are known, which automatically select voltage doubling and rectification of the input voltage when a 110V line voltage is applied and select full wave rectification when a 220V line voltage is applied. Examples of such circuits may be found described in US patent numbers 4,665,323 4,845,607 4,933,832 and British patent numbers 1,299,560 2,144,931 2,157,031. Such automatic switches may be constructed of discrete

components, or constructed within an integrated circuit. Both the integrated type, and the type constructed with discrete components use a full-wave rectifier bridge, with a switching element and two capacitors, allowing both voltage doubling rectification and bridge rectification to be performed. The switching elements of the prior art are electrically operated mechanical switches (relays) or solid state bidirectional switches, for example triacs. The conducting state of such a triac is controlled by the presence or absence of a bias voltage applied to its control gate, such voltage being supplied by an automatic circuit as a function of the voltage applied to the equipment. The known designs of automatic doubler/bridge switch usually produce either a continuous bias voltage or a continuous series of firing pulses to the gate of triac T. Whilst this ensures immediate recovery of output voltage following a missing cycle, an unacceptably large power consumption results. In some circuits, up to 12W of power may be consumed by the control circuitry, and 80% of this in triac gate firing pulses.

Equally, a manually controlled circuit could use a triac or equivalent as the switching element T with a manual switch controlling the presence or absence of a bias voltage to the triac control terminal.

When such an automatic doubler/bridge circuit operates in voltage doubling rectifier mode under constant AC supply, the triac switching element T conducts from the moment a firing pulse is provided by the control circuit until the current through its main terminals falls below the holding current. During a positive half cycle, current flows through diode D_1 to charge the positive half cycle smoothing capacitor C_1 while the input AC voltage V_{AC} is higher than the voltage across the terminals of that capacitor. The capacitor charges up through the triac until the point of maximum charge, usually just after the peak value of the input AC voltage. At this point, the capacitor charging current ceases as the input AC voltage V_{AC} drops, and the triac turns off. Similarly, during a negative half cycle, current flows through diode D_2 to charge the negative half cycle smoothing capacitor C_2 until its point of maximum charge, just after the peak negative input voltage of the AC mains. In this way, the voltage across each one of capacitors C_1 , C_2 is almost equal to the peak AC mains input voltage, and the total DC voltage available at the output terminals 4, 5 for application to load L is approximately double the peak AC

input voltage. The diodes D_1, D_2 are reverse biased after the AC input voltage has dropped below the voltage across the terminal of the capacitor and hence the charge stored on capacitors C_1, C_2 is prevented from discharging through them.

When a load L is connected to terminals 4, 5 the capacitors discharge through the load and supply it with the required DC current. This discharging causes the voltage across the capacitors C_1, C_2 to decrease, until each one is charged during the following positive or negative mains half cycle, respectively. This discharging and charging causes a ripple voltage on the DC output voltage. The size of the capacitors C_1, C_2 is chosen so that the charge stored smoothes the DC output voltage to have an acceptable level of ripple.

One integrated circuit implementation described in US patent number 5,162,984 has particular advantages due to its small size and extremely low power consumption. Triac firing pulses are produced only during a limited time period soon after zero crossing points of the AC voltage, thus ensuring efficient triac turn-on, whilst the current consumption by the triac firing pulses is minimised. It has become a popular circuit for AC to DC conversion.

Figure 2 shows a circuit incorporating such an automatic doubler/bridge control circuit. AC mains input voltage V_{LN} is applied to power supply lines V_L, V_N connected to nodes 2, 3 of the bridge rectifier formed by diodes D_1-D_4 . An integrated circuit automatic doubler/bridge control circuit 7 is connected to the neutral mains input line V_N , which may be regarded as a supply voltage. The doubler/bridge control circuit 7 is further connected to node 9, which may be regarded as a virtual ground voltage for the IC supply. Node 9 is itself connected by capacitor 11 to the neutral AC input line V_N , and to the live AC input line V_L by a series arrangement of a resistor 13 and a diode 15. Two series connected resistors 17, 19, are connected between the node 9 and the live mains input line V_L , the node 21 between the resistors 17, 19 being connected to control circuit 7. A resistor 23 is connected between the node 21 and the neutral mains input line V_N . An output of the control circuit 7 is connected to the gate of the triac switching element T through a current limiting resistor 25.

The half wave rectifier comprising diode 15, resistor 13 and capacitor 11

provides a DC supply voltage V_C to the control circuit 7. This supply is typically 9V lower than the voltage of the neutral mains supply line V_N , regulated by a voltage regulator internal to the control circuit 7.

Resistors 17, 19, 23 scale down and bias the AC input voltage V_{LN} to a voltage at node 21 which is used by the control circuit 7 to produce triac firing pulses to triac T just after every mains zero crossing point if a low range AC voltage is in use (i.e. if voltage doubling rectifier mode is required). The control circuit 7 generates and uses internally: a signal RI, being the output of a voltage comparator, which indicates whether the AC supply voltage falls within a first, high range of supply voltages Rge1, or whether the AC mains lies within a second, low range of supply voltages Rge2; a clock signal Ck; and a zero cross detection signal T1 is a short active high pulse generated in response to each zero crossing of AC supply.

Figures 3A to 3F show a typical timing relationship for the operation of such a known automatic doubler/bridge circuit operating in voltage doubling rectifier mode during a period of constant AC supply, with the load L connected to the DC output. In figure 3A, V_{LN} represents the input AC voltage; in figure 3B, V_{GT} represents the triac gate voltage; in figure 3C, V_{C1} represents the voltages across the terminals of capacitor C_1 and V_{CO1} represents the open circuit voltage which would appear across terminals 4, 6 in the absence of the load and the capacitor C_1 , with the triac becoming conductive at the first triac pulse after zero crossing; in figure 3D, I_T represents the current flowing through the main terminals of the triac T; in figure 3E, V_{C2} represents the voltages at the terminals of capacitor C_2 and V_{CO2} represents the open circuit voltage which would appear across terminals 5, 6 in the absence of the load and the capacitor C_2 , with the triac becoming conductive at the first triac pulse after zero crossing; and in figure 3F, $(V_{C1} + V_{C2})$ represents the total DC output voltage between terminals 4, 5.

In figures 3C, 3E, the dashed lines representing the open circuit voltages V_{CO1} , V_{CO2} represent the maximum possible voltage which could be applied to the capacitors C_1 , C_2 at any particular instant.

The AC input waveform V_{LN} crosses the zero voltage level at zero crossing points $t_{z0} - t_{z3}$.

As shown in figure 3B, a short time d_i after each zero crossing, at times $t_{d0} - t_{d3}$, a series of pulses lasting for a period d_p are produced on the triac gate voltage V_{GT} . These triac firing pulses are active-low; during the active state the triac gate terminal is held at the voltage of the virtual ground, node 9 in figure 2 and at other times the triac gate is held at the voltage of the neutral line, V_N and node 3 in figure 2. The timing of these triac gate pulses is designed to allow the triac to be conductive as soon as possible after the voltage across the triac is sufficient to maintain a holding current. This corresponds to times $t_{i0} - t_{i3}$ in figure 3C, when the voltage available to charge the capacitor V_{CO1} first exceeds the voltage V_{C1} across capacitor C_1 sufficiently to hold the triac on. Times $t_{i0} - t_{i3}$ vary in their temporal location as the load current supplied by the circuit, and hence the ripple voltage, varies. An increased load will mean a greater capacitor discharge between charging half cycles and hence an increased ripple voltage and an earlier location of time t_{i0} . A sequence of triac gate firing pulses is required to ensure that the triac is turned on as early as possible, independently of the ripple voltage at any particular instant, but the duration d_p of the series of pulses should be no longer than necessary, to avoid excessive current consumption.

Considering only the first half cycle of mains, between times t_{c0} and t_{c1} , as shown in figure 3D, the triac begins to conduct current I_T at time t_{i0} , which charges capacitor C_1 . With the triac conductive, the full AC supply is applied across capacitor C_1 . In the periods d_i between the zero crossing points $t_{c0} - t_{c3}$ and the associated triac turn on time $t_{i0} - t_{i3}$ the rectifier circuit is operating in bridge rectifier mode and the input AC voltage is applied across the series combination of both capacitors.

The terminal voltage V_{C1} across the capacitor C_1 rises, as shown in figure 3C. The open circuit voltage available V_{CO1} exceeds the capacitor terminal voltage V_{C1} during this period, due to resistive losses caused by the current flowing to the load L and the current charging the capacitor.

After reaching its peak value, the mains voltage falls and a time t_{x0} is reached, soon after the peak voltage of AC mains, where difference between the capacitor terminal voltage V_{C1} and the voltage available V_{CO1} is less than the

voltage required to maintain the minimum holding current through the triac. At this time, t_{x0} , the triac turns off and the current I_T through the triac falls to zero (figure 3D). At this time, t_{x0} , the capacitor C_1 is charged to a voltage almost equal to the peak value of AC mains input voltage.

For the remainder of this half cycle, from time t_{x0} to time t_{i2} , diodes D_1 and D_3 are reverse biased and the charge on the capacitor discharges through the load L. This causes the capacitor terminal voltage V_{C1} to drop during this period (figure 3C).

Symmetry of the circuit and the AC mains applied dictates identical operation during the negative half cycle, from time t_{c1} to time t_{c2} . Zero crossing at time t_{c1} causes a series of triac firing pulses starting at time t_{d1} , for a period of d_p . Capacitor C_2 is charged through diode D_2 and triac T, between times t_{i1} and t_{x1} . The charge stored discharges through the load between times t_{x1} and t_{i3} . The capacitor terminal voltage V_{C2} will drop, shown in figure 3E, during this period by an amount which depends on the current demand of the load, and the size of capacitor C_2 .

Figure 3F shows the output voltage, which is supplied across both capacitors C_1 and C_2 , achieving a DC output voltage ($V_{C1} + V_{C2}$) approximately double the AC input voltage. The voltage drop of each capacitor's terminal voltage gives rise to a ripple voltage V_r in the DC output voltage ($V_{C1} + V_{C2}$), at double the frequency of the AC input. For any given load requirement, the size of the capacitors C_1 and C_2 is chosen to reduce this ripple voltage V_r to a tolerable magnitude.

The voltage waveforms V_{C1} , V_{C2} across the output capacitors C_1 , C_2 respectively are identical to those resulting from the use of a conventional voltage doubling circuit with an electrical connection in the place of the triac T.

The remaining ripple voltage V_r in the output voltage ($V_{C1} + V_{C2}$), exaggerated for clarity in the diagrams, depends on the amount of discharge the capacitors C_1 and C_2 undergo during the period between triac turn-on times t_{i0} - t_{i3} and hence the loading applied to the output. The maximum output level V_{DCP} of DC output voltage ($V_{C1} + V_{C2}$) is obtained at each triac turn-off time t_{x0} - t_{x3} . This level will be used as a reference below.

During a missing cycle, the voltage V_{LN} will be held at the voltage of the AC

mains input when the power interruption started, by the capacitance of a mains filter habitually connected across the input mains terminals of switched mode power supplies and the like, to prevent incoming or outgoing noise on the AC supply line or the capacitance of the AC line and circuit itself, decaying towards zero as the capacitance discharges.

The automatic integrated doubler/bridge switching circuit described in US patent number 5,162,984 works well with a constant sinusoidal AC supply voltage but suffers when missing cycles occur on the mains input.

This circuit reacts in two very different ways to missing cycles of AC mains, depending on whether the mains input recovers with the same or the opposite polarity to that which it had at the interruption of power.

Figures 4A - 4E show timing relationships for the operation of a known automatic doubler/bridge circuit in voltage doubling rectifier mode during and after a missing cycle of power supply which recovers with the opposite polarity to that when the interruption started. Features identical to those in figures 3A - 3E have identical reference symbols.

At time t_{ms} , the AC supply V_{LN} is interrupted, shown in figure 4A; it returns with the opposite polarity at time t_{mf} , rather less than one period later. During the missing cycle between times t_{ms} and t_{mf} , the capacitors C_1 , C_2 discharge through the applied load and so the output voltage ($V_{C1} + V_{C2}$) drops. The rate of voltage decay depends on the current demand of the applied load and the size of capacitors C_1 , C_2 . Due to the lack of input power, the current I_T through the triac, shown in figure 4D, falls below its holding current and it turns off at time t_{ms} . When the power returns at time t_{mf} , the AC supply voltage which has been held above zero by inherent capacitance in the mains supply system and the electrical apparatus containing the circuit crosses the zero voltage line to attain the polarity of the recovered AC input. The control circuit interprets this as a standard zero crossing detection, and initiates triac firing pulses a delay d_t later, at time t'_{d1} , as after a normal zero crossing point. This initiates triac conduction, figure 4D, and further charging of the capacitor C_2 , raising the capacitor's terminal voltage V_{C2} , figure 4E.

and the DC output voltage, figure 4F. Voltage doubling mode thus recommences very soon after the recovery of the AC mains, and full DC output voltage is achieved at time t_R , during the second full half cycle after AC supply recovery time t_{mf} . The maximum reduction in output voltage dV_{DC} below the reference value V_{DCP} is minimised by the fact that the input voltage resumption at time t_{mf} instantly causes a zero crossing, and resumption of voltage doubling mode. The triac firing pulses generated after the resumption of power at time t_{mf} are stopped if a further zero crossing t_{c2} occurs before the triac firing pulse generation period d_p has elapsed. After the next zero crossing time t_{c2} , normal operation resumes with the generation of triac firing pulses at time t_{d2} .

Figures 5A - 5F show analogous timing relationships for the operation of such an automatic doubler/bridge circuit operating in voltage doubling rectifier mode during and after a missing cycle which recovers with the same polarity as that when interrupted. Features identical to those in figures 3A - 3F have identical reference symbols.

At time t_{ms} , the AC supply V_{LN} is interrupted; it returns with the same polarity at time t_{mf} , somewhat less than one period later. During this missing cycle the capacitors C_1 , C_2 discharge through the applied load and so the output voltages V_{C1} , V_{C2} drop. The rate of voltage decay depends on the current demand of the applied load L . At the time of power interruption t_{ms} , the current I_T through the triac stops and the triac turns off.

When the power returns at time t_{mf} the circuit is in bridge rectifier mode, as the triac is turned off. For the remaining part of the half cycle until time t_{c2} , there are no valid zero crossings to initiate triac firing pulses and hence triac conduction and voltage doubling. Following the resumption of power at time t_{mf} , the voltage V_{OC1} available to capacitor C_1 is half that which it would have been without a missing cycle, the other half of the voltage also being available to capacitor C_2 . This may help the recovery of DC output voltage ($V_{C1} + V_{C2}$), figure 5F, (depending on the state of discharge of the capacitors C_1 , C_2) but the DC output voltage remains much reduced. Following the next valid zero cross at time t_{c2} , the next triac firing pulse series begins at time t_{d2} , and voltage doubling rectifier mode is resumed. As shown in figure 5F, the DC output voltage ($V_{C1} + V_{C2}$) is reduced from the time of

the power interruption t_{ms} until the second full half cycle after power resumption (one of each polarity), even though full power has been available since the resumption of power at time t_{mr} . The output voltage drop dV_{DC} is greater than that in the case of power resumption with opposite polarity, figure 4F. This reduction
 5 in output voltage dV_{DC} can be significant when moderate to heavy loads are applied to the output DC supply. This voltage drop can impair the functioning of computers and video equipment by causing loss of stored data and faulty video signals.

An object of the current invention is to provide an automatic doubler/bridge circuit consuming a minimum amount of power in the generation of triac firing
 10 pulses, which is able to respond quickly to the resumption of low voltage range AC power following a missing cycle, in order that voltage doubling be resumed as soon as possible, to obtain full voltage output, minimising the voltage drop at the output during a missing cycle.

Preferred embodiments of the invention seek to provide an automatic voltage
 15 doubler/bridge switch which detects the presence of a missing cycle over the entire range of possible input frequencies, and acts to initiate triac conduction if the AC voltage before interruption was within the lower defined range of voltages Rge2 and not to initiate triac conduction if the AC voltage before interruption was within the higher defined range of voltages Rge1.

20 They also seek to provide an automatic doubler/bridge circuit which recovers quickly from missing cycles and will not double a high range supply voltage if such a voltage occurs upon supply resumption.

The invention provides a circuit for converting an AC input voltage lying within a predetermined range of frequencies and which varies on either side of a base line
 25 voltage into a DC output voltage at or above a predetermined minimum level comprising:

a voltage rectification circuit which is operable in a first mode to rectify an AC input voltage lying in a first range of values to produce said DC output voltage

and which includes a switch element having a control terminal for receiving a control signal to select the first mode;

baseline voltage crossing detection circuitry arranged to detect baseline crossings of the AC input voltage and to generate the control signal responsive to each baseline crossing;

a timer which is reset at each baseline crossing and which commences measuring a delay from each reset, the timer being operable to generate the control signal when the delay reaches a predetermined value, the predetermined value of the delay being greater than the half period of the lowest of the predetermined range of frequencies.

The particular features of the invention substantially reduce the drop in output DC voltage of an AC to DC converter when a missing cycle of AC supply voltage occurs, while maintaining a low power consumption by the circuit. The control signal is applied to the switching element for a period of time when a missing cycle is detected.

A particular embodiment of the invention provides a circuit wherein the control signal is generated at a predetermined time after each detected baseline crossing, the predetermined time being much shorter than the half period of the lowest of the predetermined range of frequencies. This ensures that the first mode of operation commences as soon as possible after each baseline crossing detection, without consuming excessive power in generating the control signal for a longer period than necessary.

Particular embodiments of the invention provide a circuit wherein the first mode of operation increases and rectifies the AC input voltage and a second mode of operation rectifies the AC input voltage when the AC input voltage lies above the first range of values, the switch element being operable to select between the first and second modes of operation. This allows a substantially constant DC output voltage to be produced when different AC input voltages are applied.

A voltage level detection circuit may be provided for determining whether the AC voltage lies in the second range of values and for producing a detection signal. This allows the selection of the mode of operation based on the input AC

voltage level.

Means may be provided for inhibiting supply of the control signal to the switch element when the detection signal indicates that the AC input voltage is inside the second range of values. This allows the prevention of increasing an AC input voltage lying within the second range.

The switching element may be a triac. The control signal will then consist of a plurality of pulses applied to the gate terminal of the triac.

The various periods of time may be measured by one or more digital counters, being supplied with a clock signal. This allows easy integration into an integrated circuit, and accurate control over the timing periods.

A first digital timer may be provided to measure the predetermined time after each detected baseline crossing; a second digital timer may be provided to measure the first time period from the first initiation of the pulses; a third digital timer may be provided to measure the predetermined value of the delay and a fourth digital timer may be provided to measure the second time period from the second initiation of the pulses.

Alternatively, a single digital timer may be used in conjunction with logic circuitry to measure both the predetermined delay and the second time period from the second initiation of the pulses.

One embodiment of the invention will be described in detail below, with reference to figures 6A to 10 of the accompanying diagrams, in which:

Figure 1 is a circuit schematic of a doubler/bridge rectifier circuit;

Figure 2 is a circuit schematic diagram of an automatic voltage doubler/bridge rectifier circuit of the prior art, incorporating an integrated control circuit;

Figures 3A - 3F are timing diagrams of various voltages applied to and supplied by an automatic doubler/bridge circuit such as that of figure 2, operating in voltage doubling rectifier mode during a period of constant AC supply;

Figures 4A - 4F are timing diagrams of various voltages applied to and supplied by an automatic doubler/bridge circuit such as that of figure 2, operating in voltage doubling rectifier mode during a period including an interruption of the

AC supply which recovers with opposite polarity to that which it had just before being interrupted;

Figures 5A - 5F are timing diagrams of various voltages applied to and supplied by an automatic doubler/bridge circuit such as that of figure 2 during a period including a different interruption of the AC supply which recovers with the same polarity as it had just before being interrupted;

Figures 6A - 6F are timing diagrams of various voltages applied to and supplied by an automatic doubler/bridge circuit of the invention during a period including an interruption of the AC supply identical to that in figures 5A - 5F;

Figure 7 is a circuit schematic diagram of circuitry according to a first embodiment of the present invention;

Figure 8 is a circuit schematic diagram of a counter according to a second embodiment of the invention 7; and

Figures 9 and 10 are circuit schematic diagrams of circuitry according to a third embodiment of the invention.

Figures 6A - 6F show timing diagrams, analogous to those of figures 5A - 5F, for the operation of the circuit of the invention operating in voltage doubling mode during and after a missing cycle which recovers with the same polarity as that when interrupted. Identical features to those in figure 5A - 5F have identical reference symbols.

The circuit of the invention detects a missing cycle by sensing a missing zero crossing. A timer counts from each AC voltage zero-crossing time t_{c0} until a certain time period d_{zc} has expired, such time period being greater than the half period of the lowest frequency AC voltage input likely to be encountered. Under normal operation the timer is reset at each zero crossing and never reaches the end of its timing period.

When a missing cycle, such as that between times t_{ms} and t_{mr} in figure 6A occurs, the timer counting the time period from the zero crossing time t_{c0} is not reset before the expiry of its timing period d_{zc} . Upon expiry of this period, at time t_{c0} , repeated triac firing pulses begin (figure 6B). Timing period d_{zc} is fixed such that time t_{c0} is approximately that at which a peak voltage of a maximum frequency

input is due. The generation of continued triac firing pulses on $V_G T$, figure 6B, ensures that when the AC mains recovers at time t_{mf} , triac conduction immediately begins, shown as an increase in I_T in figure 6D, and the whole input voltage available from AC input voltage V_{LN} is applied to capacitor C_1 (figure 6C). In the case illustrated in figure 6C, capacitor C_1 is fully charged at time t_{x2} , as for a normal positive half cycle.

The continued triac firing pulses are stopped at the next valid zero crossing time t_{c3} as this indicates the resumption of AC power. Triac firing pulses on $V_G T$ are then produced at time t_{d3} as normal operation resumes (figure 6B).

A further timer is provided so that in case the interruption of AC mains lasts longer than one cycle, continuous triac firing pulses continue for a time at least equal to one period of lowest frequency AC mains and then stop.

The circuit of the invention ensures that voltage doubling recommences at time t_{mf} , as soon as AC input power is available, minimising the greatest drop in DC output voltage, dV_{DC} . Full DC output is resumed at time t'_R , during the first normal half cycle after resumption of AC power.

Figure 7 represents a circuit according to an embodiment of the invention. The circuit forms part of the integrated control circuit 7 of figure 2 and uses the signals T1, Ck and RI generated within that integrated control circuit, as described above. Four digital counters 31, 33, 35, 37 are supplied with the clock signal Ck generated within the integrated circuit. The counters have their reset terminals 41, 43, 45, 47 connected together so as to receive the signal T1, generated within the integrated circuit, which supplies a short HIGH pulse at every zero crossing. Counters 31, 35 provide a LOW output when reset, changing to a HIGH at the end of their respective count periods; counters 33, 37 provide output signals of opposite polarity.

Counter 33 has a second, positive edge-triggered, reset input 53 so that it may also be reset by a rising edge on the output of counter 31; counter 35 has a second, negative edge-triggered reset input 55 so that it may also be reset by a falling edge on the output of counter 33; counter 37 has a second, positive edge triggered reset input 57, so that it may also be reset by a rising edge on the output of counter 35.

The outputs of counters 31, 33 are each connected to one input of AND gate 61; the outputs of counters 35, 37 are each connected to one input of AND gate 63. The output of each of the AND gates 61, 63 is connected to an input of OR gate 65. The output of gate 65 is connected to one input of three-input AND gate 67. The second input of gate 67 receives the clock signal Ck and the third input receives the active high signal RI, generated within the integrated circuit, which indicates that the AC supply voltage lies within the lower defined range. The output of gate 67 is connected to the control terminal of transistor 69, whose source is connected to a -9V supply voltage, and whose drain is connected to the control gate of the triac T.

Counters 31, 33, 35, 37 are used in succession. All are reset by a valid zero cross detection signal T1, taking the outputs of 31, 35 low and the outputs of 33, 37 high. With reference to figures 6A - 6F and figure 7, the first counter 31 counts the delay d_t from the zero crossing points $t_{c0} - t_{c3}$ until the commencing of triac firing pulses at times $t_{d0} - t_{d3}$. When the delay d_t has elapsed, the output of 31 goes high, producing a high output from OR gate 65. Provided the circuit is in doubler mode, indicated by a high signal RI, repeated triac firing pulses are then produced by the propagation of the clock signal Ck by AND gate 67 to the control electrode of transistor 69, which connects the gate of triac T to the -9V supply voltage. These pulses continue for the period of time d_p , determined by a second counter 33. At the end of its count period, the output of counter 33 goes low, which removes the high outputs of gates 61, 65 disabling propagation of clock signals Ck through gate 67 and also resetting counter 35.

This counter 35 counts a timing period which, when added to the time periods d_t and d_p counted by the first two counters, measures a total period equal to the delay d_{zc} .

In normal operation with an AC input voltage of the lower range Rge2, the third counter 35 is reset at each zero crossing point $t_{c0} - t_{c3}$, occurring every half cycle, and so never reaches the end of its count period. When a missing cycle is encountered, no AC input zero crossing occurs within time period d_{zc} , the third counter 35 is not reset and counts to the end of its period. The output of this third counter 35 then goes high, resetting counter 37 and producing a high through gates

63, 65 to gate 67, enabling the propagation of clock pulses and hence triac firing pulses. These pulses continue until either the next valid zero cross is detected, resetting the counters and indicating the resumption of normal AC supply or until the fourth counter 37 has counted for a certain time, which is at least one period of the lowest expected frequency AC supply, at the end of which its output goes low and stops the generation of triac pulses by turning off gate 67. This is necessary so that, in the case of missing cycles lasting longer than one supply period, the control circuit does not generate continuous triac pulses, as the power consumed by the control circuit would discharge the supply smoothing capacitor (11 in figure 2) below the minimum supply voltage required by the circuit.

The use of the low AC range indication signal RI at gate 67 ensures that triac firing pulses are only generated provided that the AC supply voltage just before loss of power was within the lower defined range of voltages. If, during the period of continuous triac pulse generation, a supply voltage in excess of the upper limit of the lower defined range is detected, the triac pulses immediately cease, due to a low signal RI at gate 67, preventing the doubling of a high range voltage.

This embodiment incorporates separate timers for timing the normal firing pulse delay d_i , the normal period of generation of firing pulses d_p , the missing cycle detection period d_{zc} , and the time limit for firing pulse generation following missing cycle detection. However, the functions of two or more of the counters 31, 33, 35, 37 described may in fact be tapped from one single counter so that rather than each counter being reset at the end of its cycle, the single counter signals when each period has elapsed. The single counter is then reset by a zero crossing detection signal T1.

Two alternative embodiments will be described using this principle.

In a particular implementation of the invention, suitable for use with the control circuit sold as the AVS-3 of SGS Thomson Microelectronics, the normal triac firing pulses are produced in a time window from 1.61ms to 5.52ms after each zero crossing point. Seventeen pulses are produced, from a clock signal Ck of 10% duty cycle, 4.4kHz frequency and a period of 230 μ s. The higher range of voltages Rge1 is from 176 to 264Vrms, the lower range of voltages Rge2 is from 88 to

132Vrms and the expected range in AC input frequency is from 47 to 63Hz. This example will be used in the following discussions.

Figure 8 shows a circuit for timing the period of firing pulse generation following a missing cycle independently of the normal firing pulse delay d_f and period of firing pulse generation d_p . The clock signal Ck is provided via OR gate G1 to a D-type flip-flop F0. This D-type flip-flop has its inverted output QN connected to its input D. Identical flip-flops F1 - F7 are cascaded to the output of F0. All the flip-flops F0 - F7 have their reset terminals RN connected together, and these are further connected to receive a signal from NAND gate G2 and an inverter G3. NAND gate G2 has its second input available for use as a second reset input, which receives an active LOW pulse from other circuitry within the integrated circuit to indicate the end of the normal triac firing period d_p . NOR gate G4 receives the inverted outputs of flip-flops F5 and F7. Flip-flop F8 has its input connected to the output of a NAND gate G5, whose inputs are connected to the inverted outputs of flip-flops F8 and F5. The reset terminal of F8 is connected to the output of NOR gate G6, whose inputs are the output of NOR gate G4 and the output of an inverter G7, whose input is the reset signal from inverter G3. The inverted output of flip-flop F8 is inverted by inverter G8. The zero crossing detect signal T1 is applied to inverter G9, whose output is connected to the first input of NAND gate G2.

The signal from inverter G3 is normally high, but becomes low, and hence resets the flip-flops F0 - F7 connected to it, when a zero crossing occurs on the AC mains supply, indicated by the signal T1 pulsing high and causing inverter G9 to send a LOW pulse to the first input of NAND gate G2, or at the end of the normal series of firing pulses, when a LOW reset pulse is applied to the second input of NAND gate G2. With all the flip-flops reset, their inverted outputs QN are all 1. The clock signal Ck is supplied to the input D of flip-flop F0. This flip-flop is connected as a divide-by-two counter, thus its output is a periodic waveform of 50% duty cycle and half the frequency of the input clock Ck. Similarly, the output of flip-flop F1 is at a frequency one quarter that of the clock frequency and so on until the output of flip flop F7 counts one cycle for 256 cycles of the clock signal Ck.

Flip-flop F8 is connected as a latch. When the active-low reset signal is supplied by inverter G3 at zero crossing or the end of the normal firing pulse period d_p , the inverter G7 and the NOR gate G6 propagate this to flip-flop F8. When the output of inverter G3 goes high again after the reset pulse, the output of NOR gate G4 will be low, and the active-low reset pulse to flip-flop F8 will end. Its inverted output will therefore be high, as will be the inverted output of flip-flop F5. Hence, the output of NAND gate G5, and the input to flip-flop F8, will be 0 and flip-flop F8 will remain in a stable state. This represents the start of the missing cycle detection period $d_{zc} - (d_t + d_p)$.

After 32 cycles of clock Ck, being 7.3ms with the 230 μ s clock, the inverted output of flip-flop F5 will go low, causing the output of NAND gate G5 to go high, and the inverted output of flip-flop F8 to change state to 0 at the next clock pulse. This keeps the output of NAND gate G5 at 1 after the output of flip-flop F5 has changed state again at 64 clock cycles. The latch F8 is now in a second stable state and retains a 0 inverted output, supplying a 1 at the output of gate G8. This represents the expiry of the missing cycle detection period, d_{zc} , a total of 12.8ms after the previous zero crossing.

The output of NOR gate G4 goes HIGH after 160 input clock cycles, being the time at which both of its inputs are zero: the output of flip-flop F7 goes to zero after 128 cycles of Ck, and the output of flip-flop F5 next goes low after a further 32 cycles. The high output from NOR gate G4 causes a low output from NOR gate G6, and the latch F8 will reset, returning its inverted output to 1, and the output of inverter G8 to 0. This corresponds to 36.8ms after the end of the previous normal firing pulse generation period d_p , and the end of the continuous firing pulse generation after missing cycle detection. Once the output of NOR gate G4 is HIGH, this places OR gate G1 in a HIGH state, which prevents the transmission of any further clock pulses. The counter comprising flip-flops F0 - F7 therefore stops. The counter holds the value 10100000 and the output of gate G1 is held high until the counter is reset by the next mains voltage zero crossing point.

The output of inverter G8 is connected to circuitry such as gate 67 receiving signals Ck and RI, transistor 69, triac T and a -9V supply as shown in figure 7. The output of gate G8 takes the place of the output of gate 65 at the first input of gate

67, enabling the generation of continuous triac gate firing pulses when in a HIGH state.

In this way, the required functionality of enabling continuous triac firing pulses starting at 7.36ms, being 32 clock periods, after the end of the normal triac triggering pulse period d_p , or 12.9ms after the previous zero crossing is achieved. These pulses continue until either the next zero crossing or for a maximum period of 29.44ms, being 128 clock cycles, which ends 160 clock cycles or 36.4ms, after the end of the normal triggering pulse period d_p . Different frequency clock signals may be used, with the connections of gates G4 and G5 changed to ensure correct timing. In this embodiment, the counter for the missing cycle detection is independent from the counters for the normal triac window, except for the reset signals provided at the end of the normal triac firing period.

Figures 9 and 10 represent, schematically, a third embodiment of the invention, where a single counter is used to count the periods d_i from zero cross to start of triac gate pulse firing window, the duration of triac firing window d_p , the time from the zero crossing to the end of the missing cycle detection delay d_{ZO} and the time period for generation of continuous triac firing pulses.

Again, a cascade of eight D-type latches H0 - H7 is used, each one being configured as a divide-by-two counter, with its inverted output QN being fed back to its input D. The clock signal Ck is supplied to AND gate J0, which receives a normally high stop input S on its other input. The reset inputs RST of the latches are connected together, and connected to the active-HIGH zero crossing signal T1 by inverter J1. The cascade of flip-flops then functions as an 8-bit counter. Connections are made to the inverted (QN0 - QN7) and non-inverted (Q0 - Q7) outputs of each of these counters.

NAND gates J2, J3, J4, J5, J7 have their inputs connected to selected inverted and non-inverted outputs (QN0 - QN7, Q0 - Q7).

NAND gate J2 has its inputs connected to the non-inverted outputs Q0, Q1 of flip-flops H0, H1 and the inverted outputs QN2, QN4, QN5, QN7 of flip-flops H2, H4, H5, H7; NAND gate J3 has its inputs connected to the non-inverted outputs Q2, Q4 of flip-flops H2, H4 and the inverted outputs QN0, QN1, QN5.

QN7 of flip-flops H0, H1, H5, H7; NAND gate J4 has its inputs connected to the non-inverted outputs Q0, Q2, Q4, Q5 of flip-flops H0, H2, H4, H5 and the inverted outputs QN1, QN7 of flip-flops H1, H7; NAND gate J5 has its inputs connected to the non-inverted outputs Q5, Q7 of flip-flops H5, H7 and NAND gate J7 has its inputs connected to the inverted outputs QN3, QN6 of flip-flops H3, H6.

The outputs of NAND gates J2, J3, J4, J5 are each connected to an input of a four-input AND gate J6. The outputs of J6 and J7 are connected to inputs A, B of a three-input OR gate J8. The third input C is connected to the clock signal Ck. The output of J8 is connected to the input of toggling latch M, whose reset input is connected to the output of AND gate J9. The output of NAND gate J5 supplies the signal S to AND gate J0. AND gate J9 produces an active low reset signal to latch M when either the inverted zero crossing detection signal $\overline{T1}$ from gate J1 or the signal S is low. After a reset pulse from zero crossing signal T1, all non-inverted inputs Q0 - Q7 will be low and all inverted outputs QN0 - QN7 will be high, and the output Q_M of toggling latch M will be low.

The toggling latch M may be a D-type flip flop with its inverted output $\overline{Q}_M$ connected to its input D_M and receiving toggling pulses on its clock input C_M .

Active-low pulses are provided to the toggling latch M by gating single pulses of clock signal Ck through OR gate J8. Propagation of clock pulses at other times is prevented by holding one of the inputs of J8 high.

Triac firing pulses are enabled by a high level on the output of the toggling latch M which is connected to an input of AND gate 67 in figure 7, whose other inputs are connected to the clock signal Ck and the low AC range indication signal RI as described earlier.

The output of gate J7 holds the output of J8 high and so preventing propagation of any clock pulses to toggling latch M unless Q6 and Q3 are simultaneously low.

The active-low output of NAND gate J2 holds the output of gate J6 low when the state 0X00X010 occurs on counters H7 - H0 respectively; NAND gate J3 functions identically for the state 0X01X100, gate J4 for the state 0X11X101 and gate J5 for the state 1X1XXXXX.

Active-low pulses are produced by gate J8 when both of its inputs A and B

are low, and an active low clock pulse occurs. Its input A is low when one or more of the outputs of gates J2, J3, J4 and J5 are low. The input B is low when the output of J7 is low (i.e. $QN3=QN6=1$; $Q3=Q6=0$).

Using this counter, the normal triac firing pulses are first enabled by the output of toggling latch M going high. The first low pulse is generated from gate J2 at a count of 00000010. This corresponds to time t_{d0} in figure 6B. When the counter reaches a count of 00010100, gate J3 generates a low pulse, which is propagated by gates J6, J8 to return the output of toggling latch M to low. Between these two events, seventeen clock cycles occur, and seventeen triac firing pulses are generated. This represents the triac firing period d_p for the normal mode of operation during periods of constant AC supply. At a count of 00110101, representing time t_{r0} in figure 6B, 12.2ms after zero crossing, triac firing pulses are re-enabled by the output of gate J4 going low, causing a further active-low pulse to be propagated to change the output of toggle latch M to a high state. In normal circumstances, the counter is reset before 10.7 ms after zero crossing, by the next zero crossing indication on signal T1, and the count required to change the output state of gate J4 is never reached.

If no zero crossing and hence counter reset, has occurred before the counter has reached a count of 10100000, being 36.8ms after the last zero crossing, gate J5 enables a further active-low pulse to toggling latch M, disabling generation of further triac pulses. This output S from gate J5 is also supplied to the S input of AND gate J0, which prevents further clock pulses from reaching latch H0, hence stopping the clock at a count of 10100000.

The current invention therefore fulfills its objectives by detecting missing cycles of AC mains and ensuring that voltage doubling mode, if required, is initiated as soon as mains voltage returns, reducing both the magnitude and duration of the drop in DC output voltage during the missing cycle. The circuit of the current invention ensures that doubling of a high voltage does not occur. The power consumption of the circuit is kept to a minimum by producing only a limited number of triac firing pulses during normal operation under constant AC supply.

The circuit may be used in an environment where voltage doubling is always required. In this case, the invention acts to protect the load from any random surges of line voltage e.g. transmitted by a supply line in the vicinity of a lightning strike, by immediately disabling voltage doubling. The circuit of the invention is also useful
5 in minimising the loss of DC power during missing cycles. If protection from line voltage surges were not required, the range detection signal RI could even be omitted.



CLAIMS:

- 1 A circuit for converting an AC input voltage lying within a predetermined range of frequencies and which varies on either side of a base line voltage into a DC output voltage at or above a predetermined minimum level comprising:
- 5 a voltage rectification circuit which is operable in a first mode to rectify an AC input voltage lying in a first range of values to produce said DC output voltage and which includes a switch element having a control terminal for receiving a control signal to select the first mode;
- 10 baseline voltage crossing detection circuitry arranged to detect baseline crossings of the AC input voltage and to generate the control signal responsive to each baseline crossing;
- a timer which is reset at each baseline crossing and which commences measuring a delay from each reset, the timer being operable to generate the control signal when the delay reaches a predetermined value, the predetermined value of the delay being greater than the half period of the lowest of the predetermined range of frequencies.
- 15
2. A circuit according to claim 1 wherein the control signal is generated at a predetermined time after each detected baseline crossing, said predetermined time being much shorter than the half period of the lowest of the predetermined range of frequencies.
- 20
3. A circuit according to claim 1 or 2 wherein the first mode of operation increases and rectifies the AC input voltage.
4. A circuit according to claim 3 wherein the voltage rectification circuit is operable in a second mode of operation to rectify the AC input voltage when the AC input voltage lies above the first range of values, the switch element being operable to select between the first and second modes of operation.
- 25





5. A circuit according to claim 4 which includes a voltage level detection circuit for determining whether the AC voltage lies in the second range of values and for producing a detection signal.
- 5 6. A circuit according to claims 4 and 5 which includes means for inhibiting supply of the control signal to the switch element when the detection signal indicates that the AC input voltage is inside the second range of values.
7. A circuit according to any preceding claim wherein the switching element is a triac and the control signal comprises a plurality of pulses for repeatedly firing the triac.
- 10 8. A circuit according to claim 7 wherein the pulses are generated for a first time period from a first initiation of the pulses on detection of a baseline crossing
9. A circuit according to claim 8 wherein the pulses are generated for a second time period from a second initiation of the pulses when the measured delay reaches a predetermined value.
- 15 10. A circuit according to claim 9 wherein the pulses are terminated on detection of a baseline crossing of the AC input voltage by the baseline crossing detection circuitry.
- 20 11. A circuit according to any preceding claim wherein the voltage rectification circuit includes at least one smoothing capacitor.
12. A circuit according to any preceding claim which comprises at least one digital timer.





13. A circuit according to claim 12 when appended to claims 2, 8 and 9 wherein a first digital timer measures the predetermined time after each detected baseline crossing; a second digital timer measures the first time period from the first initiation of the pulses; a third digital timer measures the predetermined value of the delay and a fourth digital timer measures the second time period from the second initiation of the pulses.
14. A circuit according to claim 13 wherein the digital timers are connected in sequence and each digital timer is reset both at each detected baseline crossing and at the expiry of the time measured by the preceding digital timer.
15. A circuit according to claims 9 and 12 wherein a single digital timer is used in conjunction with logic circuitry to measure both the predetermined delay and the second time period from the second initiation of the pulses.
16. A circuit according to claim 16 wherein the single digital timer is reset at each detected baseline crossing, and the output of the logic circuitry changes state at the expiry of the predetermined delay and changes state at the expiry of the second time period from the second initiation of the pulses.
17. A circuit according to any of claims 12 to 17 wherein the digital timer comprises a digital counter connected so as to receive a periodic signal.
18. A circuit according to claim 17 wherein the digital counter is a multistage counter and supplies inverted and non-inverted outputs at each stage, the inverted and non-inverted outputs being connected to a latch via logic circuitry, to generate a signal to change the state of the latch when the appropriate time periods have been measured.



19. A circuit according to claim 18 wherein the signal to change the state of the latch is derived from the periodic signal supplied to the counter.
20. A circuit according to either of claims 7 and 17 wherein a logic gate receiving the periodic signal and the detection signal from the baseline crossing detection circuitry and which propagates the periodic signal to generate pulses for repeatedly firing the triac.
21. A circuit according to claim 23 wherein the periodic signal propagated by the logic gate is supplied to the gate of a transistor, whose source and drain are connected to a supply voltage and the gate of the triac, respectively.
22. A circuit substantially as hereinbefore described with reference to or as shown in the accompanying drawings.

This Sheet Has Been Replaced

