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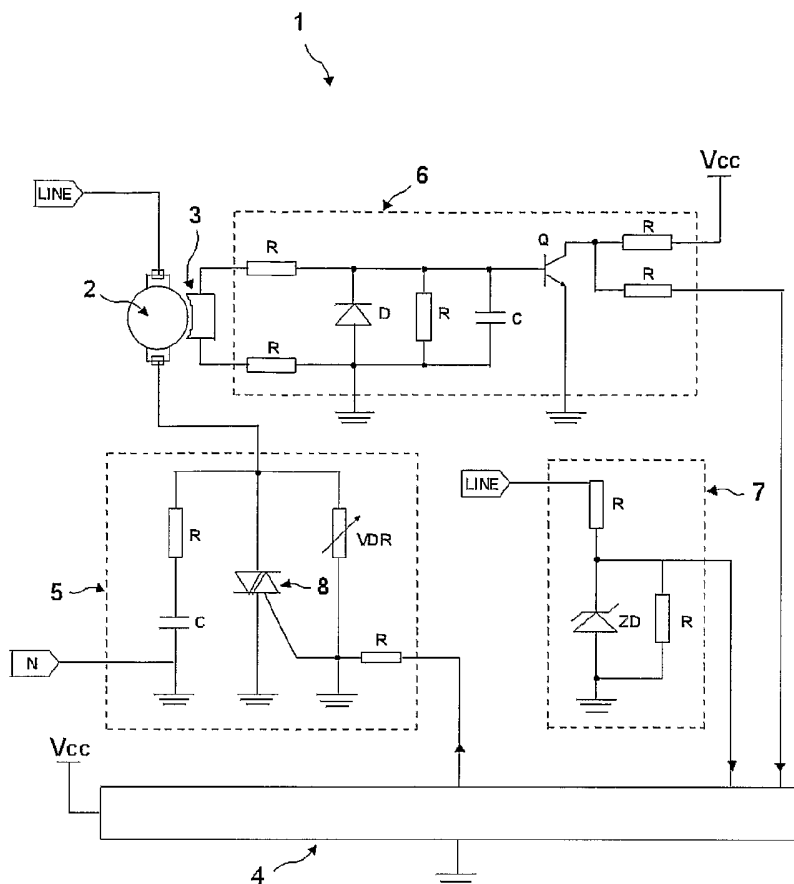
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(54) Title: A MOTOR CONTROL CIRCUIT



(57) Abstract: This invention relates to a motor control circuit (1) which increases the efficient power of Universal AC motors (2) used in actuating high capacity washing machines without leading to a reduction of life expectancy of current conducting components of the motor (2) like brush, collector etc.



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Description

A MOTOR CONTROL CIRCUIT

- [001] This invention relates to a motor control circuit which increases the effective power generated by electric motors.
- [002] In household appliances, preferably in washing machines, actuation is provided extensively by Universal AC motors and the speed control of these motors are generally actualized by utilizing triacs controlling AC voltage. In washing machines there is an increase in operation speed range of drive motors as a result of user demands and ever increasing amounts of washing loads are attempted to be handled in wider speed ranges. This situation necessitates the utilization of electric motors with bigger package sizes and with more winding, however, motors with increased sizes may lead to reduction in motor efficiency due to the decrease of power factor ($\cos\phi$). In motor speed control by the triac, the zero crossings (ZC) of alternating voltage coming in fluctuating positive and negative cycles are determined and the triac is fired with specified time delays referenced to zero point crossings. These time delays are called firing angles (α). Current is obtained when the triac is fired from zero network voltage (V) after a firing angle α . Switching off the current of the motor cannot be interfered by the triac, the current decreases in the negative cycles of the voltage and when it is zero the triac closes again to fire. The speed of the motor is implemented by adjusting the firing angle α . If the speed of the motor is high, then α is increased to reduce the applied voltage to the motor, if the speed of the motor is low, α is decreased to increase the applied voltage to the motor by utilizing PI (Proportional Integral) or PID (Proportional Integral Derivative) control methods. The state-of-the-art triac firing techniques are shown in Figures 2 to 7. When high power generation is demanded from the motor for handling big volume loads in washing machines, the current is cut very late as the current in one cycle switches to the other cycle and since the firing angle α cannot precede the cutting point of the current, sufficient power can not be generated (Figure 2). In Figure 3 and Figure 4, the graphs of the firing of triac by positive gate trigger pulses in negative and positive cycles of alternating current and the firing of triac by negative gate trigger pulses in negative and positive cycles of alternating current are shown. A forced work field is created in the driving (triac firing) technique by the positive or negative gate trigger pulses and EMI (Electro Magnetic Interference) problems might arise in each area. In this case, in an inductive load, trying to fire the triac before the current in opposite direction comes to zero, will be futile since the triac will not function before the current is zero, thus the desired current can not be generated. To overcome EMI problems, triac firing by positive gate trigger pulses in positive cycles of AC current, and by negative gate trigger pulses in negative

cycles (Figure 5) or by multiple pulsing method (Figure 6) is employed or in consecutive cycles by variable firing angles α , for example in each cycle instead of $\alpha = 90^\circ$ α firing angle, in consecutive cycles triac is fired with $\alpha = 45^\circ$ and $\alpha = 135^\circ$ firing angles (Figure 7). In state-of-the-art triac firing techniques, the desired motor efficiency can not be achieved and the cost of circuit elements tends to be high.

- [003] The aim of the present invention is to realize a motor control circuit which improves the motor power without reducing the life expectancy of current conducting elements like brush, collector etc. in a household appliance actuated by an AC electric motor.
- [004] The motor control circuit realized in order to attain above mentioned aim of the present invention is illustrated in the attached drawings, where:
- [005] Figure 1 – is the schematic view of a motor control circuit.
- [006] Figures 2 to 7 – are the diagrams of state-of-the-art triac firing techniques.
- [007] Figure 8 – is the diagram of a triac firing in skipped cycle with firing angle different from zero.
- [008] Figure 9 - is the diagram of a triac firing in skipped cycle with zero degree in a positive cycle of AC voltage waveform.
- [009] Figure 10 - is the diagram of a triac firing in skipped cycle with zero degree in the negative cycle of AC voltage waveform.
- [010] Figure 11 - is the diagram of a triac firing in skipped cycle in the positive and negative cycles of AC voltage waveform.
- [011] Each of the parts in the drawings are numbered as follows:
1. Motor control circuit
 2. Motor
 3. Tacho generator
 4. Microcontroller
 5. Drive circuit
 6. Tacho circuit
 7. Zero crossing circuit
 8. Triac
- [012] Household appliances, for example washing machines are actuated by an AC electric motor (2). The control of the motor (2) is achieved by a motor control circuit (1) and motor (2) speed is measured by means of signals generated by a tacho generator (3) connected to the motor (2).
- [013] The motor control circuit (1) comprises a microcontroller (4) which actuates the motor to operate with desired current values (I) by evaluating the data received and energized by a small feed voltage (Vcc), a drive circuit (5) which evaluates signals received from the microcontroller (4) for performing verification, a tacho circuit (6)

which sends speed measurement signals received from the tacho generator (3) in 0 – 5 V square waveform to the microcontroller (4) to be evaluated and a zero crossing circuit (7) which determines the zero crossing points (ZC) of AC voltage (V) coming from the network and sends in 0 – 5 V square waveform to the microcontroller (4) to be evaluated.

[014] The drive circuit (5) comprises a microcontroller (4) which regulates the firing periods of the triac (8) which transmits the controlled AC voltage (V) to the motor (2), one or more resistors (R), a capacitor (C), and a voltage regulator (VDR) and is fed by the network voltage (V).

[015] The tacho circuit (6) comprises one or more resistors (R), a capacitor (C), a transistor (T), and a diode (D) and it is energized by a low feed voltage (Vcc).

[016] The zero crossing circuit (7) comprises one or more resistors (R), and a Zener diode (ZD) and is fed by the network voltage (V).

[017] In the motor control circuit (1) which is the object of the present invention, the zero crossing points (ZC) of AC voltage (V) coming from the network are detected by the zero crossing circuit (7), according to the desired current value (I) for the motor (2), a firing angle (α), defined as a specific delay starting from the zero crossing point (ZC) is assigned by the microcontroller (4) and the firing (TF) of the triac (8) integrated in the driving circuit (5) is performed in skipped cycles of voltage (V) waveform.

[018] In the motor control circuit (1), the microcontroller (4) assigns a negative or a positive cycle of the AC voltage (V) fluctuating in negative and positive areas as the starting point, and fires (TF) the triac (8) with a delay as much as the firing angle (α) beginning from the zero crossing point (ZC) of this cycle, continuing the triac (8) firing (TF) in the cycle assigned as the starting point and at each consecutive cycle with the same sign and skipping the cycles of the voltage (V) waveform with other sign without triac (8) firing (TF).

[019] In the motor control circuit (1), the triac (8) is fired (TF) by choosing a positive or negative cycle of the voltage (V) waveform and the negative cycle following the positive cycle where triac (8) is fired (TF) or the positive cycle following the negative cycle where triac (8) is fired (TF) is skipped without triac (8) firing (TF) and when the cycle of AC voltage (V) waveform turns back to the initial positive or negative area where the triac(8) first fired (TF), the triac (8) firing (TF) is actualized again with the same firing angle (α).

[020] Given the way that AC voltage (V) is described as fluctuations between positive and negative areas, when the zero crossing points at the transitions from positive to negative or from negative to positive is defined as $ZC=Zci$, the triac (8) firing (TF) in skipped cycles of voltage (V) waveform is actualized by the software of the microcontroller (4) containing the following steps:

given $ZC = ZC_i$ then fire (TF) the triac (8) with α time delay
 given $ZC = ZC_{i+1}$ then wait
 given $ZC = ZC_{i+2}$ then fire (TF) the triac (8) with α time delay
 given $ZC = ZC_{i+3}$ then wait

- [021] In the motor control circuit (1), when the triac (8) is fired (TF) at the first zero crossing point (ZC) of AC voltage (V) in the chosen positive or negative cycle area after a delay as much as the firing angle (α), high current (I) values are attained at preferably small firing angles (α), whereas in the following cycle at the point that the current (I) is zeroed for firing (TF) the triac (8) once more with the same firing angle (α), the current (I) falls freely without confronting a constraint for the necessity of firing. The current (I) nears its zero value by free falling in this cycle which is passed without triac (8) firing (TF) and zeroing of the current (I) is guaranteed with the transition into the following cycle where triac (8) firing (TF) will be actualized.
- [022] In the embodiment, where maximum current (I) and thus maximum motor (2) power efficiency can be attained, triac (8) firing (TF) can easily be actualized with firing angle (α) values almost equalling to zero. The current (I), reaches the maximum value and starts going downward at the first cycle where triac (8) firing (TF) is actualized with firing angle (α) values almost equalling to zero, the downward trend of current (I) continues in the second cycle and since triac (8) firing (TF) will not be performed in the cycle where the downward trend of current (I) continues, it zeroes freely. In the following cycles, like in the first and second cycles, the motor (2) is operated with a firing angle (α) almost equalling to zero. by following the (wait- fire) sequence.
- [023] In one embodiment of the present invention, the triac (8) firing (TF) is performed only in the positive cycles of AC voltage (V) waveform. In this embodiment any positive cycle of AC voltage (V) waveform is chosen as the starting point, the triac (8) firing (TF) is performed with a zero or different from zero firing angle (α) chosen by the microcontroller (4) for attaining the desired current (I) value. In the negative cycle following the positive cycle where the triac (8) firing (TF) is performed, the triac (8) firing (TF) is not performed and the current (I) is waited to fall to zero by free falling. In the next positive cycle the triac (8) is fired (TF) again with the same firing angle (α) and the cycle continues. (Figure 9)
- [024] In another embodiment of the present invention, the triac (8) firing (TF) is performed in only the negative cycles of AC voltage (V) waveform. In this embodiment any negative cycle of AC voltage (V) is chosen as the starting point, the triac (8) firing (TF) is performed with a zero or different from zero firing angle (α) chosen by the microcontroller (4) for attaining the desired current (I) value. In the positive cycle following the negative cycle where the triac (8) firing (TF) is performed,

the triac (8) firing (TF) is not performed and the current (I) is waited to fall to zero by free falling. In the next negative cycle, the triac (8) is fired (TF) again with the same firing angle (α) and the cycle continues. (Figure 10)

[025] By performing the triac (8) firing (TF) in only the positive or negative cycle of AC voltage (V) waveform the desired increase in power is attained, however, the current (I) is forced to reach high values in one direction there may be one-way scraping in the brush-collector setup of the motor (2) and therefore some amount of decrease may be seen in the life expectancy.

[026] In another embodiment of the present invention the triac (8) firing (TF) is performed by the microcontroller (4) alternately in positive and negative cycles of AC voltage (V) waveform. In this embodiment, when the positive cycle of AC voltage (V) is chosen as the starting cycle, and the triac (8) is fired (TF) in the positive cycle, a predefined number of (n) and as $n > 1$ the negative cycles are skipped, and later while the triac (8) is fired (TF) in (n) number of negative cycles and the positive cycles are skipped. (Figure 11)

[027] Similarly, when the negative cycle of AC voltage (V) waveform is chosen as the starting cycle, while the triac (8) is fired (TF) in a predefined number (n) and as $n > 1$ of the negative cycle by the microcontroller (4), the positive cycles are skipped and later while the triac (8) is fired (TF) in (n) number of positive cycles and the negative cycles are skipped.

[028] The choice of the triac (8) firing (TF) number (n) referred to in the positive or negative cycles is made taking into consideration the brush-collector life expectancy and the desired symmetrical scraping in brush-collector setup, and consequently a longer life expectancy is achieved by the voltage-power oscillations of the motor (2), in $n=5$ or $n=10$ values. In this embodiment, when the sign of the cycle where triac (8) firing (TF) is actuated changes from positive to negative or from negative to positive, cycle skipping is not performed, instead the triac (8) is fired (TF) by calculating the firing angle $\alpha = \alpha_{\text{limit}}$ which guarantees the current (I) to be zeroed in the cycle entered. During transition, the desired results are attained between values of $\alpha_{\text{limit}} = 90^\circ - 180^\circ$.

[029] In a washing machine drive motor (2) actuated by a standard AC phase control which has to perform with high capacity, the loss of performance resulting from low power factor is prevented by the cycle skipping or alternating cycle skipping triac (8) firing (TF) method and the efficient motor (2) power is increased without damaging the motor (2) components which conduct the current like brush, collector etc.

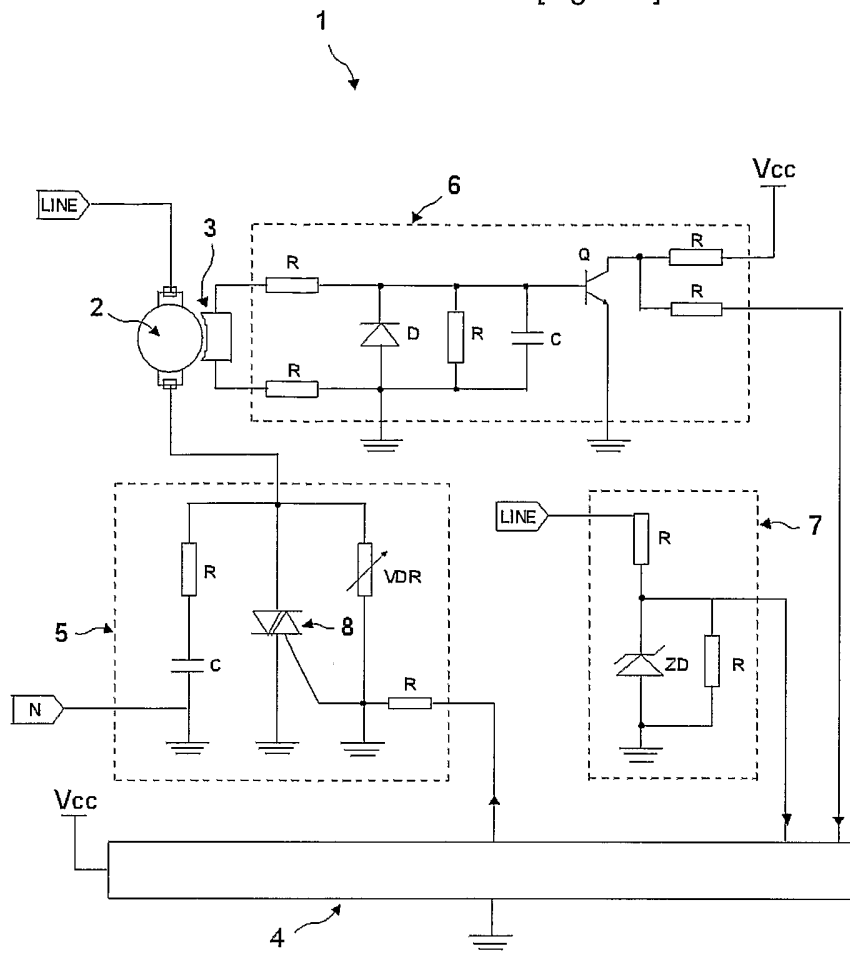
Claims

- [001] A motor control circuit (1) comprising a microcontroller (4) which controls an AC electric motor (2), evaluating the data received enabling the actuation of the motor (2) with desired current (I) values, an actuator circuit (5) performing verification by evaluating the signals received from the microcontroller (4) and having a triac (8) the firing periods of which are regulated by the microcontroller (4) enabling transmission of AC voltage (V) to the motor (2) in a controlled fashion, and a zero crossing circuit (7) which detects and sends the zero crossing points (ZC) of the AC voltage (V) coming from the network to the microcontroller (4) to be evaluated, characterized by a microcontroller (4) which assigns a negative cycle or a positive cycle of the applied AC voltage (V) waveform fluctuating in negative and positive areas as the starting point according to the desired current (I) value for the motor (2), and fires (TF) the triac (8) with a time delay as much as the firing angle (α) beginning from the zero crossing point (ZC) of this cycle and continuing the triac (8) firing (TF) in the cycle assigned as the starting point and each consecutive cycle with the same sign and skipping the cycles with different signs without triac (8) firing (TF).
- [002] A motor control circuit (1) as in Claim 1, characterized by a microcontroller (4) which enables triac (8) firing (TF) only in the positive cycles of the AC voltage (V) waveform.
- [003] A motor control circuit (1) as in Claim 1, characterized by a microcontroller (4) which enables triac (8) firing (TF) only in the negative cycles of the AC voltage (V) waveform.
- [004] A motor control circuit (1) as in Claim 2 or 3, characterized by a microcontroller (4) which enables triac (8) firing (TF) with firing angles (α) almost equalling to zero.
- [005] A motor control circuit (1) as in Claim 1, characterized by a microcontroller (4) which assigns a positive cycle the applied AC voltage (V) waveform as the starting point, enabling the triac (8) firing (TF) to be performed in positive cycles of a predetermined number (n) greater than 1 and skipping the negative cycles, and afterwards enabling the triac (8) firing (TF) to be performed in negative cycles of a predetermined number (n) greater than 1 and skipping the positive cycles.
- [006] A motor control circuit (1) as in Claim 1, characterized by a microcontroller (4) which assigns a negative cycle of the applied AC voltage (V) as the starting point, enabling the triac (8) firing (TF) to be performed in negative cycles of a predetermined number (n) greater than 1 and skipping the positive cycles, and

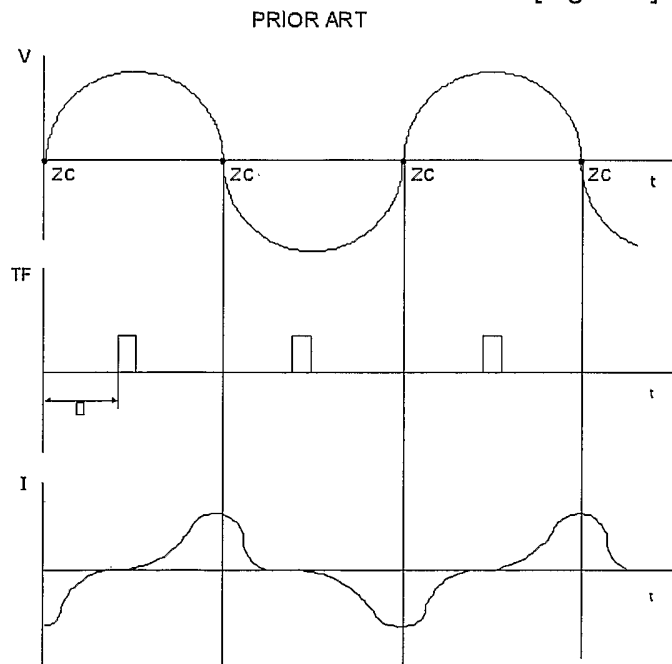
afterwards enabling the triac (8) firing (TF) to be performed in positive cycles of a predetermined number (n) greater than 1 and skipping the negative cycles.

[007] A motor control circuit (1) as in Claim 5 or 6, characterized by a microcontroller (4) which enables the triac (8) firing (TF) by calculating the firing angle $\alpha = \alpha_{\text{limit}}$ which guarantees the zeroing of the current (I) in the cycle entered when the sign of the cycle where triac (8) firing (TF) is performed changes from positive to negative or from negative to positive.

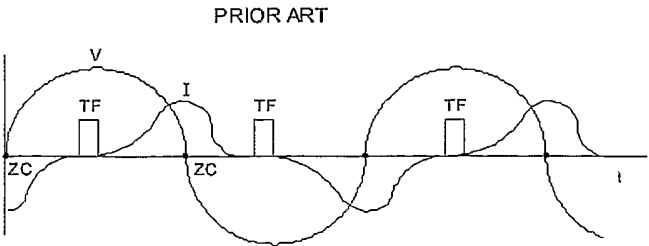
[Fig. 001]



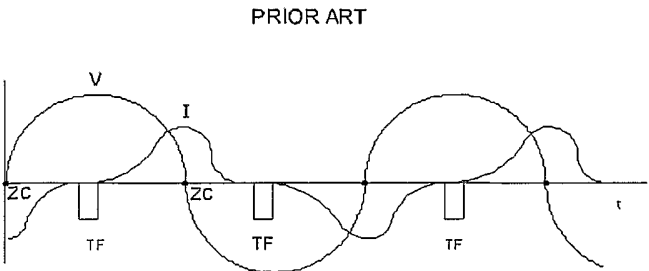
[Fig. 002]



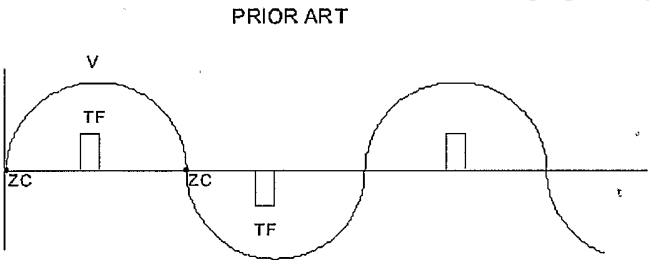
[Fig. 003]



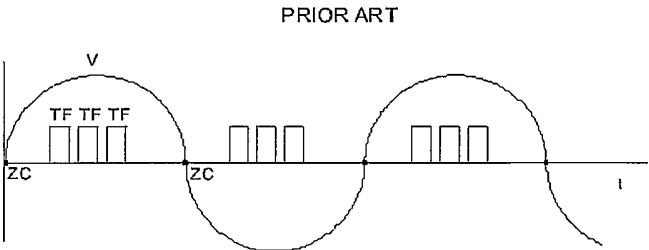
[Fig. 004]



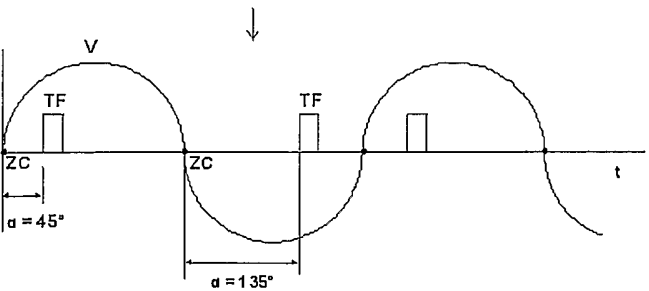
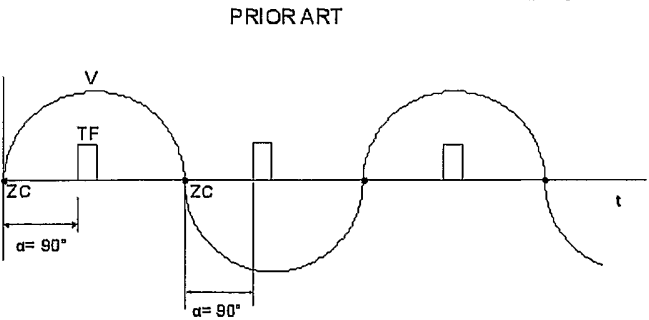
[Fig. 005]



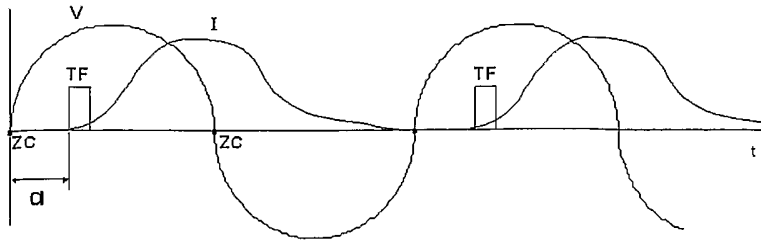
[Fig. 006]



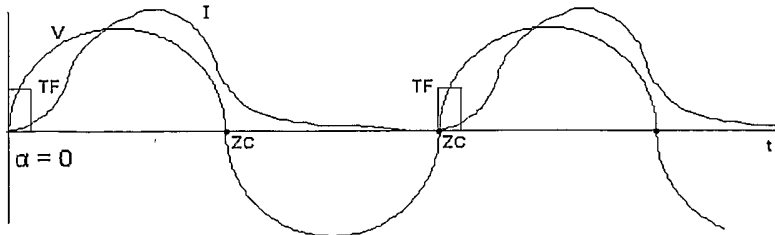
[Fig. 007]



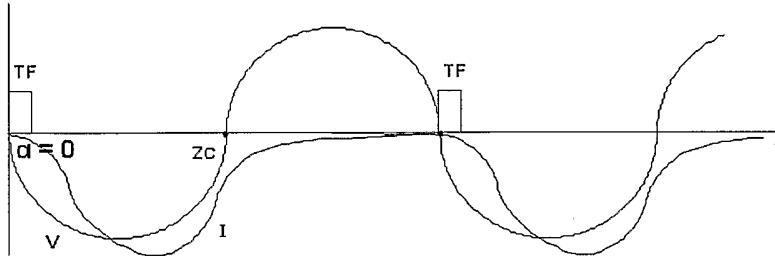
[Fig. 008]



[Fig. 009]



[Fig. 010]



[Fig. 011]

