METHOD AND APPARATUS FOR CONNECTING OR DISCONNECTING AN ELECTRICAL LOAD CIRCUIT

Method and apparatus for connection or disconnection respectively of a load circuit (L) in relation to an electrical alternating current supply network by means of an electro-mechanical switch element (R), such as a relay or contactor device, controlled by an electronic control circuit (SE) for the purpose of switching on or switching off at the instant when the mains or supply voltage or the load current has a zero crossing. Beforehand in the control circuit there is inserted and estimated time delay between application of control current to the switch element and the switching on or off thereof, based on given time parameters for the switch elements or drive voltage concerned. After having received a control signal (11) for connection or disconnection the control circuit applies control current (15) to the switch element (R) at an instant calculated from sensed zero crossing(s) and said estimated time delay. The control circuit (SE) is adapted to measure any time deviation between the actual zero crossing concerned and the real switching instant and thereby a real time delay for the switch element (R). Moreover the control circuit is adapted to store the real time delay for use in calculating an instant for applying control current at the subsequent connection or disconnection respectively or the switch element.
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METHOD AND APPARATUS FOR CONNECTING OR DISCONNECTING AN ELECTRICAL LOAD CIRCUIT.

This invention relates to a method and an apparatus for connection and/or disconnection of a load circuit with respect to an electric alternating current network or installation by means of an electro-mechanical switch element.

The switch element can be a relay or a contactor device and is controlled by an electronic control circuit in order to switch on or switch off the load at the instant when the supply voltage or load current has a zero crossing. Thus the control circuit is adapted to sense at least the supply or mains voltage for determining its zero crossing.

What is aimed at by such a method is in the first place one or more of the following features:
- to minimize electric noise which is generated at the switching instant
- to miniaturize the switching equipment, preferably at reduced costs
- to obtain a longer lifetime of switching equipment and
- to employ a potential free switch element, i.e. a switch element having no noticeable voltage drop when the load is connected.

Obvious fields of use for this method and apparatus are in all electrical installations where it is desirable to have remote control or automatic switching on or off an electric load, e.g. equipment and units in a data installation.

When connecting and disconnecting electric loads in alternating current networks it is desirable to employ switch elements which are potential free and which switch on or switch off respectively, at voltage or current amplitudes being approximately equal to zero (zero crossing). This is particularly important when switching large loads since such a controlled switching procedure can to a high degree
prevent the generation of electric noise, which can occur both as wire-bound noise and as radiated noise, at the same time as deterioration or destruction of contact members in the switch element are prevented or delayed.

The apparatus or switching equipment in principle can be regarded as a two-part arrangement. In the first place there is the actual switch element which effects the physical connection or disconnection of the load circuit. In the second place the control circuit mentioned is involved, which supplies a switching signal in the form of a control current to the switch element in order to activate this element. For various reasons, such as safety of persons and equipment, noise suppression and problems related to a common potential over long distances, it is moreover a desire to have a galvanic separation between the control circuit and the load circuit. As far as noise suppression is concerned this can be of interest also at other times than at the actual instant of switching. Besides, as mentioned, it is desirable that the complete switching equipment has as small physical dimensions as possible.

As switch elements there are today mainly two types being applied, namely the purely electronic switch elements and electro-mechanical contactors or relays.

The electronic switch elements may be transistors, thyristors and the like, which in a relatively simple manner can be connected to a phase detector sensing the times at which the load voltage or current is equal to zero. * A substantial drawback with this type of element is that they are not potential free, require coding, do not tolerate peak currents well and are comparatively expensive with phase detectors.

Accordingly this invention is based on the employment of electro-mechanical switch elements which have the advantage, inter alia, that they are potential free as switch elements. However, they do not by themselves involve a control of the actual switching time in relation to the phase of the load voltage or current. The switching
instant, therefore, in most cases will be when the phase is different from zero, or in other words outside the zero crossings. As mentioned this leads to the generation of wire-bound and radiated electro-magnetic noise, which can disturb more or less adjacent electronic equipment, e.g. computer equipment. In addition to such problems disconnection in particular may result in an electrical arc bridging a contact gap and cause burning or oxidation of contact surfaces. This in turn may lead to heating in relays and contactors as well as a switch element which is no longer potential free. In order to avoid such arcing switching relays and contactors are frequently designed with ample dimensions in order to tolerate relatively high voltages and currents, which result in physically large and expensive units of equipment.

Previously, attempts have been made to find solutions to the difficulties discussed above, but the technical solutions being known hitherto are far from satisfactory when considered in relation to the desired functions, requirements and objects, towards the fulfilment of which the present invention is directed.

German patent specification No. 2.816.558 relates to a control unit for connecting a load, which sends a signal to a mechanical relay somewhat before the zero crossing of the voltage. By disconnection a corresponding signal is applied to the relay somewhat after the zero crossing. The purpose of this seems to be that the respective mechanical closing and opening times of the relay be compensated.

German patent specification No. 3.427.478 describes a circuit breaker having a pure zero crossing detector connected in series with a manual switch. Its function is that connection of the load is effected at the first zero crossing of the voltage after actuation of the manual switch. When the manual switch is turned off the load is disconnected immediately without any consideration of the phase or voltage time variation. Both connection and disconnection are delayed by a time interval given by the switching times of the mechanical relay employed.
Both the above patent specifications are based on the sensing of the voltage both at connection and disconnection, and they do not describe any form of adjustment or adaption making it possible to take into account inaccuracies in the switching instants, if the control does not cause the actual switching to take place exactly at the zero crossing instants.

Although considered to be of somewhat less interest in this connection than the above two German patent specifications, the following patent specifications shall also be mentioned.

German patent No. 2.753.765 is directed to contact closing and breaking respectively at the zero crossing region, however, alternatively before and after the zero crossing, so that contact material which is burnt off will migrate in both directions. This is supposed to increase the lifetime of the contacts.

German patent specification No. 2.721.499 describes an electronic switching device arranged in parallel to a mechanical contact arrangement in order that the electronic device take care of the more critical portion of the switching procedure.

European patent application No. 275.960 relates to a switching device for an inductive load, e.g. a microwave oven, based on a similar combination as in the German patent specification just mentioned.

British patent No. 1.143.889 is concerned with an electrical circuit breaker for high currents, constructed to provide for breaking during a quarter of a period after the zero crossing of the current, in an arrangement with several switching units in parallel.

On the above background the invention provides a method and an apparatus having novel and specific features as stated more closely in the claims. The most important features being obtained through the solutions stated here, are as follows:

- the load is switched on at zero voltage over the switch element,
the load is switched off at zero current through the switch element,
the voltage drop over the switch element is substantially equal to zero when current is supplied to the load,
a very high electrical resistance is present between the control circuit on one side and the load circuit as well as the complete alternating current network and plant on the other side.

By utilising these advantageous features when switch elements are designed and dimensioned in a practical installation, the result will be a smaller and therefore less expensive switching equipment, at the same time as this equipment will generate little electrical noise which might disturb the environment, because of the accurate phase control of the connecting and disconnecting operations being made possible by the invention.

In the following description the invention will be explained more closely with reference to the drawing, in which:

Fig. 1 shows a simplified block diagram including a switch element, a control circuit and a load, representing one embodiment of the apparatus according to the invention,
Fig. 2 is also a block diagram, however, illustrating in somewhat more detail the function of the control circuit in Fig. 1,
Fig. 3 shows as a time diagram somewhat more than one period of an alternating voltage or current, in order to explain certain time relationships in connection with the invention, and
Fig. 4 is a diagram showing varying delay times at switching on and switching off respectively, of relays and contactors.

In Fig. 1 as an example there is shown a load L to be connected into or to be disconnected from an alternating current supply of common mains voltage 230 V and frequency 50 Hz. For this connection and disconnection there is shown a contactor represented by a winding R and an associated
switch contact in series with the load circuit. For
actuating the contactor winding R there is provided a
control circuit SE which is adapted to operate when it
received a control signal So at one input 11.

For sensing the current amplitude in the load circuit
there is provided a sensor A connected to the control
circuit SE in order to apply an important input signal
thereto. The sensor A may be a Hall-effect sensor, i.e.
either a Hall element generating a voltage or a Hall
resistor. This sensor must be located in the neighbourhood
of a current supplying conductor from the alternating
current network to the load circuit, e.g. vertically in
relation to the magnetic field from the conductor. In
practice, if necessary a ring of magnetic material can be
arranged around the load conductor in order to amplify the
magnetic field to be sensed by the Hall sensor. By means of
a resistance value or Hall voltage measured, the zero
crossing of the load current can then be determined.

Further, at B1 and B2 capacitive couplings are shown
between the load conductor and the control circuit, these
being located respectively in front of and behind the load
switch contacts belonging to the contactor R. When this
switch is open a capacitive current may pass through the
control circuit SE and bypass the contactor. The capacitors
B1 and B2 can be included in a resistance bridge (not shown)
in the control circuit, so that a voltage will be generated
over the resistance bridge when the contactor is open. In
this manner the mains voltage zero crossing can be sensed
and recorded.

As shown with dashed lines in fig. 1 contactor R, in
addition to the load switch contact referred to, can also be
provided with one or more auxiliary contacts as indicated at
25 with an associated input lead 21 to control circuit SE,
in order that this circuit can receive a positive signal
indicating the exact and actual switching instant of
connection and disconnection respectively, by means of the
contactor load switch or contacts.

In the somewhat more detailed block or functional
diagram of fig. 2 the switch element R is shown at the left-hand side of a dashed vertical division line, whereas the arrangement at the right-hand side of this dashed line represents the contents of the control circuit block SE in fig. 1. According to fig. 2 the control circuit is regarded as sub-divided into two main units, i.e. a calculating unit 10 and a timing unit 20. The latter unit has an input 21 from switch element R, corresponding to the connection from auxiliary contact 25 to control circuit SE in fig. 1. Voltages and currents (B1-B2 and A in fig. 1) being sensed, are applied to an input 13 of calculating unit 10. Besides this unit at 11 receives the control signal So. An additional input 12 to the calculating unit serves to apply or store a pre-estimated time delay with respect to one or more types of switch element R and possibly varying drive voltages for these. This will be explained somewhat more closely in connection with fig. 4 below.

The output 15 from calculating unit 10 serves to supply control current for activating the switch element R. The time for applying this control current is also detected by means of an input 22 of timing unit 20, which provides for a comparison between this time and the actual switching instant of switch element R. As will be seen from fig. 3 unit 20 will therefore act as a time difference measuring unit and at its output 14 will supply a signal which represents a time delay Δt which is an input signal to calculating unit 10 for the purpose of adjusting or recalculating the time for the next connection or disconnection.

Calculating unit 10 or the control circuit as a whole can comprise a battery as indicated at 19, which will serve to maintain the contents of one or more memory circuits intact when the remaining equipment is switched off or disconnected from an installation.

In the diagram of fig. 3 the time variation of an alternating current or voltage is shown over somewhat more than one period of the mains frequency, whereby the various time aspects in connection with the invention are considered
in relation to a zero crossing denoted by t=0. This can be
the zero crossing, possibly the last, having been recorded
by the control circuit before a connection or a
disconnection of the load circuit is to take place. In such
case the equipment can be adapted to provide for this
switching as close to as possible, and preferably exactly at
the following zero crossing, i.e. at the instant tp which
consequently is located one half period T/2 after the
starting instant t=0. In order to take into account the
unavoidable delay in switch element R the control current
must be applied thereto at a certain time prior to the
intended switching instant at the time tp, and in fig. 3 the
control current is meant to be applied at the time tsl,
based upon an estimated time delay Te. This estimated time
delay, however, will not usually be determined with
sufficient accuracy, so that the real switching instant will
be at a time tv, i.e. with a time difference or deviation
Δt in relation to the zero crossing tp. In other words
there has occurred an actual time delay Tm which in this
case is larger than the estimated delay Te.

If now fig. 2 is considered again, it is made apparent
that the function of the units of control circuit SE consist
in generating a signal on the lead 14 between timing unit 20
and calculating unit 10, which represents the deviation Δt,
based on comparison between the input signals at 21 and 22,
so that this deviation Δt can be taken as a basis in
calculating unit 10 for an adjustment of expected switching
time or time delay Tm at the subsequent connection or
disconnection of load circuit L. The calculations mentioned
here can for example be carried out by more or less
conventional table look-up in data stored in calculation
unit 10, or by calculation in a micro-controller which can
be incorporated in control circuit SE.

The first time a switching operation is effected after
installation or putting the equipment into operation, the
control circuit will start up from a pre-set standard
switching time (estimated delay Te) which is based on an
assumption or determination of how long time after a zero
crossing the control current to the switch element must be activated or de-activated in order that the switch element will switch on or alternatively switch off at the next zero crossing. At this point it is remarked that the delay time can be different at connection and disconnection, and it is obvious that the solutions described here can take such difference into account.

The magnitude of the time delays concerned, depends on several factors, including the mechanical inertia and friction in moveable parts of the contactors and relays, the rise time of the drive current in contactor and relay windings and how high voltage is applied to the windings.

The diagram in fig. 4 shows and example of how the time delay can vary with different types of relays depending on the applied drive voltage. It can be presumed that the statistical distribution of the time delay within a certain type of relay, is relatively moderate. Under this condition the correct or estimated time delay can be calculated or selected from a table when the type of relay and the relay voltage are known.

With a battery as indicated at 19 in calculating unit 10 in fig. 2, the switching or delay times which have been learned by the control circuit, can be retained even if the control circuit is removed to another installation or to another load circuit. Without such retainment the control circuit at the first time of operation in a new installation will start with its (pre-set) switching times and then learn from possible deviations (Δt) as explained above.

During subsequent switching operations the switching instant therefore will coincide more exactly with the actual zero crossing, since the control circuit each time detects any deviation and corrects itself for the purpose of operating with a higher degree of accuracy the next time.

It is obvious that components and devices being mentioned as examples with reference to the drawings, can be replaced with other components having a more or less analogue function. Thus the Hall elements or Hall resistor for current sensing as described, can be replaced by another
suitable device for current or field sensing. In order to detect the zero crossing of the mains voltage, there are shown capacitors as an example in the drawings, but these can also be replaced by other components or devices, such as in a high-resistance connection or possibly means for electro-optic transfer of corresponding signals to the control circuit.
CLAIMS

1. Method for connecting or disconnecting respectively, a load circuit in relation to an electrical alternating current supply, by means of an electro-mechanical switch element (R), such as a relay or contactor device, controlled by an electronic control circuit (SE) in order to switch on or switch off respectively at the instant when the supply voltage or the load current has a zero crossing, whereby the control circuit (SE) senses at least the supply or mains voltage, characterized in
   a) that in the control circuit there is pre-stored an estimated time delay (Te) between applying a control current to the switch element and the switching on or off thereof, based on given time parameters for the switch element and drive voltage concerned,
   b) that the control circuit after having received the control signal for switching on or switching off applies the control current to the switch element at a time (ts1) calculated from sensed zero crossing(s) and said estimated time delay (Te),
   c) that the control circuit is adapted to measure any time deviation (Δt) between the actual zero crossing (tp) concerned and the real switching time (tv) and thereby a real time delay (Tm) for the switch element, and
   d) that the control circuit is adapted to store the real time delay (Tm) for use when calculating an instant (ts2) for applying the control current at the subsequent connection or disconnection of the switch element.

2. Method according to claim 1 characterized in that the control circuit (SE) when a load (L) is connected, senses the load current for determining its zero crossing(s) in order to calculate the instant (ts1, ts2) for applying the control current during disconnection.
3. Method according to claim 1 and 2 characterized in that the above steps (b, c and d) are repeated at each subsequent connection and disconnection respectively, for new updating of the real time delay (Tm), whereby the real time delay (Tm) as last stored is entered instead of said estimated time delay (te) in step b) during subsequent connections or disconnections.

4. Method according to claim 1, 2 or 3 characterized in that an estimated time delay (Te) is pre-inserted in the control circuit (SE) for each of a number of combinations of type of switch element (R) and voltage supplied by the control circuit for applying control current to the switch element concerned.

5. Apparatus for connection or disconnection respectively of a load circuit (L) in an electrical alternating current supply network by means of an electro-mechanical switch element (R), such as a relay or contactor device, controlled by an electronic control circuit (SE) in order to switch on or off at the instant when the mains voltage or load current has a zero crossing, said control circuit being connected to a device for sensing at least the mains voltage, characterized in
a) that the control circuit (SE) comprises a device (10) for storing of at least a pre-estimated time delay (te) between application of a control current to the switch element (R) and the switching on or switching off of this element, based on given time parameters relating to the switch element and drive voltage concerned,
b) that the control circuit (SE) has an output (15) which is adapted to — after having received a control signal (So) for connection or disconnection — apply control current to the switch element (R) at an instant (ts1) calculated from sensed zero crossing (S) and said estimated time delay (Te),
c) that the control circuit comprises a device (20) for measuring any time delay (Δt) between the actual zero crossing concerned (tp) and the real switching time (tv) and
thereby a real time delay (\(T_m\)) for the switch element, and

d) that the control circuit comprises a device (10) for
storing the real time delay (\(T_m\)) for use in calculating an
instant (\(t_{s2}\)) for applying control current at the subsequent
connection or disconnection respectively of the switch
element (R).

6. Apparatus according to claim 5
characterized in that the control circuit (SE)
is connected to a sensor device for sensing the load current
when a load is connected, for determining the zero
crossing(s) of the current for use in calculating the
instant (\(t_{s1}, t_{s2}\)) for applying the control current during
disconnection.

7. Apparatus according to claim 5 or 6
characterized in that the control circuit (SE)
has an input (21) connected to an auxiliary device (25) of
the switch element (R) e.g. in the form of at least one
auxiliary contact, for applying a signal at the actual
switching on or switching off of the switch element (R), to
the control circuit (SE).

8. Apparatus according to claim 5, 6 or 7
characterized in that the control circuit (SE)
is provided with a battery (19) for uninterrupted function
of said storing devices.
FIG. 1

FIG. 2
### INTERNATIONAL SEARCH REPORT

**International Application No.** PCT/NO 90/00044

#### I. CLASSIFICATION OF SUBJECT MATTER

According to International Patent Classification (IPC) or to both National Classification and IPC

**IPC5:** H 01 H 9/56

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**SE, DK, FI, NO classes as above**

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<td>DE, A1, 3110314 (LGZ LANDIS &amp; GYR ZUG AG) 1 April 1982, see the whole document --</td>
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#### IV. CERTIFICATION

- **Date of the Actual Completion of the International Search:** 5th June 1990
- **Date of Mailing of this International Search Report:** 1990-06-12
- **International Searching Authority:** SWEDISH PATENT OFFICE
- **Signature of Authorized Officer:** Bertil Nordenberg

*Form PCT/ISA/210 (second sheet) (January 1985)*
ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.PCT/NO 90/00044

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