Abstract: The invention relates to a method and apparatus for suppressing an inrush current of a three-phase transformer (15) connected to a three-phase power supply via a triple-pole circuit breaker (20), the transformer (15) being connected and disconnected from the power supply by closing and opening the circuit breaker (20), wherein the method comprises monitoring a property of at least two phases of the transformer (15), determining a residual flux pattern after the circuit breaker (20) is opened, computing an equivalent opening moment (60) of the circuit breaker (20) using the property monitored, wherein at the equivalent opening moment (60) of the circuit breaker (20), the phases of the transformer (15) are de-energized simultaneously, deriving a closing time window (64) for closing the circuit breaker (20) on the basis of the equivalent opening moment (60), and closing the poles of the circuit breaker (20) simultaneously within the closing time window (64).
Method and apparatus for suppressing an inrush current of a transformer

The present invention relates to a method and apparatus for suppressing an inrush current of a three-phase transformer connected to a three-phase power supply via a three-phase circuit breaker.

A circuit breaker is typically used for disconnecting a transformer from the power supply in an electrical network. The circuit breaker disconnects the transformer from the power supply by opening its poles. On the transformer being disconnected from the power supply the former is de-energized. On the transformer being de-energized, the current becomes zero and the phase flux follows the hysteresis loop of the core of the transformer, resulting in certain residual flux left at the core at zero current. Typically, residual flux is the magnetic flux density that remains in a material when the magnetizing force is zero. The residual flux may be typically, about 20% to 70% of the rated flux. In certain aspects, the residual flux may be as high as 80% to 90% of the rated flux. Connecting the transformer to the power supply at an inappropriate moment may create flux asymmetries and may cause saturation of the magnetic flux at the core of the transformer.

Saturation of the magnetic flux at the core of the transformer may cause high amplitude currents that have a high direct current component and considerable harmonic contents, generally referred to as inrush current. The inrush current may cause the protective devices and fuses to function improperly and thus, may damage the transformer windings due to the electromagnetic stress. The inrush current may also have significant impact on the power system and neighboring equipments, such as electrical resonance in the power system resulting from harmonics, false operation of
sensitive electronics due to voltage drop of the power supply, and increase of motor vibrations and ageing owing to the direct current component.

It is an object of the embodiments of the invention to reduce inrush current of a three-phase transformer.

The above object is achieved by a method of suppressing an inrush current of a three-phase transformer connected to a three-phase power supply via a three-phase circuit breaker, the transformer being connected and disconnected from the power supply by closing and opening the circuit breaker according to claim 1.

When the poles of the circuit breaker are opened simultaneously, the phases of the transformer are not de-energized simultaneously due to arcing effect. Typically, the residual flux pattern is determined after the poles of the circuit breaker are opened when the phases of the transformer are de-energized. An equivalent opening moment of the circuit-breaker can be derived based on the residual flux pattern, where all transformer windings are assumed to be de-energized simultaneously and the residual flux pattern is identical to the determined residual flux pattern. The equivalent opening moment of the circuit breaker enables in deriving a closing time window. The closing time window is derived encompassing a closing moment where the prospective flux is equal to the residual flux. Typically, the closing moment is after the equivalent opening moment when the phase angle of the power supply is equal to the phase angle of the equivalent opening moment. The poles of the circuit breaker may be closed within the closing time window to connect the transformer to the power supply. Additionally, connecting the transformer to the power supply within the closing time window enables in suppressing the inrush current of the transformer as the phases are re-energized simultaneously, thus, avoiding flux asymmetry and saturation of flux at the transformer. Additionally, closing the poles of the circuit breaker within
the closing time window eliminates the requirement of stringent closing time deviation.

According to another embodiment, the property includes at least one from the group consisting of a voltage and a current. The property of the phases monitored may be either the voltage or the current or both.

According to yet another embodiment, the equivalent opening moment is derived using the residual flux pattern. The equivalent opening moment may be derived using a relation between the residual flux pattern and the property of the phase. In an aspect, the property may be current of the phase. In another aspect, the property may be voltage of the phase.

According to yet another embodiment, the determination of the residual flux pattern comprises detecting a de-energizing sequence of the phases of the transformer. The de-energizing sequences of the phases may be detected using the monitored property of the phases. In an aspect, the de-energizing sequence of the phases may be detected using the monitored current or voltage of at least two phases.

According to yet another embodiment, the residual flux pattern is determined using the de-energizing sequence of the phases and a phase angle of the property of the phase at which the poles of the circuit breaker are opened. In an aspect, the residual flux pattern may be determined using the de-energizing sequence of the phases and the phase angle of the voltage or the current when the poles of the circuit breaker are opened.

According to yet another embodiment, wherein the residual flux pattern is determined using the de-energizing sequence of the phases and a pattern of the current in each phase at the de-energizing moment. The pattern of the current includes detecting whether the current is rising, i.e., becoming zero
from a negative value or descending, i.e., becoming zero from a positive value, from the moment the transformer is disconnected from the power supply to the de-energizing moment. Thus, the residual flux pattern may be computed using the de-energizing sequence of the phases and whether the current in each phase is rising or descending.

According to yet another embodiment, the residual flux pattern is determined using a value of a residual flux of each phase. The residual flux of a phase may be computed as the integral of the phase voltage acting on a phase core of the transformer, prior to being de-energized.

Another embodiment includes, an apparatus for suppressing an inrush current of a three-phase transformer connected to a three-phase power supply via a three-phase circuit breaker, the transformer being connected and disconnected from the power supply by closing and opening the circuit breaker, the apparatus comprising a monitoring unit for monitoring a property of at least two phases of the transformer, a controller configured to determine a residual flux pattern after the circuit breaker is opened, compute an equivalent opening moment of the circuit breaker using the property monitored, wherein at the equivalent opening moment of the circuit breaker, the phases of the transformer are de-energized simultaneously, derive a closing time window for closing the circuit breaker on the basis of the equivalent opening moment, the closing time window being derived around a closing moment which is after the equivalent opening moment at the phase angle of the power supply being equal to the phase angle of the equivalent opening moment, and provide a control signal to close the poles of the circuit breaker simultaneously within the closing time window.

Embodiments of the present invention are further described hereinafter with reference to illustrated embodiments shown in the accompanying drawings, in which:
FIG 1 illustrates an exemplary apparatus for suppressing energizing inrush current in a transformer in a three phase electric system, according to an embodiment herein,

FIG 2 illustrates an example of a schematic representation of a residual flux of a three-phase transformer having primary delta windings and secondary grounded y windings after the transformer is disconnected from the power supply, wherein each phase of the transformer is de-energized at a natural current zero point, and

FIG 3 illustrates an equivalent opening moment at which all the phases of a three phase transformer, having primary delta windings and secondary grounded y windings, are de-energized simultaneously according to an embodiment herein,

FIG 4 illustrates an example of an inrush current of a three-phase transformer with primary delta windings and secondary grounded y windings with a residual flux pattern \((0, -R, +R)\), when it is closed within a closing time window based on the equivalent opening moment shown in FIG 3,

FIG 5 illustrates an example of a schematic representation of an energizing inrush current of a three-phase transformer with primary delta windings and secondary grounded windings, when the transformer is connected to the power supply using a circuit breaker at any moment within a closing time window, and

FIG 6 is a flow diagram illustrating a method of suppressing an inrush current of a three-phase transformer according to an embodiment herein,
Various embodiments are described with reference to the drawings, wherein like reference numerals are used to refer to like elements throughout. In the following description, for purpose of explanation, numerous specific details are set forth in order to provide a thorough understanding of one or more embodiments. It may be evident that such embodiments may be practiced without these specific details.

FIG 1 illustrates an exemplary apparatus 10 for suppressing energizing inrush current in a transformer 15 in a three phase electric system, according to an embodiment herein. The apparatus 10 comprises a circuit breaker 20, one or more monitoring units 22 and a controller 35. Typically, the circuit breaker 20 is a triple-pole circuit breaker. The triple-pole circuit breaker may be a dependent pole circuit breaker or an independent pole circuit breaker. Typically, the dependent-pole circuit breakers are used in medium and low voltage power systems, and the independent-pole circuit breakers are used for high voltage power system. The circuit breaker 20 is configured to connect and disconnect the transformer 15 to the power supply by closing and opening its poles respectively. Typically, the circuit breaker 20 is opened or closed responsive to a control signal provided by the controller 35. However, the circuit breaker 20 may also be opened or closed manually.

Still referring to FIG 1, the monitoring unit 22 may monitor a property of at least two phases. The property monitored may include voltage, current and the like. In an aspect, the monitoring unit 22 may comprise voltage sensors 25 to measure the voltage at each phase of the core of the transformer 15. The monitoring unit 22 comprising the voltage sensors 25 may be typically arranged at the supply side of the circuit breaker 20 to measure the voltage of each phase. In another aspect, the monitoring unit 22 may comprise current sensors 30 to measure the current of each phase. The monitoring unit 22 comprising the current sensors 30 may be typically arranged at the load side of the circuit breaker 20 to
measure the current of each phase. In an embodiment, the voltage of two phases may be measured and the voltage of the third phase may be derived from the measured voltage of the two phases. Similarly, the current of two phases may be measured and the current of the third phase may be derived from the measured current of the two phases. The sensors 25, 30 of the monitoring unit 22 may be operably connected to the controller 35 such that the measured voltage and/or the current data may be provided to the controller 35. In an aspect, the current and/or the voltage may be measured continuously and the measured data may be provided to the controller 35. In an aspect, the controller 35 may comprise a memory 40 for storing the measured data. Typically, the controller 35 may comprise a processor or a microcontroller, and the like. The controller 35 may be configured to compare the measured data or the stored data with threshold values stored at the memory 40 to detect if the circuit breaker 20 should be opened or closed.

In the shown example of Fig 1, the circuit breaker 20 opens its poles upon receiving the control signal from the controller 35 for opening the poles. Due to arcing phenomenon, the phases of the transformer 15 may not be de-energized immediately, even though mechanical disconnection exists between contact points of each pole of the circuit breaker 20. Typically, each phase of the three phase transformer 15 are de-energized at a natural current zero point of the respective phases of the line current. Typically, the natural current zero point of each phase is the point at which the current becomes zero after the poles of the circuit breaker are opened.

During the de-energizing period, fluxes of each phase of the three-phase transformer 15 are interacted and are not constant, until all the phases are de-energized. When the phases of the transformer 15 are de-energized, typically, the residual flux of three-phase transformers with three-limb cores may sum to zero, and may form a pattern with near zero
residual flux in one phase and a negative and a positive finite value in the other two phases respectively. The residual flux pattern may exhibit several specific combinations when the three-phase transformer 15 is disconnected from the power supply, such as, (0, +R, -R) for the respective phases A, B, C, (+R, 0, -R) and (-R, 0, +R), where 0 represents that the residual flux is near zero in one phase, and R represents the absolute value of residual flux in the other two phases. In certain aspects, the absolute values of the residual flux in the phase with a negative flux may be slightly different from that of the phase with a positive flux.

FIG 2 illustrates an example of a schematic representation of a residual flux of a three-phase transformer having primary deالة windings and secondary grounded y windings after the transformer is disconnected from the power supply, wherein each phase of the transformer is de-energized at a natural current zero point. In the shown example of Fig 2, the dashed Line 45 indicates the moment the poles of the circuit breaker 20 of FIG 1 are opened and the transformer 15 of FIG 1 is disconnected from the supply. The circuit breaker 20 opens its poles randomly, and in the present example it can be seen that the poles are opened at a phase angle of 0 degree of VAB, wherein VAB is the line voltage between phase A and phase B of the transformer 15. Similarly, VCA is the line voltage between phase C and phase A of the transformer 15 and VBC is the line voltage between phase B and phase C of the transformer 15. Each phase A, B, C of the three phase transformer 15 is de-energized at a natural current zero point of the line current IA, IB, IC, of the respective phases A, B, C, wherein IA is the line current of phase A, IB is the line current of phase B and IC is the line current of phase C.

In the shown example of FIG 2, the dashed line 50 indicates de-energizing moment of phase B. It can be seen that phase B is de-energized 30 degrees later than the dashed line 45, at
the natural current zero point of IB. Phase C and phase A are
de-energized 150 degrees later than the dashed line 45,
designated as the dashed line 55, at the natural current zero
to at the moment 50, phase A and phase C are de-
energized subsequently and simultaneously when the current IA

Still referring to FIG 2, it can be seen that the fluxes \( \phi_A \),
\( \phi_B \), \( \phi_C \) of the respective phases A, B, C of the three-phase
transformer 15 are interacted and are not constant, until the
phases A, B, C are de-energized. In the shown example of FIG
2, it can be seen that the residual flux \( \phi_A = 0.1376 pu, \phi_B =
-0.8822 pu, \phi_C = 0.7446 pu \) of the phases A, B, C respectively,
designated by the rectangle 57, follow the residual flux
pattern \( 0, -R, +R \).  

Referring now to FIG 1, the controller 35 may be configured
to determine the residual flux pattern of the three phase
transformer 15 when the circuit breaker 20 opens the poles.
In an aspect, the residual flux pattern may be determined
using the de-energizing sequences of the phases and the phase
angle of the voltage or the current when the circuit breaker
20 opens the poles. The controller 35 may be configured to
measure the de-energizing sequences and the phase angle of
the voltage or the current at which the circuit breaker 20
opens the poles using the measured voltage or current data.

The de-energizing sequence is the power-off sequence of the
phases of the transformer 15, i.e., the order that which
phase is de-energized first, which phase follows and which
phase is de-energized last. The de-energizing sequence can be
detected by monitoring a property of at least two phases of
the transformer 15 during the de-energizing period. For
example, de-energizing sequences of two phases may be
measured using voltage or current data of two phases and the
de-energizing sequence of the third phase may be derived
using the de-energizing sequences of the measured two phases,
Referring now to FIG 2, the de-energizing sequence is the
order that phase B is de-energized first when the current IB
becomes zero at the moment 50, phase A and phase C are de-
energized subsequently and simultaneously when the current IA
and IC become zero at the moment 55. In another aspect, the residual flux pattern may be determined using the de-
energizing sequences of the phases and a pattern of the current when the circuit breaker 20 opens the poles. The
pattern of the current includes detecting whether the current is rising, i.e., becoming zero from a negative value or
descending, i.e., becoming zero from a positive value, from the moment the transformer is disconnected from the power
supply to the de-energizing moment. In yet another aspect, the residual flux pattern may be determined using values of
residual flux at each phase of the transformer 15. The value of residual flux at each phase may be derived as an integral
of the phase voltage acting on the phase core prior to the transformer 15 being de-energized. For measuring the voltage
acting on the phase core of the transformer 15, the current sensors 30 of the monitoring unit 22 may be substituted with
voltage sensors. Advantageously, the determined flux pattern may be stored at the memory 40, so that the same may be
retrieved by the controller 35 later.

Referring still to FIG 1, once the residual flux pattern has been determined, the controller 35 may be configured to
compute an equivalent opening moment of the circuit breaker 20 using the residual flux pattern determined. In an aspect,
the equivalent opening moment may be derived using the relation between the residual flux pattern and the property
of the phase 10. The property of the phase may be the voltage or the current. Typically, at the equivalent opening moment,
all the phases of the transformer 15 are de-energized simultaneously and the residual flux pattern is identical to
the determined residual flux pattern.

FIG 3 illustrates an equivalent opening moment at which all the phases of a three phase transformer, having primary delta
windings and secondary grounded y windings, are de-energized simultaneously according to an embodiment herein. In the
shown example of FIG 3, the equivalent opening moment is illustrated using a dashed line 60. The circuit breaker 20 of
FIG 1 opens its poles at the equivalent opening moment 60 and all phases of the transformer 15 are de-energized almost at the same time, designated by the de-energizing moment 61. In the shown example of FIG 3, the circuit breaker 20 opens its poles at a phase angle 90 degrees of VAB. In the illustrated example of FIG 2, the residual flux (\(\varphi_A = -0.0874\text{pu}, \varphi_B = -0.6543\text{pu}, \varphi_C = 0.7417\text{pu}\)) of the phases A, B, C respectively are substantially identical to the residual flux pattern 57 of FIG 2.

Referring now to Fig 1, after the computation of the equivalent opening moment, the controller 35 may be configured to derive a closing moment, which is a number of cycles later after the equivalent opening moment when the phase angle of the power supply equals the phase angle of the equivalent opening moment. Typically, at the closing moment, the prospective flux of each phase is substantially equal to the respective residual flux. Re-energizing the transformer 15 exactly at the closing moment, may enable is eliminating flux asymmetry and inrush current. However, re-energizing the transformer 15 exactly at the closing moment may be difficult due to the closing time deviation of the circuit breaker 20. Advantageously, the transformer 15 may be re-energized at the moment which leads or lags the phase angle at the derived closing moment by some degrees. After deriving the closing moment, the controller 35 may be configured to derive a closing time window encompassing the closing moment within which substantial flux asymmetry may not be caused due to the time deviation from the derived closing moment and the magnitude of inrush current can be limited to a specific tolerance range of the magnitude. Advantageously, the closing time window may be derived using the equivalent opening moment. Simulations and experiments have shown that the closing time window may range about 120 degrees, i.e., from a moment which leads the phase angle of the equivalent opening moment by about 60 degrees to a moment which lags behind the phase angle of the equivalent opening moment by about 60 degrees. Advantageously, the phases of the transformer may be
closed simultaneously within the closing time window for suppressing the inrush current.

FIG 4 illustrates an example of an inrush current of a three-phase transformer with primary delta windings and secondary grounded y windings with a residual flux pattern \((0, -R, +R)\), when it is closed within a closing time window based on the basis of the equivalent opening moment shown in FIG 3. In the shown example of FIG 4, the circuit breaker 20 of FIG 1 closes its poles simultaneously within the closing time window, at a moment, designated as the dashed line 62. Typically, the closing moment may be at center point of the closing time window. As the closing time window encompasses the closing moment, the transformer 15 of FIG 1 may be advantageous connected to the power supply around the closing moment. In the shown example of FIG 4, it can be seen that the transformer 15 is connected to the power supply at a phase angle 90 degrees of VAB. The phase angle 90 degrees of VAB is the phase angle of VAB at which the equivalent opening moment, illustrated in FIG 3, occurs. The prospective flux of each phase is substantially equal to the respective residual flux at the moment 62. As the respective prospective fluxes of the phases are substantially equal to the respective residual flux of the phases at the moment 62, flux asymmetry and saturation of flux at the transformer may be avoided. Thus, the inrush energizing inrush current may be effectively suppressed when the poles of the circuit breaker 20 are closed at any appropriate moment within the closing time window, as illustrated in FIG 4.

FIG 5 illustrates an example of a schematic representation of an energizing inrush current of a three-phase transformer with primary delta windings and secondary grounded windings, when the transformer is connected to the power supply using a circuit breaker at any moment within a closing time window 64. In the shown example of FIG 5, it can be seen that the energizing inrush current is effectively suppressed within the closing time window 64. For example, if the transformer
of FIG 1 is disconnected from the power supply by opening the poles of the circuit breaker 20 of FIG 1 at a phase angle 0 degree of VAB, the equivalent opening moment is at a phase angle 90 degrees of VAB, and the closing moment will be at 90 degree of VAB a number of cycles later after the transformer is disconnected from the power supply. In an aspect, the closing time window 64 is derived in reference to VAB may range from about 30 degrees to about 150 degrees, i.e., around the closing moment. Accordingly, if the range is between 30 degrees to 150 degrees, the inrush current may be limited to under 0.5pu when the transformer 15 of FIG 1 is connected to the power supply by the circuit breaker 20 at a phase angle within the range of 30 to 150 degrees of VAB of the closing moment, as illustrated in FIG 5. In another aspect, the range of the closing time window may be a range larger than the range 30 degrees to 150 degrees or smaller than the range 30 degrees to 150 degrees.

Referring now to FIG 1, in an aspect, when the transformer 1b is required to be connected to the power supply, the controller 35 sends a control signal to the circuit breaker 20 at an appropriate time, which is determined by the closing time window 64 of FIG 5 and the phase angle of the power supply. The circuit breaker 20 closes all the phases of the three-phase transformer 15 simultaneously within the closing time window 64. In an aspect, the closing time window 64 of FIG 5 may be derived by taking into consideration pre-arcing phenomena and closing time deviation of the circuit breaker 20.

As the energizing inrush current may be effectively suppressed at any a closing time window, the circuit breaker 20 adapted to open and close the transformer 15 has no stringent requirement of closing time deviation. The poles of the circuit breaker 20 may be at any moment within the closing time window 64 of FIG 5. As the poles of the circuit breaker 20 may be opened and closed simultaneously, the embodiments described herein may be adapted to dependent-pole
circuit breakers for connecting and disconnecting the transformer from the power supply. The embodiments described herein may also be adapted to independent pole circuit breakers. However, the poles of the independent pole circuit breakers will have to be opened or closed simultaneously.

FIG 6, with reference to FIG 1 through FIG 5, is a flow diagram illustrating a method of suppressing an inrush current of a three-phase transformer according to an embodiment herein. The transformer 15 is connected to a three-phase power supply via a three-phase circuit breaker 20, the transformer 15 being connected and disconnected from the power supply by closing and opening the circuit breaker 20. At block 70, current or voltage of at least two phases of the transformer 15 are monitored. Next, at block 72, a residual flux pattern is determined after the circuit breaker is opened. Moving next to block 76, an equivalent opening moment of the circuit breaker is computed, wherein at the equivalent opening moment of the circuit breaker, the phases of the transformer are de-energized simultaneously. Next, at block 78, a closing time window is derived for closing the circuit breaker on the basis of the equivalent opening moment. At block 80, the poles of the circuit breaker are closed simultaneously within the closing time window.

The embodiments described herein enable suppressing inrush current of a three-phase transformer. As the embodiments may be adapted to dependent pole circuit breakers, inrush current in transformers implemented in medium and low voltage power systems may be suppressed. Additionally, as the inrush current is suppressed within a closing time window, the circuit breaker adapted to connect and disconnect the transformer from the power supply has no stringent requirement of closing time deviation. Moreover, as the circuit breaker has no stringent requirement of closing time deviation, the same is manufacturer independent.
While this invention has been described in detail with reference to certain preferred embodiments, it should be appreciated that the present invention is not limited to those precise embodiments. Rather, in view of the present disclosure which describes the current best mode for practicing the invention, many modifications and variations would present themselves, to those of skill in the art without departing from the scope and spirit of this invention. The scope of the invention is, therefore, indicated by the following claims rather than by the foregoing description. All changes, modifications, and variations coming within the meaning and range of equivalency of the claims are to be considered within their scope.
Patent Claims:

1. A method of suppressing an inrush current of a three-phase transformer (15) connected to a three-phase power supply via a triple-pole circuit breaker (20), the transformer (15) being connected and disconnected from the power supply by closing and opening the circuit breaker (20), the method comprising:
   - monitoring a property of at least two phases of the transformer (15),
   - determining a residual flux pattern after the circuit-breaker (20) is opened,
   - computing an equivalent opening moment (60) of the circuit breaker (20) using the property monitored, wherein at the equivalent opening moment (60) of the circuit breaker (20), the phases of the transformer (15) are de-energized simultaneously,
   - deriving a closing time window (64) for closing the circuit breaker (20) on the basis of the equivalent opening moment (60), the closing time window being derived encompasses a closing moment which is after the equivalent opening moment (60) at the phase angle of the power supply being equal to the phase angle of the equivalent opening moment (60), and
   - closing the poles of the circuit breaker (20) simultaneously within the closing time window (64).

2. The method according to claim 1, wherein the property includes at least one from the group consisting of a voltage and a current.

3. The method according to claim 1 or 2, wherein the equivalent opening moment (60) is derived using the residual flux pattern.

4. The method according to claims 2 or 3, wherein the determination of the residual flux pattern comprises detecting a de-energizing sequence of the phases of the transformer (15).
5. The method according to claim 4, wherein the residual flux pattern is determined using the de-energizing sequence of the phases and a phase angle of the property of the phase at which the poles of the circuit breaker (20) are opened.

6. The method according to claim 4, wherein the residual flux pattern is determined using the de-energizing sequence of the phases and a pattern of the current in each phase at the de-energizing moment.

7. The method according anyone of the claims 1 to 3, wherein the residual flux pattern is determined using a value of a residual flux of each phase.

8. An apparatus (10) for suppressing an inrush current of a three-phase transformer (15) connected to a three-phase power supply via a three-pole circuit breaker (20), the transformer (15) being connected and disconnected from the power supply by closing and opening the circuit breaker (20), the apparatus comprising:

- a monitoring unit (22) for monitoring a property of at least two phases of the transformer (15),
- a controller (35) configured to:
  - determine a residual flux pattern after the circuit breaker (20) is opened,
  - compute an equivalent opening moment (60) of the circuit breaker (20) using the property monitored, wherein at the equivalent opening moment (60) of the circuit breaker (20), the phases of the transformer are de-energized simultaneously,
  - derive a closing time window (64) for closing the circuit-breaker (20) on the basis of the equivalent opening moment (60), the closing time window being derived encompasses a closing moment which is after the equivalent opening moment (60) at the phase angle of the power supply being equal to the phase angle of the equivalent opening moment (60), and
- provide a control signal to close the poles of the circuit breaker (20) simultaneously within the closing time window (64).

9. The apparatus according to claim 8, wherein the property includes at least one from the group consisting of a voltage and a current.

10. The apparatus according to claims 8 or 9, wherein the monitoring unit comprises at least two sensors selected from the group consisting of voltage sensors (25) and current sensors (30).

11. The apparatus according to anyone of the claims 8 to 10, wherein the controller (35) is configured to derive the equivalent opening moment (60) using the residual flux pattern.

12. The apparatus according to anyone of the claims 9 to 11, wherein the controller (35) is configured to detect a de-energizing sequence of the phases of the transformer (15).

13. The apparatus according to claim 12, wherein the controller (35) is configured to determine the residual flux pattern using the de-energizing sequence of the phases and a phase angle of the property of the phase at which the poles of the circuit breaker (20) are opened.

14. The apparatus according to claim 12, wherein the residual flux pattern is determined using the de-energizing sequence of the phases and a pattern of the current in each phase at the de-energizing moment.

15. The apparatus according to anyone of the claims 8 to 11, wherein the controller (35) is configured to determine the residual flux pattern using a value of a residual flux of each phase.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

H02H9/02(2006.01)ji
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC:H02H9/-; H02H7/-;H01H33/

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI; EPDOC; CPAT; CNKI; INRUSH+ W CURRENT, TRANSFORMER?; BREAKER?, VOLTAGE; SIMULATAN+ TRANSUDER? OR SENSOR?; RESIDUAL W FLUX, ENERG+, DEENERG+, CONTROL+ OR PROCESS+, THREE W PHASE, OPEN+; CLOS+, TIME W WINDOW

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tbody>
<tr>
<td>Y</td>
<td>CN101563744A(KABUSHIKI KAISHA TOSHIBA)21 Oct.2009(21.10.2009), page 9 line 25-page 1 line 1, figs.2-1</td>
<td>1-15</td>
</tr>
<tr>
<td>A</td>
<td>CN101647169A(MITSUBISHI ELECTRIC CORPORATION)10 Feb.2010(10.02.2010), the whole document</td>
<td>1-15</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:
  "A" document defining the general state of the art which is not to be considered of particular relevance
  "E" earlier application or patent but published on or after the international filing date
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  "&" document member of the same patent family

Date of the actual completion of the international search 27 Nov. 2010(27.11.2010)

Date of mailing of the international search report 30 Dec. 2010 (30.12.2010)

Name and mailing address of the ISA/CN
The State Intellectual Property Office, the P.R.China
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Facsimile No. 86-10-62019451

Form PCT/ISA /210 (second sheet) (July 2009)

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<table>
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<tr>
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