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(54) Title: A THREE-PHASE ON-LOAD TAP CHANGER

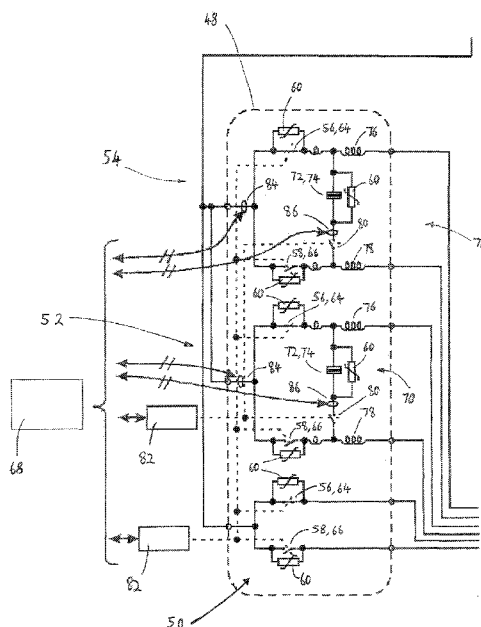


Figure 2(b)

(57) Abstract: A three-phase on-load tap changer (40) comprises a selector (42) which has first, second, and third pairs of contact sets. Each pair of contact sets corresponds to a respective phase. One contact set within a given pair is to carry a load current portion while the other contact set selects the next tap. The three-phase tap changer (40) also includes a diverter (48) which has first, second and third pairs of switches (50, 52, 54). Each switch pair (50, 52, 54) corresponds to a respective phase and is operable to switch a corresponding portion of the load current between the contact sets of the corresponding first, second, and third pairs of contact sets. Each of the second and third switch pairs (52, 54) includes a commutation circuit (70) electrically connected therewith to commutate respective arcs across the switches (56, 58) within each of the second and third switch pairs (52, 54). The diverter (48) further includes an actuator (62) that is coupled with each of the first, second and third switch pairs (50, 52, 54) to simultaneously operate each switch pair (50, 52, 54) to switch the corresponding portion of the load current between respective contact sets in each of the first, second and third pairs of contact sets.

A THREE-PHASE ON-LOAD TAP CHANGER

This invention relates to a three-phase on-load tap changer and, in particular, such a tap changer
5 for use in a primary winding of a three-phase transformer to provide a desired voltage across a secondary winding of the transformer.

The basic arrangement of a conventional tap changer 10 is illustrated schematically in Figure 1.

10 The conventional tap changer 10 includes a diverter 12 and a selector 14 arranged in electrical connection within a single-phase primary winding 16 of a transformer 18.

The selector 14 includes a pair 20 of contact sets 22, 24. In the arrangement shown a first contact set 22 carries a load current while a second contact set 24 is off-load, i.e. is not carrying a load current. As such the second contact set 24 can be moved to select the next tap 26 in the primary winding 16.

20 Once the next tap 26 has been selected the diverter 12 switches the load current from the first contact set 22 to the second contact set 24. A further tap 26 can then be selected with the first contact set 22 and the load current switched back from the second
25 contact set 24 to the first contact set 22. The foregoing steps may be repeated as required to select an appropriate tap 26 to provide a desired voltage across a secondary winding 28 of the transformer 18.

30 Such conventional tap changers 10 are essentially electromechanical arrangements which are slow in operation, taking between 3 and 5 seconds to

operate, and have a fundamental failure mode where the diverter 12 fails to break the circuit between adjacent taps which causes severe damage to the transformer 18.

It is known to include vacuum switches (not shown) in the diverter 12 to improve the reliability with which the circuit between adjacent taps is broken, and hence reduce the likelihood of the transformer being damaged. However, such vacuum switches are often required to break a high load current and so quickly wear out.

WO 2006/103268 discloses the possibility of providing a commutation circuit which utilises a tap voltage to forcibly commutate an arc across the vacuum switch that is breaking the load current. The inclusion of such a commutation circuit reduces the arcing period to around only 3ms and so the aforementioned wear of the vacuum switches is reduced.

The commutation circuit is, however, very bulky and expensive, and so its inclusion in each of three single-phase tap changers operating in a three-phase system is neither practical nor economical.

There is, therefore, a need for an improved tap changer arrangement for use in a three-phase system which continues to produce low wear on the switch elements without a total reliance on commutation circuits to maintain the said low wear.

According to an aspect of the invention there is provided a three-phase on-load tap changer, for use in a primary winding of a three-phase transformer to provide a desired voltage across a

secondary winding of the transformer, the three-phase tap changer comprising:

a selector having first, second, and third pairs of contact sets, each pair of contact sets corresponding to a respective phase of the transformer, one contact set within a given pair being to carry a load current portion while the other contact set selects the next tap; and

a diverter including first, second and third pairs of switches, each switch pair corresponding to a respective phase and being operable to switch a corresponding portion of the load current between the contact sets of the corresponding first, second, and third pairs of contact sets, and each of the second and third switch pairs including a commutation circuit electrically connected therewith to commute respective arcs across the switches within each of the second and third switch pairs, the diverter further including an actuator coupled with each of the first, second and third switch pairs to simultaneously operate each switch pair to switch the corresponding portion of the load current between respective contact sets in each of the first, second and third pairs of contact sets.

The provision of a diverter including first, second, and third pairs of switches, together with an actuator coupled with each of the switch pairs to simultaneously operate each switch pair results in a relatively compact three-phase tap changer which is able to control the arcing between respective switches in each of the various switch pairs without total

reliance on commutation circuits, commutation circuits being required only in each of the second and third switch pairs to help to maintain low wear of the switches in each of the second and third switch pairs
5 without unnecessarily increasing the bulk and cost of the three-phase tap changer..

Preferably each commutation circuit includes an energy store and a secondary switch to disconnect the energy store from the corresponding
10 commutation circuit.

The inclusion of a secondary switch in such an arrangement helps to reduce the likelihood of subsequent, secondary arcing occurring between one or other of the switches in each of the second and third
15 switch pairs as the selector operates.

Preferably the actuator is moveable between first and second positions to define a simultaneous switching operation for each of the first, second and third switch pairs, each of the corresponding first,
20 second and third switching operations including breaking the switch within each switch pair carrying the corresponding load current portion before making the other switch within each switch pair.

Such an arrangement allows the conducting
25 switch in each pair, i.e. the switch that is initially carrying the load current portion, to briefly maintain conduction by arcing while the other switch in each pair closes, which together leads to a natural transfer of current between the switches.

30 A preferred embodiment of the three-phase on-load tap changer includes a control module to

control the actuator and thereby control the switching operation of each switch pair, the control module being configured to complete the first switching operation of the first switch pair when the tap voltage of the first phase is zero.

The inclusion of such a control module means that an arc across each of the switches in the first switch pair is naturally extinguished on completion of the switching operation when the tap voltage of the first phase reverses, thereby obviating the need for any secondary extinguishing apparatus, i.e. any commutation circuit, for the first switch pair.

The control module may be further configured to complete the second and third switching operations when each of the commutation circuits has sufficient energy to oppose the corresponding load current portion flowing through a respective one of the switches in each of the second and third switch pairs.

The inclusion of such a control module helps to ensure that the arc across the switches in each of the second and third switch pairs is suitably extinguished by the corresponding commutation circuit.

Optionally the control module is still further configured to complete the switching operation of each switch pair before the corresponding load current portion is zero.

Providing a control module which ensures that the switching operation of each switch pair is completed before the corresponding load current portion is zero helps to avoid the generation of a very high

voltage across respective switches in each of the various switch pairs.

In another preferred embodiment of the invention the control module is configured to make the other switch in the first switch pair a predetermined period of time before completing the first switching operation.

Including such a control module helps to reduce the surge in load current which generates an arc during the first switching operation, and so allows the use of less expensive switches which have lower performance characteristics.

Preferably the predetermined period is selected to ensure the second and third load current portions are driven through zero before the tap voltage of the corresponding second or third phase reaches zero.

The predetermined period may be approximately 0.3ms or more.

Such features help to ensure desirable functioning of the switches.

According to another aspect of the invention there is provided a three-phase transformer comprising a three-phase on-load tap changer according to any preceding claim.

The three-phase transformer of the invention shares the advantages associated with the corresponding features of the three-phase on-load tap changer.

There now follows a brief description of a preferred embodiment of the invention, by way of non-

limiting example, with reference to the accompanying drawings in which:

Figure 1 shows a schematic view of a conventional tap changer;

5 Figure 2(a) shows a schematic view of a three-phase tap changer according to a first embodiment of the invention;

Figure 2(b) shows an enlarged portion of the tap changer shown in Figure 2(a);

10 Figure 3 illustrates schematically the switching operation of a switch pair within the tap changer shown in Figure 2(a);

Figure 4 shows a Lissajous Diagram of load current against tap voltage during a tap down operation of the tap changer shown in Figure 2(a); and

15 Figure 5 shows four Lissajous Diagrams each of which illustrates one of the four possible tap change operations of the tap changer shown in Figure 2(a).

A three-phase on-load tap changer according to a first embodiment of the invention is designated generally by the reference numeral 40.

The tap changer 40 includes a selector 42 which has first, second and third pairs of contact sets (not shown). The selector 42 is connectable, in use, within the primary winding 44 of a three-phase transformer 46 such that each pair of contact sets is associated with a corresponding first-, second-, or third-phase primary winding 44(i), 44(ii), 44(iii) of the transformer 46.

30 One contact set within each pair of contact sets is to carry a load current portion (corresponding

to an associated first, second or third phase of the transformer 46) while the other contact set selects the next tap in the corresponding primary winding 44(i), 44(ii), 44(iii).

5 The tap changer 40 also includes a diverter 48 that has first, second and third pairs of switches 50, 52, 54. The first switch pair 50 is associated with the first phase of the transformer 46, the second switch pair 52 is associated with the second phase of
10 the transformer 46, and the third switch pair 54 is associated with the third phase of the transformer 46.

 In the embodiments shown each switch 56, 58 in each switch pair 50, 52, 54 is a vacuum switch, although in other embodiments of the invention other
15 switches may be used. Each switch 56, 58 includes a metal oxide varistor (MOV) 60 connected in parallel therewith to provide a degree of voltage protection to the switch 56, 58.

 Each switch pair 50, 52, 54 is operable to
20 switch a corresponding load current portion between the contact sets of the corresponding first, second and third pair of contact sets.

 The diverter 48 also includes a first actuator 62 which is mechanically coupled with each
25 switch 56, 58 in each switch pair 50, 52, 54.

 The first actuator 62 is moveable between first and second positions to define a switching operation for each of the first, second and third switch pairs 50, 52, 54, as illustrated schematically
30 in Figure 3.

Each of the first, second and third switching operations includes breaking the conducting switch 64 within each switch pair 50, 52, 54, i.e. the switch 56, 58 within each switch pair 50, 52, 54 that
5 is carrying the corresponding load current portion, before making the other, non-conducting, switch 66 in the switch pair 50, 52, 54.

Each of the second and third pairs of switches 52, 54 includes a commutation circuit 70 that
10 is electrically connected in parallel therewith to commutate respective arcs across each of the switches 56, 58 in the second and third switching pairs 52, 54 during their respective switching operations.

Each commutation circuit 70 is essentially
15 identical and includes an energy store 72, in the form of a capacitor 74, and first and second inductors 76, 78, each of which is connected adjacent to the corresponding first switch 56 or second switch 58. In the embodiment shown the capacitor 74 additionally
20 includes a further MOV 60 connected in parallel therewith to provide a degree of voltage protection, i.e. voltage limiting, to the capacitor 74. The further MOV 60 also helps to provide a degree of damping to the operation of the commutation circuit 70.

25 A secondary switch 80 is connected in series with the capacitor 74 of each commutation circuit 70, and each of the secondary switches 80 is, in turn, mechanically coupled to a second actuator 82. The second actuator 82 is operable to cause each
30 secondary switch 80 to open and thereby disconnect the

capacitor 74 from the corresponding commutation circuit 70.

The ability to selectively disconnect each capacitor 74 reduces the likelihood of subsequent arcing taking place across the other, non-conducting switches 66 of the second and third switch pairs 52, 54 while the selector 42 operates.

The tap changer 40 of the invention also includes a control module 68 to control operation of the first actuator 62, and hence control the switching operation of each switch pair 50, 52, 54. In particular, the control module 68 is configured to complete the first switching operation of the first switch pair 50 when the tap voltage of the first phase winding 44(i) is zero.

The control module 68 is further configured to complete the second and third switching operations when the commutation circuit 70 of each of the second and third switch pairs 52, 54 has sufficient energy to oppose the corresponding current portion flowing through the switches 56, 58 in each of the second and third switch pairs 52, 54.

The control module 68 is also configured to complete the switching operation of each switch pair 50, 52, 54 before the corresponding load current portion is zero.

In addition the control module 68 is configured to make the other switch 66 in the first switch pair 50 a predetermined period of time before completing the first switching operation. The predetermined period is selected to ensure that the

second and third load current portions are driven through zero before the tap voltage of the corresponding second or third phase winding 44(ii), 44(iii) reaches zero.

5 Preferably the predetermined period is selected to ensure that the peak of any surge in load current across either of the switches 56, 58 in the first switch pair 50 does not exceed twice the load current rating of each respective switch 56, 58.

10 In practice the predetermined period is 0.3ms or more, and in the embodiment shown is approximately 0.6ms.

 In addition to the features mentioned above each of the second and third switch pairs additionally
15 includes a first current sensor 84 which monitors the load current portion flowing through one or other of the switches 56, 58 in the respective switch pair 52, 54, and a second current sensor 86 which monitors the current flowing through the corresponding capacitor 74.

20 An integration of the commutation capacitor current during normal power frequency operation, as monitored by the second current sensor 86, is used to provide the timing for switching of the switch pairs 50, 52, 54 within the diverter 48 by the first actuator
25 62.

 In a preferred embodiment of the invention each current sensor is a current transformer which is sufficiently well insulated from the remainder of each commutation circuit 70. One benefit of including
30 current transformers is that their output can be processed to provide logic level signals, and so low

power electronics can be powered directly from a current transformer output to relay the logical information to the control module 68 via, e.g. fibre optics.

5 The respective first current sensors 84 can be used to detect a respective load current portion for each of the second and third phase windings 44(ii), 44(iii), and so allow the detection of a load current portion that might be in excess of that which can be
10 commutated by the corresponding commutation circuit 70.

In the embodiment shown the control module 68 includes a number of redundant control channels to help ensure a desirable level of operational reliability for the tap changer 40 as a whole.

15 In use functioning of the tap changer 40 is best described with reference to Figure 4, and the Lissajous diagram for a tap down (positive load current flow) operation illustrated therein.

In particular the Lissajous diagram in
20 Figure 4 illustrates the locus of load current flowing through the transformer 46 against the tap voltage of the transformer 46, rotating in an anti-clockwise direction, for a tap down operation with a transformer load which has a power factor of 0.8.

25 In this embodiment the tap voltage is only slightly larger than the arcing voltage, which is approximately 60V, of the switches 56, 58 in each switch pair 50, 52, 54.

The charge present in the capacitor 74 in
30 each commutation circuit 70 is determined by subtracting the arc voltage, i.e. 60V, from the tap

voltage. In order to provide forced commutation the stored capacitive energy charge must be high enough to translate into sufficient inductive energy to oppose the load current portion flowing through the respective commutation circuit 70. The required inductive energy reduces with reduced load current, and so the portion of the Lissajous diagram during which insufficient energy is available (and so forced commutation cannot occur) is illustrated by a V-shaped low energy region 88 around the arc voltage of 60V.

First, second and third dashed lines 90, 92, 94 respectively illustrate simultaneous operation of the first, second and third switch pairs 50, 52, 54 in the tap changer 40. Such simultaneous operation is affected by movement of the first actuator 62 between the first and second positions mentioned above.

Travelling in the direction of the locus, i.e. in an anti-clockwise direction in this embodiment, the first point on each dashed line 90, 92, 94 is the start of a respective first, second or third switching operation and the last point is the end of the respective switching operation.

The first switching operation 90 of the first switch pair 50 completes when the tap voltage of the first phase, i.e. of the first phase winding 44(i), is zero.

The three phases of the three-phase transformer 46 are equally balanced, i.e. separated by 120° from one another, and so the relative timing of each of the second and third switching operations, i.e. the position of the second and third dashed lines 92,

94 on the locus of the Lissajous diagram, follows directly from the timing of the first switching operation, i.e. the position of the first dashed line 90 terminating at a zero tap voltage.

5 Neither of the second or third switching operations, i.e. the second and third dashed lines 92, 94 terminates within a low energy region 88, and so the associated commutation circuit has sufficient energy to achieve forced commutation of the arc formed across
10 each of the switches 56, 58 in those switch pairs 52, 54.

 Moreover, none of the switching operations, i.e. none of the dashed lines 90, 92, 94, terminates on or close to zero load current, and so the generation of
15 a very high voltage across the respective switches 56, 58 in each of the various switch pairs 50, 52, 54 is avoided.

 During the first switching operation the conducting switch 64 is opened and arcing begins
20 between the contacts of that switch 64, as illustrated schematically in Figure 3. Shortly thereafter, and typically only a few milliseconds later, the other non-conducting switch 66 is moved towards a closed position resulting in an increase in load current across the
25 now-arcing other switch 66. However this load current reverses when the tap voltage passes through zero and so the arc across each switch 64, 66 is extinguished through natural commutation.

 Closing the other switch 66 approximately
30 0.6ms before the tap voltage reaches zero helps to ensure that the increase in load current does not

exceed twice the current rating of each switch 56, 58 in the first switch pair 50..

During the switching operation of the second and third switch pairs 52, 54 each conducting switch 64 is opened and arcing begins between the contacts of that switch 64, as illustrated in Figure 3. A short time thereafter, typically a matter of a few milliseconds later, the other non-conducting switch 66 closes and forced commutation takes place.

Having each other switch 66 in each of the second and third switch pairs 52, 54 close approximately 0.6ms before termination of each of the second and third switching operations, as determined by the closing of the other switch 66 in the first switching operation, additionally helps to ensure that the corresponding commutation circuit 70 has sufficient time to drive the corresponding load current portion through zero before the corresponding tap voltage, i.e. the tap voltage of the corresponding second or third phase winding (44(ii), 44(iii)), reverses.

Figure 5 illustrates respective Lissajous diagrams for each of the four possible operations of the three-phase tap changer 40, i.e.: a tap down operation with positive load current flow (Figure 5(a); a tap down operation with positive load current flow (Figure 5(b)); a tap down operation with negative current flow (Figure 5(c)); and a tap up operation with negative current flow (Figure 5(d)).

Figure 5(a) is, of course, a simplified version of Figure 4.

The direction of rotation of the locus of each diagram is marked, as is the arc voltage, i.e. approximately 60V, of the switches 56, 58.

Also marked on each diagram is the
5 initiation point for the first switching operation, i.e. when switching of the first switch pair 50 (i.e. the switch pair without an associated commutation circuit 70) starts, to ensure the switching operation terminates when the tap voltage of the first phase is
10 zero. The initiation and termination points of the second and third switching operations (not shown in Figure 5) are derived by the 120° separation from one another of the equally balanced first, second and third phases, and so it is possible to map the first, second
15 and third switching operations for each of the possible tap change operations identified above.

CLAIMS

1. A three-phase on-load tap changer (40),
for use in a primary winding of a three-phase
5 transformer to provide a desired voltage across a
secondary winding of the transformer, the three-phase
tap changer comprising:

a selector (42) having first, second, and third
pairs of contact sets, each pair of contact sets
10 corresponding to a respective phase of the transformer,
one contact set within a given pair being to carry a
load current portion while the other contact set
selects the next tap; and

a diverter (48) including first, second and third
15 pairs of switches (50, 52, 54), each switch pair (50,
52, 54) corresponding to a respective phase and being
operable to switch a corresponding portion of the load
current between the contact sets of the corresponding
first, second, and third pairs of contact sets, and
20 each of the second and third switch pairs (52, 54)
including a commutation circuit (70) electrically
connected therewith to commute respective arcs across
switches (56, 58) within each of the second and third
switch pairs (52, 54), the diverter (48) further
25 including an actuator (62) coupled with each of the
first, second and third switch pairs (50, 52, 54) to
simultaneously operate each switch pair (50, 52, 54) to
switch the corresponding portion of the load current
between respective contact sets in each of the first,
30 second and third pairs of contact sets.

2. A three-phase on-load tap changer (40) according to Claim 1 wherein each commutation circuit (70) includes an energy store (72) and a secondary switch (80) to disconnect the energy store (72) from
5 the corresponding commutation circuit (70).

3. A three-phase on-load tap changer (40) according to Claim 1 or Claim 2 wherein the actuator (62) is moveable between first and second positions to
10 define a simultaneous switching operation for each of the first, second and third switch pairs (50, 52, 54), each of the corresponding first, second and third switching operations including breaking the switch (56, 58) within each switch pair (50, 52, 54) carrying the
15 corresponding load current portion before making the other switch (56, 58) within each switch pair (50, 52, 54).

4. A three-phase on-load tap changer (40)
20 according to any preceding claim further including a control module (68) to control the actuator (62) and thereby control the switching operation of each switch pair (50, 52, 54), the control module (68) being configured to complete the first switching operation of
25 the first switch pair (50) when the tap voltage of the first phase is zero.

5. A three-phase on-load tap changer (40) according to Claim 4 wherein the control module (68) is
30 further configured to complete the second and third switching operations when each of the commutation

circuits (70) has sufficient energy to oppose the corresponding load current portion flowing through a respective one of the switches (56, 58) in each of the second and third switch pairs (52, 54).

5

6. A three-phase on-load tap changer according to Claim 4 or Claim 5 wherein the control module (68) is still further configured to complete the switching operation of each switch pair (50, 52, 54) before the corresponding load current portion is zero.

10

7. A three-phase on-load tap changer (40) according to any of Claims 4 to 6 wherein the control module (68) is configured to make the other switch (56, 58) in the first switch pair (50) a predetermined period of time before completing the first switching operation.

15

8. A three-phase on-load tap changer (40) according to Claim 7 wherein the predetermined period is selected to ensure the second and third load current portions are driven through zero before the tap voltage of the corresponding second or third phase reaches zero.

20

9. A three-phase on-load tap changer (40) according to Claim 7 or Claim 8 wherein the predetermined period is approximately 0.3ms or more.

25

10. A three-phase transformer comprising a three-phase on-load tap changer (40) according to any preceding claim.

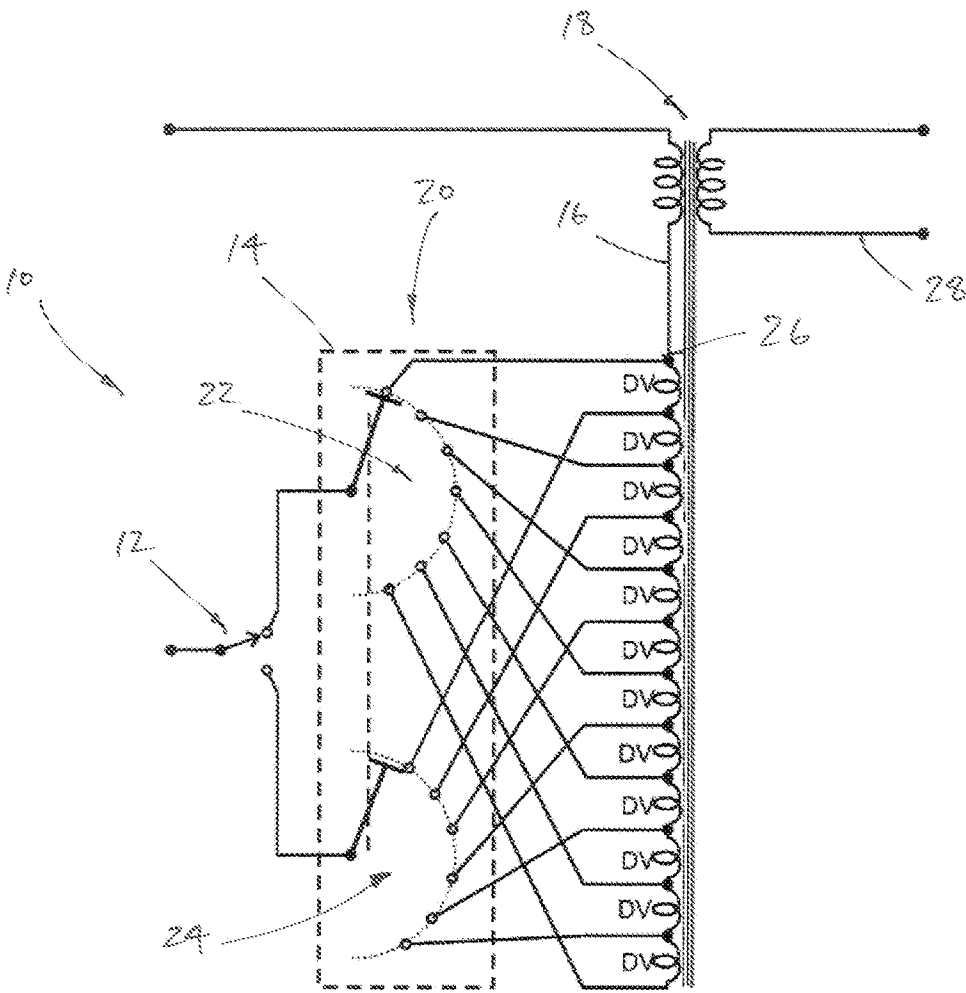


Figure 1

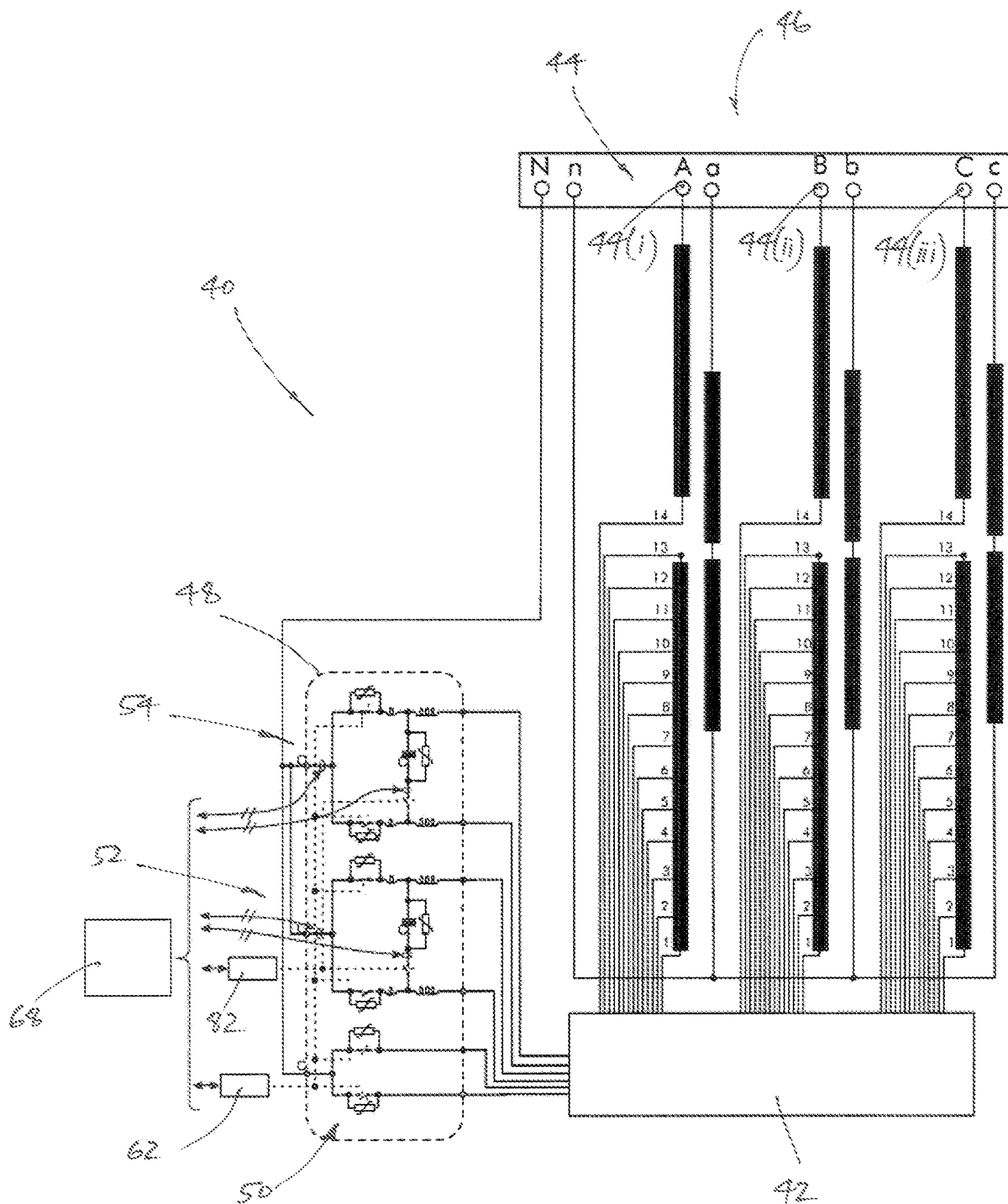
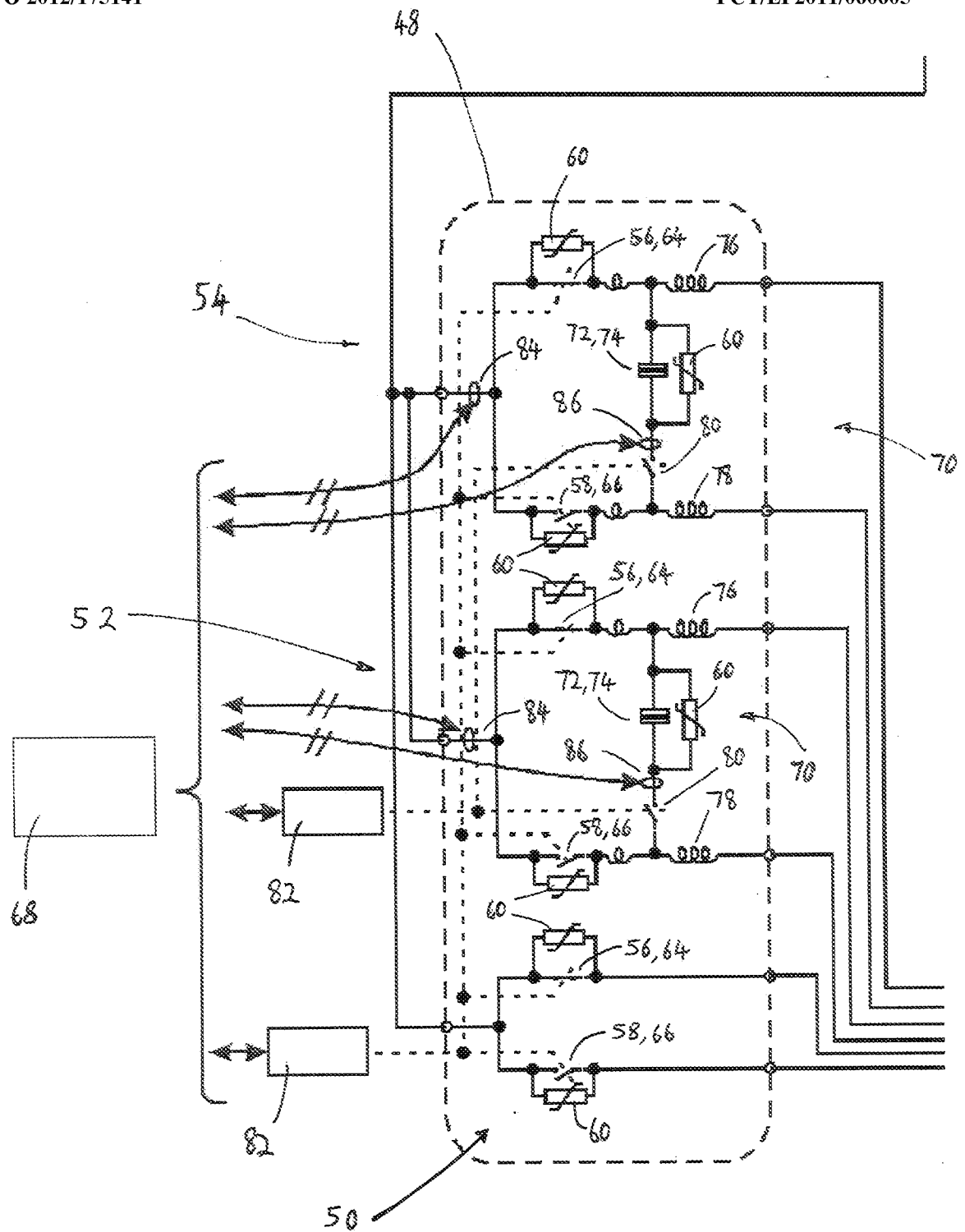
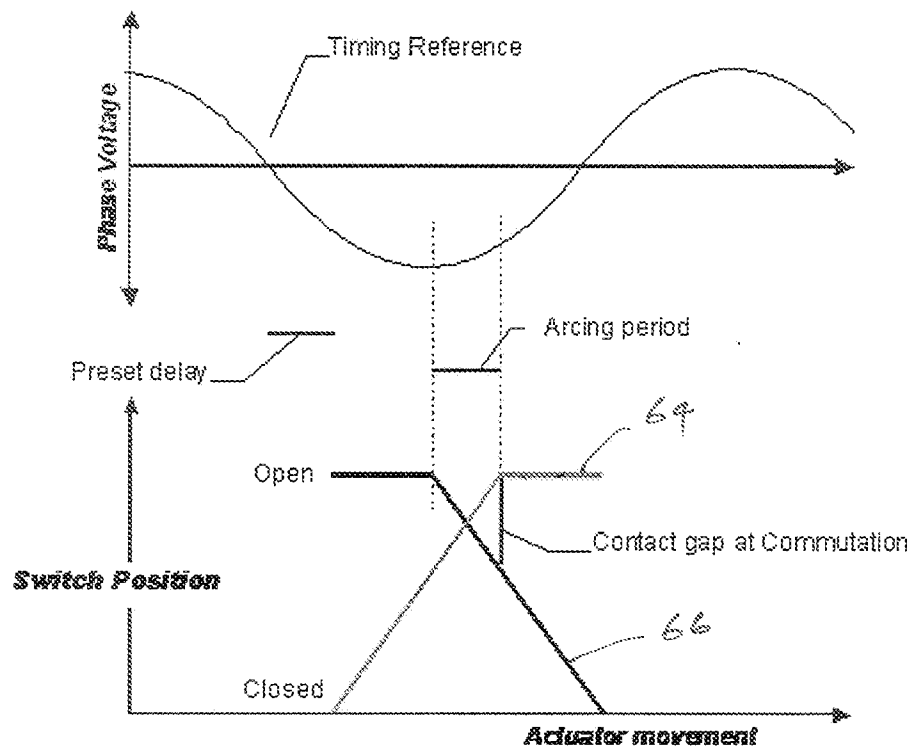


Figure 2(a)

**Figure 2(b)**

**Figure 3**

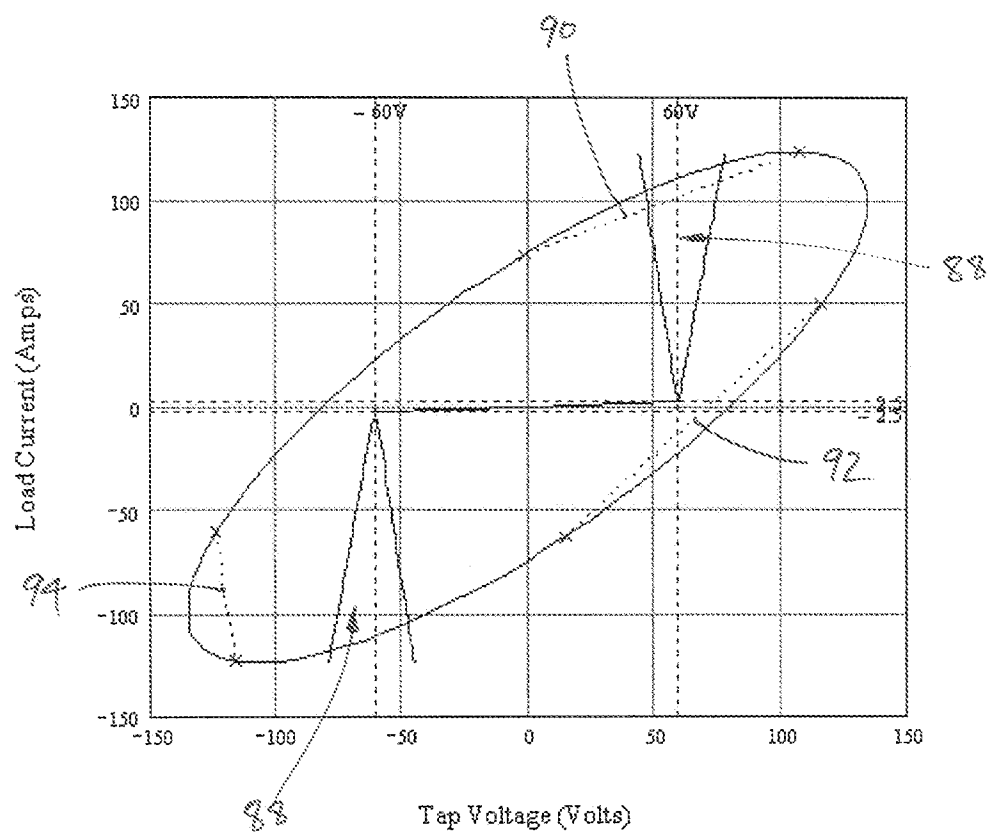
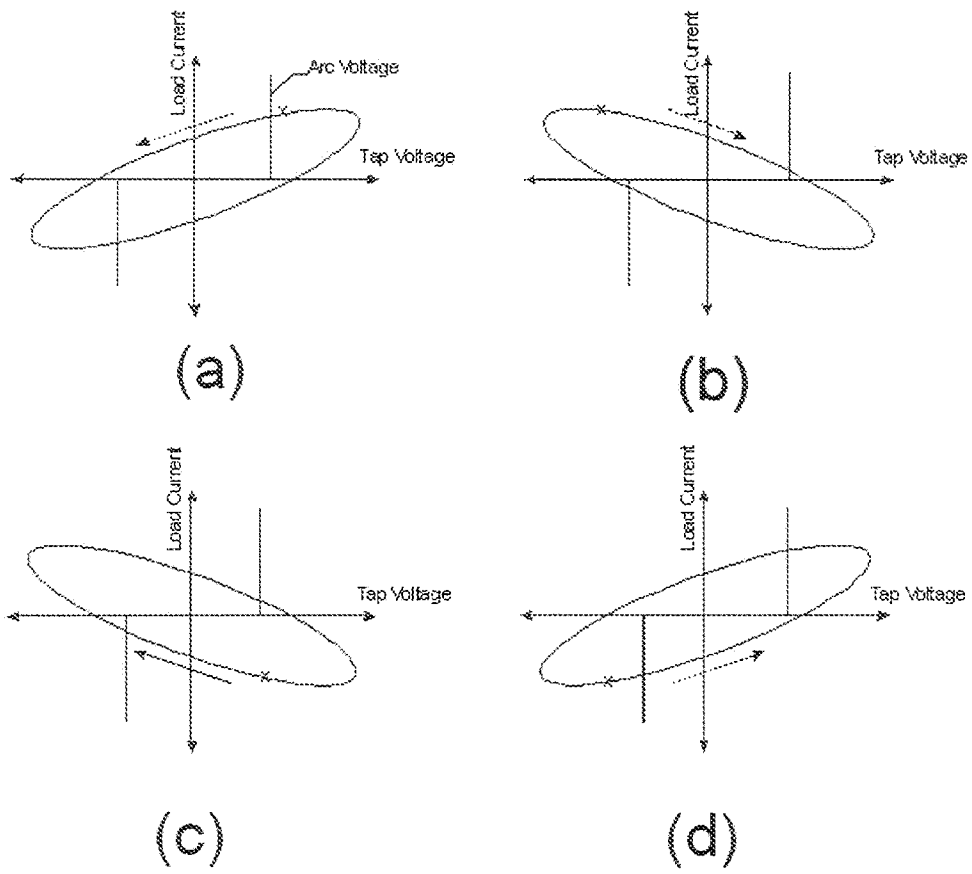


Figure 4

**Figure 5**

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/060605

A. CLASSIFICATION OF SUBJECT MATTER INV. H01F29/04 H01H9/00 H01H9/54 H01H9/30 ADD.		
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) H01F H01H G05F		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used) EPO-Internal		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2006/103268 A2 (AREVA T & D SA [FR]; OATES DONALD COLIN MURRAY [GB]) 5 October 2006 (2006-10-05) cited in the application abstract; figures 1b,5 ,6 page 18, line 10 - page 19, line 19 page 3, line 30 - page 4, line 10 -----	1,3,10
X	WO 2011/033254 A2 (IMP INNOVATIONS LTD [GB]; GREEN TIMOTHY CHARLES [GB]; ROGERS DANIEL JA) 24 March 2011 (2011-03-24) abstract page 21, line 7 - page 22, line 26; figure 3 page 31, lines 1-24; figures 5,6 -----	1,2,10
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
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Date of the actual completion of the international search 13 February 2012		Date of mailing of the international search report 05/03/2012
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Reder, Michael

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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