VOLTAGE CONTROL IN A DIRECT CURRENT POWER SYSTEM

A converter station (12) in a direct current power system (10) connected between an alternating current power line (30) and a direct current power line (14) comprises a transformer (18), a converter (20) equipped with converter valves of which at least a first set is connected to the transformer and a control unit (22) controlling the converter station for providing a DC voltage ($V_{DC1}$) at one end of the direct current power line for contributing to the forming of a voltage difference together with another DC voltage ($V_{DC2}$) generated by a further converter station (16) at an opposite end of the direct current power line for enabling a feeding of power over the direct current power line. The control unit controls the converter to provide a DC voltage through using firing angle control of the converter valves connected to the transformer.

FIG. 1
VOLTAGE CONTROL IN A DIRECT CURRENT POWER SYSTEM

FIELD OF INVENTION

The present invention generally relates to power transmission systems. More particularly, the present invention relates to a converter station in a direct current power system, a method and computer program product for controlling the DC voltage provided by such a converter station as well as such a system.

BACKGROUND

In power systems such as power transmission systems and then especially in High Voltage Direct Current (HVDC) power transmission systems, the voltages used in power transmissions are getting higher and higher. Today 800 kV is used in many situations. However, even higher levels are contemplated for the future, such as 1000 kV or even 1200 kV. A converter in a converter station here typically converts between a high AC voltage and such a high DC voltage.

The use of such high levels lead to various types of problems. One specific type of problem is the insulation. Extraordinary measures may need to be made in order to ensure insulation that can handle the required voltage levels, which makes the equipment bulkier and more expensive.

One particular piece of equipment in a converter station being influenced is the transformer. The transformer includes a primary winding and a secondary
winding, where one of these is a winding for interfacing an alternating current (AC) power line and the other is a winding for interfacing converter valves. The transformer also includes a regulating winding for controlling the voltage provided at the valve winding. The regulating winding is then connected to a tap changer for allowing this control to be performed. A converter is thus normally regulated through a no-load DC voltage being changed by the tap changer connected to the converter transformer. The regulating winding is thus used in controlling the DC voltage in the conversion between AC and DC.

All these windings have to have insulation and this will at the high voltage levels mentioned above lead to an extremely bulky transformer, which may be hard to transport. There may furthermore exist restrictions in transformer dimensions at such transportation that cannot be met.

One way to reduce the size is to remove the regulating winding. However, if this is done the above way of controlling the DC voltage cannot be used.

There is therefore a need for a different way to control the DC voltage when converting between AC and DC.

Delay angles have been previously used in the control of converters, however not for providing DC voltages on a DC power line. Some examples are given in GB 2295506, US 4648018, US 2009/0219737, US 7499291 and US 3339083.
Another example is described in "Flexible Reactive Power Control in Multigroup Current-Sourced HVDC Interconnections" by Nick J. Murray, Jos Arrillaga, Yong He Liu, and Neville R. Watson, IEEE Transactions On Power Delivery, Vol. 23, No. 4, October 2008, page 2160 - 2167. Here firing angle control of inverters and rectifiers in a DC system is used in order to maintain a specified DC power transfer when reactive power is injected into an AC system.

SUMMARY OF THE INVENTION

One object of the present invention is to provide a converter station which uses an alternative way of controlling the DC voltage of a power line.

This object is according to a first aspect of the present invention achieved through a converter station in a direct current power system connected between an alternating current power line and a direct current power line, the converter station comprising: a transformer, a converter equipped with converter valves of which at least a first set is connected to the transformer, and a control unit configured to control the converter station for providing a DC voltage at one end of the direct current power line for contributing to the forming of a voltage difference together with another DC voltage generated by a further converter station at an opposite end of the direct current power line for enabling a feeding of power over the direct current power line,
wherein the control unit is configured to control the converter to provide a DC voltage through using firing angle control of the converter valves connected to the transformer.

This object is according to a second aspect of the present invention also achieved through a method for controlling the DC voltage provided by a converter station in a direct current power system, the converter station being connected between an alternating current power line and a direct current power line and comprising:

- a transformer, and
- a converter equipped with converter valves of which at least a first set is connected to the transformer,

said method comprising the step of:

controlling the converter station to provide a DC voltage at one end of the DC power line through controlling the converter valves connected to the transformer using firing angle control in order to contribute to the forming of a voltage difference together with another DC voltage generated by a further converter station at an opposite end of the direct current power line for enabling a feeding of power over the direct current power line.

This object is furthermore achieved through a computer program product for controlling the DC voltage provided by a converter station in a direct current power system, the converter station being connected between an alternating current power line and a direct current power line and comprising a transformer and a converter equipped with converter valves of which at least a
first set is connected to the transformer, the computer program product comprising computer readable means carrying computer programs code, the program code being configured to control the converter station to provide a DC voltage at one end of the DC power line through controlling the converter valves connected to said transformer using firing angle control in order to contribute to the forming of a voltage difference together with another DC voltage generated by a further converter station at an opposite end of the direct current power line for enabling a feeding of power over the direct current power line.

This object is furthermore achieved through a direct current power system connected between a first and a second alternating current power line, the direct current power system comprising: a first converter station with a first transformer, a first control unit and a rectifier equipped with converter valves of which at least a first set is connected to the first transformer, a second converter station with a second transformer, a second control unit and an inverter equipped with converter valves of which at least a first set is connected to the second transformer, a direct current power line having a first end connected to the first converter station and a second end connected to the second converter station, wherein the first control unit is configured to control the first converter station for providing a first DC voltage at the first end of direct current power line and the second control unit is configured to control the second converter station to provide a second DC
voltage at the second end of the direct current power line for providing a voltage difference feeding power over the direct current power line, wherein the first control unit is configured to control the rectifier to provide the first DC voltage using delay angle control of the rectifier converter valves connected to the first transformer and the second converter is configured to control the inverter to provide the second DC voltage using commutation margin control of the converter valves connected to the second transformer.

The present invention has a number of advantages. It allows the transformer to be made smaller without a regulating winding, i.e. lacking a regulating winding, thereby simplifying the design and also making the transformer easier to transport.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The present invention will in the following be described with reference being made to the accompanying drawings, where

fig. 1 schematically shows a power transmission system including a first and a second converter station according to a first embodiment of the invention, fig. 2 shows a flow chart of a number of method steps according to the first embodiment of the invention being performed in the first converter station, fig. 3 shows a flow chart of a number of method steps according to the first embodiment of the invention being performed in the second converter station, and
fig. 4 schematically shows the first converter station according to a second embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

A direct current power system including converter stations according to the invention will in the following be described in relation to power transmission systems and then more particularly in relation to a High Voltage Direct Current (HVDC) power transmission system. However, it should be realized that the invention is not limited to this type of system, but can be applied in any type of DC system employing converter valves for instance in back-to-back DC systems.

In fig. 1 there is schematically shown an HVDC system for connection between two alternating current (AC) power lines 30 and 32. These power lines 30 and 32 may each be a part of an AC power transmission system. The HVDC system 10 includes a first and a second substation or converter station 12 and 16, where the first converter station 12 includes a first transformer 18 and a first converter 20 for conversion between AC and DC, which first converter 20 in this example is a rectifier. The first transformer 18 here has a primary side connected to the first AC power line 30 and a secondary side connected to an AC side of the first converter 20. The first converter 20 also has a DC side connected to a first end of the DC power line 14. There is here also a first control unit 22. This unit 22 is connected to the first AC power line 30 for obtaining a first AC measurement voltage $V_{M1}$ from the power line.
30, to the first end of the DC power line 14 in order to obtain a first DC measurement voltage as well as to the first converter 20 in order to control this converter. The DC power line 14 has a second end and this second end is connected to a second converter station 16. The second converter station 16 also converts between AC and DC and is in this example an inverter. The second end of the DC power line 14 is more particularly connected to the DC side of a second converter 26, which also has an AC side connected to a secondary side of a second transformer 24. The second transformer 24 also has a primary side, which primary side is connected to the second AC power line 32. Finally there is a load 34 connected to the second AC power line 32.

It can therefore be seen that the first converter station is connected between the first AC power line 30 and the first end of the DC power line 14, while the second converter station 16 is connected between the second AC power line 32 and the second end of the DC power line 14, which second end is also the opposite end of the DC power line 14. Also here in the second converter station 16 there is a control unit, a second control unit 28, connected to the second AC power line 32 for obtaining a second AC measurement voltage $V_{M2}$, to the second end of the DC power line 14 in order to obtain a second DC measurement voltage as well as to the second converter 26 in order to control it.

The HVDC system 10 in fig. 1 is a monopole system. The invention will in the following be described in relation to such a system. It should however be
realized that the invention may also be provided in a bipole system. The HVDC system can furthermore be more complex and include several more power lines and converter stations.

The converters 20 and 26 are with advantage line-commutated Current Source Converters (CSC), although other types may be envisaged.

Fig. 2 shows a flow chart of a number of method steps being performed by the first control unit in the first converter station according to the first embodiment of the invention, while fig. 3 shows a flow chart of a number of method steps performed by the second control unit in the second converter station according to the first embodiment of the invention.

The first embodiment of the invention will now be described in relation to the transmission of power over the DC power line 14 through the control of the first and second converter stations.

In the exemplifying first embodiment the first converter 20 is a rectifier and the second converter 26 is an inverter, i.e. the first converter 20 receives power from the first AC power line 30 and delivers this power to the second converter 26, which power is then supplied to the load 34 via the second AC power line 32. It should here be realized that the situation may be the opposite in that the second converter 26 may just as well deliver power to the first converter 20, and the first converter 20 thereby operate as an inverter and the second converter 26 act as a
rectifier. Moreover in order to deliver power the first converter 20 will provide a first DC voltage $V_{DC1}$ to the first end of the DC power line 14 and the second converter 26 will provide a second DC voltage $V_{DC2}$ to the second end of the DC power line 14. These two voltages $V_{DC1}$ and $V_{DC2}$ contribute to the forming of a voltage difference, which is thus a difference between the first DC voltage and the second DC voltage. If the first converter is acting as a rectifier, then the first DC voltage $V_{DC1}$ is higher than the second DC voltage $V_{DC2}$, thereby delivering power to second DC power line 32 and eventually to the load 34. If the second converter is acting as a rectifier, then the second DC voltage will instead be higher.

In order to provide the first DC voltage $V_{DC1}$ the first control unit 22 controls the converter valves of the first converter 20 using firing angle control. This is more particularly performed through the first control unit 22 varying the time of firing of the converter valves of the first converter 20 in order to keep the DC current of the DC power line 14 at a desired level through varying the first DC voltage, step 35. This may be done through obtaining a first DC measurement voltage at the first end of the DC power line and generating a valve control signal based on a difference between a target voltage for the first DC voltage, which is the desired voltage level, and the first measured DC voltage. Here it is possible that the control signal is generated through a proportional control branch in parallel with an integrating control branch. The control signal is then used to fire thyristors in the converter valves. The thyristors of
the rectifier are here fired with a delay in relation to a voltage zero crossing and therefore the control is a delay angle control. This may involve an increase or a decrease of the delay in order to keep the first DC voltage $V_{DC1}$ at the desired level. However the regulation can also be a regulation towards a minimum delay.

In order to handle this situation, the first control unit 22 obtains a first AC measurement voltage $V_M$ of the first AC power line 30, step 36, which measurements are obtained using conventional measurement units like voltage transformers. The first AC measurement voltage $V_M$ is then compared with a first reference voltage $V_{REFi}$, step 38. The first reference voltage is here set such that it represents the case when the first power line has an AC voltage corresponding to a minimum firing angle or a minimum delay. If the first AC measurement voltage is higher than the reference value $V_{REFi}$, step 40, then the first control unit 22 continues to control the converter valves through varying the firing angles using the original target, step 35. However, if the first AC measurement voltage $V_M$ is below the first reference voltage $V_{REFi}$, step 40, then the first control unit 22 cannot vary the firing of the converter valves because these are fired with a minimum firing angle. Instead the first control unit 22 reduces the first DC voltage $V_{DCi}$, step 42. This lowering may be made based on the relationship between the first measurement AC voltage $V_M$ and the first reference voltage $V_{REFi}$. It is here possible that the relation used is the proportion of the first AC measurement voltage to the first reference voltage $V_M/V_{REFi}$. This
therefore involves a lowering of the target voltage, based on the proportion of the first AC measurement voltage, to the first reference voltage $V_{M}/V_{REF}$. It is here possible that the second control unit 28 will take over the responsibility of the current control in order to establish a stable control point. In this case the minimum angle will continue to be used by the first control unit until the first DC measurement voltage falls below the new target. When the level of the first DC voltage has been sufficiently lowered, the first control unit 22 resumes control and continues and varies the firing of the converter valves in order to obtain the first DC voltage $V_{DCi}$, step 35. As an alternative it is possible that the first control unit 22 informs the second control unit 28 that it should lower the target voltage that it uses with the same amount as the first control unit 22 lowers its own target. In this case the first control unit 22 retains the current control and the firing angle is possible to be increased or decreased in order to decrease or increase the current. The phase angle thus still needs to have a control interval within which it is controlled despite being at the minimum firing angle. In case the minimum firing angle is 10 degrees this interval may be between 5 and 15 degrees. It should here mentioned that in case the first AC measurement value again rises above the first reference voltage, normal control may be resumed through applying the original target voltage.

The same approach is according to the first embodiment of the invention also taken in the second converter station 16. Therefore the second control unit 28
controls the second converter 26 through firing angle control and more particularly through varying the firing of the inverter converter valves for obtaining the second DC voltage $V_{DC2}$, step 44. This here normally involves an increase or decrease of the firing angle for keeping the second DC voltage $V_{DC2}$ constant. The second DC voltage $V_{DC2}$ is thus obtained using firing angle control. This may also here be done through obtaining a second DC measurement voltage from the second end of the DC power line 14, comparing it with a target voltage and providing a control signal used to fire thyristors in the converter valves based on the difference. Since the second converter 26 is an inverter, it is here also clear that the second control unit 28 performs regulation of the margin of commutation. However, a minimum margin of commutation should always be maintained.

Therefore the second control unit 26 obtains a second AC measurement voltage $V_{M2}$ from the second AC power line 32, step 46. These measurements are also here obtained using conventional measurement units. The second control unit 28 then compares the second AC measurement voltage $V_{M2}$ with a second reference voltage $V_{REF2}$, step 48, and if this measurement voltage $V_{M2}$ is higher than the second reference voltage $V_{REF2}$, step 50, then the second control unit 28 continues to control the converter valves through varying the firing angle using the original target.

However, if the measured second AC voltage $V_{M2}$ is below the second reference voltage $V_{REF2}$, step 50, then the second control unit 28 reduces the second DC voltage
V_{DC2} based on the relationship between the second AC measurement voltage V_{M2} and the second reference voltage V_{REF2}, i.e. in the same way as was described for the first control unit, step 52. After the second DC voltage has been sufficiently lowered, the second control unit 28 thereafter continues and varies the commutation margin for obtaining the second DC voltage according to the new target, step 44. If the measured AC voltage rises above the reference voltage, then the original target may again be used.

In this first embodiment of the invention all the converter valves of both the first and second converters were controlled in the above described way for providing a DC voltage using firing angle control. During ordinary firing angle control it is possible that each firing angle could be in the range of 5 - 75 degrees during the normal firing angle control.

Because the DC voltages are controlled in this way and not through the use of tap changers, the first and second transformers can be provided without regulating windings and therefore smaller and less bulky transformers can be used. This is of importance when the converter station is to be used at very high voltage levels such as 1000 or 1200 kV. The transformer can then have a simpler design and thereby be easier to produce. This also leads to a transformer that is easier to transport, which may otherwise also be difficult or sometimes even impossible.

By firing angle control it is possible to maintain the direct voltage of the line constant. However, the use
of firing angle control will cause the no load voltage to increase and thereby increase the reactive power consumption of a converter. This in turn leads to an increase in the transformer power rating. This overrating of the transformer is reduced through the above described reduction of the DC voltage.

There are a number variations that can be made of the invention. It should here first of all be realized that it is possible to omit the above mentioned lowering of the DC voltage.

This type of DC voltage lowering can be omitted in both rectifier and inverter or in only one of them. It may then be necessary to communicate the change of target voltage to the other converter in order to uphold the desired voltage difference on the DC power line.

It should also be realized that one of the converter stations, for instance the second converter station, may employ conventional control for obtaining the DC voltage, i.e. through using tap changer control of a regulating winding, while the other uses firing angle control.

It is furthermore possible to vary the inventive concept even further in that tap changer control is combined with firing angle control in order to provide a DC voltage. Such a situation will now be described with reference being made to fig. 4.
Fig. 4 shows an electrical circuit diagram of a part of the first converter station 12 according to a second embodiment of the invention.

5 In fig. 4 there is a first and a second set SI and S2 of converter valve elements. These converter valve elements are made up of semiconductor elements and in the embodiments shown here of thyristors. The first set is here provided in a first converter 20A of the converter station 12, while the second set is provided in a further converter 20B of the converter station 12.

10 In fig. 4 the converter valve elements of each converter are connected in series for forming a phase leg. In fig. 4 there is only one phase leg shown for each converter in order to provide a clearer understanding of the invention. It should be realized that there are normally more such phase legs in parallel with each other, like two. In case the connected first AC power line is a three-phase power line, which is the normal case, there are three phase legs in each converter. The first converter 20A is here connected between the first DC power line 14 and an intermediate point, while the further converter 20B is connected between ground and the intermediate point. Fig. 4 also discloses two transformers, the first transformer 18A and a further transformer 18B. The transformers 18A and 18B both have primary windings connected to the first AC power line and secondary windings connected to the phase legs. In case the AC system is a three phase system there are thus three primary windings and three secondary windings.
As mentioned earlier, the converter valve elements are connected in series with each other. In this exemplifying figure there is furthermore a first, second, third and fourth converter valve element CV1, CV2, CV3 and CV4 connect in series between the first end of the DC power line 14 and ground. This means that the fourth converter valve element CV4 is at a first end connected to ground and at a second opposite end connected to a first end of the third converter valve element CV3. The third converter valve element CV3 has a second end connected to a first end of the second converter valve element CV2, the second end of which is connected to a first end of the first converter valve element CV1. The second end of the first converter valve element CV1 is connected the first end of the DC power line 14. The first transformer 18A is connected to the junction between the first and the second converter valve elements CV1 and CV2, while the further transformer 18B is connected to the junction between the third and the fourth converter valve elements CV3 and CV4.

The first and second converter valve elements CV1 and CV2 here form the first set S1 of converter valve elements in the first converter 20A, while the third and the fourth converter valve elements CV3 and CV4 in the further converter 20B form the second set S2 of converter valve elements. In this embodiment there are thus two converter valve elements in the first and second sets. It should however be realized that it is possible with more or fewer converter valve elements in both sets. The first set of converter valve elements is at one end, at the second end of the first converter
valve element CV1, provided at the highest possible potential, which is the potential of the first DC voltage $V_{DC1}$ and at an opposite end, at the intermediate point or the junction between the first and second sets of converter valve elements, provided at a lower potential.

Because of the way that the first and the further transformer 18A and 18B are connected to the converter valve elements the first transformer 18A is operating at the highest potential and the further transformer 18B is operating at the lower potential.

As the further transformer 18B is operating at a lower potential, it can be made smaller than the first transformer 18A. It may therefore also be equipped with a regulating winding, which is the case here, while the first transformer 18A lacks such a regulating winding. To this regulating winding (not shown) there is furthermore connected a tap changer 54.

In this second embodiment of the invention, tap changer control is combined with firing angle control. This is done through the first control unit 22 providing control signals to the tap changer 54 for making the further transformer 18B contribute to the lower potential at the junction between the first and second sets of converter valves, while at the same time providing control signals for firing the converter valves CV1 and CV2 in the first set SI of converter valves. In this way it can be seen that the first control unit 22 combines the control such that the further transformer 18B operating on the lower
potential is controlled using tap changer to make a first contribution and the first and second converter valves CV1 and CV2 of the first set SI connected to the first transformer 18A are controlled through controlling their firing angles to make a second contribution, which contributions together form the desired DC voltage. In a rectifier it can thus be seen that the tap changer control is combined with delay angle control for providing the first DC voltage $V_{DC1}$. Therefore, it is accomplished that the top voltage converter transformer design is simplified, while regular tap changer control of the station can still be achieved.

In the second embodiment the first and second sets of converter valves were provided in different converters. It should be realized that they may as an alternative be provided in the same converter.

It is also here possible that the first control unit 22 does compare an AC measurement voltage with a reference voltage and changes target voltage depending on this comparison. It should here also be realized that the second converter station could be realized in the same way as the above described first converter station and thereby that the second control unit combines tap changer control with commutation margin control.

In variations of this second embodiment it is also possible with further sets of converter valves connected to a transformer without regulating winding and being phase angle controlled. It is also or instead
possible with further sets of converter valves being connected to transformers with regulating windings, which windings are controlled using tap changers.

The control unit may be realized in a number of different ways. It may for instance be realized in the form of a computer carrying computer program code implementing the above described control functionality.

The invention can also be provided as a computer program product comprising computer readable means carrying the computer programs code, such as a memory like a CD Rom disc or a memory stick carrying the above mentioned program code. The program code of the computer program product performs the functionality of the invention when the carrier is being loaded into a computer. The functionality can also be provided in a server and downloaded from there to a computer functioning as the control unit.

From the foregoing discussion it is evident that the present invention can be varied in a multitude of ways. It shall consequently be realized that the present invention is only to be limited by the following claims.
CLAiMs

1. A converter station (12; 16) in a direct current power system (10) connected between an alternating current power line (30; 32) and a direct current power line (14), the converter station comprising:
- a transformer (18; 24; 18A),
- a converter (20; 26; 20A) equipped with converter valves (CV1, CV2) of which at least a first set (SI) is connected to the transformer, and
- a control unit (22) configured to control the converter station for providing a DC voltage \( V_{DC1} \), \( V_{DC2} \) at one end of the direct current power line for contributing to the forming of a voltage difference together with another DC voltage \( V_{DC2}, V_{DC1} \) generated by a further converter station (16; 12) at an opposite end of the direct current power line for enabling a feeding of power over the direct current power line, characterized in that said control unit is configured to control the converter to provide a DC voltage through using firing angle control of the converter valves (CV1, CV2) connected to the transformer (18A).

2. A converter station according to claim 1, wherein said control unit is configured to obtain a measurement voltage \( V_{M1}, V_{M2} \) of the AC power line connected to the converter station, compare the measurement voltage with a reference voltage \( V_{REF1}, V_{REF2} \) and reduce the DC voltage if the measurement voltage is below the reference voltage.
3. A converter station according to claim 2, wherein said control unit is configured to reduce the DC voltage according to a relationship between the measurement voltage and the reference voltage.

4. A converter station according to claim 2 or 3, wherein the reference voltage is set to correspond to a voltage of the alternating current power line at a minimum firing angle value.

5. A converter station according to any previous claim, said transformer (18A) being only connected to a first set (SI) of converter valves (CV1, CV2) and operating at the highest possible potential and further comprising a further transformer (18B) having a regulating winding, being connected to a second set (S2) of converter valves (CV3, CV4) of the converter station and operating at a lower potential as well as a tap changer (54) connected to the regulating winding, wherein said control unit is configured to control the further transformer through tap changer control of the regulating winding in order to contribute to the DC voltage.

6. A converter station according to any previous claim, wherein the converter is a rectifier and the control unit is configured to control the valves connected to said transformer using delay angle control.

7. A converter station according to any of claims 1 - 5, wherein the converter is an inverter and said control unit is configured to control the valves
connected to said transformer using commutation margin control.

8. A method for controlling the DC voltage provided by a converter station (12; 16) in a direct current power system (10), said converter station being connected between an alternating current power line (30; 32) and a direct current power line (14) and comprising:

- a transformer (18; 24; 18A), and
- a converter (20; 26; 20A) equipped with converter valves (CV1, CV2) of which at least a first set (SI) is connected to the transformer, said method comprising the step of:

  - controlling (35; 44) the converter station to provide a DC voltage \( V_{DC1} \) at one end of the DC power line through controlling the rectifier converter valves connected to said transformer using firing angle control in order to contribute to the forming of a voltage difference together with another DC voltage \( V_{DC2} \) generated by a further converter station (16; 12) at an opposite end of the direct current power line for enabling a feeding of power over the direct current power line.

9. A method according to claim 8, further comprising the steps of obtaining (36; 46) a measurement voltage \( V_{AC1} \) of the AC power line, comparing (38; 48) the measurement voltage with a reference voltage \( V_{REF1}, V_{REF2} \) and reducing (42; 52) the DC voltage if the measurement voltage is below said reference voltage.
10. A method according to claim 9, wherein the step of reducing the DC voltage comprises reducing the DC voltage according to the relationship between the measurement voltage and the reference voltage.

11. A method according to claim 9 or 10, wherein the reference voltage is set to correspond to a voltage of the alternating current power line at a minimum firing angle value.

12. A method according to any of claims 8 - 11, wherein said transformer (18A) is only connected to a first set (S1) of converter valves (CV1, CV2) and operating at the highest possible potential and the converter station further comprises a further transformer (18B) having a regulating winding, being connected to a second set (S2) of converter valves (CV3, CV4) and operating at a lower potential as well as a tap changer (54) connected to the regulating winding, wherein the step of controlling comprises controlling the further transformer through tap changer control of the regulating winding in order to contribute to the DC voltage.

13. A method according to any of claims 8 - 12, wherein the converter is a rectifier and the step of controlling through varying the firing angle comprises controlling the valves connected to said transformer using delay angle control.

14. A method according to any of claims 8 - 12, wherein the converter is an inverter and the step of
controlling through varying the firing angle comprises controlling the valves connected to said transformer using commutation margin control.

15. A computer program product for controlling the DC voltage provided by a converter station (12; 16) in a direct current power system (10), said converter station being connected between an alternating current power line (30; 32) and a direct current power line (14) and comprising a transformer (18; 24; 18A) and a converter (20;) equipped with converter valves (CV1, CV2) of which at least a first set (SI) is connected to the transformer, said computer program product comprising computer readable means carrying computer programs code, said program code being configured to control the converter station to provide a DC voltage \( V_{DC1} \) at one end of the DC power line through controlling the converter valves connected to said transformer using firing angle control in order to contribute to the forming of a voltage difference together with another DC voltage \( V_{DC2} \), generated by a further converter station (16; 12) at an opposite end of the direct current power line for enabling a feeding of power over the direct current power line.

16. A direct current power system (10) connected between a first and a second alternating current power line (30, 32), the direct current power system comprising:

- a first converter station (12) with a first transformer (18; 18A), a first control unit (22) and a rectifier (20; 20A) equipped with converter valves...
(CV1, CV2) of which at least a first set (SI) is connected to the first transformer,
- a second converter station (16) with a second transformer (24), a second control unit (28) and an inverter (26) equipped with converter valves of which at least a first set is connected to the second transformer,
- a direct current power line (14) having a first end connected to the first converter station and a second end connected to the second converter station,

wherein the first control unit (22) is configured to control the first converter station for providing a first DC voltage \( V_{\text{DC}1} \) at the first end of direct current power line and the second control unit is configured to control the second converter station to provide a second DC voltage \( V_{\text{DC}2} \) at the second end of the direct current power line for providing a voltage difference feeding power over the direct current power line,

characterized in that the first control unit is configured to control the rectifier to provide the first DC voltage using delay angle control of the rectifier converter valves connected to the first transformer and the second converter is configured to control the inverter to provide the second DC voltage using commutation margin control of the converter valves connected to the second transformer.
FIG. 1

VARY FIRING TO PROVIDE $V_{DC1}$

OBtain First AC Measurement Voltage $V_{M1}$

Compare $V_{M1}$ With $V_{REF1}$

$V_{M1} > V_{REF1}$?

Y

N

Reduce $V_{DC1}$ in relation to $V_{M1}/V_{REF1}$

FIG. 2
2 / 2

VARY FIRING TO PROVIDE $V_{DC2}$

OBTAIN SECOND AC MEASUREMENT VOLTAGE $V_{M2}$

COMPARE $V_{M2}$ WITH $V_{REF2}$

$V_{M2} > V_{REF2}$?

Y

N

REDUCE $V_{DC2}$ IN RELATION TO $V_{M2}/V_{REF2}$

FIG. 3

FIG. 4
**INTERNATIONAL SEARCH REPORT**

**A. CLASSIFICATION OF SUBJECT MATTER**

INV. H02M5/45 H02M7/757 H02J3/36

ADD.

According to International Patent Classification (IPC) and to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

H02M H02J

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, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
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<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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<td>EP 0 707 368 A2 (ASEA BROWN BOVERI [SE] ABB AB [SE]) 17 April 1996 (1996-04-17)</td>
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**See patent family annex.**

* Special categories of cited documents:

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- **P** document published prior to the international filing date but later than the priority date claimed

**Date of the actual completion of the international search**

2 August 2011

**Date of mailing of the international search report**

17/08/2011

**Name and mailing address of the ISA/IB European Patent Office, P.B. 5818 Patentlaan 2 NL-2280 HJ Rijswijk**

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**Authorized officer**

Zettl er, Karl-Rudolf
### DOCUMENTS CONSIDERED TO BE RELEVANT

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