Power Collection and Integration on the Electric Grid from Offshore Wind Parks

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***Abstract*—There is a lot of potential in offshore wind parks due to the amount of available area. The parks get bigger in size and will continue to grow in the future. In this article a new converter topology for offshore wind parks is proposed. This topology is meant to be for large offshore wind parks sited far from shore and it is based on DC collection and transmission. All the converters are located in the nacelle of the wind turbines and the turbines are connected in series directly connected to shore without any transformation stages. The electrical system, from the generator to the grid connection of the turbine, is modeled in PSCAD. The model consists of an induction machine, a 3-phase AC to 1-phase AC converter, a high frequency high power transformer and a full-bridge converter. The AC-AC converter has a new type of reverse-blocking IGBTs and the switches are controlled with a dedicated switching pattern. The simulations show that the switching pattern gives the expected square wave voltage from the AC-AC converter. The new converter topology reduces the converter losses due to fewer converter stages, the architecture of the reverse-blocking IGBT and the new switching pattern.**

***Index Terms*—Bidirectional/AC-AC converter, reverse-blocking IGBT, offshore wind parks, HVDC, switching pattern AC-AC converter, high frequency transformer**

I. INTRODUCTION

The existing offshore wind parks are connected to the onshore grid with high voltage AC (HVAC) cables. They are not located far from shore, and the maximum size in operation is 166 MW [1]. In future, the size of offshore wind parks will increase and the distance to shore will be longer. In HVAC cables there will be generated reactive current due to high capacitance which reduces the active current-carrying capacity. This leads to limitations of the length of the cable without compensation devices [2]. According to [3] HVAC systems lead to the lowest transmission losses for distances up to 55-70 km depending on the size of the wind parks. For longer distances high voltage DC (HVDC) transmission has the lowest losses, as shown in Fig.1. The figure is based on an average wind speed of 9 m/s. In the figure the blue line indicates the border between AC and line commutated converter (LCC) HVDC transmission. The dashed red lines show the percentage loss variation.

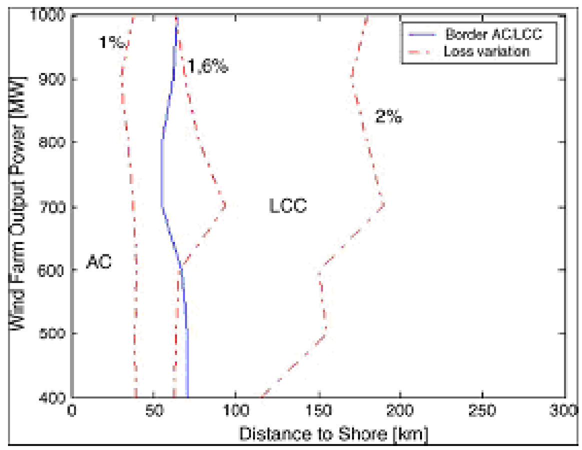

Fig. 1. Comparison of LCC HVDC and HVAC transmission for different wind park sizes and distances to shore for an average wind speed of 9 m/s [3]

Today there are two different HVDC link types, line commutated converter (LCC) HVDC and voltage source converter (VSC) HVDC. The LCC is cheaper than the VSC solution [2] but has a large offshore substation required for the converters and the auxiliary equipment. Because of the PWM technique used in VSC, this technology requires fewer auxiliary filters than the LCC technology. There is no need for switchable AC harmonic filters for reactive power control in VSC technology, because the converters are able to control reactive power in both ends of the cable. VSC converter stations take only half of the area of an LCC transmission station [4] but the price for the total VSC HVDC offshore substations can be about 10 times higher than an AC substation [5]. One disadvantage with the VSC is the high switching losses which leads to higher power losses (3.5 % at full load) than LCC (1.5 %) [4]. The need for large offshore substations and auxiliary equipment makes LCC not so well suited for large scale offshore wind parks.

Despite of heavy transformers at line frequency, heavy capacitors and converter losses VSC is a promising technology.

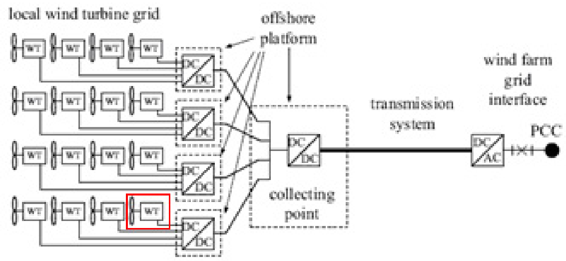

Fig. 2. Parallel connected wind turbines with offshore substations as presented in [7]

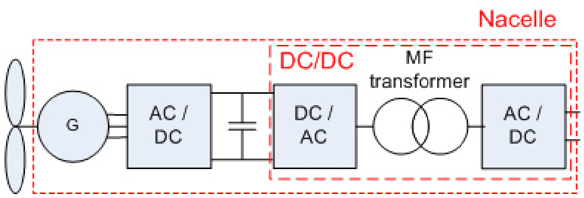

Fig. 3. Conventional converter topology in the nacelle of the turbine as of [7]

The purpose of this article is to illustrate a possible offshore wind park topology made by using the reverse-blocking IGBT type of semiconductor device with a dedicated switching pattern to reduce the converter losses [6].

II. New topology for DC based offshore wind parks

A. The conventional converter topology

One of the previously proposed DC based offshore wind park layouts is the parallel connected turbines with one or more offshore substations, Fig. 2. This layout must have offshore converter stations to raise the voltage before transmission to shore. It is assumed that only one transformer stage is needed if the output voltage of the wind turbine is 20-40 kV[7]. Then the wind turbines will be connected in radials to the collecting point in Fig. 2. With a lower output voltage of the wind turbine, about 5 kV, two transformer stages are needed. The wind turbines will then be divided into clusters and connected one by one to the first transformer stage. Then the clusters will be connected to the collecting point as shown in Fig. 2.

For this type of wind park layout each wind turbine (WT), marked with a red rectangle in Fig. 2, has an AC-DC converter, DC-DC converter and a capacitor between, as shown in Fig. 3. DC-DC converters are also used for the two transformer stages in the layout. The AC-DC converter has either diode or IGBT switches depending on the type of machine used in the wind turbine, synchronous or induction machine. A DC-DC converter consists of one rectifier, one inverter and a medium frequency transformer. In [8] a loss and energy production cost study of different DC/DC converters for DC based offshore wind parks is carried out. Full-bridge converter, single active bridge converter and series parallel resonant converter are compared for the three different sites in the park, resulting in lowest losses for the resonant converter independent of the site. The single active bridge converter resulted in the highest losses, but the full-bridge converter gave slightly higher losses than the resonant converter. The resonant converter has a larger transformer and more IGBT modules than the full-bridge converter, which results in a higher energy production cost for some positions in the grid, even though the losses are lower. This topology also has a capacitor between the two converters to make sure the input to the DC-DC converter is smoothed properly.

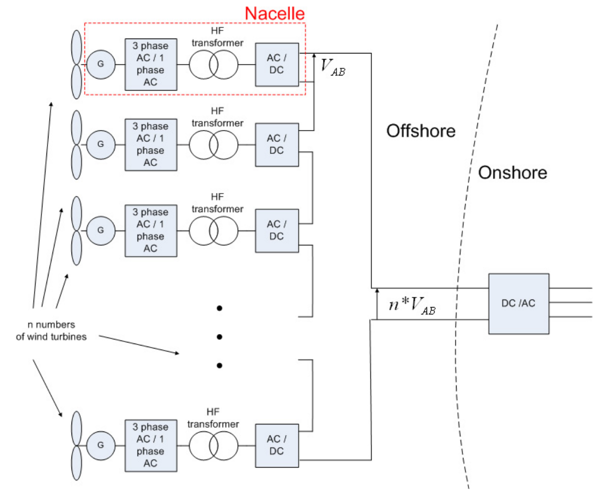

Fig. 4. DC based wind park with proposed converter topology

B. The proposed converter topology

The proposed topology uses only one cable with series connected turbines as the local grid, as can be seen in Fig. 4. Each wind energy conversion unit will consist of a generator, the turbine, a 3-phase AC to 1-phase AC converter, a high frequency (HF) transformer and a 1-phase AC-DC converter. The turbines will be connected to an offshore DC network and the power will be transmitted directly to shore without any transformation stages. This is possible since the turbines are connected in series and the voltage level required for transmission will be obtained by the series connection and/or the turn ratio of the HF transformer. By converting the AC voltage output from the generator to DC voltage directly in the nacelle of each turbine, a wind park layout without offshore substations is made possible [9]. In [10] the similar conversion is proposed, but only the AC-AC converter is placed in the wind turbines. This leads to a square wave voltage collection grid and an offshore substation for the AC-DC converter.

In the proposed topology the DC side of the AC-DC converter of each turbine will be connected in series with the other wind turbines to obtain the required voltage level before the transmission to shore. This is possible through the high frequency transformer. It allows the current from the DC grid to flow through the secondary side of the transformer before entering the AC-DC converter again, but from the AC side. Then the current can continue further to the next wind turbine.

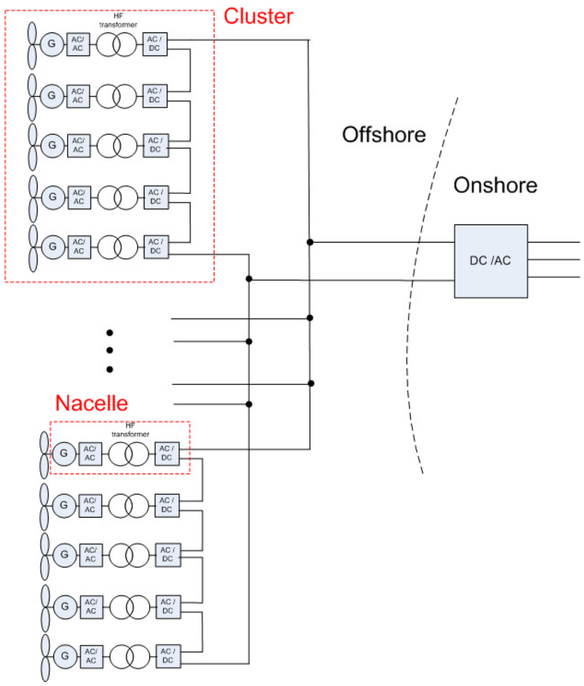

Fig. 5. Series connected wind turbines in clusters

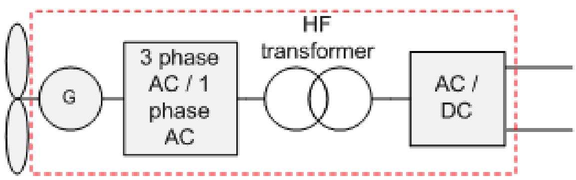

Fig. 6. Wind turbine with proposed topology

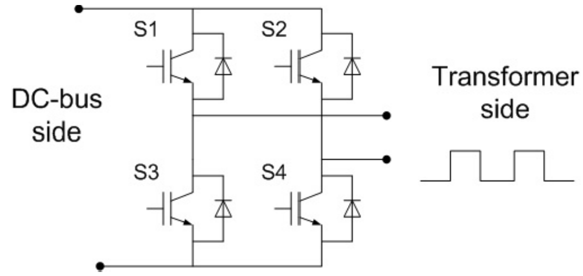

Fig. 7. H-bridge with IGBTs and anti parallel diodes

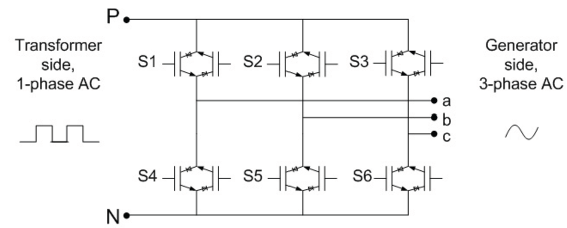

Fig. 8. Bidirectional AC link with new reverse-blocking IGBTs

Another DC based layout option is to connect a few wind turbines in series to make clusters. These clusters will then be connected in parallel to the transmission line, see Fig. 5. By using this layout, the consequences during fault on cables might be less severe. Only the faulty cluster needs to be disconnected and the park can still produce power.

The generator in Fig. 6 is a squirrel cage induction machine with a rated line-to-line voltage of 690 V and a rated power of 750 kVA (660 kW). The future generators will be able to generate more than today, so an output higher than 1000 V and a power rating of up to 10 MW can be assumed as realistic for use in these wind turbines. This leads to fewer turbines needed in series to obtain the required voltage level for transmission and perhaps lower ratio of the transformers.

The AC/DC converter in Fig. 6 is a full-bridge converter, also called an H-bridge, with switching modules consisting of IGBTs and diodes in anti parallel, Fig. 7. The converter has two legs, each with two switches (S1, S3) and (S2, S4), and is able to convert a DC voltage to a square wave voltage and vice versa. By connecting the converter to the DC bus and transformer, as shown in Fig. 7, the required square wave form is obtained when starting the generator. To achieve square wave output when magnetizing the windings a PWM square wave switching scheme is used. The upper switch in one leg and the lower switch in the other are switched simultaneously, when not considering the blanking time. The two switches form a switch pair, i.e. the converter has two switch pairs. The switch pairs are on for a half cycle of the output frequency (10 kHz), i.e. a duty ratio of 0.5.

The 3-phase AC to 1-phase AC converter consists of three legs each with two switches. The switches are a new type of reverse-blocking IGBTs, as can be seen in Fig. 8. They do not have any anti parallel diodes and therefore reduce the converter losses. On the generator side of the converter there will always be an alternating voltage independent of the way the power flows.

1) Proposed high frequency high power transformer: A 1.3 kV and 750 kW transformer is not often made. For a frequency of 10 kHz transformers with power ratings of 100 kW would not be a problem, but with higher power ratings the frequency is normally about 1-2 kHz. The weight will decrease with increasing frequency, but smaller size makes the cooling difficult and that will increase the losses. For the prototype of this system a 50 kW transformer with 10 kHz will be designed.

As material for the cores there are two options, amorphous alloys or ferrite materials. The amorphous alloys have higher saturation flux density than the ferrite materials, which is good for high currents, but the ferrite material has no eddy current losses. The shape of the core could be E, U or toroid. The disadvantages with the toroid cores are that they are difficult to wind and the cooling is also difficult. For the U-core it is possible to separate the secondary and primary windings on to legs, but this will lead to more leakage inductance. It is also possible to wind both windings on one leg. The E-core is easy to use and has low leakage inductance since both of the windings are wound on the center leg. The windings can be wound on a bobbin and then afterward the bobbin is placed on the core.

For the material of the windings there are two possibilities, copper and aluminium. Copper is the most used one because of the low conduction losses compared to aluminium. Copper is more expensive than aluminium (10 $ to 3 $ per kg) so if aluminium is used it is to reduce the cost. The density of copper is 8.96 g/cm3 and 2.70 g/cm3 for aluminium (both in solid state at room temperature), so aluminium can also be used to reduce the weight of the transformer. Aluminium transformers can be found in airplanes for weight reduction and for other applications if the investment costs should be kept low, but it is very rare. For this application losses are important and should be reduced. Therefore copper windings should be chosen. The shape of the windings can be wire or foil. Foils reduces the skin and proximity effect of the winding. If aluminium where chosen, it would not be a problem to make foils. Since copper is the preferred material due to lower conduction losses, it is more difficult to make foil windings. Copper is not as easy flattened as aluminium.

To reduce the skin effect and proximity effect at high frequencies litz wires are used for frequencies above 100 kHz. Litz wire consists of many small wires individually coated with an insulating film and twisted or woven together. It can also be used for lower frequencies, but the available conducting area is smaller due to many small wires instead of one big one. There will be more unused space in the litz wire compared to the wire with only one copper wire. For high power transformer one copper wire should be used because one wire can cope with higher currents than many individually isolated small ones. It is also more difficult to make thin windings of copper.

For the cooling of transformers with a power rating above 100 kW the best one will be water cooling. The water pipes will take a lot of space when they are wound around the windings and a pump and pipes from the ground are needed. This will give a weight increase and might not be the best alternative for wind turbines. The other option for cooling of transformers is air cooling. To make air cooling possible the core has to be bigger to let the air through.

For the design of the prototype transformer leakage inductances, flux densities and the size of the core and windings should be calculated. Ferrite material should be used for the core and as mentioned the windings should be of copper not aluminium. Even though weight reduction is important for offshore wind turbines, the weight gain will not be so remarkable since more aluminium wires are required to carry the same current as the copper wires.

2) New reverse-blocking IGBT: The reverse-blocking IGBT can form a bidirectional switch without the use of diodes. This leads to a voltage drop reduction of the switch [6]. The same functionality of reverse-blocking IGBTs (RB-IGBTs) can be obtained by two IGBTs with anti parallel diodes in series, left side in Fig. 9. The new reverse-blocking IGBTs do not have the anti parallel diodes as shown in Fig. 9 on the right side. In [11] the new RB-IGBT is used in a AC-AC direct converter resulting in an efficiency increase of 1.9 point compared to a conventional device. As can be seen from Fig. 9, for the switch

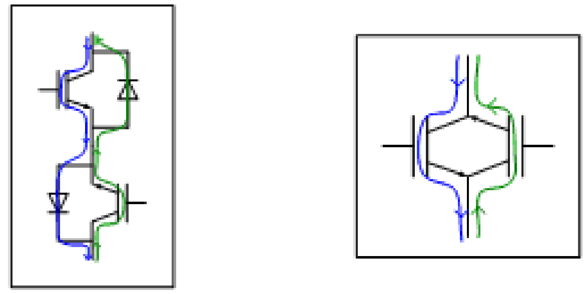

Fig. 9. Bidirectional switches with IGBTs, left: two IGBTs with anti parallel diodes in series, right: new reverse-blocking IGBT

consisting of two IGBT modules in series, the current has to pass through two components independent of the direction of the current flow. Both the current flowing from the top to the bottom of Fig. 9, the blue line, and the current flowing from the bottom to the top, the green line, have to pass through one IGBT and one diode. This would result in more on-state losses than the new RB-IGBT, which has just one component to pass through in both directions. The more components to pass through, the more on-state losses is generated.

C. Converter losses

To calculate the losses in a converter the losses in every switch in the converter need to be calculated. Which losses that will occur in the switches is dependent on which type of semiconductor device that is used. For the controllable devices there are four different types of losses; conduction losses, turn on losses, turn off losses and recovery losses. To calculate these losses the data sheet of the device has to be used. In the AC-AC converter the switches consists of RB-IGBTs. The losses are calculated for one RB-IGBT and multiplied by the total number of devices in the converter. Each switch consists of two RB-IGBTs, so in this case the number is twelve.

The conduction losses are the losses in the semiconductor device when the device is conducting, i.e. in on-state. There will always be some kind of voltage drop in on-state and this voltage drop leads to losses. To calculate the conduction losses for the RB-IGBT the collector current I_C and the gate-emitter voltage V_{GE} has to be known. From the data sheet the curve Collector current vs. Collector-Emitter voltage should give the on-state voltage V_{CE}. By knowing the I_C and V_{GE} the collector-emitter voltage can be found and multiplied with the current 1.

$$P_{cond} = V_{CE} I_C \tag{1}$$

The turn on and turn off losses are the losses connected/involved to the on and off switching of the device. The current and voltage need some time to go back to zero or to increase to max during to turn on and off of the device. These delays will lead to switching losses. To find the switching losses of the RB-IGBT there will be a graph in the data sheet giving the different switching losses, Switching losses vs. Collector current. The collector current I_C has to be known, so

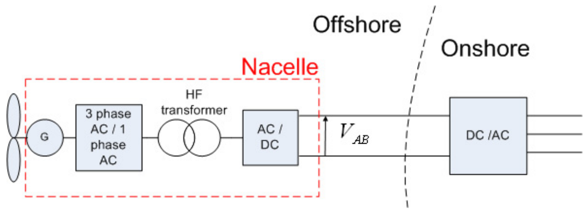

Fig. 10. Model implemented in PSCAD for simulation

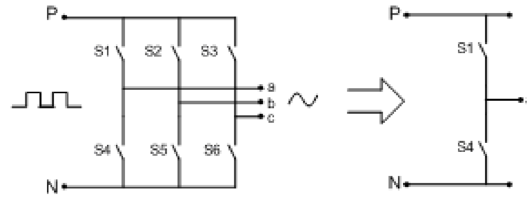

Fig. 11. AC-AC converter leg analysed in Fig.12.

the energy losses for the turn-on, turn-off and recovery losses can easily be found. Since the losses are given in switching energy(J), they have to be converted into power losses(W) with T in 2 as the switching period for the device:

$$P_{loss} = \frac{E_{loss}}{T} \tag{2}$$

The total losses per device will be the sum of all the four losses described above:(total loss of switching frequency period)

$$P_{tot} = P_{condIGBT} + P_{condDiode} + P_{on} + P_{off} + P_{rr} \tag{3}$$

Averaging total losses:

$$P_{totavr} = \int_0^t P_{tot} f_{out} \tag{4}$$

f_{out} is the frequency of the output, not the switching frequency.

III. Simulation System

A. Simulation model

To be able to test the proposed converter topology a model was built. A model of the wind turbine is made in PSCAD to simulate the losses in the converters [9]. The model consists of the components from the generator connected to the rotor of the wind turbine to the converter connected to the DC collection grid in the offshore wind park. The DC collection grid is modelled as a DC voltage source with a resistance and a large capacitor in parallel. As can be seen from Fig. 10 the system also consists of a wind generator, bidirectional converter, high frequency transformer and a DC/AC converter (H-bridge).

The wind generator in the model is a squirrel cage induction machine. The machine parameters are from Vestas 750 kVA (660 kW) wind generator found in [12]. The transformer in the model is a single phase two winding transformer with a rated power of 0.75 MVA. The frequency is 10 kHz because that is the switching frequency of the converters which leads to the frequency of the square wave voltage in the transformer. The rated voltage is 1.3 kV for both windings which is the calculated output of the bidirectional converter. Every high frequency high power transformer is designed for a specific system. Therefore it is not easy to find parameters to use for the simulation model. PSCAD suggests some parameters which are used in the model for the rest of the parameters needed to do the simulation.

The 3-phase AC-1-phase AC converter in Fig. 10 is a bidirectional converter consisting of three legs with two switches, Fig. 8. The switching frequency is 10 kHz and the bidirectional switches are made of two IGBTs of the new type described in II.B.1). The parameters for the IGBTs are the standard PSCAD values for semiconductor devices. The P and N connection points in Fig. 8 are connected to the transformer side and there is always a square wave voltage input from the transformer. Each leg in the converter is connected to one phase on the generator side. The switches are controlled by using a dedicated switching pattern. A triangular carrier signal (10 kHz) is compared to the 3-phase sinusoidal 50 Hz reference signal. The sinusoidal reference signal is inverted for half of the carrier signal period. There is one reference signal for each leg controlling the switching of the two switches in the leg. The reference signals are generated by a control box. The switches in the same leg will never be ON at the same time, but there will always be three switches ON, one from each leg.

The full-bridge converter, also called H-bridge, has two legs with two switches, Fig. 7. The switches consist of one IGBT and one diode in anti parallel. The parameters used for the diodes and the IGBTs in the converter are the standard one suggested by PSCAD. Each switch gets a control signal from the control system, 1 for ON and 0 for OFF.

B. New switching pattern

The bidirectional converter uses a dedicated switching pattern for the switching of the RB-IGBT switches. Considering the switching of the two switches in one leg, see Fig.11, the upper and the lower switch will never be ON at the same time. When the upper one is ON, i.e. the control signal to the switch is 1, the lower one will be OFF, control signal 0, and vice versa. The violet curve, number three from the top in Fig. 12, shows when the upper switch is ON and OFF with a DC input into the converter. This switching control can be obtained by using a switching technique called Pulse Width Modulation (PWM) [13]. This technique can be explained by looking at the second graph from the top in Fig. 12 and only considering the upper one of the two blue lines (made up of dark and light blue pieces). This blue line is actually a sinusoidal reference signal for one leg or phase (50 Hz) and will decide the frequency of the output. The green triangular signal is called a carrier and it decides the frequency with

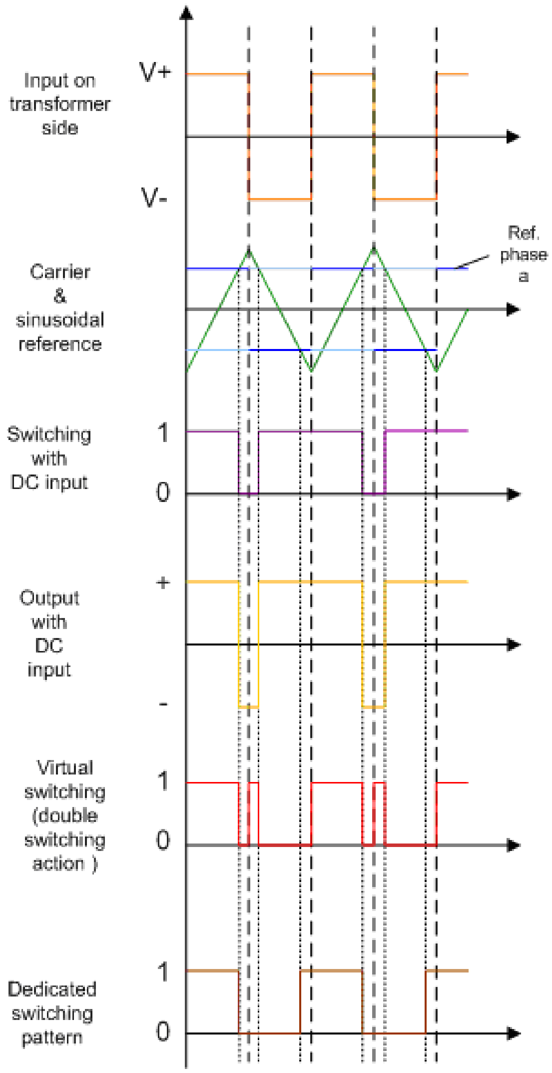

Fig. 12. Dedicated switching pattern for the RB-IGBTs [9]

which the switches are switched. Since this carrier has a frequency of 10 kHz, the sinusoidal reference signal can be considered as a straight line for the small time intervals as in Fig. 12. When the sinusoidal reference signal is higher than the carrier signal the upper switch of the phase leg will be turned ON and the lower switch will be turned OFF. They will remain ON and OFF until the reference signal is lower than the carrier signal. At that moment the upper switch turns OFF and the lower one turns ON, until the reference signal again is higher than the carrier signal. This leads to a positive output of the leg when the upper one is ON and a negative output when the lower one is ON, as the yellow curve, fourth one from the top, in Fig. 12 shows.

The orange curve at the top of Fig. 12 shows the square wave voltage input to the converter from the transformer. To obtain the sinusoidal output as required for the converter the switches need to be switch oppositely for the negative period of the square wave input as for the positive period. Considering the upper switch S1 in the a-phase leg in Fig. 11 the red curve, second one from the bottom in Fig. 12 shows how the switch is switched. In the beginning the P-pole is positive and the N-pole is negative. S1 is ON connecting the a-phase to the positive P-pole. Then after a while S1 is turned OFF and the lower one S4 is turned ON.

The lower switch then connects the a-phase to the negative N-pole. Since the voltage between P and N is a square wave the polarity of P becomes negative after a while, and the polarity of N becomes positive. Phase a still has to be negative so S1 is turned ON and S4 OFF since P now is negative and N is positive. To get a positive output on phase a in this period, the lower switch S4 will have to be turned ON and the upper switch OFF. The square wave will then enter a period where P again becomes positive and N negative. This switching pattern is the pattern that would have given the desired output.

With the dedicated switching pattern, a sinusoidal output can be achieved with less number of switching sequences. The sinusoidal reference signal is inverted for half of the carrier period, the dark blue curve, second from the top in Fig. 12. Using this blue reference signal and the green carrier for the PWM switching technique, the upper switch will be ON and OFF as shown in the brown curve at the bottom in Fig. 12. In the beginning the switch is ON because the blue reference signal is above the green carrier signal. Almost at the end of the first half period, the positive one of the input, the switch is turned OFF due to higher carrier than reference signal. For the negative half of the input period, the reference is inverted and remains below the carrier for a longer time than if it where not inverted. The switch will be turned ON before the second positive half period of the input begins. The reference signal in this positive half period is not inverted and the switch will remain ON until the reference signal again is below the carrier signal and so forth.

C. Simulation results

With the dedicated switching pattern the number of times switched each period is reduced. The red and brown patterns, the second one and the one at the bottom in Fig. 12, gives the switching sequence of one switch with the virtual pattern and the dedicated pattern. Considering these patterns, the brown one shows that the number of times switched per switch is halved, from four times to two. This is important at high voltage levels because of slower devices, due to longer delay time. By reducing the number of times switched, the switching losses are reduced and this results in less converter losses.

In the simulation model the dedicated switching pattern is used for the bidirectional converter. The triangular carrier signal (10 kHz) and a sinusoidal reference signal for one phase (50 Hz) is shown in the top of Fig. 13. As can be seen from the figure, the sinusoidal reference signal is inverted for half of the carrier signal period which is 100 s. There is one sinusoidal reference signal for each phase just delayed with 120° and 240°. By using this technique there will always be three switches on at any instant of time. The square wave voltage, U_{out} in Fig. 13, is the input to the converter on

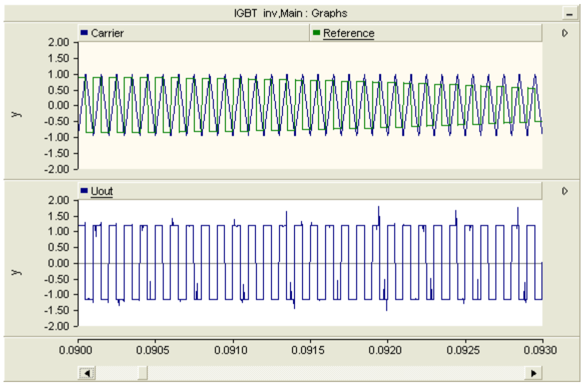

Fig. 13. Switching pattern, top: sinusoudal reference for one phase, bottom: output voltage on transformer side

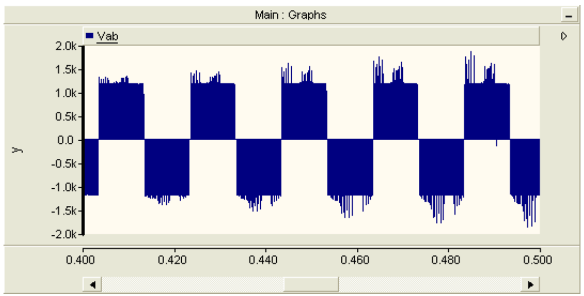

Fig. 14. Phase-to-phase voltage output on generator side

the transformer side. Fig. 14 shows the output phase-to-phase voltage V_{ab} from the converter. This voltage is the voltage between the a-phase leg and the b-phase leg in the converter in Fig. 12. By using filters this will result in a sinusoidal output voltage.

IV. Discussion

A series connected wind farm is to prefer due to no transformer substation, but the reliability at faults in the cables or turbines can be lower than with parallel or radial connected turbines [14]. When the turbines are connected in series the economical consequences of a cable fault is much larger than if they were connected in parallel. In parallel, Fig. 2, only the single turbine which is connected to the cable with a fault needs to be disconnected. If the fault is on the cable from the cluster to the connecting point, only this cluster needs to be disconnected. Therefore there will always be some wind turbines producing, even though there are faulty cables in the park. For the series connected wind turbines in Fig. 4, there need to be some extra cables connecting different parts of the series connected turbines together to prevent the whole park from being disconnected during cable faults. If a fault arises, the current will need another path to flow, so the extra cable connections have to be connected to keep the park running. Where and how many of these extra cables to install in the offshore grid, will be a trade off between installation costs of the cables and the lost revenue due to lost production during fault and post-fault period [14]. This will also be a subject for

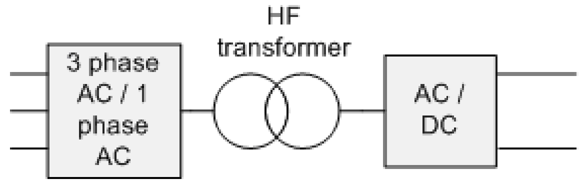

Fig. 15. Proposed converter topology

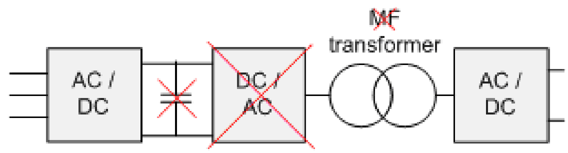

Fig. 16. Conventional converter topology

further investigation.

By connecting a few wind turbines in series in clusters and the clusters in parallel the reliability increases. Now only the faulty cluster needs to be disconnected and the park can still produce some power. With a radial network the loss of production due to turbine disconnection depends on where the fault on the cable is located. If it is located near the connection to the substation, all of the turbines connected to the cable will be disconnected. If it is located between some of the turbines, the turbines between the substation and the fault will still be able to continue production.

If a turbine fault arises in a series connected wind park, i.e. a turbine must be disconnected, there should be switchgears disconnecting the turbine, but allowing the rest of the turbines to produce power. To obtain the same voltage across the turbines, the remaining turbines have to increase their production accordingly. There should also be switchgears allowing turbine disconnection in a radial park so the rest of the turbines in the radial can continue production. For the parallel connected turbines, there is only one turbine connected to one cable, so the other turbines are not affected by the faulty line. If there is a fault in the main transmission cables to shore, the whole park will be shut down independent of the layout. The only possibility to still deliver power to shore during such faults is to install extra cables to shore. Independent of the layout, a cable fault always leads to a decrease in revenue due to lower production.

Considering the converter topologies, i.e. the conventional one and the proposed one, some important differences are worth noticing. In the proposed one in Fig. 15 there will be three steps of conversion, 3-phase AC-1-phase AC, transformer (AC-AC) and AC-DC. As seen from Fig. 16, there will be four steps in the conventional converter topology, AC-DC, DC-AC, transformer (AC-AC) and AC-DC. One converter less in the proposed topology leads to fewer switches. Fewer switches give less switching losses. This is a great advantage since the converter losses contribute a lot to the total losses.

The conventional topology also has a capacitor to smoothen the DC output of the rectifier before it enters the DC-DC converter. A capacitor is normally a heavy component, which is a disadvantage for a wind turbine. For wind turbines, especially floating ones, the weight of the components should be minimized to minimize the counterbalance of the foundation. For the same reason, the new topology has a high frequency (HF) transformer in stead of a medium frequency transformer. Transformers' size and weight is reduced with increasing frequency. Both the reduction in weight and the reduction in switching and ON-state losses are great advantage of the proposed topology.

V. Conclusion/Further work

In this paper a new converter topology for large offshore wind parks has been presented, explained and compared with a conventional one. A PSCAD model of the converter topology is explained and results described. The turbines are connected in series and directly connected to shore without any transformer stages. Since the voltage across the series connected wind turbines are high enough to be transmitted directly, offshore transformer substations are unnecessary. The risk of such a series connected park has to be considered and a trade off between extra cable installations and lost revenue at cable faults is unavoidable. The new topology with a 3-phase AC to 1-phase AC converter, a HF transformer and a full-bridge converter, consists of fewer converter stages than the conventional topology. With one converter less the converter system has fewer switches and less switching and ON-state losses come in to being. This is important because the converter losses are a great contributor to the total losses in the entire wind park. The proposed converter topology does not include a heavy capacitor and the transformer is smaller due to higher frequency. This is a weight reduction which is important to achieve for floating wind turbines.

The switches used for the AC-AC converter are a new type of reverse-blocking IGBT. This switch replaces the series connected IGBTs with anti parallel diodes. By using this new reverse-blocking IGBT without the anti parallel diode, the on-state losses are reduced due to fewer devices for the current to pass through. By introducing the dedicated switching pattern the number of switching actions is reduced. Compared to the virtual pattern the number of times is halved.

On the basis of the mentioned weight reduction and the no offshore substation, the proposed topology might be better suited for the large offshore wind parks. The reduction of switches, reduction of times switched with the new pattern and the new RB-IGBT reduce the converter losses which is the great contributor to the total losses in the electrical system.

The study of this offshore wind park topology has just started. The converter topology and its work in the whole system need to be further investigated. The switching pattern and the switch need to be tested and simulated to document good results. Some further tasks to prove the results of this report:

- Simulations in PSCAD of a model with a generator with the characteristics of a real wind turbine
- Design of the high frequency transformer
- Loss calculations and simulations in PSCAD for the switches and the total converter system
- Development of prototype, implementation of switching pattern and loss measurements
- Simulations of the whole wind park and its connection to the onshore grid during operation and faults, especially when one turbine is disconnected.

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