FUZZY CONTROLLED VSC–HVDC SYSTEMS TO DECREASE THE VOLTAGE DROP AND WIND FARM FAULT EFFECTS IN TRANSMISSION

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Abstract—Fuzzy logic can model or control non-linear systems that are difficult to model mathematically. The fuzzy logic is chosen for VSI compensator as it gives appropriate performance for varying dynamics, higher convergence speed, robust and simple to design compared to conventional methods. Voltage-source converter high-voltage dc (VSC-HVDC) transmission systems have evolved from simple two-level converters to neutral-point clamped converters and then to true multilevel converters such as modular converters. Present VSC-HVDC transmission systems rarely on their converter station control systems and effective impedance between the point-of-common-coupling (PCC) and the converter terminals to ride-through dc side faults.A VSC-HVDC transmission system is a candidate to meet these challenges due to its operational flexibility, such as provision of voltage support to ac networks, its ability to operate independent of ac network strength therefore makes it suitable for connection of weak ac networks. Verified using matlab/simulink

Index Terms— **Doubly fed induction generator (DFIG), fault ridethrough (FRT), high-voltage DC transmission (HVDC), offshore wind farm, voltage-source converter (VSC).**

I. INTRODUCTION

Nowadays, wind generation has become a substantial share of the total power generation. According to the Global Wind Energy Council, the annual wind capacity during 2012 was almost 45 GW. In Figs 1.1-1.2 is shown the global annual and cumulative installed wind capacity from 1996 to 2012 respectively

The number and size of wind farms (WFs) and their share of wind power in the overall generation mix continues to rise. In countries with large-scale wind power development, onshore sites with good wind condition are mostly used up. As result, a significant amount of power infeed is already coming from offshore sites, and the trend is set to continue at a significantly higher pace well into the future. Off the European coasts, a number of sites ranging up to hundred kilometers from the grid connection point are in various stages of planning or development. The resulting long transmission routes make the use of acsubmarine cables problematic due to the high charging currents, and HVDC transmission may be the more feasible solution. Of the alternative HVDC technologies, an increasing number of offshore WFs use voltage-source-converter (VSC)-based HVDC lines these days. Since this technology continues to mature, the likelihood is that more and more offshore wind farms will opt for VSC–HVDC submarine cables.

The VSC technology enables a decoupled control of active and reactive power and allows the connection of weak or even passive networks. In addition, the high switching frequencies (ca. 1–2 kHz) enable the use of lower-rated filters and the insulated-gate bipolar transistor (IGBT) valves themselves have a smaller size compared to thyristor valves of comparable rating used in classical HVDC systems. The converter stations as a result leaves a smaller footprint and, thus, the technology is more suitable for applications where the space requirement is a major consideration, such as offshore platforms.

It is now generally accepted that large WFs with ratings comparable to those of conventional power plants cannot simply trip during and in the immediate aftermath of a fault. Current grid codes require a fault ridethrough (FRT) capability by WFs even at zero voltage for fault durations up to 150 ms [1]. This requirement is particularly challenging for the VSC-based HVDC transmission system connecting the WF to the grid as the power flow from the WF cannot be blocked immediately by the sending-end converter (SEC). Any fault in the ac grid fed by the HVDC line obviously reduces the voltage at the connection point which, in turn, reduces the power fed into the grid by the receiving-end converter (REC) instantaneously. The resulting imbalance between the infeed at the sending end and what is delivered at the receiving end is stored in the form of electric-field energy in the capacitance of the HVDC line. In the absence of suitable countermeasures, this would lead to increased dc voltage and potential equipment damage in the installation [2]–[4]. \

This paper focuses on the Taking into account the above requirements, this work studies the implementation of computational intelligence to the control systems of WTs in order to enhance their FRT capability. The first part of the dissertation studies the issue of the FRT capability of a WF of induction generators, which is connected to an ac grid through an HVDC link based on Voltage Sourced Converters (VSCs). This work proposes a control strategy which is implemented with fuzzy controllers and deals with every different type of fault with a corresponding appropriate action.

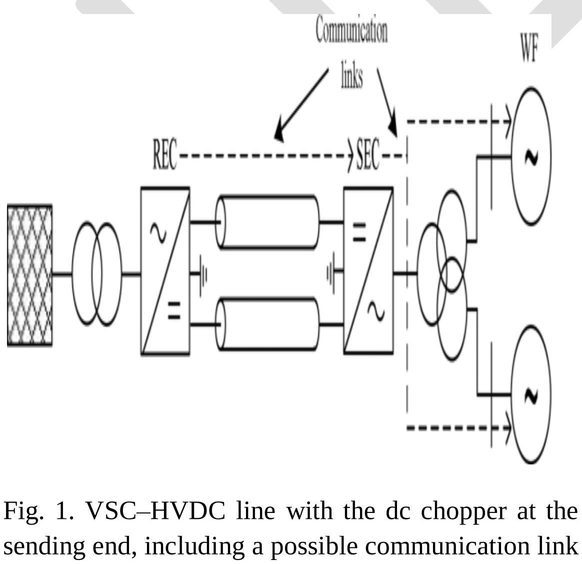


Fig. 1. VSC–HVDC line with the dc chopper at the sending end, including a possible communication link for voltage drop control

II. OVERVIEW OF THE FRT ENHANCEMENT METHODS

The VSC-based HVDC control system provides multiple options as the converters enable fast and decoupled control of active and reactive current, in addition to the WF control itself which also offers similar control possibilities. During normal operation, the SEC of the HVDC line performs active power control, while the REC control is responsible for maintaining the transmission voltage at the prescribed value. In addition, the REC reactive current control channel can optionally be used for reactive power, power factor, or voltage control according to setpoints specified by the dispatcher, whereas the SEC is required to control the voltage in the WF grid. During grid faults, however, the provision of voltage support in accordance with the grid-code requirements overrides the control options adopted during normal operation.

Enhancing the FRT capability in the context of WFs connected to the grid via the VSC-based HVDC link is to be understood as maintaining the HVDC transmission voltage at an acceptable level during fault by balancing the power transfer between SEC and REC. One option is dissipating the energy fed by the SEC so that it will not be delivered to the ac network through the REC. Alternative techniques are based on the coordinated control of the WF–VSC HVDC system to reduce the power fed to the SEC in the event of a fault.

A. Using a Chopper-Switched Braking Resistor

One straightforward and probably the easiest solution to reduce the power imbalance between the SEC and REC in an HVDC line is the use of dc choppers, in which a chopper-switched braking resistor dissipates the energy that cannot be transferred to the ac grid as a result of voltage reduction following a fault (Fig. 1). The main advantage of this technique is the fact that the power supply by the WT remains unchanged and only the power reaching the REC is reduced. The disadvantage, of course, is the additional cost of the chopper, which increases the overall cost of the installation.

B. Active Current Reduction

The other option involves the reduction of the power fed into the REC by reducing the active current setpoint either at SEC or at the WF control system (Fig. 2). The occurrence of fault can be detected by monitoring the voltage either in the ac network or in the dc line. In the former case, a communication link is required to transmit the fault information to the SEC.Depending on the depth of the voltage dip and the actual measured WF output power, the reduction factor can be calculated. However, the slow rate of power reduction that can be achieved limits the practical application of this method.

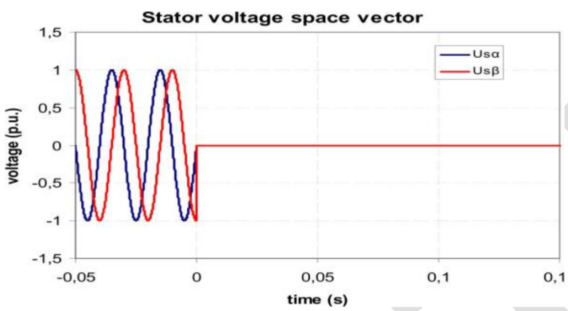


Fig. 2. Sudden voltage reduction

The need for a communication link from the SEC to an individual WT can be obviated by using the frequency in the WF collector network as a fault indicator for power reduction. In this approach, when a fault is detected, the frequency is increased by the SEC, and on the basis of which the WT output power is reduced. For fixed speed machines, this is the natural response since the power directly depends on the machine slip. For converter- based WTs fast frequency control has to be implemented, which reduces the WT output power when the frequency increases.

Theoretically, any of the fault detection methods described before can be used. But because of fewer communication requirements, which result in faster response, the dc voltage measurement seems to be a better indicator for fault detection. The main disadvantage of this approach is the need for fast Frequency control that has to be implemented additionally for converter-based WTs. It is also difficult to measure fast frequency deviations in a fraction of a period. This fact and the controller dynamics of the power controllers in the WT are the limiting factors for the performance of this approach.

C. Voltage Reduction

The next method to achieve fast power reduction of the WF output following a fault is voltage reduction using the SEC control.This approach requires no modifications in the WT control, and achieves the fastest power reduction and, thus, it is the most reliable dc voltage limitation (apart from the dc chopper). The downside of the abrupt voltage reduction by SEC is that its effect on the machine is the same as any short circuit in the grid. Depending on the instant at which the voltage reduction was introduced, the short-circuit current can contain a significant dc component. This leads to high mechanical stress on the WT drive train and electrical stress on the IGBT modules of the HVDC and WT converters. The effect of the abrupt voltage reduction can be mitigated to a degree by reducing the gradient of the voltage reduction. But this at the same time reduces the effectiveness of the method in terms of achieving quick power reduction.

This paper introduces a new method that enables the SEC control to reduce the dc current component arising from the sudden voltage drop. This, on the other hand, will result in considerable reduction of the mechanical stress on the generators and the entirle WT drive train. Besides, due to the fact that the WT converter system will not face such a high peak currents, the blocking of the converter that otherwise would be necessary to protect the IGBTs can be avoided.

III. CONTROLLED VOLTAGE REDUCTION WITH SUPPRESSION OF SHORT-CIRCUIT DC CURRENT

Before going into the details of the proposed control scheme, an expression that establishes a relationship between the level of voltage reduction and the current flowing as a result will be introduced.

A. Stator Current as a Function of Voltage Reduction

The effect of abrupt voltage reduction as viewed by the generator at its terminals—whether it is caused by a grid fault or by a targeted control action using the

SEC control (like in this case)—is a transient current in the stator winding of the machine, including possibly a dc component. A simplified version of the resulting expression is given by the following relationship [4], [5]:

The detailed derivation of an analytical expression for the transient current is somewhat involved. In [4], a formula is derived under the assumption that the WF is represented by one equivalent generator connected through an impedance to the HVDC converter. The equivalent impedance is determined through network reduction by neglecting line capacitance. Since the cables in the WF grid are usually relatively short, this grid impedance is largely determined by the transformer impedance. This simplification is permissible since the R/X ratio (rather than the absolute value of the impedance) is the determining factor for the behavior of the system upon the introduction of the voltage drop. In addition, to reduce the complexity of the mathematical relationship, the effect of the stator step voltage change on the rotor current is neglected. Equation (1)q is a further simplified version of the aforementioned expression (that can be found in [4]) and is based on the Thévenin equivalent circuit of the wind farm as a whole as viewed from the SEC side of the HVDC line. Equation (1) reveals that the current caused by the voltage drop is composed of a stationary ac and decaying ac as well as dc components. The fact that the stationary component in (1) is constant is to be considered as a further simplification since, in reality, the current—depending on the control and protection.

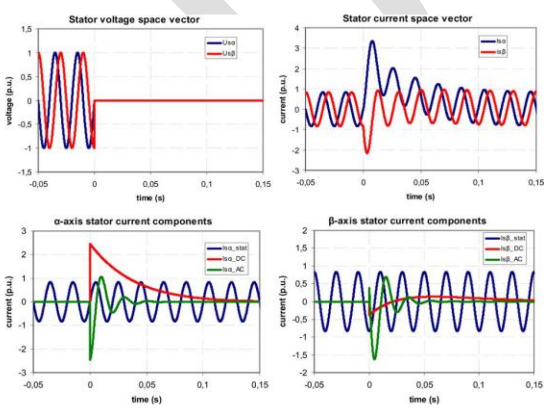


Fig. 3. Short-circuit current as a result of sudden voltage reduction.

concepts adopted—will change. For example, voltage support through reactive power injection will obviously result in a current change or a converter blocking would force the current to zero. However, these factors can be considered secondary when the discussion revolves around the effectiveness of the proposed control approach at a conceptual level. The somewhat complex relationships for admittance factors and (for details, please refer to [1]) as well as and are not provided here. Suffice it to say that they are functions of generator and network impedances. To illustrate the effect on the stator current of the machine, a sudden voltage drop is introduced as shown in Figs. 2, and 3 shows the resulting current in the DFIG-based WT. The peak current, as can be seen in Fig. 3, can easily be several times higher than the current during normal operation. It also contains a dc component. The time constant of the dc current is determined by the grid and stator impedances. It is obvious that this would need to be considered by additional reserve margins in choosing the rating of the power-electronic components. If the current increases above a certain limit, pulses in the IGBTs will be blocked which, on the other hand, means that the controllability of the converter is lost for at least 5–20 ms. The dc current may also cause a fast increase in the dc-link voltage of the WT converter, which can trigger the dc-link chopper. In addition, it can attain a level of current that can cause significant mechanical stress on the generators and the entire WT drive train.

B. Reducing the DC Component of the Short Circuit

In contrast to voltage drop resulting from grid faults, the voltage reduction in this case is introduced by the SEC control supplying the HVDC line. The idea behind the proposed approach, therefore, is to augment the functionality of the SEC control itself to reduce or eliminate the dc component of the current arising from the voltage reduction by injecting a dc voltage pulse. The procedure is illustrated in Fig. 4. In response to the short circuit (voltage reduction), a dc current starts to flow, which decays with the time constant determined by the equivalent impedance of the circuit. To initially limit and then eliminate

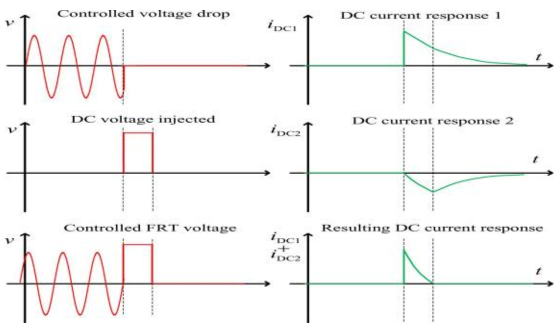


Fig. 4. Controlled voltage reduction with suppression of the dc component

this dc current, a dc voltage (of defined magnitude and duration) is applied in such a way that it drives a dc current in the opposite direction (with the original current as a reference), thus reducing the overall current [6], [7]. As the dc current increases exponentially starting from the initial value of zero, the total current (the superposition of the original dc current and that caused by the injected dc voltage) decreases faster than what would otherwise be. When the aggregate current drops to zero, the dc voltage is switched off. The entire procedure is illustrated in Fig. 4.

C. Magnitude and Duration of the DC Voltage

As stated before, the dc voltage is to be introduced together with the ac voltage drop at the WF. The resulting current rises exponentially with a gradient depending on the magnitude of the applied dc voltage and the time constant of the equivalent circuit. In order to compensate the dc current component fully, the dc voltage has to be sustained until the superimposed dc current and the dc component arising from the ac voltage drop cancel each other out, at which point the dc voltage is switched

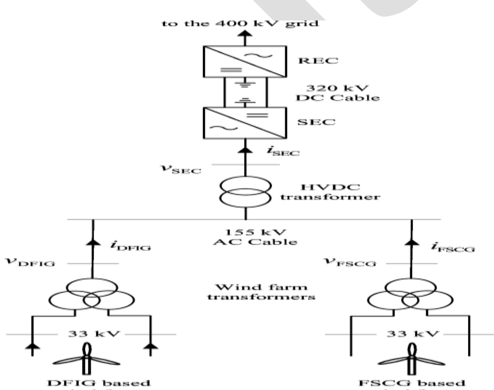


Fig. 5. Test network.

off. From that point onwards, both dc current components will decay with the same time constant and cancel each other out until both have died down. For successful application of themethod, a proper selection of the pulse duration , magnitude , and phase angle of the dc voltage are essential. This enables that the dc voltage be switched off exactly at the same instant at which the two dc current components are equal, as described before. For the determination, the pulse duration , the AC voltage drop to be introduced, the DC voltage amplitude, and its phase angle (starting point synchronized with the ac system as a reference) need to be specified first. The procedure can be summarized as follows. • First choose the ac voltage drop and the value of the accompanying dc voltage to be introduced. The ac voltage drop is determined on the basis of the power reduction that needs

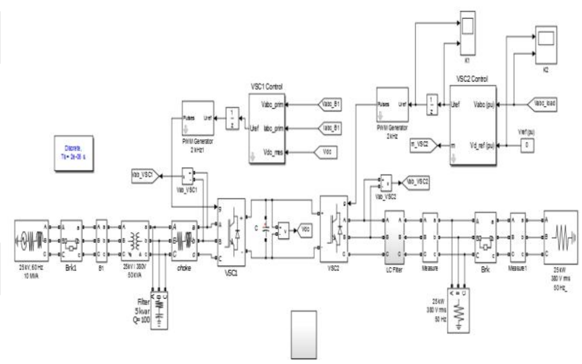
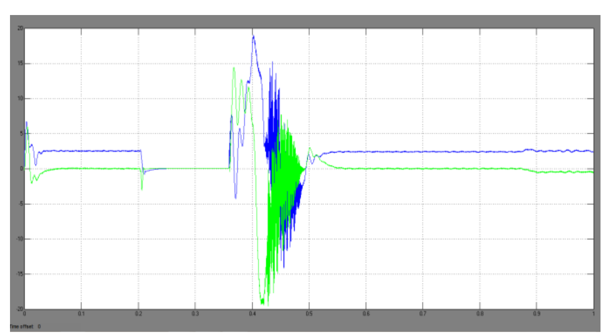


Fig. 6. Simulation circuit of the HVDC line after application of a sudden voltage drop at SEC without dc voltage injection

P & Q at sending end



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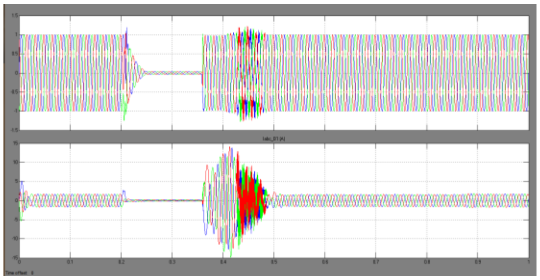
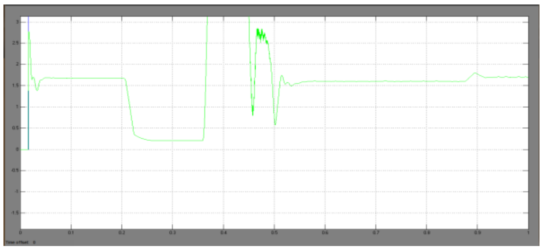
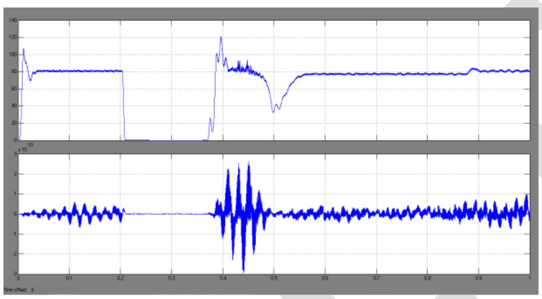


HVDC voltages at sending end



P & Q at receiving end



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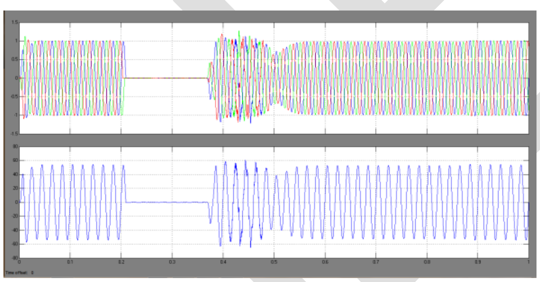


HVDC voltages at receiving end

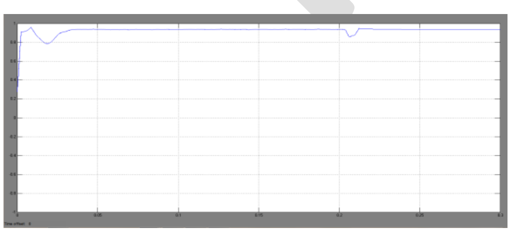
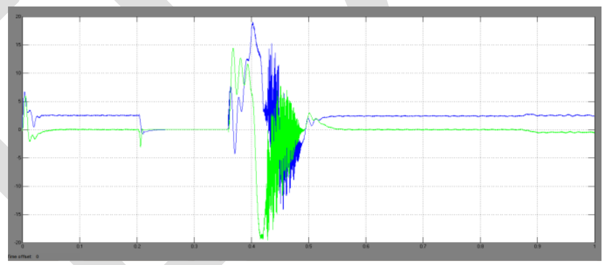


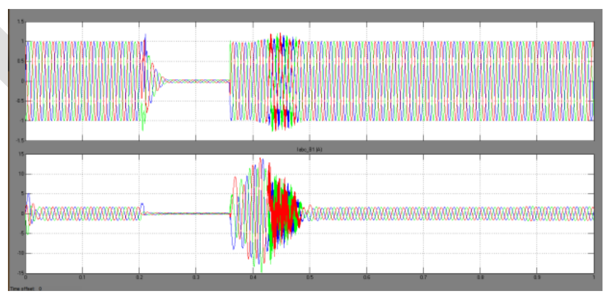
Fig. 7. Simulation results of the HVDC line after application of a sudden voltage drop at SEC without dc voltage injection

to be introduced depending on the severity of the fault. If a fast communication link between REC and SEC is not available, it would make sense to introduce 100% voltage reduction at the SEC end of the WF grid. The same applies to the dc voltage as well, that is, the application of the maximum possible dc voltage. The maximum value is given by the converter limit, and that, in turn, is determined by the available dc voltage and degree of modulation. Applying the full voltage is therefore recommended because that makes the entire process faster and enables a more effective cap on voltage rise in the HVDC line following a fault.

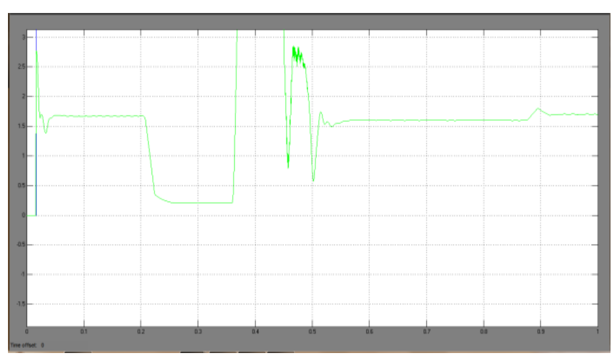
. P & Q at sending end



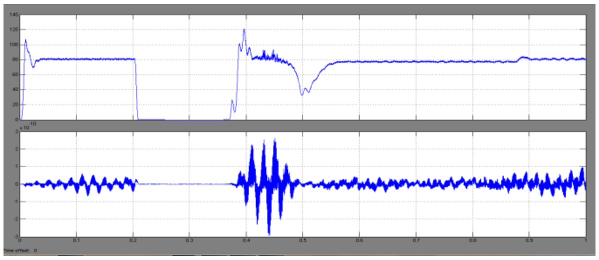
V & I at sending end



HVDC voltages at sending end



P & Q at receiving end



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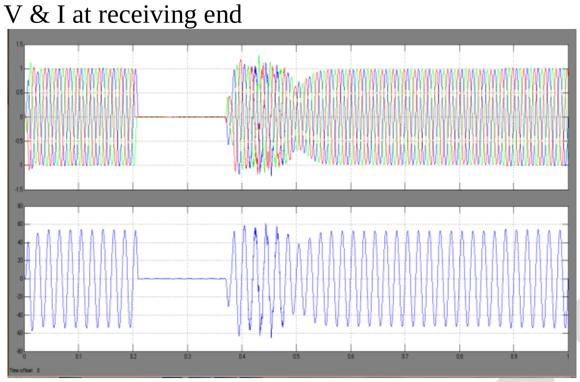


HVDC voltages at receiving end

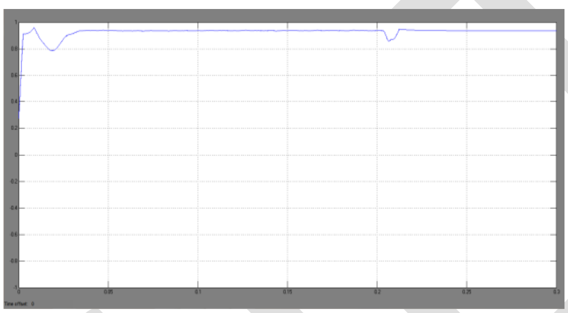


Fig. 8. Simulation results of the HVDC line after application of a sudden voltage drop at SEC and using the proposed method.

• With the ac and dc voltages specified, one can then determine (by equating the expressions for both dc currents) the phase angle and the duration of the dc voltage. (A detailed derivation can be found in [1].)

It should be mentioned that the approach described before is fraught with a small error arising from the use of simplified network impedance. But this error can be detected and accounted for by HVDC converter control. Due to the fast converter control capability, the fully rated converter WT can reduce the dc current component considerably on its own. Therefore, reducing the high peak current, which is the main objective of the proposed method, is rather an issue of concern primarily in DFIGbasedWT. The effectiveness of the approach used formore than one HVDC station is also yet to be tested. Since the speed of the voltage rise in the differentHVDC lines can differ, the triggering may not occur concurrently. The resulting transient process and its effect on the control system will be investigated in a future study.

IV. SIMULATION RESULTS

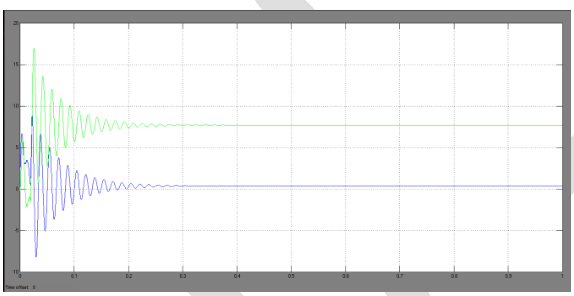
To assess the performance of the proposed scheme, a simulation was performed using the test network shown in Fig. 6. The data used for the simulation are as follows: rated power: 600 MW (2 300 MW), dc voltage: 250 kV, 155-kV cable: 5 km; HVDC transformer: 15%. The test network includes both types of WT, namely, DFIG and FSCG, as shown in Fig. 6. The WTs are represented by detailed realistic EMT-typemodels including the converters and

their control and protection systems. It should bementioned that allWTs are equipped with ac voltage controllers per the German grid-code requirement to stabilize the voltage within th e wind farm.To evaluate the improvement in terms of enhanced FRT capability that can be achieved using the proposed approach, a three-phase fault close to the connection point in the onshore grid has been simulated, which prompts the SEC (after a short delay) to a 100% wind farm ac voltage drop. The two alternative ways of introducing the voltage drop using the SEC are shown in Fig. 7. To repeat what was stated earlier, in the first alternative, merely the ac voltage is reduced to zero (Fig. 7, left-hand side), and in the proposed approach, however, together with the ac voltage drop, a dc voltage of a predefined value is introduced and sustained for a predefined time interval (Fig. 7, right-hand side).

The simulation results are summarized in Figs. 6–15. Figs. 6 and 7 compare the results obtained when voltage at the receiving end of the line collapses to zero, without the supplementary dc voltage (Fig. 8) and when augmented with the dc voltage injection (Fig. 9). As a result of the fault in the ac grid, obviously no power is being transferred to the ac network. The SEC in both cases reduces the voltage quickly to zero after a certain initial delay of some milliseconds. The SEC current shows a spike of approximately 2.0 p.u (Figs. 8–14). The dc voltage in both cases is stabilized at a value of ca. 1.15 p.u. Immediately following the fault,without the controlmeasure, the SEC causes the voltage to collapse immediately. With the proposed measure, however, the SEC holds the voltage at a certainvalue for a specified duration (in this example, for a duration of 3 ms). This causes (as can be seen in Fig. 9 by comparing it with Fig. 8) the SEC current amplitude to be reduced. The proposed method has no influence on REC. Following the voltage recovery, the active power supply is restored within a short time span.

Figs. 10 and 12 further demonstrate the effect of the proposed method on the WF generators. As can be seen, in both cases, the WTs are forced to ridethrough the fault as a result of the targeted voltage reduction initiated by the SEC. Comparing the simulation results with and without the proposed method, one easily observes the essential improvement, that is, the reduction.

- P & Q at sending end



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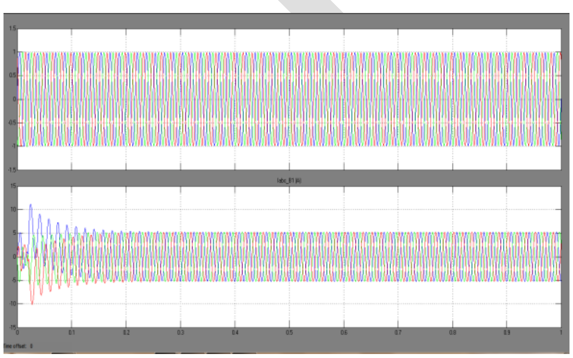
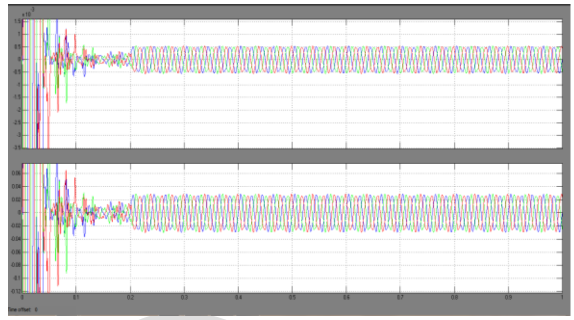


DFIG VOLTAGE AND CURRENT



DFIG Torque

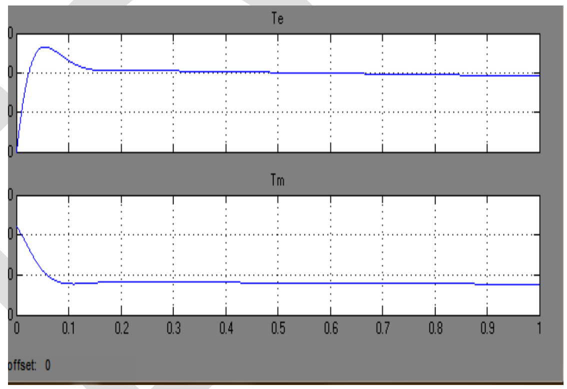


Fig. 9. Simulation results of theWF after application of a sudden voltage drop at SEC without dc voltage injection.

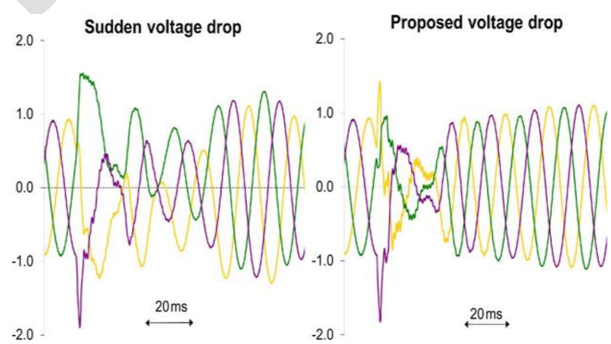


Fig 10. Comparison of SEC currents (in per unit) following a voltage drop.

of the maximum short-circuit current in the DFIG. Without the controlled voltage reduction, it would have been 2.8 p.u. (in this example), but it is reduced to 1.7 p.u.when the proposedmethod is implemented. Fig. 13 summarizes the effect of the method in reducing the stress on the WF.

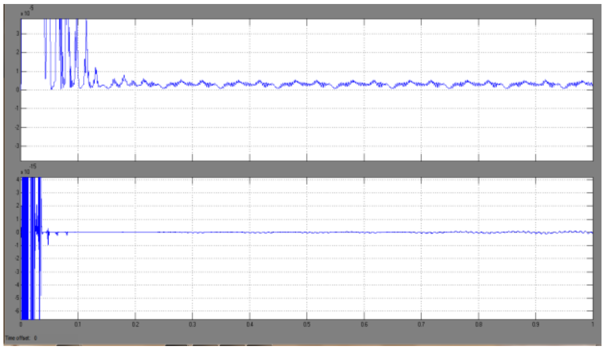


Fig. 11. Simulation results of theWF after application of a sudden voltage drop at SEC using the proposed method.

The instantaneous values of the current immediately following

BASIC FUZZY ALGORITHM

In a fuzzy logic controller, the control action is determined from the evaluation of a set of simple linguistic rules. The development of the rules requires a thorough understanding of the process to be controlled, but it does not require a mathematical model of the system. The internal structure of the fuzzy controller is shown in Fig.4.2.

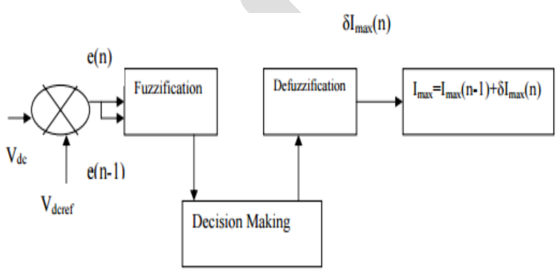


Fig. 12. Internal structure of fuzzy logic controller.

A fuzzy inference system (or fuzzy system) basically consists of a formulation of the mapping from a given input set to an output set using fuzzy logic. This mapping process provides the basis from which the inference or conclusion can be made. A fuzzy inference process consists of the following steps:

• Step 1:Fuzzification of input variables

• Step 2: Application of fuzzy operator (AND,OR,NOT) in the IF(antecedent) part of the rule

• Step 3: Implication from the antecedent to the consequent(THEN part of the rules)

• Step 4: Aggregation of the consequents across the rules

• Step 5: Defuzzification

The crisp inputs are converted to linguistic variables in fuzzification based on membership function (MF).

An MF is a curve that defines how the values of a fuzzy variable in a certain domain are mapped to a membership value μ (or degree of membership) between 0 and 1. A membership function can have different shapes, as shown in figure 4.4. The simplest and most commonly used MF is the triangular-type, which can be symmetrical or asymmetrical in shape. A trapezoidal MF has the shape of a truncated triangle. Two MFs are built on the Gaussian distribution curve: a simple Gaussian curve and a two-sided composite of two different Gaussian distribution curves. The bell MF with a flat top is somewhat different from a Gaussian function. Both Gaussian and bell MFs are smooth and non-zero at all points.

The basic properties of Boolean logic are also valid for Fuzzy logic. Once the inputs have been fuzzified, we know the degree to which each part of the antecedent of a rule has been satisfied. Based on the rule, OR or AND operation on the fuzzy variables is done. The implication step helps to evaluate the consequent part of a rule. There are a number of implication methods in the literature, out of which Mamdani and TS types are frequently used. Mamdani, proposed this method which is the most commonly used implication method. In this, the output is truncated at the value based on degree of membership to give the fuzzy output. Takagai-Sugeno-Kang method of implication is different from Mamdani in a way that, the output MFs is only constants or have linear relations with the inputs. The result of the implication and aggregation stpes is the fuzzy output which is the union of all the outputs of individual rules that are validated or "fired". Conversion of this fuzzy output to crisp output is defines as defuzzification. There are many methods of defuzzification out of which Center of Area (COA) and Height method are frequently used. In the

COA method (often called the center of gravity method) of defuzzification, the crisp output of particular variable Z is taken to be the geometric center of the output fuzzy value µout(Z) area, where this area is formed by taking the union of all contributions of rules whose degree of fulfillment is greater than zero. In height method of defuzzification, the COA method is simplified to consider the height of the each contributing MF at the mid-point of the base. Here in this scheme, the error e and change of error ce are used as numerical variables from the real system. To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big) [6]. The fuzzy controller is characterized as follows:

• Seven fuzzy sets for each input and output. • Triangular membership functions for simplicity.

• Fuzzification using continuous universe of discourse.

• Implication using Mamdani's 'min' operator.

• Defuzzification using the 'height' method.

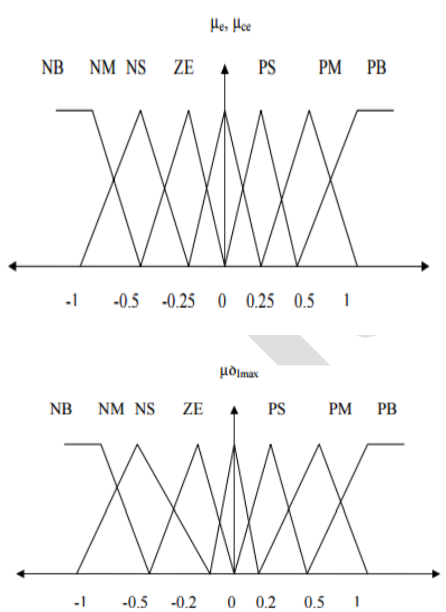


Fig.13. Normalized triangular functions used in fuzzification (a)Membership functions for e and ce (b)Membership function for δImax

DESIGN OF CONTROL RULES

The fuzzy control rule design involves defining rules that relate the input variables to the output model properties. As FLC is independent of the system model, the design is mainly based on the intuitive feeling for, and experience of, the process. A new methodology for rule base design based on the general dynamic behavior of the process has been introduced in [18] which is further modified [14]. The input variables of the FLC are the error e and the change of error ce. The output is the change of the reference current (δImax). The time step response of a stable closed loop system.

The system equilibrium point is the origin of the phase plane. The time response has been divided into four regions A1,A2,A3, and A4 and two sets of points - cross-over (b1, b2) and peak (c1, c2).

Based on these four areas, two sets of points and phase plane trajectory of e and ce, the rule base is framed. The corresponding rule for the region 1 can be formulated as rule R1 and has the effect of shortening the rise time

R1 : if e is + ve and ce is - ve, then δImax is +ve

Rule 2 for region 2 decreases the overshoot of the system response, which can be written as

R2 : if e is - ve and ce is - ve; then δImax is – ve Similarly, rules for other regions can be formed.

For are determined based on the theory that in the transient better control performance finer fuzzy partitioned sub- state, large errors need coarse control, which requires spaces (NB, NM, NS, ZE, PS, PM, PB) are used, and coarse input/output variables; in the steady state, are summarized in Table 4.2.1. The elements of this table however, small errors need fine control, which requires fine input/output variables. Based on this, the elements of the rule table are obtained from an understanding of the filter behavior and modified by simulation performance.

error(e) b1

A₂ A₁ c1 a,c2 Change in error(ce) A₃ A₄ b2

	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	Ps
NB	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Table1.Control rule table

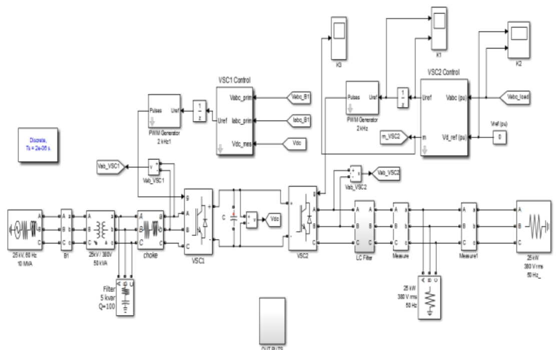
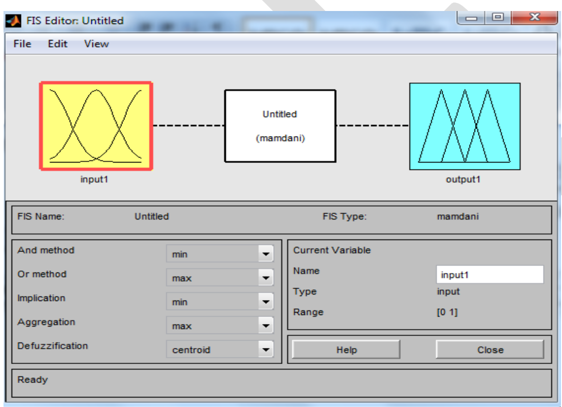
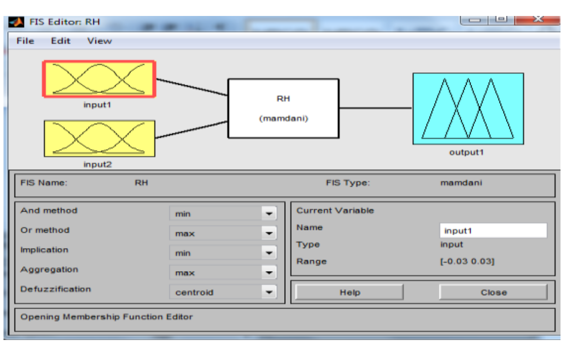
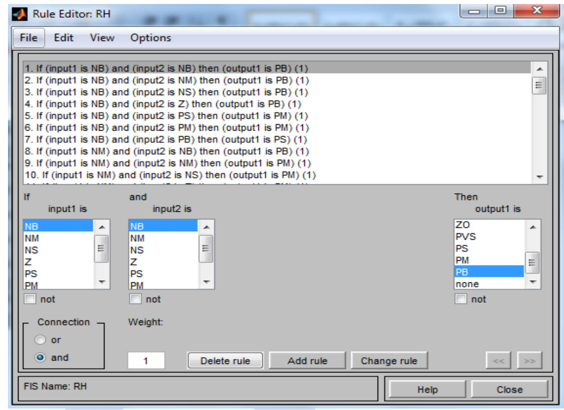
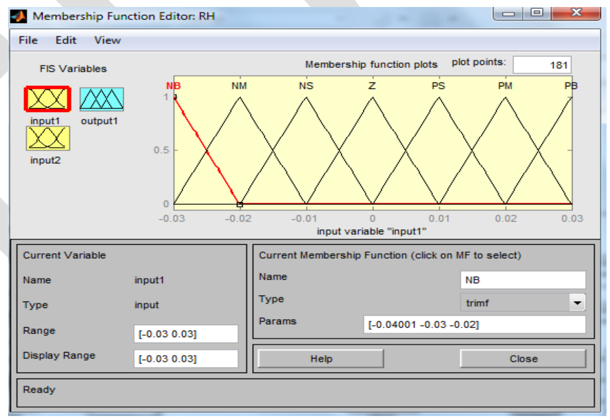


Fig. 14.Fuzzy based simulation circuit of the WF.

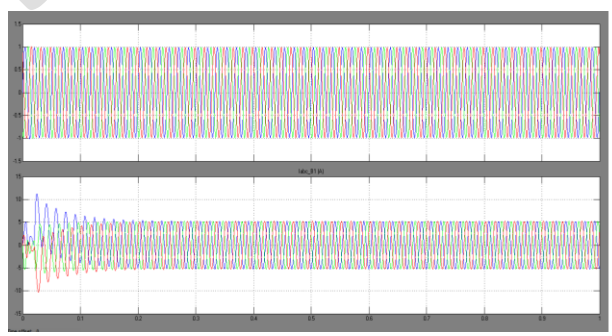




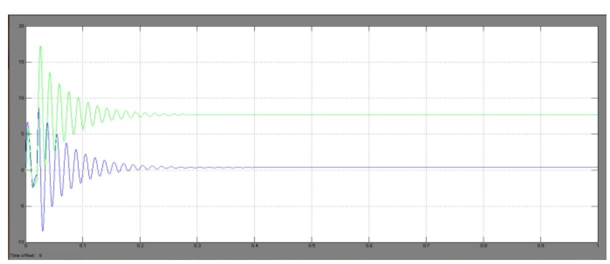




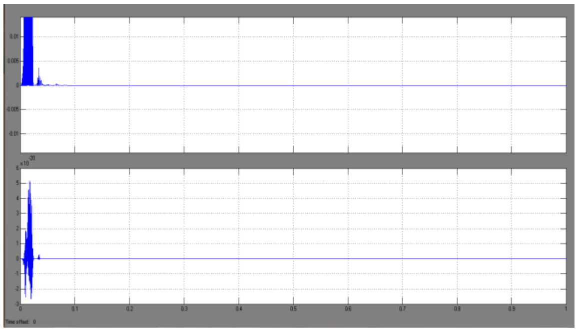
. V & I at sending end



. P & Q at sending end



P & Q at receiving end



V & I at receiving end

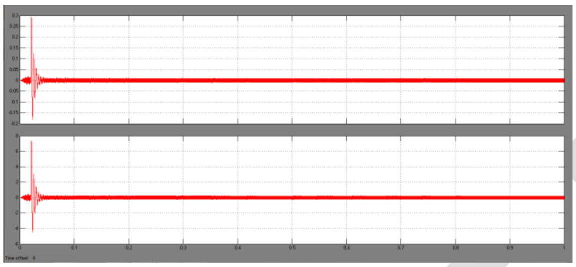


Fig. 15. Simulation results of theWF after application of a sudden voltage drop at SEC without dc voltage injection.

the voltage reduction are once again shown in Fig. 8 (for the SEC), Fig. 10 (for the DFIG). The maximum current (as stated in the previous paragraph) is reduced from 2.8 to 1.7 p.u. As can be seen in Figs. 10 and 12, the maximum value of the electromagnetic torque following the voltage drop is significantly reduced in the DFIG by the proposed method. However, the improvement in terms of the reduction of the maximum stress arising from the short-circuit current is small in the FSCG (Fig. 14). It should be noted that the current in any case is not as high as that in the DFIG. The proposed method has therefore less impact when it comes to the FSCG because the FSCG possesses a larger voltage control margin and is capable of a faster control response in grid operation compared to the DFIG.

V. CONCLUSION

In this paper A VSC-HVDC transmission system is a candidate to meet these challenges due to its operational flexibility, such as provision of voltage support to ac networks, its ability to operate independent of ac network strength therefore makes it suitable for connection of weak ac networks such as offshore wind farms, suitability for multi terminal HVDC network realization as active power reversal is achieved without dc link voltage polarity change, and resiliency to ac side faults.

This concept presents fuzzy control approach for enhancing the fault ride through capability of wind farms connected to the grid through a voltage-source-converter-based high-voltage dc transmission line. A controlled voltage drop in the wind farm collector grid is initiated upon the occurrence of fault in the high-voltage grid in order to achieve fast power reduction. In the process, a dc voltage of defined magnitude and duration is injected by the sending-end converter together with the voltage reduction to suppress the dc component of the short-circuit current arising from the voltage reduction. As a result, the electrical and mechanical stress on the wind turbines, especially on the DFIG-based units and their converters, are mitigated these analysis are performed by using MAT Lab/Simulink.

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