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Performance of a PMSG Based Wind Energy Conversion System by Using Fuzzy Logic Controller

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Abstract-

Using a fuzzy logic controller, vector control, and direct torque control, a reliable and effective control system may be developed for WECSs based on a permanent magnet synchronous generator (PMSG) to improve machine performance. When it comes to power generation and grid compliance, fast transient and steady state performance of wind energy conversion systems (WECSs) are critical. Two hysteresis current controllers and an inverter-switching table are part of the system. Fast transient and smooth steady state performance for the machine side converter of PMSGs, which regulates the DC-link voltage under grid fault circumstances, is provided by the suggested control method.

I.INTRODUCTION

In many countries, transmission system operators have produced new regulations for grid integration of wind energy conversion equipment in response to the growing penetration level of wind energy in electrical networks (WECSs). It is mandated by the grid code that WECSs stay linked to the framework and flexibly responsive force into the lattice to aid matrix voltage recuperation. Low voltage ride-through (LVRT) capacity is the term often used to describe it. Perpetual

magnet simultaneous generator (PMSG) based WECS is now the fastest-growing WECS. By virtue of their entirely appraised converters that supply absolute separation from the lattice disturbing impacts, PMSGs are less vulnerable towards matrix blames and might effectively sustain the framework amid deficient circumstances. In a PMSG control structure, regulators for the machine and matrix sides are included. Most extreme force point may be achieved under normal network circumstances by controlling the PMSG's dynamic capacity through MSC

In many countries, transmission system operators have produced new regulations for grid integration of wind energy conversion equipment in response to the growing penetration level of wind energy in electrical networks (WECSs). It is mandated by the grid code that WECSs stay linked to the framework and flexibly responsive force into the lattice to aid matrix voltage recuperation. Low voltage ride-through (LVRT) capacity is the term often used to describe it. Perpetual magnet simultaneous generator (PMSG) based WECS is now the fastest-growing WECS. By virtue of their entirely appraised converters that supply absolute separation from the lattice disturbing impacts, PMSGs are less vulnerable towards matrix blames and might effectively sustain the framework amid deficient circumstances. In a PMSG control structure, regulators for the machine and matrix sides are included. Most extreme force point may be achieved under normal network circumstances by controlling the PMSG's dynamic capacity through MSC following (MPPT), while the GSC keeps up the dc-interface voltage steady and manages the GSC responsive force yield [3]. Under matrix flaw

The GSC was unable to transfer the whole MSC yield capacity to the network due to a lack of basic coupling (PCC). To avoid damaging sensitive WECS equipment, this might cause a DC connection overvoltage. In this approach, the PMSG is unable to maintain its connection to the framework and to support the matrix voltage in the event of network failures. Equipment modification and control adjustment are the two basic categories of LVRT techniques that have been put out in the literature [4]. The LVRT capability of PMSG-based WECS may be improved by the use of equipment such as an energy storage device [5], dynamic crowbar,

slowing chopper [6, 7], FACTS (adaptable exchanging current transmission systems) [8], layout dynamic breaking resistors [9], and so on. However, these methods typically increase the overall cost and complexity of the framework, and some of them don't have the network responsiveness necessary to fulfill the most current matrix code demands in an elegant manner. To meet the need for receptive force injection, a slowing chopper can only spread power and should be coupled with other measures [4]. Because of these issues, control adjustment approaches are considered the most popular LVRT procedures. It is not necessary to use extra equipment when using PMSG-based WECS control methods such as pitch point control or consecutive converters control. As compared to the control of the converter, the improvement in pitch point control is less significant [10]. Under normal circumstances, both vector control (VC) and direct force control (DTC) are used to control MSC in exchanged obligations schemes to provide the ability to LVRT [4], [12]. On the other hand, since electric machines respond faster to DTC, it may be a suitable choice in a traded obligations scheme [11]. Using this method, a faster machine response prevents an unneeded DC-connect overvoltage by quickly reclaiming the harmony between the machine power and the matrix power when there are defects. Overall, the DTC is a good choice.

Matrix-joining wind energy isn't appealing since VC creates greater waves on machine factors [18]. A consolidated (CC) method is suggested for acceptance engines [10], [11] and DFIG-based WECSs [12], [13] in order to take use of the advantages of VC and DTC in a coordinated control framework and to overcome some of the disadvantages of both strategies. Perpetual magnet coordinated engines [11] need a further

adjustment to the technique. CC guidelines for PMSGs are established and a crucial CC method for lattice typical circumstances is described in this research. To boost LVRT capabilities while maintaining excellent control under the PMSG-based WECSs, another CC approach is developed.

This part introduces the analytical foundation and system structure of the combined control approach for regular MSC operation. Analytical evaluation of the suggested CC-based LVRT approach for MSC is then provided. In addition, a basic explanation of GSC control is given..

A. BASIC PRINCIPLES OF CC FOR PMSGs

The stator flux linkage deviations may be used to approximate (3) and express the electromagnetic torque deviation as [14, 15].]:

$$\Delta T_{em} = K_1 \Delta x + K_2 y, \quad (6)$$

where k_1 and k_2 are defined as:

common occurrences in a framework's state Fast transient response under network fault situations and smooth execution under consistent state conditions are achieved by ensuring these guarantees. All the more critically, the proposed

$$K = 3P\lambda$$

$$2L_s$$

$$K = 3P\lambda$$

reference frame, i.e. the x-y coordinates, are presented

$$2L_s$$

$$\sin(\delta), \quad (7)$$

$$\cos(\delta) \quad (8)$$

II. According to CC's analysis, the DC-connect overvoltage falls dramatically under lattice defects. Basic CC displays are compared to those of VC and DTC under lattice-normal settings. As a result, one of the most well-known approaches to LVRT is compared with a suggested LVRT strategy. In all circumstances, the suggested CC allows for an unequaled display.

III. PERMANENT MAGNET SYNCHRONOUS MACHINE MODEL

Voltage equations of PMSGs in a stator flux linkage

With the help of flux linkage components, it is possible to regulate electromagnetic torque. The angle and magnitude of the stator flux linkage are known to affect torque during DTC. The management of stator flux linkage components, as shown in (6) [14], is equivalent to torque control in DTC. In contrast, the generator current component deviations [14] might indicate the electromagnetic torque: $\Delta T_{em} = K_3 \Delta i_x + K_4 \Delta i_y, \quad (9)$

where k_3 and k_4 are obtained as:

$$3K = P\lambda$$

$\sin(\delta)$, (10) as [11]:

$$V_y = R_s i_y + \omega_s \lambda_s, \quad (1)$$

$$V = R_i + P\lambda, \quad (2)$$

$$3 \quad 2 \quad m$$

$$3$$

$$K_4 = 2P\lambda_m \cos(\delta). \quad (11)$$

$$x \quad s_x \quad s$$

Where V , I , R_s , s , and s are the generator voltage, current, stator resistance, and stator flux linkage speed and magnitude.. In the reference frame, the subscripts 'x' and 'y' denote the direct and quadrature components, respectively, while the derivative operator p signifies the difference between the two. According to [11]: The electromagnetism torque of PMSGs

Equation (9) presents a basis for control of electromagnetic torque by current components as in VC [14].

The coefficients of (6) and (9) are linearly related as:

$$K_3$$

$$= L_s, \quad (12) \quad K_1 K_4$$

$$T = 3P\lambda \sin(\delta) \quad (3)$$

$$K = L_s, \quad (13)$$

$$e_m = 2L_s \quad s_m \quad 2$$

Magnet flux linkage magnitude (MFL), stator phase inductance (L_s), magnet flux linkage magnitude (MML), pole pairs (P

and δ) and the machine's load angle (δ) are all included in this equation. [13]: The generator's active and reactive power may alternatively be derived as [14]:

$$P_m = 2(V_x i_x + V_y i_y), \quad (4)$$

Equations (12) and (13) in connection with (6) and (9) imply that:

$$\Delta \lambda_x \Delta i_x, \quad (14)$$

$$\Delta \lambda_y \Delta i_y, \quad (15)$$

(14) and (9) are shown in Fig. 1. (15). According to these proportionalities, DTC and VC perform dynamic and cyclical roles

$$3$$

$$Q = (V_i$$

$$-V_i), \quad (4)$$

receptive force control of PMSGs similarly through

$$m \quad 2 \quad y_x \quad y_y$$

Where P_m and Q_m are the machine active and reactive powers.

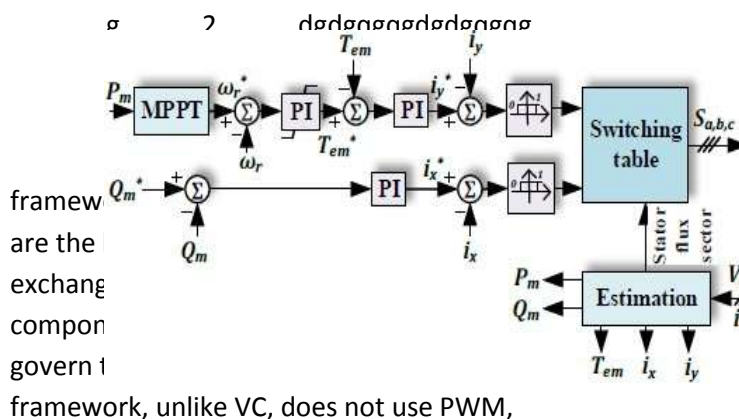
IV. CONTROL SYSTEM

either current deviations or transition linkage

deviations. As a result, it is possible to trade DTC and VC's transition linkage control and current control separately. In the same way, we may create a

the best features of DTC and VC into one comprehensive control framework. In addition, it may eliminate some of the less desirable aspects of these methods and lessen the complexity of their structures. Because of its unique sensitivity to hysteresis regulators and swapping table execution, DTC versus VC is an excellent component. Instead of having to deal with constant current, motion linkage and force flags, smooth machine operation may be achieved by using a VC framework. In addition, a VC framework includes a PWM with requiring computations in its most simple design. Fig. recalling the previous talk,.

2 delineate the CC framework with a half way DTC



which results in less demanding and faster computations. The force order is given by the speed regulator's yield, and this determines i_{xy} . Decoupling the framework and improving its dynamic activity do not need feed-forward indicators, as they do in VC frameworks. Fig. 2 shows an introduction to the CC method under network-typical settings. In spite of this, though, it forms the reason for

It happens that equations (4) and (18) lead to [18]: where the superscripts "+" and "-" differentiate between positive and negative sequences, as well as subscripts "d" and "q," which distinguish between direct and quadrature components in the grid voltage reference frame; The GSC quantities are denoted by the subscript 'g'. If i_x is assumed to be zero, a symmetrical grid has a high power factor and negligible stator resistance loss.

$$P = 3V_i \quad (19)$$

$$2$$

$$P = 3V_i +$$

$$g \quad 2 \quad d_g \quad d_g$$

presenting the new traded obligations

$$=3V \quad I$$

(20)

$$2dgdg$$

By ignoring losses, the grid power reference in swapped duty method is given by

$$p^* = K$$

$$\omega_{opt}$$

$$\omega_3 \quad (21)$$

Block diagram of basic combined control for the MSC of a PMSG-based WECS in stator flux linkage reference frame shown in Fig 2.

The LVRT approach will be discussed in detail in the paragraphs to come. To avoid ambiguity, it is thought of as the "basic" CC in Figure 2.

B. MSC CONTROL IN SWAPPED DUTY METHOD

By ignoring losses, the DC-link voltage can be calculated as

where P_g^* is the grid power reference and K_{opt} is the turbine MPPT. A mechanical time constant deviates from P_g^* in accordance with (21). Grid injected power

drops instantly when a failure occurs due to a reduction in V_{dg} . Due to the delayed reaction of the rotor's mechanical body, P_g^* remains constant. As a result, due to the grid power reference's mechanical time constant, the GSC's ability to alter its power is exceedingly sluggish. Thus, MSC's capacity to quickly transform machine-generated power into grid-injected electricity is critical. Due to the DC-link voltage control loop's low electrical time constant, the MSC is capable of completing the job. MSC dynamic response dominates DC-link voltage regulation in swapped-duty LVRT techniques.

C.

GRID FAULT CONDITIONS CONTROL

Combining the best features of both the VC and CC systems

$$C_{dc} = C_{dc} - P_m - P_g$$

$$V_{dc}$$

$$dV_{dc}$$

At that point (16) dt

Structures of DTC in a system of integrated control. Because of this, it is predicted to maintain a consistent performance level

C_{dc} and V_{dc} denote the DC-link capacitance, machine, grid, and DC-link voltage in this equation. To calculate DC-link voltage variation, we need to multiply the following expression by the

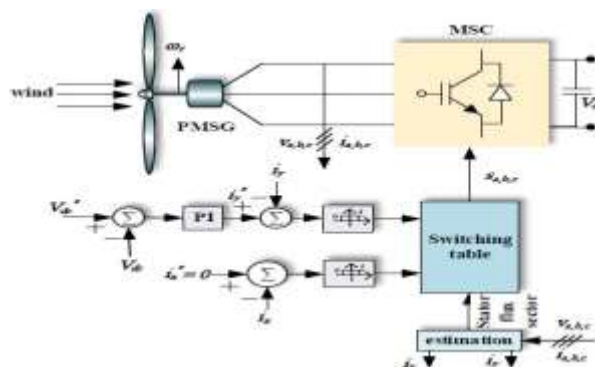
In other words, the dV_{dc} is equal to $P_m - P_g$ (17)

$$dt C_{dc} V_{dc}$$

DTC's quick transient reaction is reminiscent to VC's. In typical grid settings, it is preferable to have less torque ripple and less total harmonic distortion (THD). A rapid transient reaction to increase the ability of the LVRT to reduce the PMSG output power as quickly as feasible is desired under grid fault scenarios." Because of this,

In both normal and fault settings, the CC technique is an excellent choice for MSC control.

The LVRT capabilities of PMSG-based converters might be improved by switching the control roles of back-to-back converters.



Assuming that V_x is equal to I_x , then $I_x = I_x$ (25)

When compared to the DC-link voltage, WECSs need no extra gear. It is the GSC that performs MPPT and the MSC that regulates the DC link voltage. Electricity's various parameters

The following is the greatest generator power fluctuation when (25) is replaced with (22):

electrical variables have a much faster transient response time

3

Is $P_m = 2V_s$?

(26)

rotating speed. As a result, as described in section B, the CC approach with quick transient reaction is more effective for MSC control. The suggested control system is shown in block diagram form in Figure 3. The quadrature component of the current command is generated by the DC-link voltage controller, whereas the direct component command is zero. The hysteresis current controllers compare the current instructions with their actual values and provide output flags as inputs to the optimum switching table. The stator flux position is the table's third input.

Combination control for PMSG-based WECS with an LVRT capability is shown in Figure 3.

The stationary reference frame's linkage vector. The optimum switching table selects the states of MSC switches to provide the proper voltage vectors. Grid faults are dealt with by using a dual current controller with positive and negative sequence control and peak current limiting control on the GSC.

D. MSC RESPONSE ANALYSIS UNDER CC The machine power variation during an MSC

Fuzzy logic controller basics and implementation for wind-DG hybrid micro grid are shown in this section.

Mystical Math

Rule-based fuzzy logic is the basic technique for mapping input data into an output data space.. The sequence in which the rules are examined is irrelevant since they are all evaluated simultaneously. It is the variables and the adjectives that characterize the variables that make the rules valuable in and of themselves. Prior to creating a rule-interpreting system, you must define all of the words and adjectives you want to use to describe them in order to do so. To

It's not enough to remark that the water is hot; you need to specify the temperature range you're talking about as well.

Two times the standard deviation of the many

changeover period may be calculated as follows according to (4):3

$$\Delta P_m = 2(V_x \Delta i_x + V_y \Delta i_y) \quad (22)$$

Assuming the current magnitude deviation is constant and equal to Δi during the interval, we have:

3

$$\Delta P_m = (V_x \Delta i_x + V_y \Delta i_y) \quad (23)$$

Then, a maximum rate of change for the machine power is obtained under the following condition:

$$\partial(\Delta P_m) = 3(V - V \Delta i_x) = 0 \quad (24)$$

It is $2i^2 i^2$

s x

This has the effect of:

"Hot" refers to the temperature of anything. What follows is an example of a diagram.

the fuzzy inference process's path map It conveys a broad picture. Fuzzy logic controller basics and implementation for wind-DG hybrid micro grid are shown in this section.

Mystical Math

Rule-based fuzzy logic is the basic technique for mapping input data into an output data space.. The sequence in which the rules are examined is irrelevant since they are all evaluated simultaneously. It is the variables and the adjectives that characterize the variables that make the rules valuable in and of themselves. Prior to creating a rule-interpreting system, you must define all of the words and adjectives you want to use to describe them in order to do so. To

It's not enough to remark that the water is hot; you need to specify the temperature range you're talking about as well.

Two times the standard deviation of the mean

It is 2σ ± 2σ

s x

This has the effect of:

"Hot" refers to the temperature of anything. What follows is an example of a diagram.

the fuzzy inference process's path map. It conveys a broad picture.

FUZZY LOGIC CONTROLLER

Introduction:

Fuzzy logic controller basics and implementation for wind-DG hybrid micro grid are shown in this part.

Fuzzy Reasoning

Rule-based fuzzy logic is the basic technique for mapping input data into an output data space. It makes no difference what order the rules are assessed in. A rule's reference to

variables and the descriptive adjectives associated with those variables is an asset in and of itself. Prior to creating a rule-interpreting system, you must define all of the words and adjectives you want to use to describe them. To

To describe water as hot, you must provide the temperature range in which it can be anticipated to fluctuate as well as the range in which it can be expected to fluctuate.

"(ix)" two times

y

It is 2σ ± 2σ

s x

As a consequence of this:

When we say "hot," we mean it in the literal sense. Here is a diagram to help you visualize it.

detailed instructions for making fuzzy inferences. It reveals the species.

description of a fuzzy system on the left and a specific fuzzy system on the right.

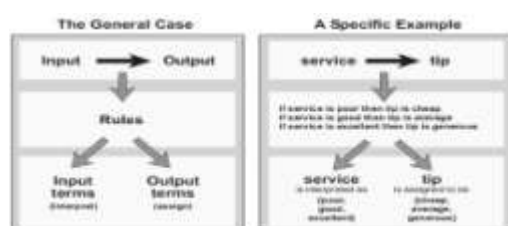


Fig: Example of Fuzzy Logic

The fuzzy inference technique represented in the figure 6.1 is a way of interpreting the values in the input vector and assigning values to the output vector based on some set of

rules. Mathematical models that obey the rules of physics, stochastic models, or models derived from mathematical logic are often used to explain control systems today. Getting from a real-world situation to an appropriate mathematical model might be challenging

when using a paradigm like this. Even though modern computer technology now makes it

feasible, it is still too difficult to manage systems of this kind.

During the modeling phase, a tolerance margin for a suitable



level of imprecision, ambiguity, and uncertainty may be used to simplify these complicated systems.. A less-than-perfect system is the end result, yet it can usually solve the issue appropriately in the vast majority of circumstances. Knowledge-based systems have been shown to be useful even when input data is lacking.

Fig: The fuzzy logic Control-Analysis method

There are various well-known rationales, including fuzzy logic, in which reality estimates of variables might be any actual value between 0 and 1. Figure 6.2 depicts the results of a fuzzy logic control study. In Boolean logic, factors' reality estimates might be as simple as 0 or 1. For those who believe in half-truths, the fuzzy reasoning has been extended to include those who believe in half-truths. There are four major components shown in the figure to construct a fuzzy rationale control system: the fuzzification interface, the fuzzy induction motor, the fuzzy logical structure and the defuzzification interface. Figure 1.

Functions of Membership

Each point in input space has a membership value (or degree of membership) of 0, which is the default value, and a membership function (MF), which specifies the range from 0 to 1. It's a fancy phrase for a basic notion, but the input space may also be referred to as the "universe of conversation." A membership function must meet just one requirement: it must change.

any one of the numeric values 0 through 1. In order to suit our needs for simplicity, convenience, speed, and efficiency, we may define the function as an arbitrary curve.

The toolbox is pre-loaded with eleven different types of membership functions. These 11 functions have a total of 11 basic functions.

a set of pieces representing linear functions

Distribution function of the Gaussian distribution.

Curves that form in the brain

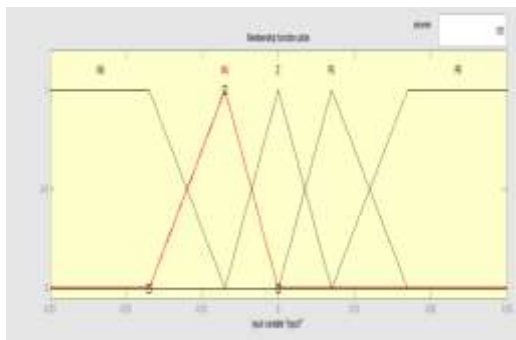
curves of quadrature and cubicity in polynomials

The simplest membership functions may be constructed using straight lines. Triangle membership function (abbreviated trimf) is the simplest. This challenge may be completed with only three points forming a triangle. The trapezoidal membership function (trapmf) seems to be nothing more than an

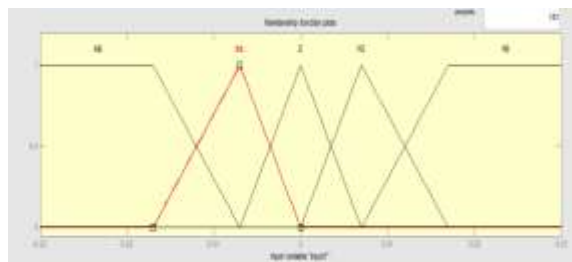
extended triangle with its flat top and truncated triangle curve. The straight-line membership functions' simplicity is a plus.

A fuzzy logic controller's membership functions are shown in an example.

below.



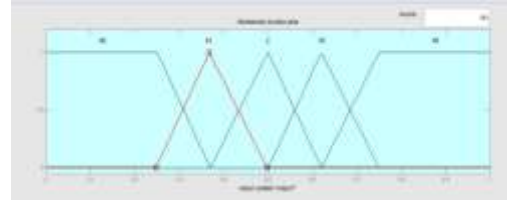
Error



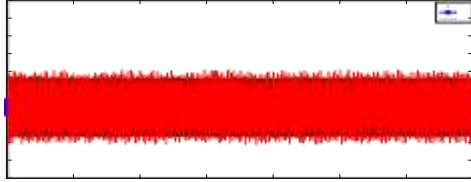
ChangeinError

Output

V.SIMULATIONRESULTS



A. PERFORMANCE OF THE SYSTEM UNDER BASICCCMETHOD



In this part, the results of the PMSG-based WECS, as shown in Fig. 2, are assessed using the basic CC approach. Q_m^* is considered to be zero in all working situations. The CC and DTC hysteresis bandwidths are set at 3% of their nominal controlled variable. Active and reactive power are considered to have a base value of 20.9 MVA, with the rated active

power of 2 MW and the power factor of 0.90. In addition, the voltage is 800 V at its lowest setting. To provide a fair comparison, the genetic algorithm (GA) is used to improve the settings of all PI controllers. $F = \int_0^t (T_{em} + |Q_s|) dt$ is the unique objective function for the optimization (27)

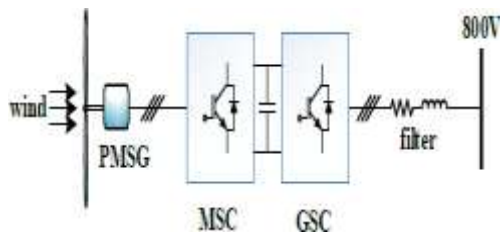


Fig.4.SimplifiedschematicoftheWECSsconnectedto network.

When the VC, DTC, or basic CCC is applied, steady-state and transient reactions of the machine are shown in Figure 5. At $t = 10$ s, the wind speed drops from 12.4 m/s to 9 m/s. Assumed that the MPPT output will achieve an appropriate speed reference at the time of 10 seconds. This will avoid the MPPT unexpected impacts on the control system

from affecting it. The generator shaft is protected from mechanical stress by limiting the speed controller's torque command output. As seen in Fig. 5, the simple CC controller gives a better steady state response than the DTC does. Consistent with VC, steady-state reaction is comparable to that under CCC

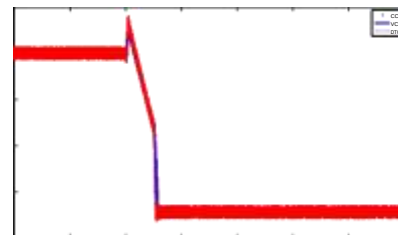
0.62

1.5

1

0.50

9.8 9.9 10 10.1 10.2 10.3 10.4 10.5



time

Fig.5.SteadyandtransientstateresponsecomparisonofbasicCC withthose ofDTCandVC.

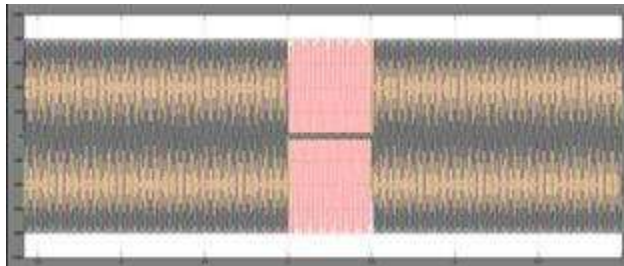


Fig.6.Gridvoltage during two-phase to ground fault.

B. PERFORMANCE OF THE PROPOSED LVRT METHOD

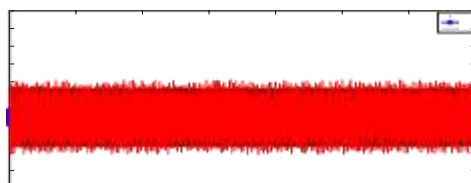
System performance under the suggested LVRT approach of the MSC is compared to the standard VC method in x-y reference frame (Fig. 3) in this section. Both the GSC and VC govern the GSC. There are no significant differences in PI controller gains between the suggested control approach and current practice. The gains of the DC-link voltage PI controller are tuned using GA in the same way as the previous ones. The GA optimization's goal function is referred to as:

An evaluation of the LVRT capacity of the device was necessary.

0.5

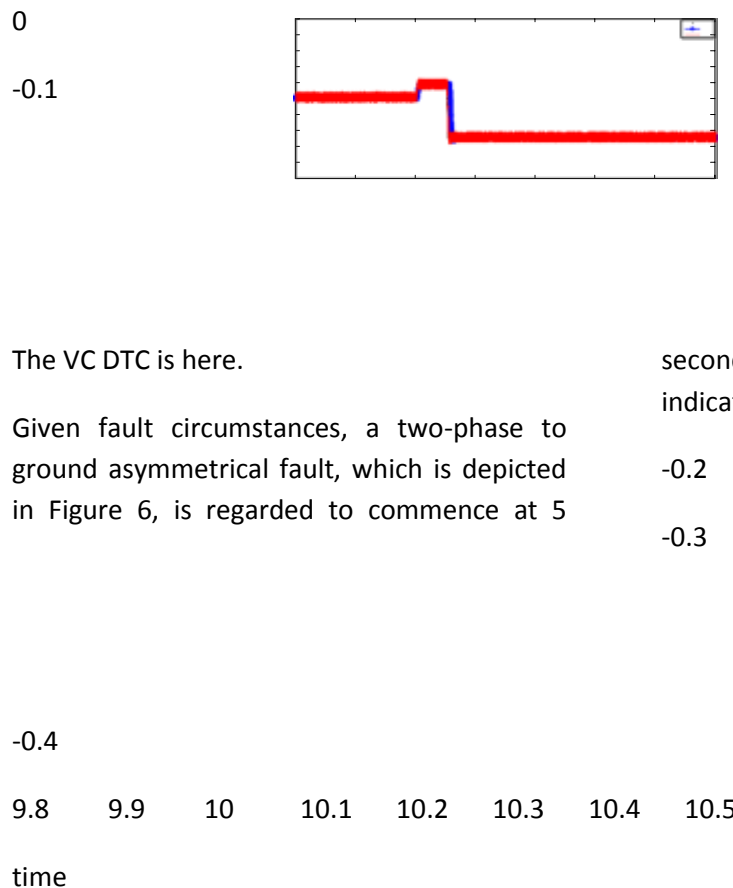
0.4

0.3



0.2

0.1



The VC DTC is here.

Given fault circumstances, a two-phase to ground asymmetrical fault, which is depicted in Figure 6, is regarded to commence at 5

seconds and be cleared at 5 minutes, as indicated in Fig. 6.

-0.2
-0.3

It is shown in Figure 7 that the suggested control technique and traditional LVRT control method have the same system performance in terms of simulation results..

Due to the quick dynamics of the proposed combined management of DC-link voltage, the suggested technique delivers a smoother DC-link voltage response under typical grid situations.

1.4

0.6

1.3

Using a brake chopper and a two-phase to ground fault, Figure 8 compares the system's transient state response by the CC and VC suggested. Under the symmetrical fault, the voltage magnitude drops to 0.65 pu at $t=5$ s. Fig. 9 compares the two control approaches under this scenario. At $t=5.5$ s, the problem is fixed. Although DC connection voltage fluctuates during a failure, these variations are substantially less than those seen in previous designs because of the suggested control mechanism.

1.2

1.1

1

0.9

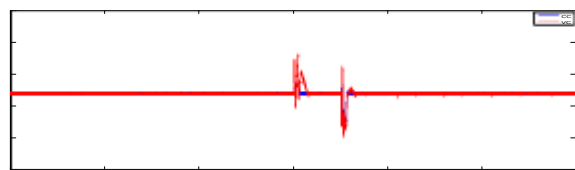
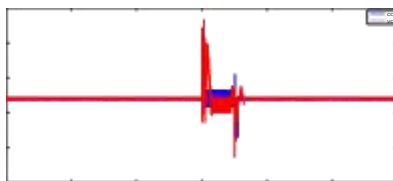
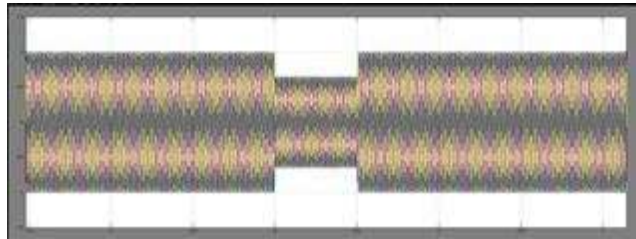
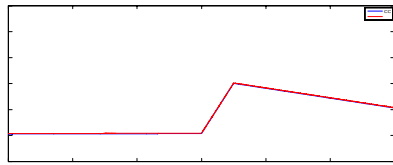
0.8

0.7

CCVCDTC

0-0.5-1

2 3 4 5 6 7 8 time



V.SIMULATION RESULTS BY USING FUZZYCONTROLLER

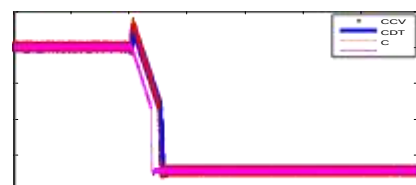
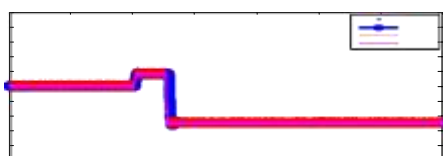
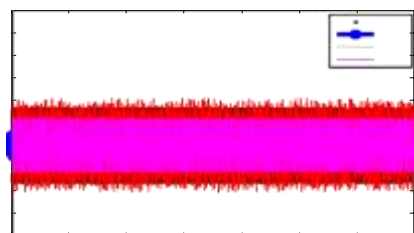
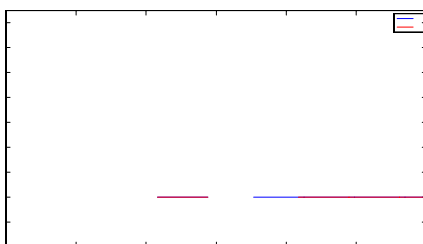


Fig.10.Steadyand transientstateresponsecomparisonofbasicCC withthose ofDTCandVC.

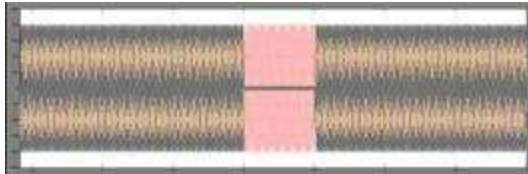
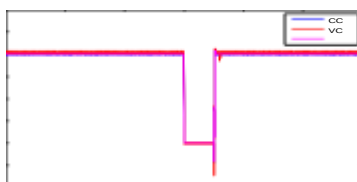


Fig.11.Gridvoltage duringtwo-phasetoground fault

500
2 3 4 5 6 7 8
1.4
1.2
4



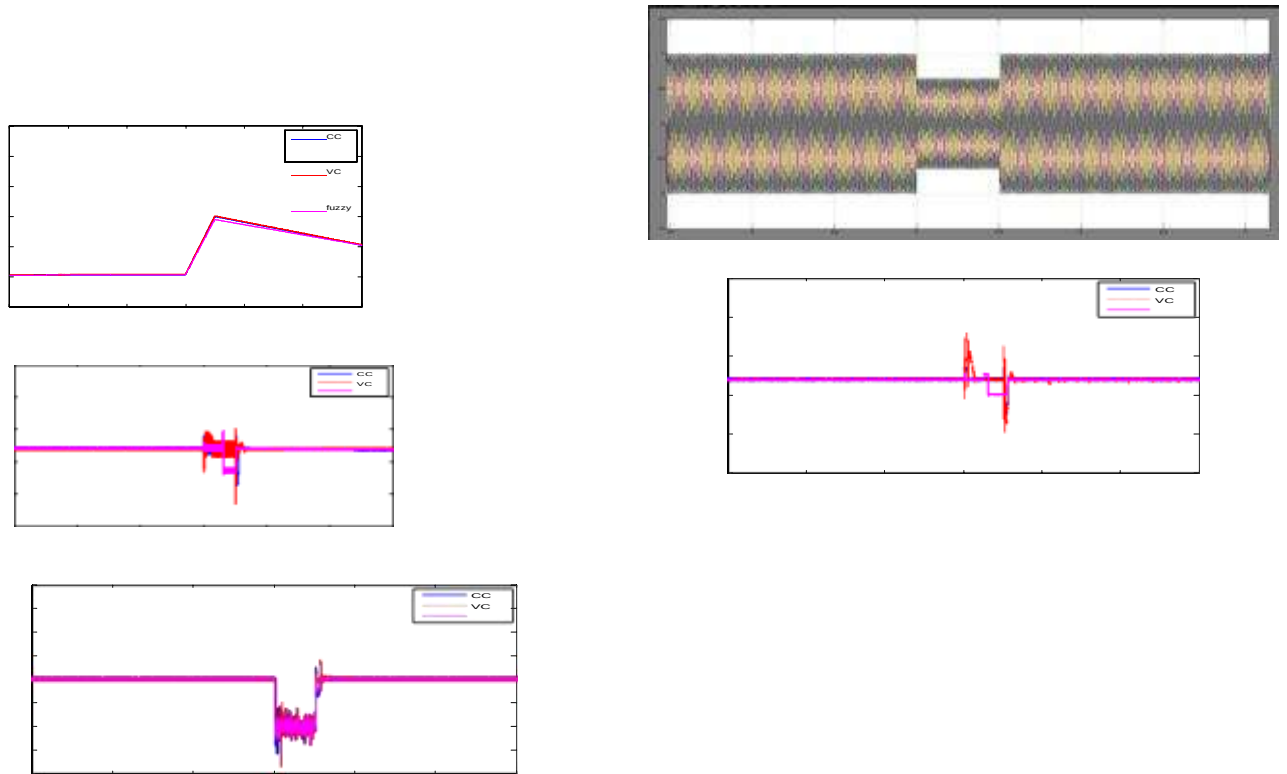


Fig.14.Comparison of transient state response of the system with the proposed CC and VC under a three-phase to ground fault.

2
1
0
-1

time

Fig.12.Comparisonoftransientstateresponseof thesystem with the proposed CC and VC under a two-phasetogroundfault.

CONCLUSION

It is necessary to model the PMSGs machine in terms of deviation variables in order to provide a solid foundation for the combined control system. This combination of a fuzzy logic controller, a deviation current vector control, and a switching table selects a voltage vector. The steady-state and transient reactions of the grid under normal circumstances

Overall, the machine's performance is increased by a large margin when compared to either VC or DTC, since the generator signals including the electromagnetic torque, power, current, and flux linkage are much improved. This approach, as compared to DTC, lessens the signal pulsations, resulting in more stable system operation. Instead of requiring time-consuming PWM calculations and feed-forward signals, it has a quicker dynamic response and lower parameter dependence than traditional vector control (VC). The MSC of PMSG-based WECSs would benefit from a new CC-based LVRT technique as well. Rather of the GSC controlling the DC-link voltage, the suggested solution has the GSC control MPPT instead. In the event of an asymmetrical grid failure, the grid current is restricted to its nominal value by means of a dual current controller operating in positive and negative sequence with peak current limiting.

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