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Design and Performance Analysis of PMSG Based WECS under Various Faults

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ABSTRACT: Fast transient and clean steady-state performance of wind energy conversion systems (WECS) is critical for sustained energy conversion and grid code fulfillment consisting of low voltage journey through capability. In this paper, an analysis of permanent magnet synchronous generator (PMSG)-primarily based WECS under vector control and direct torque control presents the premise for combining salient features of the two control strategies right into a reliable and effective control system to provide enhanced machine performance. The system consists of hysteresis current controllers in connection with an inverter-switching table. The proposed control provides fast temporary and smooth stead state overall performance for system side converter of PMSG, which controls DC-link voltage under grid fault situations. Extensive simulation consequences on a 2-MW PMSG-based WECS demonstrate the desired overall performance of the proposed manipulate device under both grid-normal and -fault conditions.

KEYWORDS: permanent magnet synchronous generator (PMSG), wind energy conversion systems (WECS), Vector control, Transient.

I.INTRODUCTION: WIND energy era has swiftly been increasing during the last a long time due to merits like cleanness, quick construction cycle and occasional going for walks cost [1]. With the continuous growth in penetration level of wind electricity, transmission gadget operators in many countries have established new codes for grid integration of wind power conversion structures (WECS). As a grid code, it is miles required that WECS to stay related to the grid under grid faults and deliver reactive energy into the grid to aid the grid voltage recuperation [2]. It is usually referred as low voltage trip through (LVRT) capability. Nowadays, the permanent magnet synchronous generator (PMSG) primarily based WECS is the maximum unexpectedly increasing WECS [3]. PMSG due to their completely rated converters, which offer whole isolation from the grid disturbances, are much less at risk of grid faults and could effectively guide the grid under fault conditions. A PMSG manage device consists of a device side converter (MSC) and grid aspect converter (GSC) controllers. Under grid regular situations, the MSC controls the PMSG lively electricity to acquire maximum power point monitoring (MPPT), at the same time as the GSC maintains the dc-link voltage regular and regulates the GSC reactive electricity output [4]. Under grid fault conditions, because of the voltage sag on the factor of not unusual coupling (PCC), the GSC could not transfer all the MSC output strength to the grid. This should lead to a DC-hyperlink over voltage and feasible destruction of sensitive WECS device. Therefore, without protective measures, the PMSG isn't capable of continue to be related to the grid and support the grid voltage underneath grid faults. Several LVRT techniques were proposed within the literatures that are divided into foremost classes: hardware amendment and manage modification [5].

In hardware change methods, a further hardware inclusive of an strength garage device [6], active crowbar, braking chopper [7], [8], flexible alternating modern transmission structures (FACTS) [9], [10], series dynamic breaking resistors [11] and many others. Are employed to enhance the LVRT capability of PMSG primarily based WECS. However, those techniques often growth the overall fee and complexity of the device and a number of them do not deliver reactive energy to the grid to fulfill the contemporary grid code necessities. A braking chopper is able to deplete energy simplest and need to be blended with different methods to meet the reactive strength injection requirement [5].

Considering those drawbacks, manage modification techniques are offered because the maximum preferred LVRT strategies. In these strategies, the PMSG-primarily based WECS manipulate including pitch perspective control or back-to-back converters control are changed as opposed to the use of more hardware [5]. Pitch perspective control development is less applicable compared to the converters control amendment because of its sluggish mechanical response [12]. In [13], a de-loading technique is proposed wherein the MSC output energy is decreased by using multiplying a DC-link voltage established coefficient into the torque command. However, it could not maintain the DC-hyperlink voltage at its rated fee beneath severe voltage sags and it have to be used with an extra hardware [5]. In [14], the control duties of lower back-to-back converters have been swapped, i.e., the MSC controls DC-hyperlink voltage and the GSC achieves MPPT. In this method, the MSC is managed thru the DC-link voltage error to lower the PMSG output strength below grid fault conditions. The energy difference between the wind turbine enter electricity and the generator output energy is converted into the kinetic strength within the rotor inertia and returns to the grid after fault clearance to save you the DC-link overvoltage [14]–[16]. In [14] and [17] a dual current controller of terrible- and superb-series is proposed, which offers terrible-series modern-day injection in asymmetrical grid faults to lessen generator electricity and DC-hyperlink voltage fluctuations. In addition, a height contemporary restricting technique is carried out to the GSC to prevent section currents from exceeding their restriction below asymmetrical grid fault situations [18].

In the swapped obligations techniques, vector control (VC) is usually taken into consideration for controlling MSC to provide LVRT capability [5], [14],while both VC and direct torque manage (DTC) are used for controlling MSC under regular conditions [4], [19]. However, DTC may be a suitable choice for a swapped responsibilities approach because it provides a quicker response to electric machines [20]. In this technique, a faster machine response ends in a faster recovery of the balance among the device energy and the grid energy beneath faults, thus stopping an immoderate DC-hyperlink overvoltage. Nevertheless, DTC, in evaluation with VC, causes higher ripples on device variables [20], which isn't always ideal in grid integration of wind strength. In order to take the blessings of VC and DTC in an incorporated control machine and conquer a few risks of both of the 2 techniques, a blended (CC) technique is proposed for induction automobiles [21], [22] and DFIG-based totally WECSs [23], [24]. The method is also adapted to permanent magnet synchronous motors [20].

II.LITARATURE REVIEW:

1) Current source generator converter topology for direct-drive wind turbines

Permanent magnet synchronous generator (PMG) based direct-drive wind generators (DDWT) have these days drawn the eye of the wind energy marketplace given their low operation and maintenance value, reliability, and longer lifetime. In this paper, a zero dc-link impedance topology for DDWT-PMG systems is offered. The proposed topology removes using the failure inclined dc bus capacitor by using replacing the grid-facet converter with a phasor pulse-width modulation (PPWM) enhance current source inverter (CSI), additionally referred to as indirect improve matrix converter. Furthermore, the newness of the proposed topology lies in making use of the synchronous inductance of the PMG because the dc-hyperlink inductor required through the improve-CSI, for that reason reducing the general system weight and size. In addition, the PPWM improve-CSI allows a high voltage boosting ratio, which lets in the layout of a low-voltage PMG. As an end result, the PMG size, weight, and excessive-price PM material volume may be reduced. The feasibility of the low-voltage generator is investigated thru finite-element computations the use of as a base for assessment an existing 1.5-MW DDWT-PMG. This contrast demonstrates a discount within the generator volume, PM material, and the whole weight of the generator. Finally, the proposed topology is demonstrated via simulations results.

2) PMSG based wind energy conversion systems: Survey on power converters and controls

The permanent magnet synchronous generator (PMSG) is dominantly used in the gift wind strength market. Reflecting the latest wind energy marketplace tendencies and research articles, this study provides a survey on critical electrical engineering elements for PMSG-based totally megawatt-stage wind electricity conversion systems (WECSs). A complete analysis on strength converter topologies for wind mills (WTs), grid integration of wind farms, virtual manage schemes, fault-experience-via compliance methods, and future trends is presented. The up to date marketplace share, generation trends, WT merchandise statistics, in-depth technical analysis, and promising studies works highlighted on this look at will help the reader to recognize the today's and rising technology for PMSG-primarily based WECS.

III.PROPOSED SYSTEM:

In this paper, the simple ideas of CC for PMSG are derived and a primary CC method is brought for grid normal conditions. It is then progressed to increase a new CC technique for controlling the swapped obligations PMSG-primarily based WECSs to provide more desirable LVRT functionality in addition to best control underneath ordinary conditions of the system. These are carried out via making sure speedy temporary response under grid fault situations and easy overall performance below constant kingdom conditions. More importantly, the proposed CC method in evaluation with the present methods reduces the DC-link overvoltage extensively below the grid faults.

3.1. PERMANENT MAGNET SYNCHRONOUS MACHINE MODEL

Voltage equations of PMSGs in a stator flux linkage reference frame, i.e., the x-y coordinates, are presented as [20]:

$V_y = R_s i_y + \omega_{s\lambda} s$, (1)

$Vx = R_s i_x + p\lambda_s$, (2)

Where V, i, Rs, ωs, and λs are the generator voltage, modern-day, stator resistance, and stator flux linkage pace and magnitude respectively. Subscripts 'x' and 'y' distinguish direct and quadrature additives in the reference body respectively and p are a spinoff operator. In addition, the electromagnetic torque of PMSGs is given as [20]:

$$T_{em} = \frac{3}{2}\frac{P}{L_s}\lambda_s\lambda_m \sin(\delta), \qquad (3)$$

Where Tem, Ls, λm, P, and δ are the electromagnetic torque, stator segment inductance, magnet flux linkage importance, pole pairs, and the weight angle of the system respectively. The generator lively and reactive strength also can be received as [25]:

$$P_m = \frac{3}{2}\left(V_x i_x + V_y i_y\right), \qquad (4)$$

$$Q_m = \frac{3}{2}\left(V_y i_x - V_x i_y\right), \qquad (5)$$

Where Pm and Qm are the machine active and reactive powers.

3.2. CONTROL SYSTEM

The analytical basis and the gadget structure of the combined control technique for everyday operation of the MSC are introduced on this section. Then, the proposed CC-based LVRT technique for MSC is provided and its overall performance deserves are investigated analytically. In addition, the control of GSC is briefly defined.

A. Basic Principles of CC for PMSGs

By considering (three) with a few approximations, the electromagnetic torque deviation may be represented through the stator flux linkage deviations as [26]:

$$\Delta T_{em} = k_1\Delta\lambda_x + k_2\Delta\lambda_y, \qquad (6)$$

where k_1 and k_2 are defined as:

$$k_1 = \frac{3}{2}\frac{P}{L_s}\lambda_m \sin(\delta), \qquad (7)$$

$$k_2 = \frac{3}{2}\frac{P}{L_s}\lambda_m \cos(\delta). \qquad (8)$$

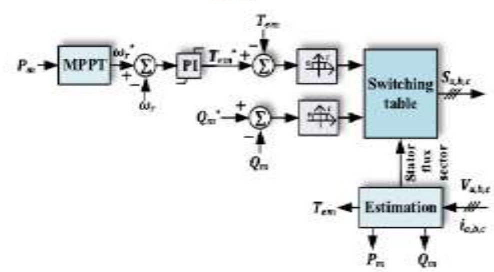

Fig. 3.1. Block diagram of MSC direct torque control of the PMSG-based WECS in stator flux linkage reference frame.

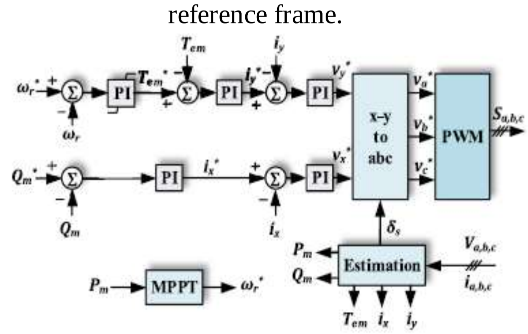

Fig. 3.2. Block diagram of MSC vector control of the PMSG-based WECS in stator flux linkage reference frame.

Equation (6) represents the basis for manage of electromagnetic torque the usage of flux linkage additives. It is thought that the torque below DTC is controlled thru the stator flux linkage

Angle and value. Equivalently, torque manage in DTC may be seemed because the control of stator flux linkage additives as offered by using (6). Fig. 1 suggests the block diagram of a DTC system where the reactive strength manipulate is substituted for the flux linkage manipulate [26]. On the alternative hand, the electromagnetic torque can be represented by using the generator current issue deviations as [26]:

$$\Delta T_{em} = k_3 \Delta i_x + k_4 \Delta i_y, \quad (9)$$

where k_3 and k_4 are obtained as:

$$k_3 = \frac{3}{2} P \lambda_m \sin(\delta), \quad (10)$$

$$k_4 = \frac{3}{2} P \lambda_m \cos(\delta). \quad (11)$$

Equation (9) affords a basis for manipulate of electromagnetic torque by using present day components as it's far proven in Fig. 2 for VC. The coefficients of (6) and (9) are linearly related as:

$$\frac{k_3}{k_1} = L_s, \quad (12)$$

$$\frac{k_4}{k_2} = L_s. \quad (13)$$

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

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

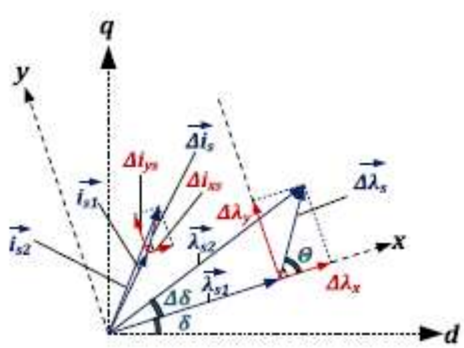

Fig. 3.3. Vector diagram of machine.

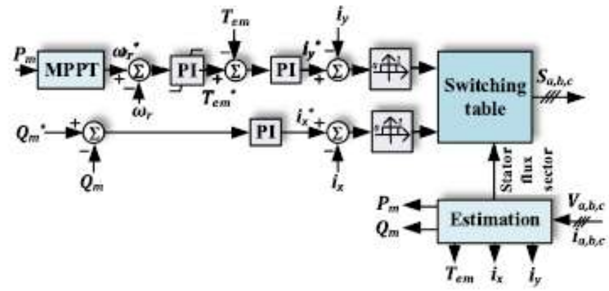

Fig. 3.4. Block diagram of the basic combined control for the MSC of PMSG based WECS in stator flux linkage reference frame.

$$\Delta \lambda_y \propto \Delta i_y. \quad (15)$$

Fig. 3.3 depicts (14) and (15). These proportionalities affirm that DTC and VC perform the lively and reactive electricity control of PMSGs within the same way via both current deviations or flux linkage deviations. Thus, it is feasible to change the flux linkage control and current manipulate of DTC and VC respectively. Accordingly, we are able to increase a manipulate device that combines good capabilities of DTC and VC. In addition, it may cast off some unpleasant capabilities of these strategies and decrease some of their shape complexities. A suitable function of DTC against VC is its speedy dynamic reaction, thanks to its hysteresis controllers and switching table implementation. However, a VC machine presents easy gadget performance in evaluation to pulsating modern-day, flux linkage and torque signals underneath DTC. Nevertheless, a VC device frequently incorporates a PWM with traumatic computations. Bearing in mind the above dialogue, Fig. Four illustrates the CC device with a partial DTC system within the proper aspect and a partial VC machine within the left side. The hysteresis controllers and the switching table are the DTC components and the torque and reactive power manipulate by means of the cutting-edge controllers are the VC components. Compared with VC, the CC device has no PWM, thus results in much less worrying and quicker computations. The output of speed controller gives the torque command that ultimately determines i∗ y. Here, there is no want for feed-ahead signals used in VC structures to decouple the gadget and improve its dynamic operation. The CC technique shown in Fig. Four is provided for grid ordinary situations. However, it shapes the idea for introducing the new swapped obligations LVRT method as can be brought in the following. Therefore, the CC of Fig. 4 is referred as the primary CC.

B. MSC Control in Swapped Duties Methods

By ignoring losses, the DC link voltage can be calculated as [18]:

$$P_m - P_g = C_{dc} V_{dc} \frac{dV_{dc}}{dt}, \tag{16}$$

Where Pm, Pg, Cdc, and Vdc are the system strength, grid electricity, DC-link capacitance, and DC-hyperlink voltage. Therefore, the DC hyperlink voltage deviation is obtained as:

$$\frac{dV_{dc}}{dt} = \frac{P_m - P_g}{C_{dc} V_{dc}}, \tag{17}$$

Where Cdc is regular and Vdc has low versions in comparison with the DC-hyperlink voltage significance. Therefore, the DC-link voltage deviation is associated with the difference among the grid and device powers. As the difference increases, the DC-hyperlink voltage overshoots and ripples boom. Therefore, the grid and system powers have to be close for a stepped forward DC-hyperlink voltage reaction. By ignoring losses, the gadget and grid powers are calculated by means of (four) and the following equation respectively [17]:

$$P_g = \frac{3}{2}(V_{dg}^{+} I_{dg}^{+} + V_{qg}^{+} I_{qg}^{+} + V_{dg}^{-} I_{dg}^{-} + V_{qg}^{-} I_{qg}^{-}), \quad ($$

Where superscripts '+' and '−' distinguish high quality- and bad-collection and subscripts'd' and 'q' distinguish direct and quadrature additives in the grid voltage reference body, respectively. Subscript 'g' represents the GSC quantities. If ix is thought 0 to have unity electricity thing and coffee stator resistance loss at the same time as a symmetrical grid fault happens, equations (four) and (18) lead to [20]:

$$P_m = \frac{3}{2} V_y i_y, \tag{19}$$

$$\begin{aligned} P_g &= \frac{3}{2} V_{dg}^{+} I_{dg}^{+} \\ &= \frac{3}{2} V_{dg} I_{dg}. \end{aligned} \tag{20}$$

By ignoring losses, the grid power reference in swapped duties methods is given by [18]:

$$P_g^{*} = K_{opt} \omega_m^3, \tag{21}$$

Where Koptω3m defines MPPT of turbine and Pg ∗ is the grid power reference. Pg ∗, According to (21), deviates with a mechanical time steady. When a fault happens, grid injected energy decreases immediately due to Vdg reduction. On the other hand, Pg ∗ stays fixed, due to slow response of rotor mechanical frame. Therefore, the capability of GSC below fault to alter its electricity is extremely gradual, due to the mechanical time consistent of grid strength reference. As a end result, the capability of MSC to alternate the device-generated energy rapidly and adapt it to the grid injected energy becomes important. The MSC can satisfy the challenge due its quick electric time consistent resulted from the DC-link voltage manipulate loop. Therefore, in swapped obligations LVRT strategies, MSC dynamic response dominates the DC-link voltage control.

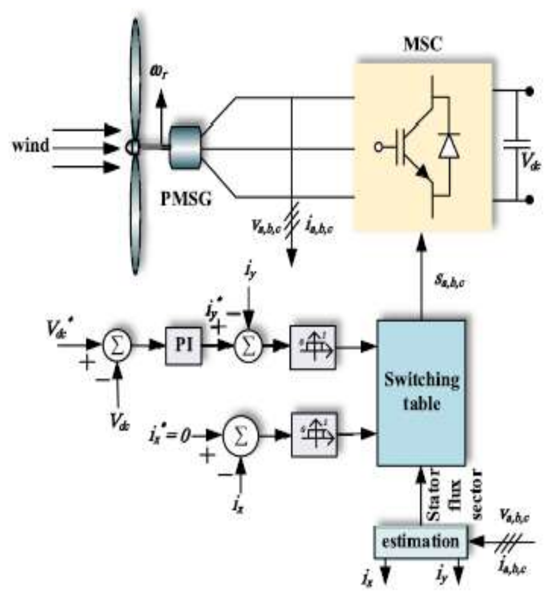

Fig.3. 5. Block diagram of the proposed combined control for the PMSG-based WECS with LVRT capability.

C. Grid Fault Conditions Control

The CC gadget combines the advantages of VC and DTC systems in an included manage device. Thus, it's far predicted to provide smooth consistent country performance like VC and rapid transient response like DTC. Under the grid ordinary conditions, clean overall performance is appropriate to have much less torque ripple and decrease total

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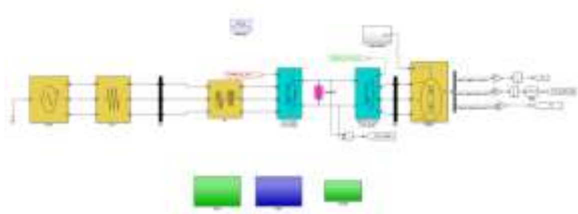
harmonic distortion (THD). On the other hand, under the grid fault conditions, speedy temporary response is suited to improve LVRT functionality by lowering the PMSG output strength as fast as feasible. Therefore, the CC technique is a superb candidate for MSC control beneath each grid regular and fault conditions. Swapping the manage obligations of lower back-to-again converters ought to enhance the LVRT functionality of PMSG-based totally WECSs without the use of extra hardware. In this example, the GSC achieves MPPT, and the MSC controls the DC-link voltage instead of rotor speed. Electrical variables like DC-link voltage have lots faster temporary reaction as compared to mechanical variables like the rotor velocity. Therefore, using the CC method with rapid temporary response for MSC manipulate turns into extra influential as cited in Section B. Fig. 3.5 shows the block diagram of the proposed manipulate device. As seen, the DC-link voltage controller generates the quadrature factor of contemporary command, whereas the direct component command is zero. The current instructions are as compared with their real values by means of the hysteresis cutting-edge controllers and create the output flags as inputs to the top-quality switching desk. The 0.33 input of the switching table is the position of the stator flux linkage vector within the desk bound reference frame. The ideal switching table affords the precise voltage vectors by deciding on the states of MSC switches.

Under grid fault conditions, the GSC is controlled by using the usage of a twin modern controller of fantastic and negative sequences and top current problem manage [18].

IV.SIMULATION RESULTS



4.1 proposed simlink diagram

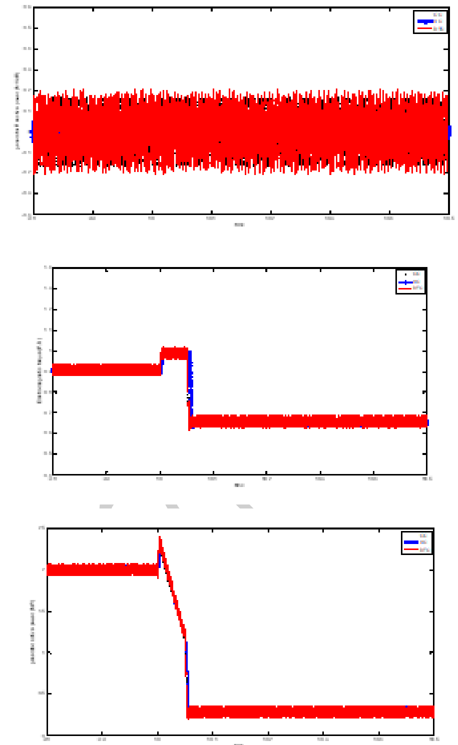
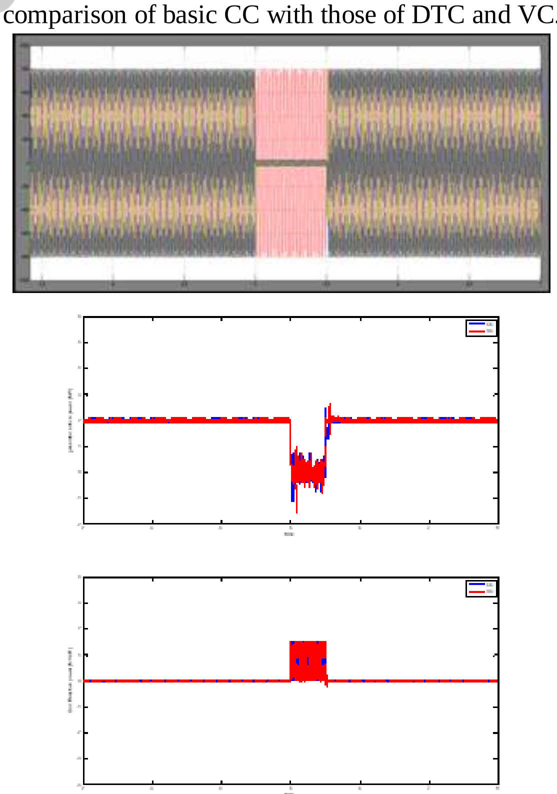


Fig. 4.2. Steady and transient state response comparison of basic CC with those of DTC and VC.



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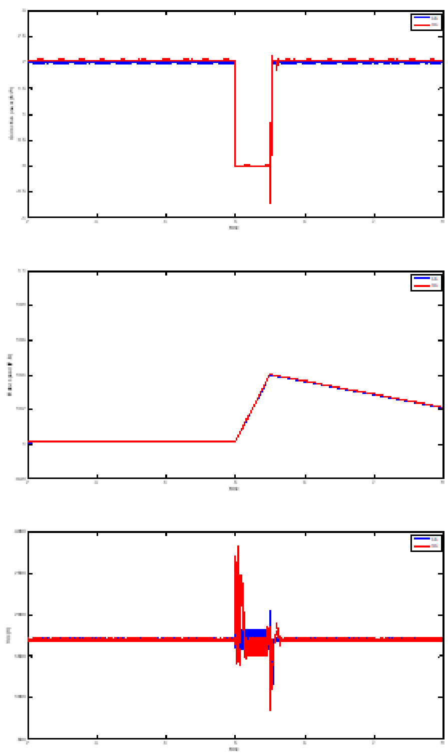

Fig. 4.3. Comparison of transient state response of the system with the proposed CC and VC under a two-phase to ground fault.

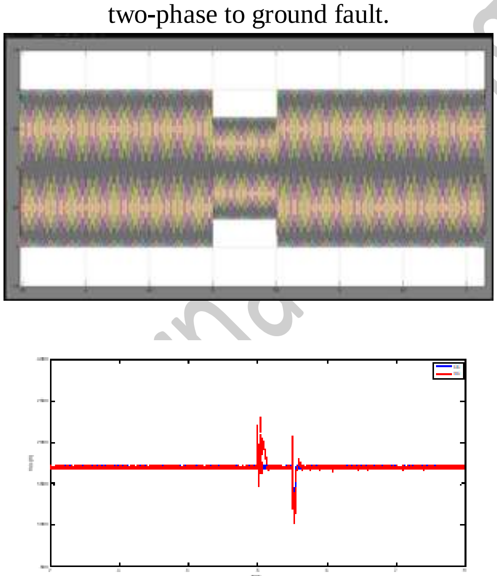

Fig. 4.4. Comparison of transient state response of the system with the proposed CC and VC under a three-phase to ground fault.

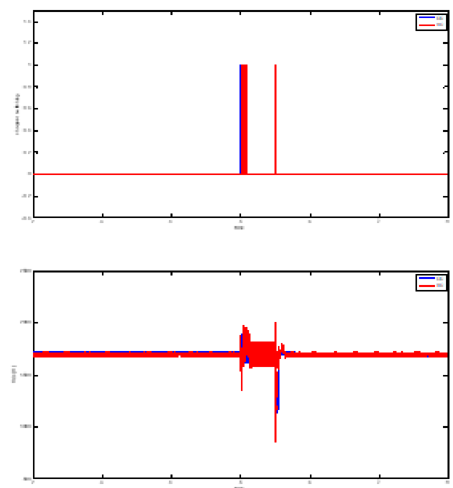

Fig. 4.5. Comparison of transient state response of the system by the proposed CC and VC by employing a braking chopper under a two-phase to ground fault.

V.CONCLUSION

The essential foundation of the error control is laid down via modeling the PMSG gadget in phrases of deviation variables. This stimulates control devices as a combination of a deviation current vector control and a voltage vector choice by means of a switching table. In grid ordinary conditions, the steady state and transient responses of the generator indicators together with the electromagnetic torque, strength, current, and flux linkage are significantly stepped forward over their responses below either VC or DTC, leading to a usual enhancement of the device performance. Comparing to DTC, the proposed approach decreases the signal pulsations, as a consequence bringing approximately smoother system performance. Comparing it with VC, it presents faster dynamic response, less parameter dependency and shortage of time-eating PWM computations and feed-forward signals. In addition, a new CC based LVRT technique is proposed for the MSC of PMSG-based totally WECSs. In the proposed technique, the manipulate responsibilities of MSC and GSC are swapped i.e., the GSC reap MPPT and the MSC controls the DC-link voltage. The GSC is controlled the usage of a dual modern-day controller of nice and bad collection with peak modern challenge to restriction the grid contemporary at its nominal fee below asymmetrical grid fault conditions. The simulation consequences show that the proposed control technique no longer simplest offers less fluctuations and faster temporary response, however also reasons less steady state ripples as compared to the ones below one of the most not unusual LVRT manage techniques. It also gives the possibility of using a braking chopper unit with lower score and cost or reduces the need for the usage of the chopper.

REFERENCES

[1] L. Fried, S. Shukla, S. Sawyer, and S. Teske, "Global wind outlook 2016," 2016.

[2] Federal Energy Regulatory Comission. (2005, Dec. 12). Regulatory Order No. 661-A: Interconnection for Wind Energy. [Online]. Avalable: http://www.ferc.gov/industries/electric/indus-act/gi/wind.asp

[3] A. Singh, J. Benzaquen, and B. Mirafzal, "Current source generatorconverter topology for direct-drive wind turbines," IEEE Trans. Ind. Appl., vol. 54, no. 2, pp. 1663–1670, Mar./Apr. 2017.

[4] V. Yaramasu, A. Dekka, M. J. Durán, S. Kouro, and B. Wu, "PMSGbased wind energy conversion systems: Survey on power converters and controls," IET Elect. Power Appl., vol. 11, pp. 956–968, 2017.

[5] M. Nasiri, J. Milimonfared, and S. Fathi, "A review of low-voltage ridethrough enhancement methods for permanent magnet synchronous generator based wind turbines," Renewable Sustain. Energy Rev., vol. 47, pp. 399–415, 2015.

[6] T.H.Nguyen and D.-C. Lee, "Ride-through technique for PMSG wind turbines using energy storage systems," J. Power Electron., vol. 10, pp. 733– 738, 2010.

[7] S. Muyeen, R. Takahashi, T. Murata, and J. Tamura, "A variable speed wind turbine control strategy to meet wind farm grid code requirements," IEEE Trans. Power Syst., vol. 25, no. 1, pp. 331–340, Feb. 2010.

[8] T. H. Nguyen and D.-C. Lee, "Advanced fault ride-through technique for PMSG wind turbine systems using line-side converter as STATCOM," IEEE Trans. Ind. Electron., vol. 60, no. 7, pp. 2842–2850, Jul. 2013.

[9] M.Mahfouz andM. A. El-Sayed, "Static synchronous compensator sizing for enhancement of fault ride-through capability and voltage stabilisation of fixed speed wind farms," IET Renewable Power Gener., vol. 8, pp. 1–9, 2014.

[10] H. Geng, L. Liu, and R. Li, "Synchronization and reactive current support of PMSG based wind farm during severe grid fault," IEEE Trans. Sustain. Energy, vol. 9, no. 4, pp. 1596–1604, Oct. 2018.

[11] A. Causebrook, D. J. Atkinson, and A. G. Jack, "Fault ride-through of large wind farms using series dynamic braking resistors (March 2007)," IEEE Trans. Power Syst., vol. 22, no. 3, pp. 966–975, Aug. 2007.

[12] T. Senjyu, R. Sakamoto,N.Urasaki,T. Funabashi, H. Fujita, andH. Sekine, "Output power leveling of wind turbine generator for all operating regions by pitch angle control," IEEE Trans. Energy Convers., vol. 21, no. 2, pp. 467–475, Jun. 2006.

[13] O. Anaya-Lara,N. Jenkins, J.B.Ekanayake, P.Cartwright, and M. Hughes, Wind Energy Generation: Modelling and Control. Hoboken, NJ, USA: Wiley, 2011.

[14] K.-H. Kim, Y.-C. Jeung, D.-C. Lee, and H.-G. Kim, "LVRT scheme of PMSG wind power systems based on feedback linearization," IEEE Trans. Power Electron., vol. 27, no. 5, pp. 2376–2384, May 2012.