Fault Ride -Through Capability Enhancement of Offshore Wind Farms Connected via VSC-HVDC Transmission

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Abstract— Voltage source converter (VSC) - based high voltage DC (HVDC) transmission is viewed as the eventual fate of offshore power transmission. This paper goes for giving a solid VSC-HVDC transmission system design between offshore wind ranches and inland grids. In this paper, an extensive limit, low-speed flywheel energy storage system (FESS) in light of a squirrel cage inductance machine is connected in parallel with the VSC-HVDC at the grid side converter. The FESS is committed for surge power control (because of power flow unevenness amid fault) retention rather than being dispersed as resistive losses. Since the length of these surges is moderately little, it has been demonstrated that the flywheel can adequately relieve this issue. In this FESS converter model existed by using PI controllers in which will get good response of power leveling operation and under fault conditions of the systems. And FESS offshore wind farms using proposed controller Fuzzy logic controller. It helps for the system improves a power levels, stability of the systems for under normal and abnormal operations compared to PI controller. HVDC system is simulated utilizing MATLAB/Simulink amid ordinary and fault conditions.

Index Terms—Fault ride through, flywheel energy storage system, HVDC, indirect field oriented control, offshore wind energy.

I. INTRODUCTION

The worldwide interest for electric energy and constraints of the conventional wellsprings of energy have prompted expanded enthusiasm for sustainable power source. Wind energy is a standout amongst the most promising sustainable power sources. Wind ranches have been introduced both coastal and offshore. Offshore breeze ranches may display higher use contrasted with their inland partners because of the maintained high offshore breeze speeds. Their offshore areas additionally imply that land possession co-ordinations and necessities are perhaps disentangled [1]. The primary hindrances of offshore breeze ranches are the high constructional cost furthermore, upkeep prerequisites. Transmission of high power from offshore breeze ranches is considered a test. High voltage DC (HVDC) transmission is an efficient contrasting option to AC transmission for long separations what's more, submarine mass power conveyance from remote sources such as offshore breeze ranches. The ordinary HVDC transmission system uses line-commutated converters (LCC). This innovation is reasonable for high power applications [2]. The fundamental concerns with respect to LCC-HVDC utilize are the required harmonic filters and VAR compensators on the AC side due to the LCC created harmonics and firing angle subordinate non-unity removal factor, notwithstanding the issues related with the likelihood of commutation failure[3]. VSC based HVDC was presented by makers in the late 1990s as HVDC Light or HVDC PLUS. Thought about to LCC-HVDC, VSC-HVDC transmission has a few focal points that have been accounted for in writing, for example,

- Better similarity with sustainable power sources
- Bring down general cost
- Higher stability and better power quality
- Active and reactive power can be independently controlled.

The control of VSCs is basic to guarantee system ability to adapt to AC system varieties and transients. One of those varieties is the conduct of the AC system amid fault periods, since network codes require that breeze ranches should remain associated amid and after a short out fault. In this way, fault ride through ability in VSC-HVDC-based breeze ranches progresses toward becoming basic. A few procedures exist for fault ride through in VSCHVDC- based offshore breeze energy systems. The principal approach is to lessen the power delivered from the wind turbines (de-loading). There are two fundamental strategies for the de-loading. The first is to lessen the generator torque by means of controlling the offshore converter keeping up system frequency consistent and diminishing the active current segment. In any case, the principle impediment of this strategy is the moderate rate of energy decrease.

The second technique is controlling the output power of the breeze cultivate through recognizing the lattice frequency amid the fault. A requirement for a high data transfer capacity correspondence medium is required to guarantee the unwavering quality of such a technique. The second approach can be accomplished by copying a short circuit on the offshore HVDC converter to forestall power transmission to the coastal side. This can be done by means of lessening the balance file of the offshore converter to decrease the terminal voltage of the offshore converter; yet high streams stream through the converter [4] which introduces a weakness of this technique.

The third technique is utilizing DC choppers with braking resistors for DC control dissemination amid AC side issues anticipating the crowbar start because of the high power on the DC side [5]. This procedure is solid and does not influence the breeze cultivate mechanical system, however it builds system cost and power losses. The lion's share of these methodologies rely upon the diminishment of energy produced by means of the breeze turbines. Regardless of its effortlessness, the power lessening approach decreases the breeze system use as this approach depends on giving up the accessible breeze control amid fault.

This exploration researches another fault ride-through system in light of energy storage innovation to store the trapped energy amid fault periods. Also, the capacity system is utilized for wind control leveling purposes amid typical operation. Flywheels are utilized as energy storage mediums; they display high execution, and can be effectively utilized with a few electrical applications, for example, power molding, frequency regulation, and voltage sag compensation because of their capacity of putting away energy as kinetic energy relying upon the rotating speed and their mass. This work was already presented in, and after that it is delineated in points of interest inside this paper.

The FESS is devoted for two purposes, control leveling what's more, fault ride-through with safeguarded strapped energy, along these lines the cost arbitrage amongst FESS and previously mentioned fault ride-through techniques isn't exact. In this manner, the cost

arbitrage is performed with another conceivable brief period energy storage medium, the super capacitors. In spite of the fact that there are a few energy storage systems (e.g., batteries and superconducting magnetic energy storage SMES), super capacitors may show a comparative execution to FESS. The two systems have normal merits, for example, high reaction, quick progression (super capacitors are somewhat better), high effectiveness, and low support prerequisites. Be that as it may, FESS has higher energy thickness, charging/releasing cycles [6].
The primary commitments of this paper are as per the following:

- An extensive limit, low-speed induction machine-based FESS is utilized at the network side converter of a VSC-HVDC transmission system for AC side fault ride-through support.
- The FESS is utilized for wind power leveling amid typical operation.
- The FESS is utilized to store the trapped energy if there should arise an occurrence of DC interface voltage swelling amid AC side deficiencies.
- A recreation contextual investigation for the proposed strategy is introduced utilizing MATLAB/Simulink, and a trial FESS is set up to examine the system execution.

II. DESCRIPTION OF THE PROPOSED SYSTEM

FESSs have a straightforward structure, high proficiency, high power what's more, energy densities, and great flow. Additionally FESSs have a extensively high cycle lifetime with low support necessities. A FESS simply comprises of a flywheel, electric machine, control transformation system, and course. The flywheel is the mass in which the active energy is put away what's more, determined through the electric machine which fills in as an engine while charging and as a generator while releasing. Perpetual magnet machines are ordinarily utilized with rapid flywheels; in any case, inductance machines are an efficient elective for low speed flywheels. A power transformation system (control hardware converters) coordinates the lattice agree with the FESS. Course are utilized to hold the flywheel (rotor) allowed to turn at a specific adjusted position. There are two sorts of orientation, to be specific, customary mechanical direction for low speed applications where steel rotors are utilized to increment the inactivity which brings about extensive and overwhelming FESS; and attractive direction for fast applications where the rotor is made of composite materials. The low speed FESSs have critical losses contrasted with the fast ones.

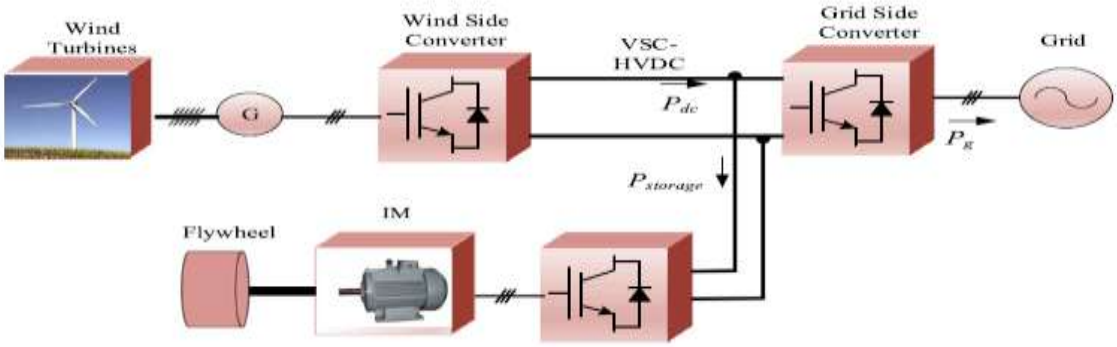


Fig. 1. FESS integrated with a VSC-HVDC transmission system.

In the proposed system, a low speed squirrel cage inductance machine based FESS is associated in parallel with the network side converter of a VSC-HVDC transmission system for offshore wind energy systems. The proposed VSC-HVDC system comprises of a consecutive VSC associating the breeze control generators to the lattice by means of a 100-km link. A schematic of the proposed system is appeared in Fig. 1. The power is delivered offshore by means of the breeze ranch's AC generators, for example, doubly-nourished inductance generators (DFIG) and changeless magnet synchronous generators (PMSG), at that point changed over into HVDC through the breeze side converter. On account of their various favorable circumstances, PMSGs are relied upon to lead the pack later on extensive scale offshore wind generators. The power is transmitted by means of DC links to the inland systems, where the HVDC is changed over into controllable Air conditioning through the system side a various strategies have been proposed to constrain this voltage increment. The secluded multilevel converters have been utilized generally with HVDC systems because of their promising highlights applicable to appropriateness for high power applications, seclusion, control losses, and output symphonious substance.

If there should be an occurrence of AC side fault, if the required active power by the lattice is lower than the created control, at that point the distinction will be put away in the DC interface capacitor then subsequently its voltage will increment. Different techniques have been proposed to restrain this voltage increment. The traditional approach goes for bypassing this additional energy utilizing a chopper circuit associated in parallel with the DC connect to be scattered in a resistor. In this paper, rather than disseminating the additional energy, the proposed FESS can be utilized to store the power distinction amongst the Pdc and Pg, i.e., no requirement for diminishing the output wind cultivate control; in the meantime, the voltage rise of HVDC gadgets is kept away from. Then again, amid typical operation and because of the discontinuity of wind energy, the FESS is used for wind control leveling. The three stage to-ground cut off is the most exceedingly terrible fault that may happen at the AC side which makes the power tend to zero. The FESS converter might be planned by the energy required to be stored amid the fault which relies upon the fault ride through prerequisites. Keeping in mind the end goal to store the appraised energy of the breeze cultivate for a fault on the AC side, the FESS converter ought to be appraised at an indistinguishable rating from the breeze cultivate. Generally for incomplete energy catching, the FESS converter can be diminished, henceforth a tradeoff exists. By and by, this system ought to be for the most part prepared with auxiliary assurance gear, for example, a crowbar protection on the off chance that the fundamental storage system falls flat or gets soaked.
The numerical demonstrating of the system is exhibited in the d-q outline in the accompanying subsections.

A. INDUCTION MACHINE AND FESS CONVERTER MODELING

The d-q model of the inductance machine and the FESS side converter is clarified quickly in (1) to (7).
The stator (converter) voltages are appeared in (1) and (2):

$$v_{ds} = r_s i_{ds} + p\lambda_{ds} - \omega_e \lambda_{qs} \quad (1)$$

$$v_{qs} = r_s i_{qs} + p\lambda_{qs} + \omega_e \lambda_{ds} \quad (2)$$

while stator power components, machine torque and stator flux are given by (3) – (7)

$$P_s = \frac{3}{2}\left(v_{ds} i_{ds} + v_{qs} i_{qs}\right)$$

$$= P_{cu_{stator}} + P_{cu_{rotor}} + T_m \omega_m \quad (3)$$

$$Q_S = \frac{3}{2}\left(v_{ds} i_{qs} - v_{qs} i_{ds}\right) = L_m \omega_e i_{ds}^2 \quad (4)$$

(4)

$$T_m = \frac{3}{2}\frac{PL_m^2}{L_r} i_{qs} i_{ds} \quad (5)$$

$$P_{fw} = P_s \quad (6)$$

$$\lambda_s = L_m i_{ds} \approx \frac{V}{\omega_s} \quad (7)$$

B. GRID SIDE CONVERTER

The DC input is changed over into AC bolstered to the network through the network side converter whose voltages and power are appeared in (8) – (10) individually:

$$v_{dinv} = v_{dg} - r_g i_{dg} - L_g p i_{dg} - \omega L_g p i_{qg} \quad (8)$$

$$v_{qinv} = v_{qg} - r_g i_{qg} - L_g p i_{qg} + \omega L_g p i_{dg} \quad (9)$$

$$P_g = \frac{3}{2}(v_{dg} i_{dg} + v_{qg} i_{qg} \quad (10)$$

Where Vinv and Vg are the inverter and grid voltages, individually, also, is the grid point. The power stream of the system can be communicated as (11):

$$P_{fw} = P_s = P_{ds} - P_g \quad (11)$$

The change in the stored energy in the flywheel can be expressed based on (12):‘

$$\Delta E = \frac{1}{2} J(\omega_2^2 - \omega_1^2) = P_{fw} t_{dish} \quad (12)$$

Where J is the flywheel inertia of idleness, $\omega_1$and ω_2 are the initial and last speeds, individually, and $t_{dish}$is the releasing time.
The energy put away in a capacitor is given by (13). Along these lines the DC interface voltage can be communicated as in (14):

$$E = \frac{1}{2} C V^2 \quad (13)$$

$$V_{dc}(t) = \sqrt{\frac{2}{C}\int\left(P_{dc} - P_g - P_{fw}\right)dt + c} \quad (14)$$

Controlling the DC interface voltage to stay consistent prompts controlling the flywheel and the DC interface powers since the grid control tends to zero amid a fault. Then again, amid typical operation, the distinction between the grid control and DC control is put away in the flywheel.

III. FAULT RIDE-THROUGH CONTROL STRATEGY

The control of the FESS amid ordinary and fault conditions is the fundamental focus of the proposed control system. The control of the inductance machine that drives the flywheel depends on the ordinary roundabout field situated control (IFOC) as appeared in Fig. 2. The DC connect control relies upon the breeze control which is resolved in light of the greatest power point following of the breeze cultivate. The control of the grid side converter under ordinary operation and the control of the FESS are certainly reliant and in light of the DC connect level; this was at that point tended to in past work.

The proposed control approach has two methods of operation; control leveling mode amid ordinary operation and DC interface voltage control amid fault operation. The coveted amount to be controlled is the torque part of the present (quadrature-pivot currenti_{qs}). Amid typical operation, the FESS stores/releases energy in light of the coveted active power profile.

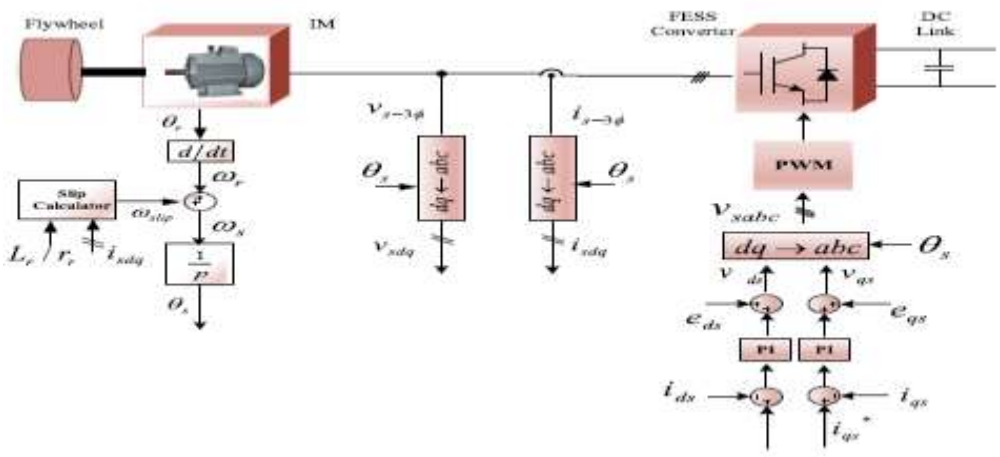


Fig. 2. Schematic of the proposed FESS control strategy based on IFOC.

The quick FESS stator active power is computed through estimating the machine voltages and streams, at that point contrasted and the distinction between wind power and grid control. The error in the power is connected to a power regulator (PI controller) as appeared in Fig. 3. The output of the power controller speaks to the quadrature-pivot current summon which is connected to the present controller. In view of the reference stator transition, the immediate pivot current part is removed. The control methodology is changed to DC interface voltage control mode amid an AC fault as the DC interface voltage begins to rise.

The fault is identified through observing the DC interface voltage level. The genuine DC connect voltage is contrasted with its reference esteem and the mistake is connected to voltage controller to create the reference quadrature-pivot current part as appeared in Fig. 3. In addition, after the DC interface voltage is constrained back to its ordinary level by means of the controller, the control system is exchanged back to the power leveling mode. The reference transition segment (coordinate pivot current) is constantly acquired by means of estimating the responsive power and contrasted with the coveted esteem, at that point connected to control controllers.

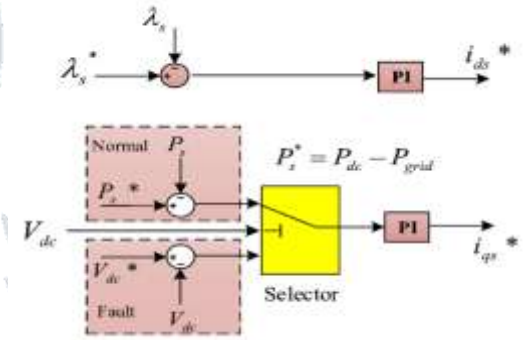


Fig. 3. Switching between normal and fault operating modes based on the DC link level

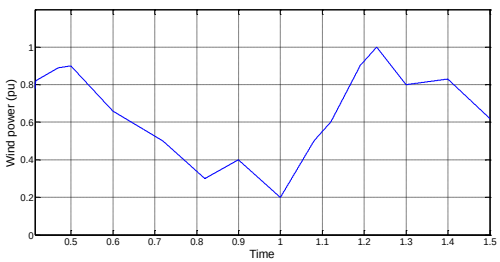
III. FUZZY LOGIC CONTROLLER

Fuzzy logic is a complex mathematical method that allows solving difficult simulated problems with many inputs and output variables. Fuzzy logic is able to give results in the form of recommendation for a specific interval of output state, so it is essential that this mathematical method is strictly distinguished from the more familiar logics, such as Boolean algebra.

Advantages of Fuzzy Controller over PI Controller

Usage of conventional control "PI", its reaction is not all that great for non-linear systems. The change is striking when controls with Fuzzy logic are utilized, acquiring a superior dynamic reaction from the system. The PI controller requires exact direct numerical models, which are hard to get and may not give tasteful execution under parameter varieties, load unsettling powers, and so forth. As of late, Fuzzy Logic Controllers (FLCs) have been presented in different applications and have been utilized as a part of the power devices field. The benefits of fuzzy logic controllers over ordinary PI controllers are that they needn't bother with a precise scientific model, Can work with uncertain information sources and can deal with non-linearity's and are more dynamic than traditional PI controllers.

IV. SIMULATION RESULT



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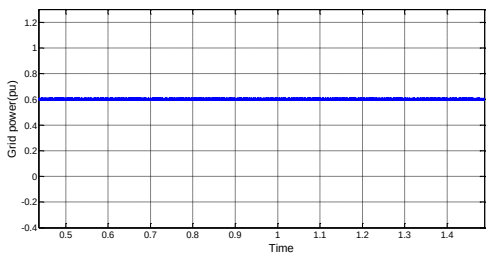

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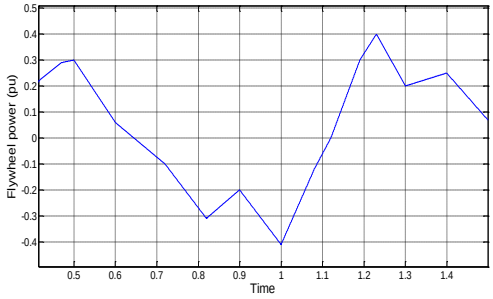

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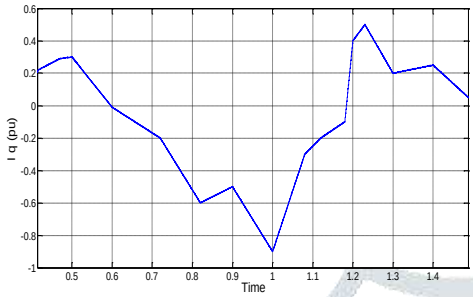

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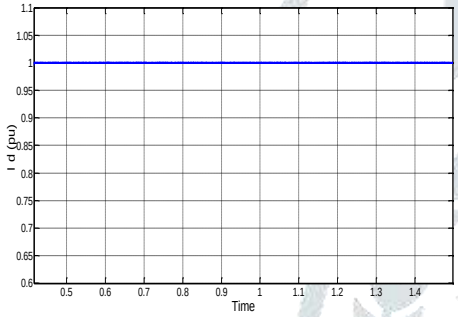

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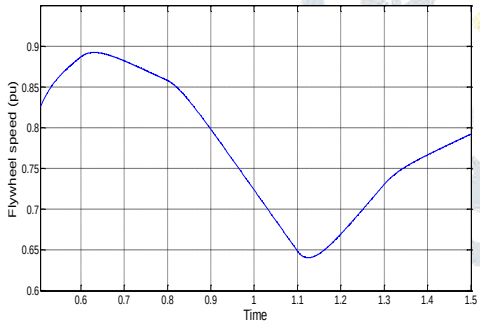
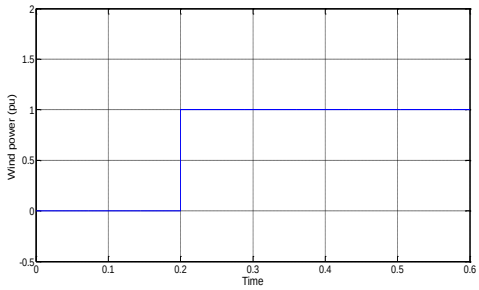
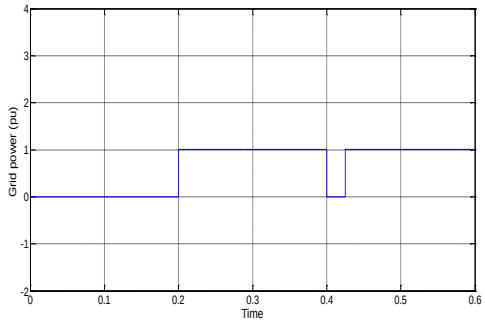
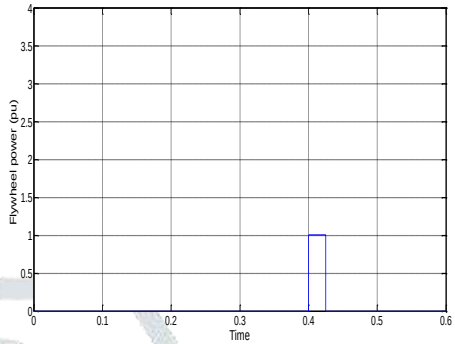


(f)

Fig.4. Simulation results of power leveling operation by using PI controller.(a) wind power, (b) grid power, (c) flywheel power, (d) IM stator quadrature-axis current, (e) IM stator direct-axis current, and (f) flywheel rotating speed







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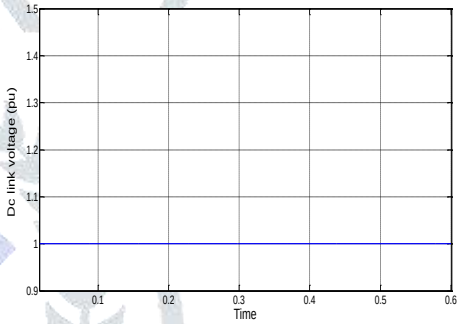

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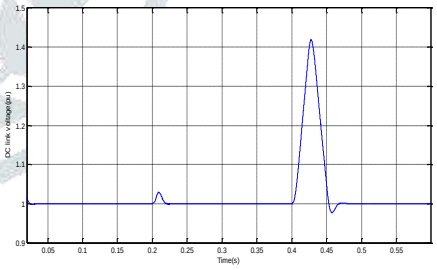

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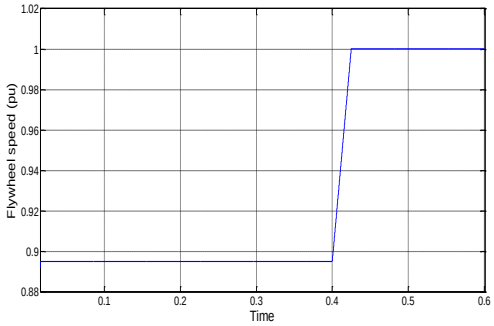

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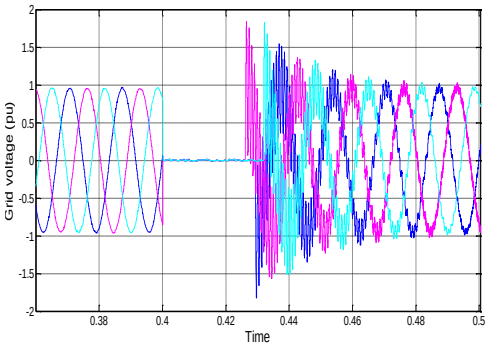

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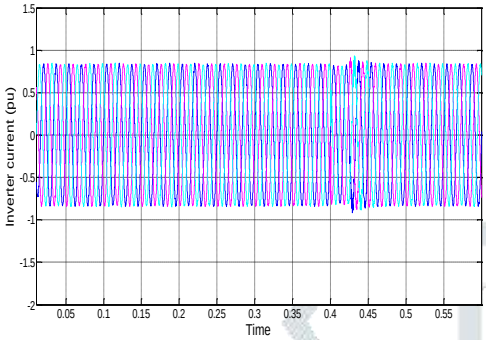

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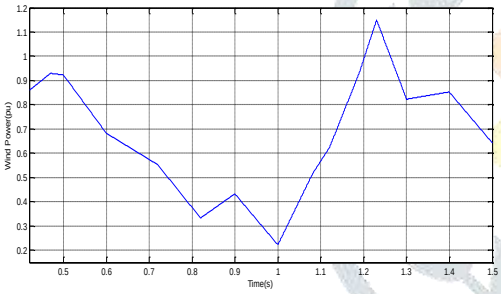
Fig. 5. Simulation results of nearby three phase to ground fault operation (a) power profiles, (b) DC link voltage, (c) Dc link voltage without Flywheel, (d) flywheel speed, (e) grid voltage, and (f) main inverter current.



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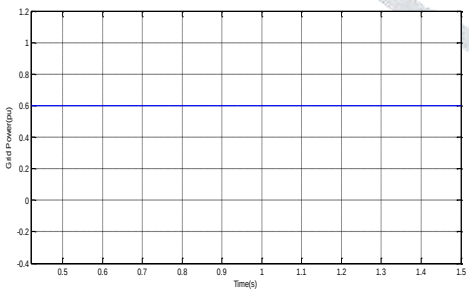

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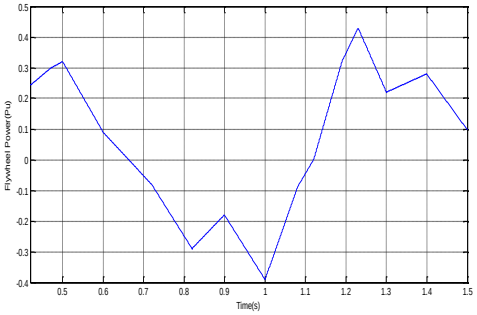

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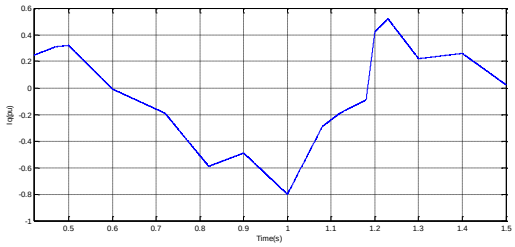

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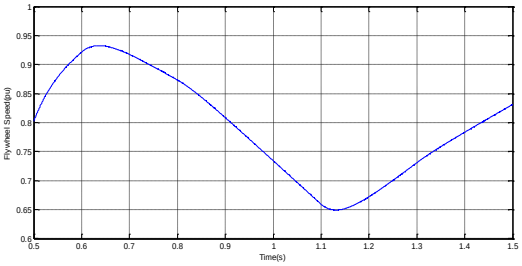

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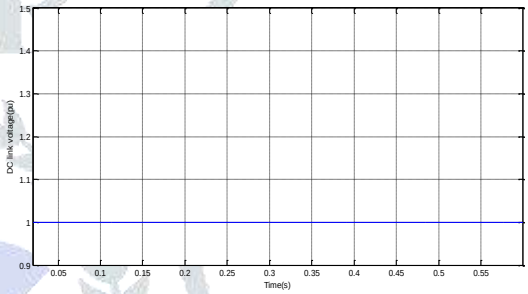
Fig. 6. Simulation results of power leveling operation by using Fuzzy logic controller (FLC) (a) wind power, (b) grid power, (c) flywheel power, (e) IM stator direct-axis current, and (e) flywheel rotating speed



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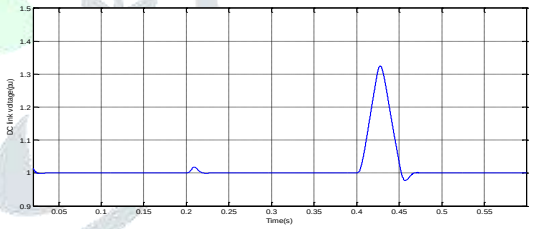

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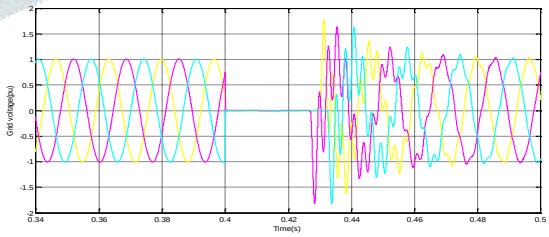

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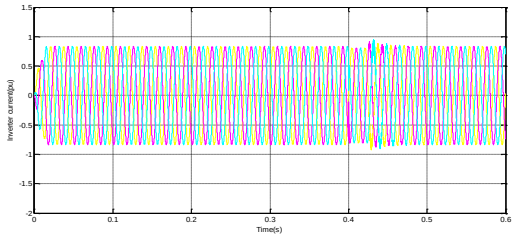

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Fig. 7. Simulation results of nearby three phase to ground fault operation by using Fuzzy logic controller (FLC). (a) DC link voltage, (b) Dc link voltage without Flywheel, (c) grid voltage, and (d) main inverter current.

VI. CONCLUSION

Fault ride-through of a offshore wind cultivate based power creating system associated with an AC network through an HVDC transmission system by using Fuzzy logic controller has been explored in this paper. Another procedure in view of FESS design is proposed with a specific end goal to permit the DC connect to discharge its energy in the FESS by means of the DC interface voltage controller. The proposed FESS with FLC is additionally utilized for control leveling amid typical operation to augment the use of the associated storage system. The connected control procedure comprises of two diverse control accounts in light of the DC interface voltage level, which gives a sign of the fault state. In view of the simulation and test comes about, the proposed FESS engineering gives vigorous execution and quick reaction for both fault ride-through and control leveling purposes. The proposed FESS design displays a few points of interest over the other talked about fault ride-through methods because of the usage of the trapped energy amid a fault.

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