To Harness Hybrid Energy Storage System for LVRT Enhancement in Wind Generation System

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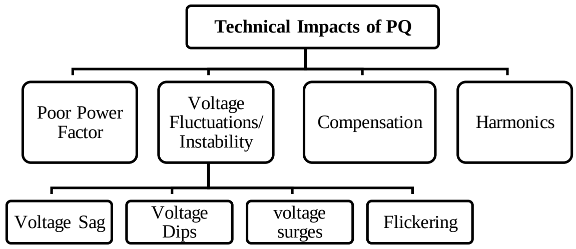
***Abstract*—Recent grid codes demand the injection of reactive current during voltage dips to enhance Low Voltage Ride Through (LVRT) capability of wind turbines. In this paper, a hybrid energy storage system is recommended, comprising a supercapacitor along with a battery to achieve an efficient and smooth power output from an intermittent wind source. In the proposed scheme, supercapacitor provides an immediate reactive power support at the time of rapid load variations. BESS stabilises the output power to the grid at the time of long duration voltage fluctuations. An overall power management strategy is designed to coordinate a smooth power flow between and for the varying source and load conditions. The simulation results presented and analysed are performed using Matlab/Simulink.**

Keywords—*Low Voltage Ride Through (LVRT); Doubly Fed Induction Generator (DFIG); Wind Energy Conversion System (WECS); Battery Energy Storage System (BESS); Super Capacitor Storage System (SCSS); Hybrid Energy Storage System (HESS);*

INTRODUCTION

In today's scenario, energy production from the renewable sources is the most viable alternative to meet the ever-increasing energy demand and environmental degradation. Wind, amongst the various renewables available, found to be best in contributing significant amounts of electric power, when installed in locations where adequate amount of wind is available. Wind power is the cleanest power source, as it emits no greenhouse gasses or air pollutants during its operation and uses minimal amount of water as well. Wind energy is growing exponentially year by year [1] and has gained a lot of interest due to the lower investment cost and the advanced technology in manufacturing high-power wind turbines [2]. But like other renewable sources like solar and tidal, wind is also uncertain and uncontrollable. This intermittent characteristic of wind raises the technical difficulty in ensuring a good power quality, stability, and reliability of the electric power grid [3].

Power quality is defined as power that enables the equipment to work properly. A poor power quality means: Voltage fluctuations, Sag/Swell etc**.** There are various technical impacts of poor power quality listed below, affects the system reliability and leads to malfunctioning of the system.



Modern grid codes require wind turbines to remain connected to the grid even in the case of severe dips, that is, to have a low voltage ride through (LVRT) capability [4]. Moreover, the latest grid codes demand the injection of reactive current during voltage dips with the aim of contributing to the fault clearance and assisting the recovery of the grid voltage. According to LVRT specification, wind turbines are required to stay connected to the grid and supply reactive power when PCC voltage drops and comes under blue area [5], as shown in Fig:1

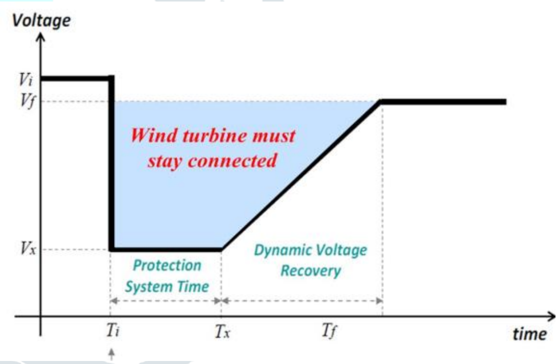


Figure-1

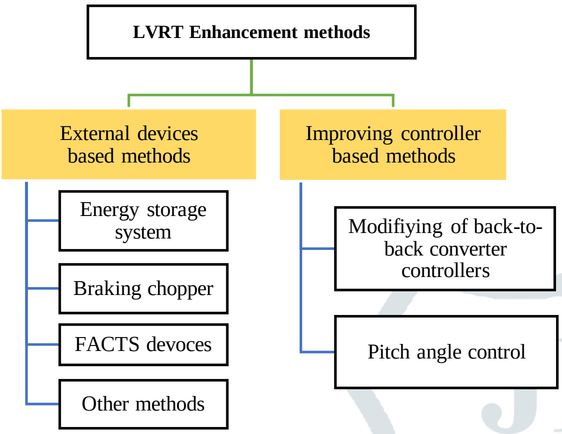
The level of the voltage sag (V_x) and fault clearance time (T_x) are decided by the turbine protection system based on the location and type of fault, i.e. severity of the fault [6]. The required fault ride through behaviour of a wind farm can be summarized into four requirements:

1) For system faults that last up to 140ms the wind farm must remain connected to the network. For super grid voltage dips of duration greater than 140ms the wind farm should remain connected to the system for any dip.
2) During system faults and voltage sags, a wind farm needs to supply maximum reactive current to the Grid System without exceeding the transient rating of the plant.
3) For system faults that last up to 140ms, upon the restoration of voltage to 90% of nominal, a wind farm must supply active power to at least 90% of its pre-fault value within 0.5 sec. For voltage dips of duration greater than 140ms, a wind farm should supply active power to at least 90% of its pre-fault value within 1 sec of restoration of voltage to 90% of nominal.

4) During voltage dips lasting more than 140ms the active power output of a wind farm must retain at least in proportion to the retained balanced super grid voltage.

The compensating devices used for active filtering, load balancing, power factor improvement and voltage variations (sag/swell) and to enhance LVRT capability of the system are shown in Table-I:

TABLE-I



The maximum and minimum voltage withstand limits of windfarms above and below the rated speed value are shown in Table-II

Table-II

Voltage withstand limits for wind farms

Nominal	Voltage (KV)		
	% Limit of variation	Maximum	Minimum
400	+5% to -10%	420	360
220	+5% to -10%	245	200
132	+10% to -9%	145	120
110	+10% to -12.5%	121	96.25
66	+10% to -9%	72.5	60
33	+5% to -10%	34.65	29.7

Energy storage system-based method to enhance LVRT capability

Nowadays energy storage systems (ESSs) are used in different applications. Various ESSs used in wind generation are like SCSS, BESS. There are various FACTS devices also, that serves to enhance the LVRT of wind generation. However, from economic and operational point of view, Hybrid systems are more efficient when compared with single ESS [7]. Because there are various limitations of every single operated ESSs. In BESS, the life time of batteries is strongly affected by the frequently charging and discharging of batteries [8, 9]. Therefore, a third energy source should be incorporated to improve the reliability of WT system. Several ideas in [10-12] propose various configurations of micro-grid using renewable energy sources. In [13], the reactive power required is provided by a synchronous compensator, while the active power is provided by a wind turbine generator. The drawbacks of this topology are its high cost and the complexity of system control.

Hybrid Energy Storage System

Here we have addressed the benefits of adding a supercapacitor to a battery storage system in a DFIG based wind generation system. The SCSS and BESS are connected to the point of common coupling (PCC) via power conversion systems (PCSs) that need to handle bidirectional power flows. In this regard, an Energy Management Algorithm (EMA) has been established between the battery storage system and supercapacitor to operate both energy storage systems in a designated manner.

Fig.2 shows the schematic diagram of HESS integrated with the Wind System to stabilize the power fluctuations. In addition, when the storages are charged, their powers are denoted by positive values (i.e. P_b > and P_s >0) and vice versa.

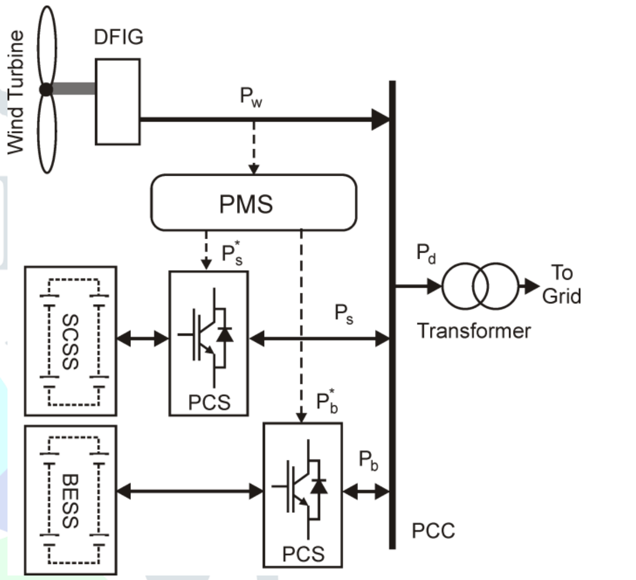


Figure 2 - Integration of hybrid energy storage system into wind energy conversion system.

POWER FLOW DISTRIBUTION CONTROL STRATEGY IN HESS

The SCSS power is determined based on the optimal ZLF whose smoothing time constant is optimized at initial time of each dispatching interval.

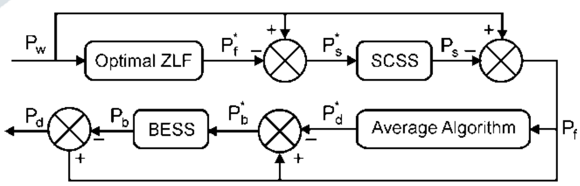


Figure 3 Proposed power allocation control scheme for the HESS.

Fig.3 shows the proposed power flow allocation control for HESS. The SCSS compensates for the fast fluctuating component of wind power (arose due to sudden changes in load) makes the filtered power P_f to be available for low variations. Subsequently, the BESS power is defined by an average dispatching algorithm based on the filtered power $P_{f,}$ to deliver a constant power P_d to the grid. According to the current development of PCS, the SCSS and BESS are assumed to be handling successfully its power references (i.e. $P_s = P_s^*$ and $P_b = P_b^*$); the power dispatch and the filtered wind power are equal to each reference, respectively i.e. $P_d = P_d^*$ and $P_f = P_f^*$

Determination of SCSS Power Flow

As SCSS is compensating for the fast fluctuating wind power components, its power is determined by the ZLF. In this paper, we have developed an optimal ZLF to eliminate the phase delay issue to minimize the storage capacity.

The ZLF means that in the pass-band region, the phase should be zero degree and its magnitude should be in decibels (Db). Meanwhile, in the stop-band region, the magnitudes should be as small as possible.

In order to illustrate the SCSS power determination, Fig. 4 shows the wind power, the filtered power, and the SCSS power by using ZLF.

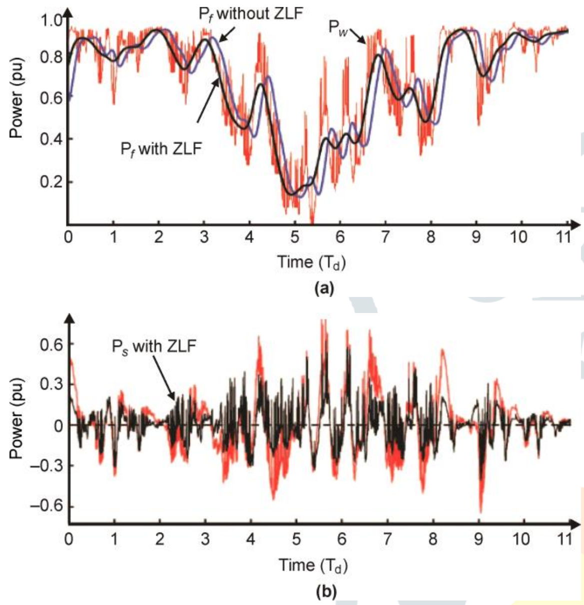


Figure 4 -The power flow of the SCSS respecting to the ZLF (a) Wind power and the filtered power. (b) SCSS power.

Dispatch Power and BESS Power

The power dispatch and the BESS power defined are based on the filtered power P_f that is for lower variations; the BESS handles only the slowly fluctuating power component as shown in Fig. 5. This feature of the proposed coordination control is able to prolong the BESS operational lifetime. In the modern electric power market, the power dispatch of all generation systems must be constant in each dispatching interval. The most effective way to achieve this requirement is to define the power dispatch by means of averaging the wind power.

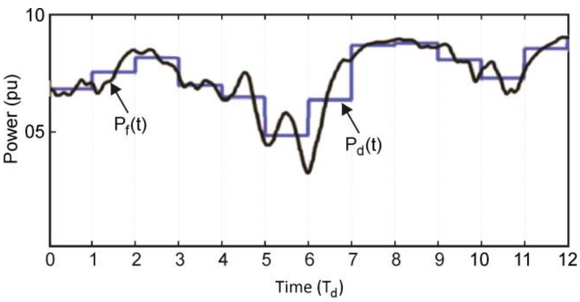


Figure 5 - The dispatch power defined by the average dispatching algorithm

The average dispatching algorithm, in which the power dispatch is constant for each dispatching interval is shown in Fig.6. By subtracting the dispatch power from the filtered power, the BESS power is obtained. As seen that the filtered power is for low variations. So, BESS power is at much less fluctuating level than the wind power.

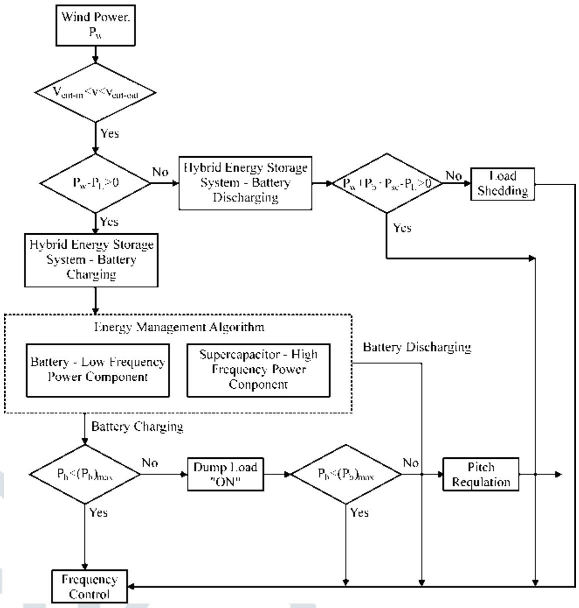


Figure-6

RESULTS AND DISCUSSION

Testing of LVRT capability of DFIG enabled wind generation system have been performed on a 2[MW] wind turbine using MATLAB simulations. The grid voltage is 0.69[kV]/60[Hz] and the switching frequency for both the converters is 2.5[kHz]. The parameters used for the simulation are shown in tables III-VI. The dynamic performance of DFIG system with and without using the ESD control strategy under an unbalanced grid voltage and a constant wind speed of 12.5m/s are compared, and the results are shown in Fig. 7.

The grid voltage performance is shown in Fig. 7(a) which seems quite satisfactory. The stator and rotor currents of DFIG are shown in Fig. 7(b) and (c), respectively which shows that they are in the allowable range. The DC-link voltage of the back-to-back converters is also kept closely to the rated value as shown in Fig. 7(d). However, as can be seen in Fig. 7, these quantities oscillate severely without using ESD.

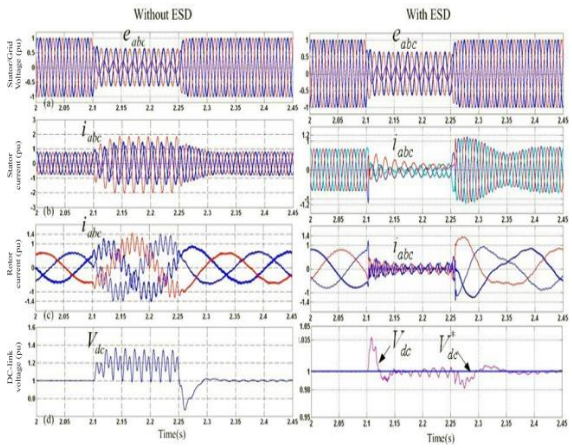


Figure 7 - DFIG wind turbine system performance with and without using ESD. (a) Grid Voltage, (b) Stator Current, (c) Rotor Current, (d) DC-link voltage.

CONCLUSION

In this paper, an optimal HESS is proposed to stabilize the variations in wind generation system. Supercapacitor provided an immediate reactive power support at the time of rapid load variations & BESS stabilised the output power to the grid at the time of long duration voltage fluctuations. An overall power management strategy results in a smooth power flow.

APPENDIX

The Wind Turbine Parameters, Simulation and Experimental Parameters for DFIG and Simulation Parameters for ESD are presented in Tables III – VI respectively.

TABLE III

Wind Turbine Parameters

Rated wind turbine power	2[MW]
Radius of turbine blades	44.18[m]
Density of Air	1.224[kg/m^3]
Coff. for power conversion	0.40
Optimal TSR	8.0
Cut-in speed	3[m/s]/25[ms]
Rated wind speed	12[m/s]
Blade inertia	6.3x106[kg.m^2]

TABLE IV

Simulation Parameters for DFIG

Rated power	2 [MW]
Stator voltage/frequency	690 [V]/60 [Hz]
Stator resistance	0.00487pu
Rotor resistance	0.00550pu
Stator leakage inductance	0.0924pu
Rotor leakage inductance	0.0994pu
Generator inertia	200[kg.m^2]

TABLE V

Experimental Parameters for DFIG

Rated power	3[KW]
Stator resistance	0.0372pu
Stator voltage/frequency	220 [V]/60 [Hz]
Rotor resistance	0.04420pu
Stator leakage inductance	0.07734pu
Rotor leakage inductance	1.5594pu
Generator inertia	0.0032[kg.m^2]

TABLE VI

Simulation Parameters for ESD

Inductor (L_f)	2.5[mH]
Supercapacitor	2.93[F]
DC operating voltage	120[V]
Switching frequency	5[kHz]

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