REACTIVE CURRENT SUPPORT OF PMSG BASED WIND FARM USING FUZZY LOGIC CONTROLLER DURING SEVERE GRID FAULT

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***Abstract:** Wind energy conversion systems (WECS) are one of the most prominent clean renewable energy sources adopted by many countries due to its reduced maintenance costs and high reliable operations. Grid codes demand WECS to get synchronized with the grid and supply reactive current when any grid faults are subjected. Reactive power compensation devices like STATCOM are used in windfarms. Reactive currents are generated by coordinated controlled operation of WECS and STATCOM using Phase locked loops (PLL) based-vector control methods. Due to imbalance in the generation and demand WECS loses synchronism with the grid during severe faults conditions. In this paper coordinated control strategy is adopted using Fuzzy logic controller for WECS and STATCOM during severe fault condition is proposed. The synchronism is maintained by balancing the active powers at both the ends. Fuzzy logic control delivers optimal operation by supplying reactive power through STATCOM to the wind farm balancing the voltage profile during abnormal conditions. Effectiveness of the proposed method is evaluated using simulation studies.*
***Keywords:** permanent magnet synchronous generator (PMSG), low voltage ride through (LVRT), windfarm, STATCOM, fuzzy logic controller(FLC)*

I. INTRODUCTION

Due to excess usage of fossil fuels, there is drastic rise in environmental concerns globally. Addressing this issue Renewable energy sources (RES) emerge as an alternative for fulfilling the energy demands by replacing the traditional conventional methods of generating power and became environment friendly by reducing the carbon footprints. Resources like wind, solar, geothermal etc. are greatly utilized to generate energy that can be used independently or integrated to the grid.Wind energy come out as one of the prominent clean energy harnessed from wind sources mostly attracted in many countries[1]. However, on integration into the grid has raised many concerns on its stability and reliability of the power system. certain grid codes are proposed to solve these concerns, where grid operator systemize the features and characteristics of the wind energy system.[2] low voltage ride through (LVRT) is a grid code that performs the operation of supporting the grid by injecting reactive power and maintains synchronization with the grid under fault conditions.[3] During grid fault conditions LVRT supplies the reactive power, the profile and reactive power requirements are as shown in the Fig.1. [4] when there is a voltage sag less than of 50%, to standardize the voltage profile an amount of twice the percentage of reactive power is supplied. If there are serious fault conditions, 100% of reactive power is contributed.

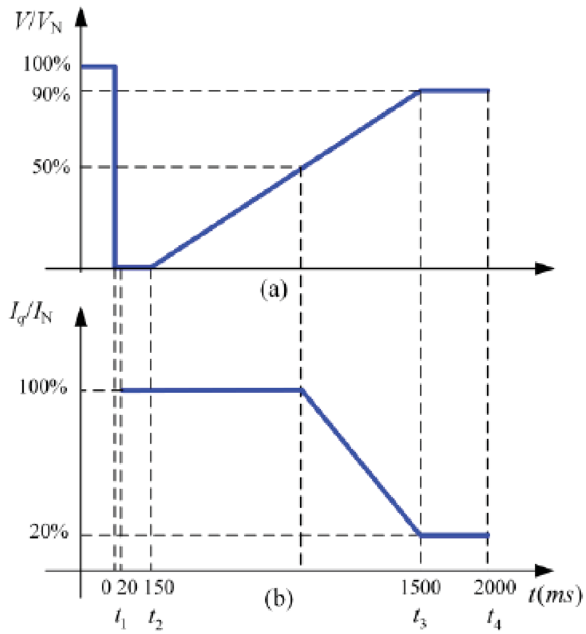


Fig .1. Profile of LVRT and Reactive power Demand

Permanentmagnet synchronous generator (PMSG) based wind energy conversion system(WECS) has many advantages on grid code LVRT implementation on compared with other wind turbines on the scale of flexibility and capability on control of active and reactive powers of the power convertors on the permanent magnet side and grid side.[5] different LVRT strategies are discussed in the literature like coordinating active power control of generator and grid side converters[6] power dissipation scheme basedon DC chopper[7]. On contrary Under severe fault conditions like Phase to phase faults the positive sequence current capacity of PMSG based WECS is degraded to 35% as defined in [8]. Addressing the issue STATCOM is used for regulation of voltage in the wind farms and is also helpful during unsymmetrical grid fault situations.

Reactive current capability is a fundamental of WECS and STATCOM for synchronizing to the main grid. However, due to some grid faults wind farm can’t be able to ride through leading to loss of synchronism (LOS). [9] voltage source converters are also impacted to LOS due to different factors like voltage sag, short circuit ratio, Phase locked loop parameters and active power capacity of VSC. To avoid the LOS different solutions are presented in the literature. Modified current injection scheme [10], isolated Phase locked loop [11], switched PLL [12], Virtual synchronous generators are proposed. But during transients under faults the active and reactive current parameters fall out of control due to slower dynamic response of the PLL, which are not accepted by the grid codes.

The LVRT needs to define the trip in contingency state to maintain the system under stable level. But when the fault occurs system stability is disturbed. It will affect power generator and results in low injection of reactive current which can't be able to compensate during faulty situation on the grid. reactive current support and voltage support by the system is the main part for recovery and effective output is obtained. In addition to that it may improve the transient performance of the wind farm with STATCOM. It is capable to drive reactive power to vary the control in the severe fault conditions. When the wind speed goes down due to insufficient power generation resulting imbalance in grid and wind system converter ends there is collapse to very low values less that of current value the low voltage ride through this is the grid code which is connected with wind system by the utility to the distribution and generation systems to follow that in this particular sections then the wind turbine made to trip. When any severe fault occurs wind, turbine is not only made to trip at particular instant. Recovery the fault currents its needs to clear. when this condition occurs certainly go for the fault clearance but up till that LVRT grid code is used for the deciding the wind turbine should go for tripping or not.The LVRT needs to define the trip in contingency state.

PMSG increase DC excitation which was provided by permanent magnet instead the converter to the it's can variables losses it can be better solution and also it has very efficiency. In Low maintenance conditions the wind speed changes that results in change in frequency, induced voltage and currents. So, in such cases the use of PMSG connected to the grid side converter over all the PMSG is economically better than the DFIG. And the PMSG is developed to provide active currents and reactive currents that are needed to wind farm.

PMSG for the variable wind speed that converts the dc power to ac power and regulated the generator power which is mechanical power to electrical power with pulsation of all the data that well defined are better quality of the power based electrical power to grid. This proposed of effective report is LOS of synchronization is reducing the active current of the voltage source converter, it works on that time it can be very difficult by the LVRT period when it is only required to the reactive current by the grid codes.

This paper enhances and improvises the methodology used by the authors in [13] by replacing proportional integral control with Fuzzy logic controller in the control mechanism of the phase locked loop of WECS and STATCOM. It analyzes the dynamic LOS of the wind farm under severe fault conditions. Effectiveness of the control strategy is obtained by simulation using MATLAB Simulink.

II. MODELING OF THE PMSG BASED WECS

The configuration of the PMSG based wind farm is as shown in the fig. 2 it has two converter ends with a dc chopper connected, the converter end with permanent magnet and another end is grid side converter. The wind farm is aggregated as the connected by wind energy conversion system. Windfarm as grid interconnected the with two transformers are connected of feeder. STATCOM is connected in between the transformers to compensate the reactive demand. The power represents by Theremins equivalent circuit. Voltage and impedance line are connected to point of the common coupling (PCC)

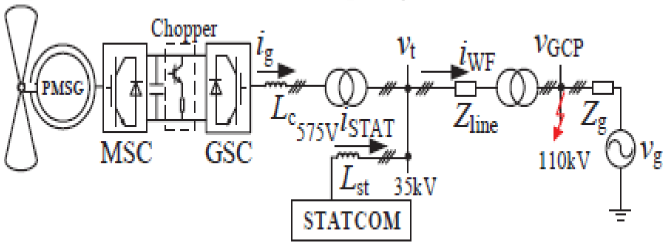


Fig .2. Structural Configuration of the PMSG based wind farm

The wind energy conversion system consists of mechanical and electrical partstwo-mass spring model is typically utilized to show its elements taking into account that the PMSG has no damping component of the generator shaft is dismissed. At that point themechanical system of the WECS is communicated as (2) and (3)

$Pm = \frac{1}{2}\pi R^2 \rho V^3 \mathrm{Cp}$ ………………… (1)

$J_{ag}\ \omega m = K\theta - Te$…………… (2)

$\theta = \omega_h - \omega_m$……………. (3)

ωh = the rotational speed of the wind turbine and generator PMSG based wind farm model can be expressed as equations as in (1)

$V_{sq} = Rs\ i_{sq} + L_d\ p_n\ \omega_m\ i_{sd} + \Psi r\ \ Pn\ \omega_n$………(4)

$Pg = \frac{3}{2}(vtd\ igd + vtg\ igd)$ ……… (5)

A.Design of Phase Locked Loop

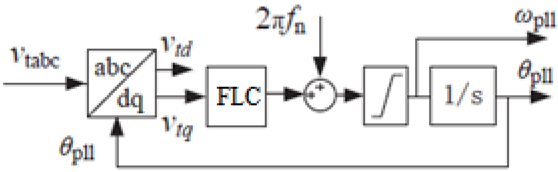


Fig .3. functional diagram of the phase locked loop

In this diagram shows the observed grid voltage and the frequency is mathematical equation for given in (4) & (5)

$\frac{dwpll}{dt} = Kp\frac{dv\ tq}{dt} + KiVtq$............(5)

Whereθpll and ωpll are the output of the PLL; Kp and Ki are controller constants

B. Synchronization Analysis of the PMSG Based Wind Farm

The synchronization of the system in WECS can bestable, It can be seen that little Kp ,Ki proportional and integral of the PLL are useful to balance out the WECS, which shows that a moderate PLL is help for the synchronization strength during severe network issue period. Additionally, a smaller Lg, which means a grid attachment, is useful to develop the synchronizing steadiness.further suggests that loss of synchronization is brought about by the dynamic power irregularity in the framework, which is comparative with the customary SG based power frameworks. Accordingly, the accompanying ends can be derived

- if Po>Pg the wind energy conversion output power is less than the generation power the frequency will be increasing.
- if Po=Pg the wind energy conversion output power equal to generation power frequency level will be stable
- if Po<Pg the wind energy conversion output power greater than generation power frequency of the WECS will keep decreasing

when the transmission fault happens at t=1s and the Grid Connection Point voltage at that point drops to 0.02 pu. During the flow time frame, the dynamic of power results generation side will be a time period during of fault situation given fig.3, the voltage, current and frequency at the grid connection point is as shown in Fig.4,5,6.It tends to be seen that the recurrence recognized by the PLL will lose synchronismwith the network recurrence when P*o is inconsistent to its real value Pg.proportional of given swinging equation as in (1)

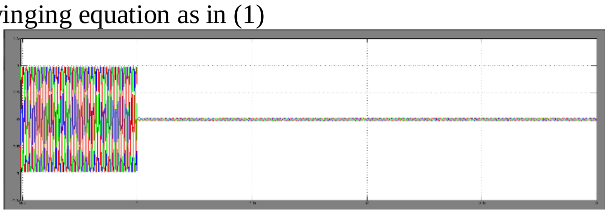


Fig. 3.Vgcp(pu) vs time (s)

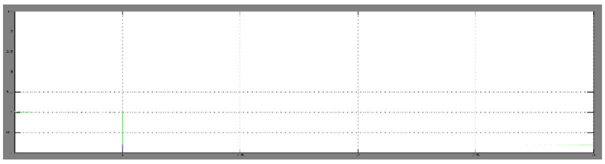


Fig.4. power (pu) vs time(s)

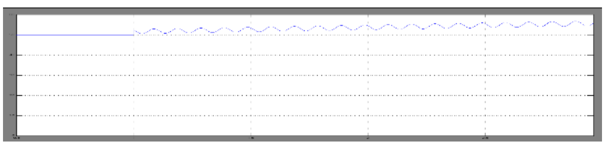


Fig.5. FPLL (Hz) vs Time(s)

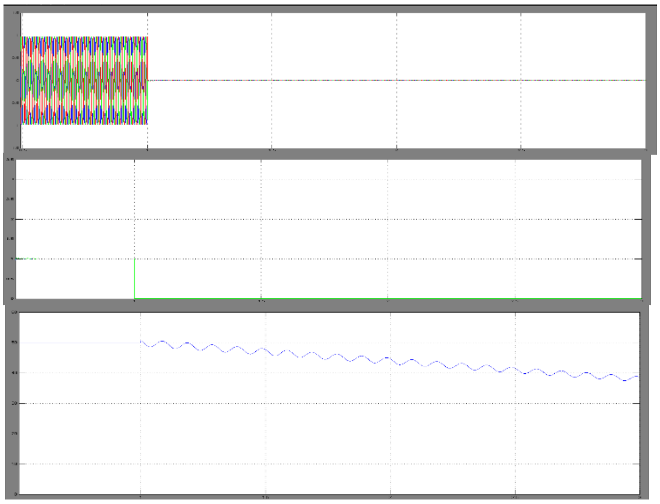


Fig.6. a, b, c for the different case of with Po >Pg.

For the WECS, its reactive power ability would decrease at the point when increasingly dynamic power is required to improve the synchronization dependability because of the present rating constraint of the power converters. So as to keep synchronization security what's more, supply characterized responsive current to help the network, the coordination of the WECS and STATCOM is essential. The WECS can assist the STATCOM with keeping synchronization with the network while the STACOM can compensate the remainder of the reactive current to fulfill the necessities of the grid codes.

III. PROPOSED METHOD OF FUZZY LOGIC CONTROLLER

The wind energy conversion system develops more active power and the less reactive power at the time voltage is increases at the time use of necessary devicethat is STATCOM, it produces reactive currents to help of the wind energy conversion. In fuzzy logic control basic control action is determined by set of language rules. The function is determined by the system. Since the numerical variables are converted into language variables mathematical modeling of the system is not required in fuzzy control. The fuzzy logic controller is consisting of mainly three parts

1. Fuzzification
2. Interface engine
3. Defuzzification

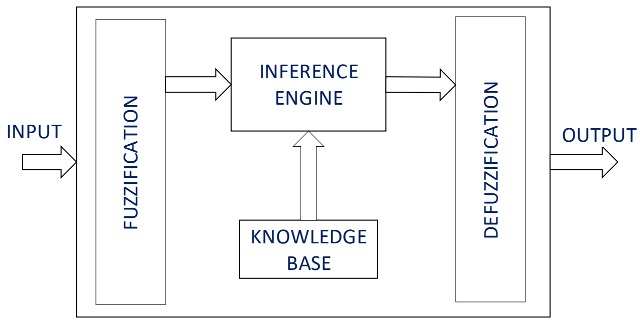


Fig.7.fuzzy logic controller block diagram

Fuzzification: In this function the input variables are converted into the linguistic variables for processing. here this function consist of five fuzzy sets are using, theyare subsets NB (Negative Big), NS (Negative Small), ZE(Zero), PS (Positive Small), PB (Positive Big).As shown in table 1. the alignment of membership function withthe input errorand change the generalized an input factor

*Inference Engine:*In this block reasoning mechanism and processing is performed. Italso consists of knowledge base where the memory of the membership functions is stored. The rules are stated in if-then statements that is similar to the human thought to perform the particular operation. It stores all the membership functions as used by the rules defined. A typical model is as shown in figure.7

*Defuzzification: in De*fuzzification stage the fuzzy variables or linguistic variables that are processed with membership functions are again converted into normal /crisp variables that is completely opposite function of a fuzzification block.

IV. CONTROL DESIGN OF THE STATCOM

The control design of the STATCOM with fuzzy logic control is shown in the fig.9. STATCOM has the LOS hazard when the network voltage plunge is serious. In the event that the STATCOM is associated at the PCC, the responsive current provided by the STATCOM would like cause active power in the load side. The active power control side because of the STATCOM can be repaid by the WECS in light of the fact that the power irregularity would cause the float of the PLL reference which in turn influence the active power reference of the WECS.

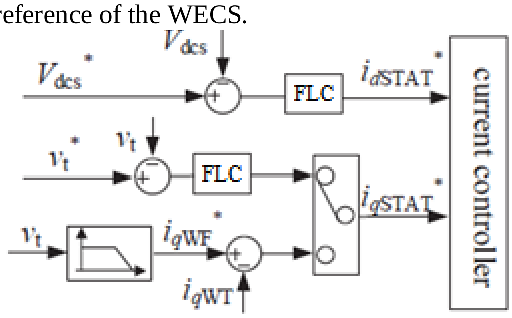
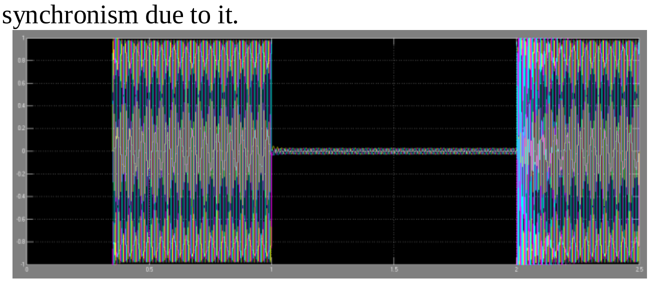


Fig.8.Control diagram of STATCOM

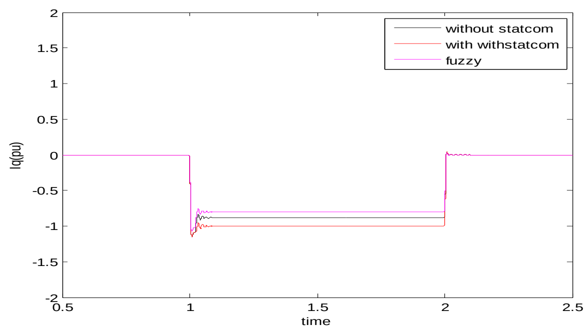
The proposed system at various voltage various levels. More active present and less reactive current would be created by the WECS when the rise of the voltage levels isincreased. It implies that the reactive current capacity of the WECS would be yielded if the imbalanced dynamic power for the synchronization steadiness is redressed. In this manner, the synchronized STATCOM is important to offer extra receptive current to enable the WECS to fulfill the LVRT system

V. SIMULATION RESULTS AND DISCUSSIONS

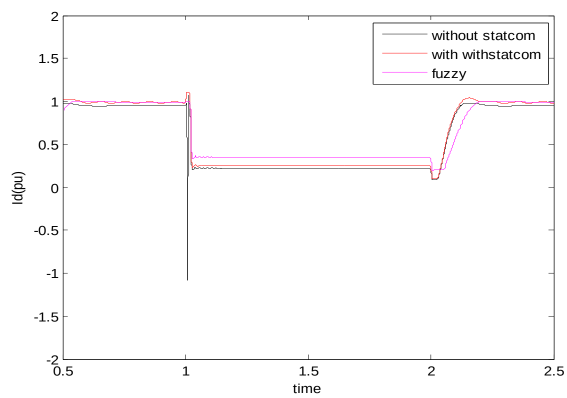
To evaluate the current control strategy, simulations are carried out on Grid integrated WECS model designed in the MATLAB Simulink. Results are obtained for different cases for performance studies. The cases include simulations with and without STATCOM and by using Fuzzy logic controller.Fault is created at t=1s and resolved at t=2s. it can be observed from the results during the initiation of fault the parameters at the grid side converter drops. The voltage at the GCP is 0.02 puas shown in fig.8. It can be controlled using the DC link voltage of the chopper at the GSC. PLL identifies the transients as shown in the figure 9 a, b, c. in fig 9. (a) the q axis current drop can be observed for different cases. The STATCOM operation caused larger drop while without STATCOM and by using fuzzy logic controller the drop is lower than the former ones. Similarly, in the case of d axis current in fig.9. (b) fuzzy based result shows effective operation than with and without STATCOM case. The frequency output waveform shown in fig. (c) gives the peak notch at the time of fault on and off conditions, it can be observed that the operation of WECS converter with STATCOM gives larger deviations of (-60 Hz) in the frequency which leads to LOS function driving the system to instability. While in the case of without STATCOM case the deviations are not much but they are capable of driving the system into LOS state. Finally, by using the proposed control of FLCthe deviations are mitigate and are limited to nearly 53Hz which is compatible and there is no loss of synchronism due to it.



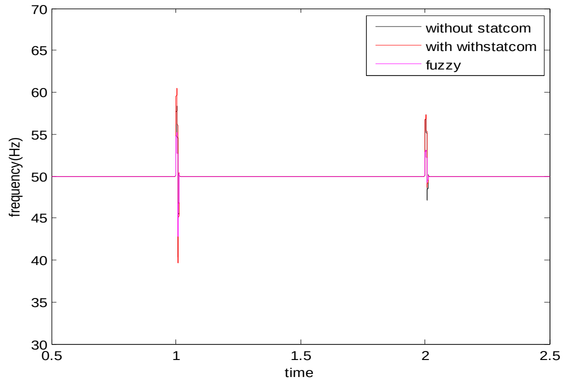
(a)



(b)



(c)



(d)

Fig.9.a,b,c,d. waveforms of voltage, id,iq and frequency for cases without statcom,with statcom and fuzzy controllers

From the three scenarios, the wind farm can keep synchronized withthe STATCOM and grid but the on stability point of view the FLC gives the effective operation, however as per the grid codes the Reactive power injection can be possible with static compensators. Without STATCOM the reactive power produced at the wind farm is lesser cant be compatible to satisfy the grid codes. The DC link voltage gets stable at the generator side end control.moreover, the network side converter accomplishes full control of the active and reactive powers injected into the utility grid.

VI. CONCLUSION

This paper analyses loss of synchronization and the LVRT strategy for PMSG based wind farm under severe fault conditions. The coordinated current control of WECS and STATCOM using fuzzy logic controller gives the effectiveness of the methodology. The results obtained has proven that by using FLC the ride through capability can be increased and maintain the grid code by supplying the required reactive power to the grid and maintain the system in synchronization. It is also observed that the system can be maintained under the grid code during symmetrical faults but maintaining the stability during unsymmetrical faults can still be a scope of discussion.

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