WIND FARM MATHEMATICAL MODELLING AND FRT IMPROVEMENT USING PMSG AND SOFT-COMPUTING

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Abstract: In this paper multi machine concept is taken for fault ride through (FRT) improvement. Here FRT capability improvements of two wind generator are considered and two wind farms are connected with multi machine. This paper incorporates a detailed mathematical model for wind turbine and it shows how input wind is converted to power and how bet'z limit varies with wind. As a soft computing technique, fuzzy logic controller is used at grid side for voltage control. Crow bar protection concept is applied and implemented between machine and greed side converters. Ground fault is created in simulation and control technique helps to improve this FRT capability due to fault which we can say due to network disturbance.

Key Words: Fault ride through, PMSG, fuzzy, mathematical modelling, multi machine.

I. Introduction:

As the world is growing, demand for energy is also considerably increasing. Now a days due to more concern on pollution free power generation sources renewable energy sources are in high demand. Wind farm is also one of the renewable energy source and its use and implementation is considerably increasing. As the wind is not constant at all the time, so generated power may vary. We can get stable power by using particular control strategies but still we need to minimize transients available in power. As well characteristics should match between generator source and load. In this paper two wind farm concept is used to generate power, and both are sullying to load. Only the difference presented in this paper is one wind farm uses variable speed permanent magnet synchronous generator and another wind farm uses fixed speed Induction generator. In this paper, active crowbar approach is presented to prevent overload condition and to match characteristic and impedance matching with load. Crowbar is a basically device which prevents circuit from overload condition.

Wind mill 1 power and Wind speed = 5MW, 12m/s
Wind mill 2 power and Wind speed = 5MW, 10m/s
Transformer 1 rating (Primary to Secondary) = 575v to 66kv
Transformer 2 rating (Primary to Secondary) = 480v to 66kv
System frequency = 50 Hz

II. Mathematical modelling for wind turbine:

Consider a one dimensional Mathematical Model for the Wind Turbine Design.

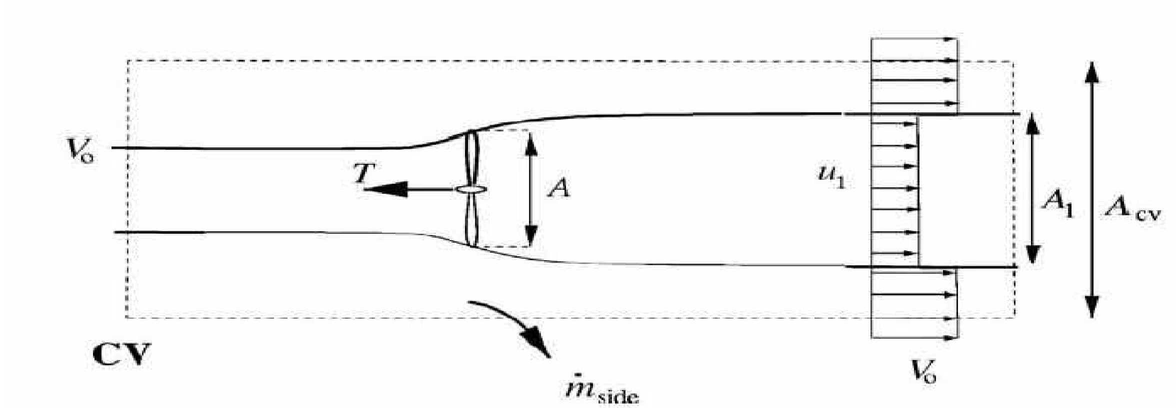

Figure 1 : Schematic View of Wind turbine wing Operation

One Dimensional fluid mechanics of wind turbines

Application of Raynold's conservation theorem for linear momentum:

$(\text{momentum})_{out} - (\text{momentum})_{in} = -F_n$ (1)

Where,

F_n= Axial thrust on Rotor

$(\text{momentum})_{out} = \rho u_1^2 A_1 + \rho V_0^2 (A_{cv} - A_1) + \dot{m}_{side} V_0$ (2)

$(\text{momentum})_{in} = \rho V_0^2 A_{cv}$ (3)

Combining equation (1) to (3), gives

$\rho u_1^2 A_1 + \rho V_0^2 (A_{cv} - A_1) + \dot{m}_{side} V_0 - \rho V_0^2 A_{cv} = -F_n$ (4)

Application of conservation of mass

$\rho A_1 u_1 + \rho (A_{cv} - A_1) V_0 + \dot{m}_{side} = \rho V_0 A_{cv}$ (5)

$\dot{m}_{side} = \rho A_1 (V_0 - u_1)$ (6)

Further,

$\dot{m} = \rho u A = \rho u_1 A_1$ (7)

$\frac{A}{A1} = \frac{u1}{u}$ (8)

Combining equation (6),(7) and equation for conservation of momentum leads to:

$F_n = \rho u A (V_0 - u_1) = \dot{m} (V_0 - u_1)$

Further, it can be shown that:

$u = 0.5 (V_0 + u_1)$ (9)

Alternate control volume consideration

Application of Energy conservation theorem

$\dot{m}_{side} \left(\frac{po}{\varsigma} + \frac{V02}{2}\right) = \Delta\dot{w} External\ work\ rate + \dot{m}\left(\frac{po}{\varsigma} + \frac{u12}{2}\right)$ (10)

$\Delta\dot{w} External\ work\ rate = \dot{m}\left(\frac{vo2}{2} - \frac{u12}{2}\right)$ (11)

$= 0.5\ \rho u A\ [v_o^2 - u_1^2]$ (12)

1. Definition of Axial Induction, "a"

$U = (1 - a)\ V_o$ (13)

But, $u = 0.5\ (V_o + u_1)$ (14)

Combining equations 13 and 14, yields :

$u_1 = (1 - 2a) V_o$ (15)

2. Introduction of Axial Induction, "a", into External work rate(Power) Equation :

We know :

$p = \Delta\dot{w} External\ work\ rate = 0.5\ \rho\ U\ A\ [Vo2 - U1^2]$

Introduce Equation 13 and 14 into equation 16 to obtain :

$p = 0.5 \rho A (1 - a)\ Vo\ [Vo2 - (1 - 2a)^2 V_o^2]$

$= 0.5 \rho A (1 - a)\ Vo^3\ [1 - (1 + 4a^2 - 4a)]$

$= 0.5 \rho A V_o^3\ [4a - 4\ a^2]$

$= 2 \rho A V_o^3\ a(1 - a)^2$ (16)

Introduction of Axial induction, "a" into axial thrust, F_n

$F_n = \rho U\ A\ [Vo - U1]$ (17)

$u1 = (1 - 2a)\ V_o$ (18)

$u = (1 - a)\ V_o$ (19)

Combining Equations 17 – 19, yields :

$F_n = \rho (1 - a)\ V_o\ A\ [Vo (1 - 2a)\ Vo]$ (20)

$F_n = 2\rho A V_o 2 \; a(1 - a)$ (21)

Definitions and Formulations

1 Available power, p_{avail}

$p_{avail} = 0.5\rho A\, vo3$ (22)

2 Available power, p_{avail}

$C_p = \frac{p}{pavail} = \frac{p}{0.5\rho A\, vo3}$ (23)

3 Thrust coefficient, C_T

$C_T = \frac{Fn}{0.5\rho A\, vo2}$ (24)

C_p in terms of induction factor, a

$C_p = \frac{p}{0.5\rho A\, vo3} = \frac{2\rho A\, vo3}{0.5\rho A\, vo3} a(1-a)3$ (25)

$Cp = 4a(1\text{-}a)2$ (26)

$\frac{dcp}{da} = 0 = a(1-a)(1-3a)$ (27)

a* = 1/3 (28)

Cpmax = 16/27 = 0.59 (29)

Optimal Value of power Extractor, pmax

$pmax = 2\rho A\, vo3\ (0.33)(1\text{-}0.33)2$ (30)

$pmax = 0.296\rho A\, vo3$ (31)

Mathematical modelling for PMSG

$$\frac{di_d}{dt} = \frac{R_s i_d}{L_d} + \frac{w_a L_q i_q}{L_d} + \frac{v_d}{L_d}$$

$$\frac{di_q}{dt} = -\frac{R_s i_q}{L_q} - \frac{w_a L_d i_d}{L_q} - \frac{w_a \lambda_o}{L_q} + \frac{v_q}{L_q}$$

III. Simulation:

Simulation at below has been implemented and simulated.

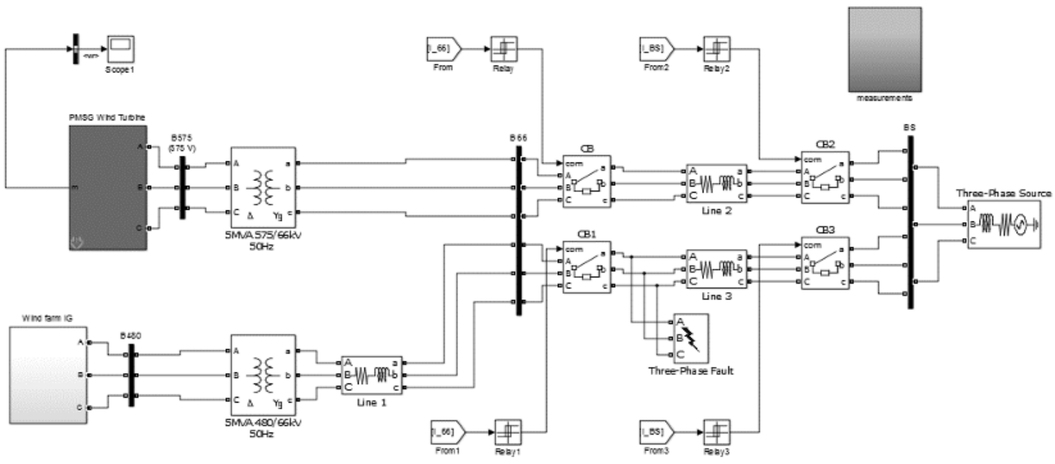

Figure 2 : MATLAB Simulink model

In Windfarm 1 PMSG is used as a generator and in wind farm 2 induction generator is used. Wind farm converts available varying wind into power by using wind turbine and generator. This generated AC is converted to required voltage using transformer and this power is ready to feed in transmission line. Here In this paper, fault is simulated on one of the transmission line of wind farm 2 at particular time. So, total load is transferred to wind farm 1. As fault occurs on transmission line, at that time voltage is reduced very highly and current is increased which may damage to connected load and devices. So, this power needs to be stabilize as soon as possible.

Here PMSG is a variable speed generator and Induction generator is a fixed speed generator. When fault occurs, at the same time that particular of transmission line is disconnected through circuit breakers and other wind farm adjusts speed of its generator to generate required power according to load.

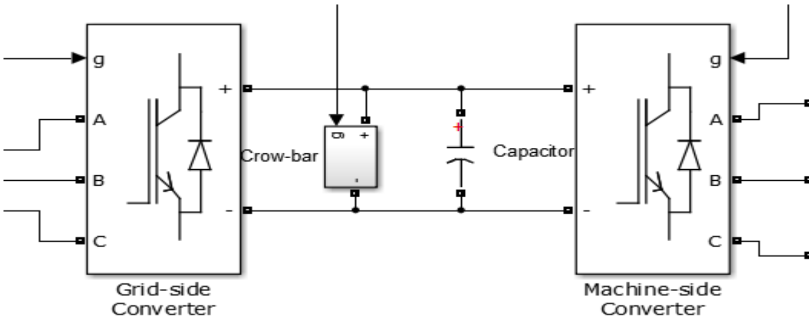

Figure 3 : MATLAB Simulink Converter Model

As PMSG is a variable speed generator, so whenever fault occurs on transmission line of fixed speed induction generator, at that time to supply the load, PMSG varies its speed and there may be a loading on generator. So, crow bar is introduced to prevent overload condition and to prevent damage to remaining construction. Whenever overload condition occurs, crowbar creates a short circuit to overload voltage and is we uses a passive crow bar, then it remains to short circuit position even overload is finished. But active crowbar used a thyristor or GTO based on gate trigger signal. Active crowbar is activated to short circuit when overload occurs, and when overload finished then crowbar closed itself.

Fuzzy Logic control

In this simulation as we have used fuzzy logic control, it is based on *Sugeno* implementation. Input and output linguistic variables are five in which inputs are triangular membership functions. Basic difference between *Mamdani* and *sugeno* is that, in *Mamdani* defuzzification method is dependent on membership function at output side linguistic variable where as in *sugeno* method defuzzification is based on fix value decided at output side, and fixed value itself is a function of input variable. Weighted average method is taken as a defuzzification.

$$f(x;a,b,c)=\begin{Bmatrix} 0, & x\le a \\ \frac{x-a}{b-a}, & a\le x\le b \\ \frac{c-x}{c-b}, & b\le x\le c \\ 0, & c\le x \end{Bmatrix}$$

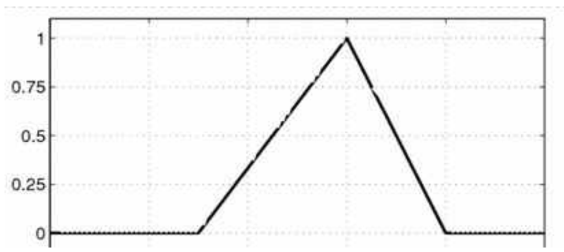

Figure 4 : Fuzzy Logic membership function

Rules

1. IF input is NB THEN output is 0.75
2. IF input is NS THEN output is 0.375
3. IF input is Z THEN output is 0
4. IF input is PS THEN output is -0.375
5. IF input is PB THEN output is -0.75

IV. Results:

In simulation fault is simulated between 0.1 and 0.2, and FRT is tried to improve through fuzzy grid side control. In each simulation on X-axis it shows a simulation time.

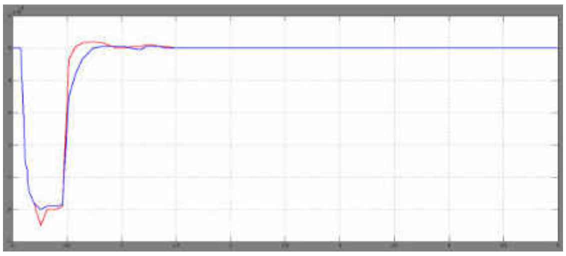

Figure 5 : Active power at Wind farm 1 (a) Without Control (b) With control

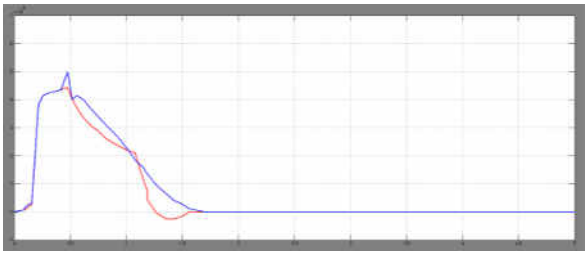

Figure 6 : Reactive power at Wind farm 1 (a) Without Control (b) With control

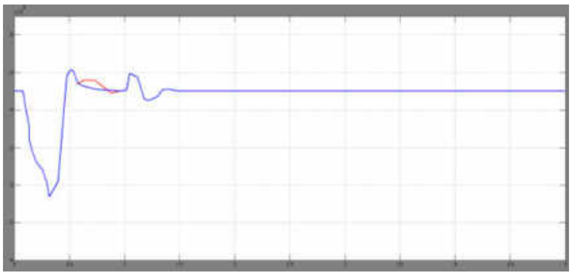

Figure 7 : Active power at Wind farm 2 (a) Without Control (b) With control

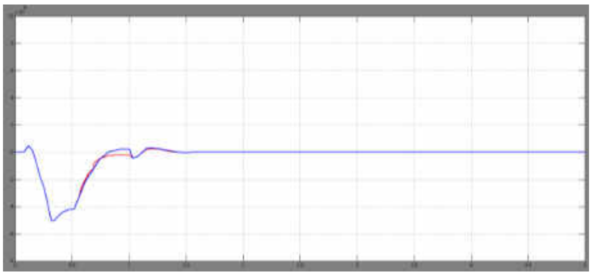

Figure 8 : Reactive power at Wind farm 2 (a) Without Control (b) With control

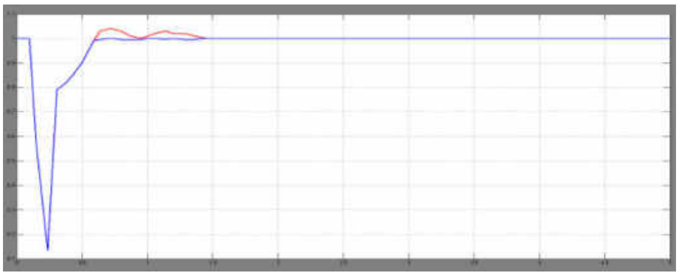

Figure 9 : Voltage at PCC and Three phase Source (a) Without Control (b) With control

V. Conclusion:

In this paper fuzzy control strategy is implemented for FRT improvement. From the results it can be observed that fuzzy is effective technique for FRT improvement. Because of this grid side control strategy an additional cost can be eliminated for reactive power compensation. Here it can be seen that whenever active power decreases at the same time reactive power is injected which maintains voltage stability level even during fault.

VI. References:

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