

Performance of Boost Converter with Fuzzy Logic Controller to Increase the DWIG Speed Range in Wind Power System



C Surya Prakash

Abstract-In this paper the wind energy conversion with a variable speed of wind turbine connected to the grid which is based on dual stator induction generator (DWIG) which is excited by Static Excitation Controller (SEC) on the Control winding side which utilized by Control –Winding Voltage Oriented Control (CWVOC), and followed by Step up converter at the power winding side which utilized Fuzzy Logic Controller in its control strategy to increase the speed range of DWIG. The performance of boost converter with FLC in increasing the wide range of speeds can be executed by using mat lab/Simulink.

Index terms: Control –Winding Voltage Oriented Control (CWVOC), Dual Stator Winding Induction Generator (DWIG), Fuzzy Logic Controller (FLC), Semiconductor Excitation Capacitor (SEC)

I. INTRODUCTION

Wind power generation has become an attractive consideration because of the rapid utilization of non-renewable energy sources and the expanding natural concerns. Normally 10%-12% of overall electrical energy is producing from wind power, due to drastically changing concerns in the world by 2030 there would be an inclination in the production of wind energy since it is a renewable source of energy [1].

Earlier wind turbines were utilizing squirrel cage induction generators for grid connection, but due to its constant rotor speed which will not match the incoming variable wind speed and gear box problems and even it is not used for obtaining maximum power. By considering all this constraints power electronic converters were introduced along with generators which is suitable for variable speed systems [2]-[3]. While most of the variable speed turbines are of costly, besides have higher efficiency. For economic considerations, Dual Stator Winding Induction Generators (DWIG) are introduced which are of low cost, but is of low efficiency. The wind condition is better at the offshore side to extract maximum wind power, so there is drastically appearing demand for offshore wind turbines. For economical transmission of power for longer distances High Voltage Direct Current (HVDC) transmission is utilized instead of AC transmission. Due to economic concerns and wide speed range operations DWIG systems are introduced in the offshore areas.

In this paper, the main aim is to increase the speed range of DWIG especially to obtain voltage in the low speed region. As the speed is low the output power obtained is also low, to obtain this a step up converter is utilized along with DWIG which increase voltage at low speeds DWIG consists of two windings namely control winding and power winding which are wound under same stator slots, In control winding part, Static Excitation Capacitor (SEC) is used to vary capacitor voltage (V_{dc}) which regulates control winding voltage (V_c). By considering v/f characteristics of DWIG in the control winding side SEC utilizes Control Winding Voltage Oriented Control (CWVO). Generally DWIG can run at between 0.66-1.6 p.u speed range. In order to obtain voltage at low rotor speed and to increase speed range at low values than usual i.e., 0.4-1.6 p.u at control winding side SEC is utilized. In power winding part there is a capacitor which is connected along with 3-phase diode rectifier, the output of this is connected to step up converter which is used to increase the output voltage using MPPT technique. From step up converter the output is connected to grid .Finally the ideal speed range is obtained and simulated.

II. DWIG BASED CONFIGURATION

To increase the output power especially at low rotor speeds to gain wide range of speed values step up converter must operate in the range where it can obtain maximum output, so as the efficiency of overall system occurs. In Fig.1 we can notice that the power vs speed curves are obtained at different speeds, we can notice that the dotted lines show usual conditions at different conditions, but to obtain maximum power the step up converter must operate as shown in thick line so that it is utilized fully at its maximum capacity. In the Fig.2 mainly consists of induction generator with two stator windings wound in same stator slots, both windings are of 3-phase star connected. Generally induction generator contain one stator winding and rotor winding, to obtain high speed electric power generation DWIG is used . The two types of windings are control winding and power winding, which are used for generator excitation and providing some part of reactive power. But at power winding side reactive power is supplied by excitation capacitor (C_{exe}).

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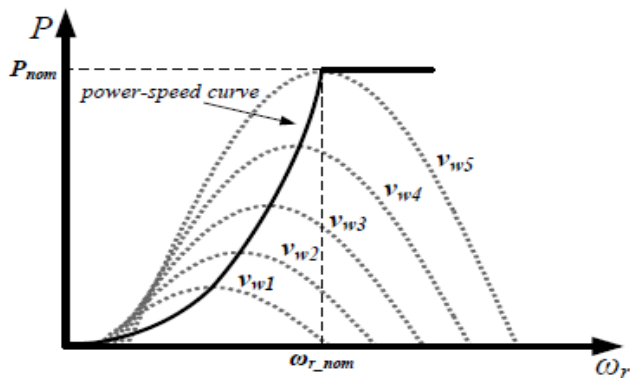


Fig.1. Power vs Speed curve of Wind turbine at different speeds (v_w).

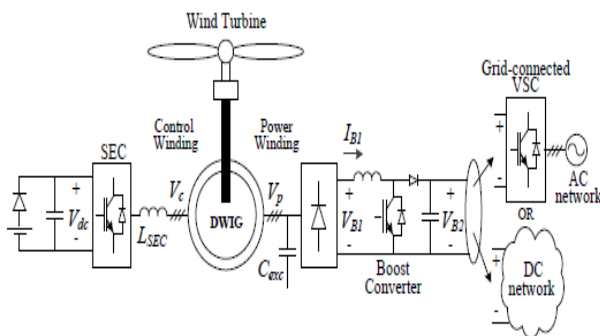


Fig.2. DWIG based configuration

SEC is connected to control winding of generator by inductor (L_{SEC}) which is used to vary DC link voltage to turn off the diode which is connected in series with a low level voltage source, by varying the link voltage more than battery voltage. The control winding voltage is mainly varied by using SEC. The frequency is dependent on speed, at low speeds due to reduction in frequency the saturation of generator occurs. In order to avoid this by considering v/f strategy to increase voltage step up converter is utilized at power winding side. A 3-stage rectifier and an excitation capacitor are connected on the power winding side. The rectifier converts AC voltage to DC voltage, similarly the rectifier converted varying voltage to constant DC voltage (V_{B1}). Thus obtained voltage is adjusted at maximum level by using MPP. By governing the input current (I_{B1}) of the step up converter this can be obtained, which prompts the control of the generator control winding current, just as the generator control. The yield voltage of the step up converter is directed at a higher steady state and used for HVDC transmission.

III. MATHEMATICAL APPROACH OF DWIG

The DWIG active voltage equations at d-q outline, in view of the technique, can be communicated as (1):

$$\begin{cases} V_{cd} = R_c i_{cd} - \omega \lambda_{cq} + d \frac{\lambda_{cd}}{dt} \\ V_{cq} = R_c i_{cq} + \omega \lambda_{cd} + d \frac{\lambda_{cq}}{dt} \\ V_{pd} = R_p i_{pd} - \omega \lambda_{pq} + d \frac{\lambda_{pd}}{dt} \\ V_{pq} = R_p i_{pq} + \omega \lambda_{pd} + d \frac{\lambda_{pq}}{dt} \\ V_{rd} = R_r i_{rd} - (\omega - \omega_r) \lambda_{rq} + d \frac{\lambda_{rd}}{dt} = 0 \\ V_{rq} = R_r i_{rq} - (\omega - \omega_r) \lambda_{rd} + d \frac{\lambda_{rq}}{dt} = 0 \end{cases} \quad (1)$$

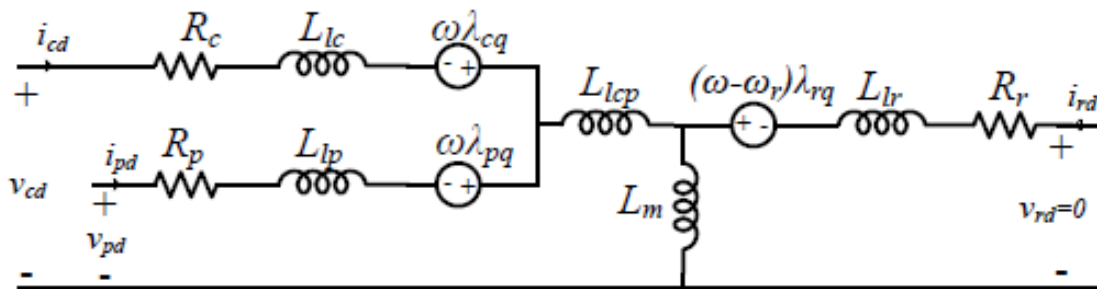
Where the rotor speed is ω_r , angular synchronous frequency is ω and flux linkage, current, voltage are λ_i and v_i individually. The records r, p and c are identified with the rotor parameters, power- winding and control- winding. In power winding side both rotor and control parameters of winding are referred. Because of the squirrel confine sort of the rotor both q and d hub rotor winding voltages are zero. The linkage transitions conditions are depicted in (2):

$$\begin{cases} \lambda_{cd} = L_c i_{cd} + L_{cp} i_{pd} + L_{cr} i_{rd} \\ \lambda_{cq} = L_c i_{cq} + L_{cp} i_{pq} + L_{cr} i_{rq} \\ \lambda_{pd} = L_p i_{pd} + L_{pc} i_{cd} + L_{pr} i_{rd} \\ \lambda_{pq} = L_p i_{pq} + L_{pc} i_{cq} + L_{pr} i_{rq} \\ \lambda_{rd} = L_r i_{rd} + L_{rc} i_{cd} + L_{rp} i_{pd} \\ \lambda_{rq} = L_r i_{rq} + L_{rc} i_{cq} + L_{rp} i_{pq} \end{cases} \quad (2)$$

Where inductances are:

$$\begin{cases} L_c = L_{lc} + L_{lcp} + L_m \\ L_p = L_{lp} + L_{lcp} + L_m \\ L_r = L_{lr} + L_{lcp} + L_m \\ L_{cp} = L_{pc} = L_{lcp} + L_m \\ L_{cr} = L_{rc} = L_m \\ L_{pr} = L_{rp} = L_m \end{cases} \quad (3)$$

in which L_{lr} is the rotor-winding spillage, L_{lc} is control-winding, L_{lp} is power-winding inductances respectively and the magnetizing inductance is L_m . Where L_{lcp} coupling leakage inductance can be disregarded in light of its irrelevant worth. Fig. 3 demonstrates the proportionate d-pivot and q-hub circuit models of the DWIG.



(a)

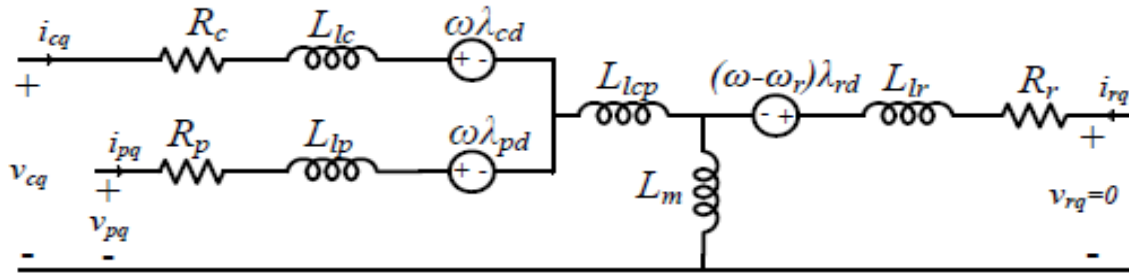


Fig.3 a) Equivalent circuit of DWIG in d-axis b) Equivalent circuit of DWIG in q-axis

IV. CONTROL APPROACH

A) Excitation approach of DWIG:

To energize DWIG, the voltage of control-winding (V_c) modification is the primary job of SEC. To expand the yield voltage level, the step up converter is utilized in the proposed topology, for low-speed output V/f system can be used for

DWIG excitation. The SEC DC-interface voltage (V_{dc}) must be managed at reference esteem for this reason. CWVO technique is utilized by SEC in order to alter the V_c and V_{dc} . Fig. 4 demonstrates the square chart of CWVO control methodology for DWIG.

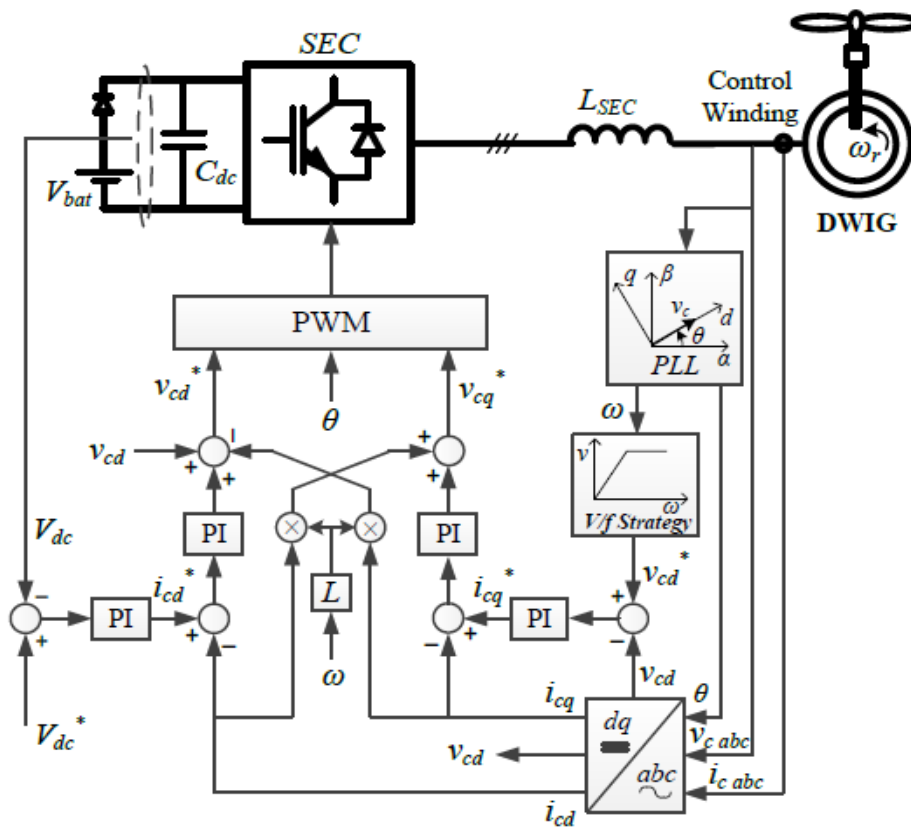


Fig.4. CWVO excitation control approach.

Adjusting the voltage in the winding side of control with the d-pivot, the q-hub voltage (v_{cq}) ends up zero and the d-hub voltage (V_{cd}) approaches the plentifulness of the control-twisting voltage as in (4):

$$\begin{cases} V_{cd} = |V_c| \\ V_{cq} = 0 \end{cases} \text{ --- (4)}$$

In this manner, as indicated by the prompt power hypothesis, the dynamic power winding side of control (p_c) and static power (q_c) are:

$$\begin{cases} P_c = \frac{3}{2} V_{cd} i_{cd} \\ q_c = \frac{3}{2} V_{cd} i_{cq} \end{cases} \text{ --- (5)}$$

For v_{cd} in equ (1), winding obstruction voltage loss ($R_c i_{cd}$) is disregarded and the control-winding d-pivot motion is thought to be consistent ($d\lambda_{cd}/dt = 0$), at that point:

$$V_{cd} \cong -\omega \lambda_{cq} \text{ --- (6)}$$

And (4) can be modified as:

$$\begin{cases} P_c \cong -\frac{3}{2}\omega \lambda_{cq} i_{cd} \\ q_c \cong +\frac{3}{2}\omega \lambda_{cq} i_{cq} \end{cases} \quad (7)$$

By constraining i_{cd} and i_{cq} individually, the demonstration of control-winding dynamic and receptive power can be done. The power balance connection between the control-winding and SEC DC-connection can be communicated as in Equ (8):

$$\frac{\partial(\frac{1}{2}C_{dc}V_{dc}^2)}{\partial t} + P_{SEC_loss} = -P_c \quad (8)$$

Where P_{SEC_loss} is the loss in power and C_{dc} is the Direct Current-interface capacitor of SEC. Like a Synchronous Static Compensator (STATCOM), for its internal loss of power SEC utilizes small amount of active power, when trading receptive influence; generally, the DC-interface voltage would not be steady. Accordingly, V_{dc} can be constrained by dynamic power of control winding. The flux linkage on the winding of control side (λ_{cq}) can be controlled by static power on the winding of control side (q_c) at similar speeds. Equ (9) can be shown by utilizing the flux linkage on winding side of control λ_{cq} and static power q_c , surrendered Equ (2) and Equ (7) separately.

$$\lambda_{cq} \lambda_{ccq} = q_c \cdot \frac{L_s}{\omega} \quad (9)$$

where λ_{ccq} is a subset of the flux linkage on the side of control part λ_{cq} , prompted by i_{sq} in the winding side of control part. Then again, Equ (4) and Equ (6) demonstrate that by controlling the winding side of control part q-pivot transition (λ_{cq}), the abundance of winding voltage at control side can be balanced. In this way considering Equations (7), (8), and (9), it very well may be communicated that:

$$\begin{cases} i_{cd} \Rightarrow p_c \Rightarrow V_{dc} \\ i_{cq} \Rightarrow q_c \Rightarrow \lambda_{cq} \Rightarrow V_c \end{cases} \quad (10)$$

Condition (10) shows that by the control of i_{cd} and i_{cq} separately, the voltage at winding side of control V_c , DC couple voltage V_{dc} can be precised.

In the CWVO excitation of DWIG as appeared in Fig. 4, To control i_{cd} and I_{cq} independently and the DWIG free parameters the controller utilizes a methodology of decoupling with PI controllers in the loop of current. To decide the winding side of control part d-hub current of reference (i_{cd}^*), V_{dc} is contrasted and its reference esteem and the yield blunder is gone through a controller of PI. So also, the q-pivot reference current (i_{cq}^*) is gotten by contrasting V_{cd} and its reference worth and utilizing another controller of PI. At the minimum-recurrence activity, relating to minimum speed of generator, methodology of V/f is applied, therefore V_{sd}^* is resolved by the working recurrence.

B) MPPT strategy of Boost converter

The voltages of DWIG are varied by applying energy at control side, the step up converter controls the dynamic power of generator dependent on MPPT. By V/f methodology, the step up converter gives a wide speed scope of activity, including minimum condition of speed, where the voltage of DWIG is decreased. Step converter suits the expansion in the yield voltage and associates the higher level voltage generator. For MPPT, the methodology of control introduced is utilized. The step up converter control plot has appeared in Fig. 5.

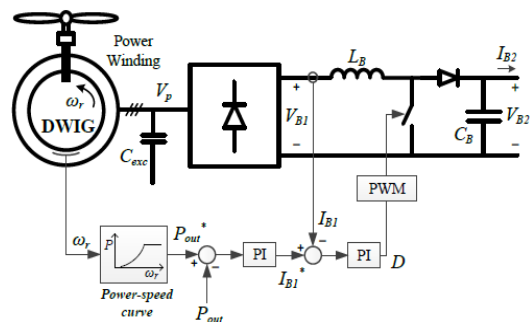


Fig. 5. Control approach for MPPT procedure by Boost converter

To accomplish MPPT, converter utilizes a table, which is obtained from the curves of speed vs power exhibited in Fig.1. The ideal power (P_{out}^*) is put away in table, for all speed of DWIG (ω_r). By the consideration of the ideal power is as a reference control in the step up controller to change the yield control at MPP. In the event that the step up converter control misfortune is disregarded, the yield influence (P_{out})

$$P_{out} = V_{B2} I_{B2} \cong V_{B1} I_{B1} \quad (11)$$

V_{B1} shall be composed as a steady proportion of the voltage of winding of power side if the voltage drop of rectifier is disregarded. Meanwhile the same air gap flux has been experienced by both the windings, controlling the control-twisting voltage prompts guideline of winding voltage intensity. In this way by replacing both the winding voltages by bearing in mind loss of impedance of generator. The voltage drop relies upon both currents of winding which are controlled by voltage on control winding side and current of rectifier/step up converter. Along these lines, V_{B1} and P_{out} can be communicated by (12) and (13), individually:

$$V_{B1} = \frac{3\sqrt{2}}{\pi} \cdot U_p = \frac{3\sqrt{2}}{\pi} \cdot \frac{n_p}{n_c} \cdot U_c - \Delta U(I_{B1} U_c) \quad (12)$$

$$P_{out} = \left(\frac{3\sqrt{2}}{\pi} \cdot \frac{n_p}{n_c} \cdot U_c - \Delta U(I_{B1} U_c) \right) \cdot I_{B1} \quad (13)$$

Where U_p and U_c indicate the intensity winding line voltage and control-twisting individually; ΔU is the change in voltage crosswise over control-winding and power-winding; n_p/n_c is the windings turns ratio. Since U_c is managed by the control excitation to its esteem reference, P_{out} - yielded in Equ (13) - can be constrained by I_{B1} . So in the power guideline circle, P_{out} is contrasted and its reference worth and by controller of PI comparison, the reference estimation of I_{B1} is acquired. In the present guideline circle, I_{B1} is contrasted and its reference esteem and the yield mistake is gone through second controller of PI to decide the step up converter obligation cycle (D) of. At long last, utilizing PWM strategy with waveform of saw-tooth, switch drive signal varies the obligation cycle.

V. FUZZY LOGIC CONTROLLER

Fuzzy logic controller (FLC) mainly depends on the rules based. It is the form of input and output. The FLC input has two values like error value and change in error value. The output value depends upon the input values and rules configuration. The limits of variable between -1 to 1. The truth value of Boolean logic the variables may be 0 or 1. The fuzzy logic controller has classified into following types as Fuzzification, rule matrix, Defuzzification. The below circuit diagram explains the relations between three controllers.

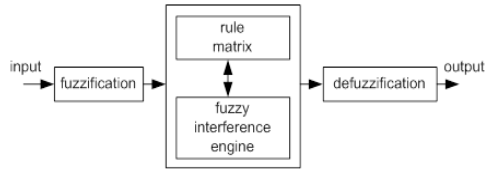
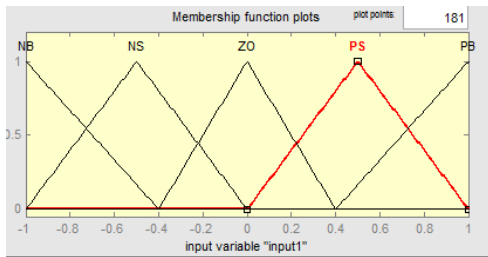
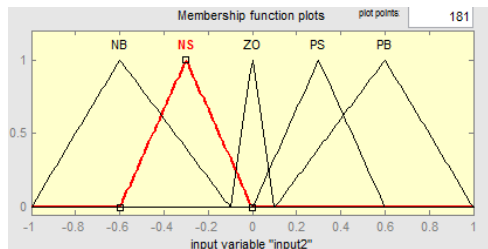


Fig.6. Fuzzy logic analysis and control

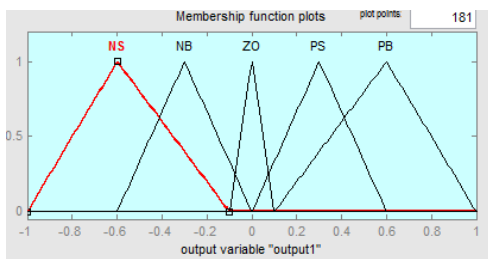
Fuzzy rules are classified depends upon input and output membership functions. The schematic circuit diagram of membership functions shown below



Input 1 Membership Function



Input 2 Membership Function



Output Membership Function

In FLC input values of error and change in error and the output. The rules are combination of 5 triangle functions for each. These fluffy sets are interfaced by 'negative huge (NB)', 'negative little (NS)', 'positive little (PS)', 'Zero (Z)', and 'Positive Big (PB)' for each fluffy participation capacities. The fluffy principles are directional by 25 for the five elements of blunder and change in mistake (Contribution of the FLC)

Table: 1 Rule based fuzzy table

Δe	NB	NS	ZO	PS	PB
e					
NB	NB	NB	NB	NS	ZO
NS	NB	NB	NS	ZO	PS
ZO	NB	NS	ZO	PS	PB
PS	NS	ZO	PS	PB	PB
PB	ZO	PS	PB	PB	PB

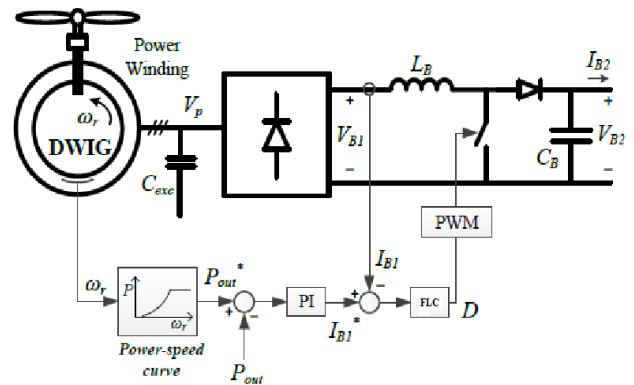
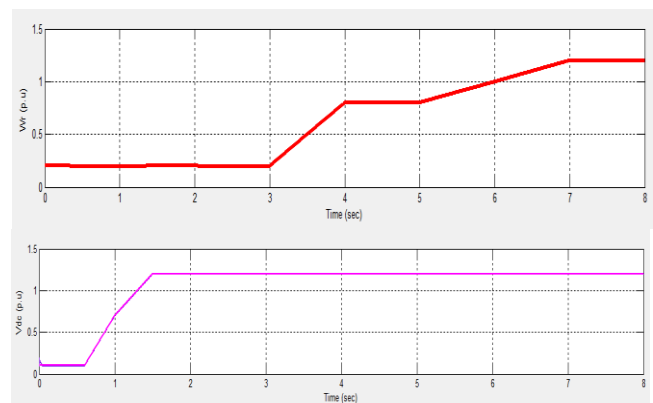


Fig.7. Boost control strategy with fuzzy logic controller configuration

VI. SIMULATION RESULTS

A) Simulation results by using PI controller:

By using pi controller in the boost converter increase the speed and improve the power. In this by considering the boost converter by using Simulink shown below.



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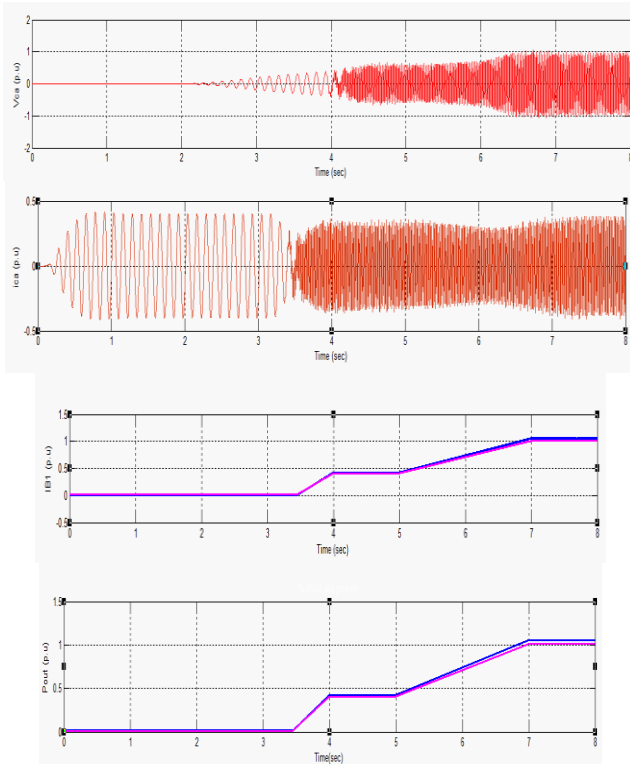


Fig.8. Simulation results of 2.3Micro grid by using Pi controller

B) Simulation results by using fuzzy logic controller:

By using the boost converter with FLC increase the speed and improve the power. In this project by considering the boost converter by using Simulink shown below.

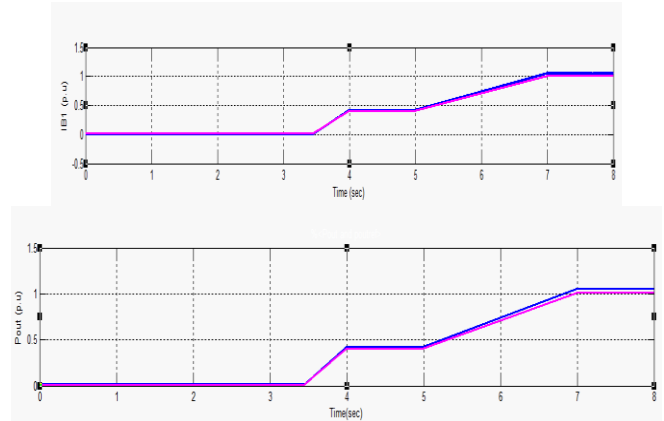
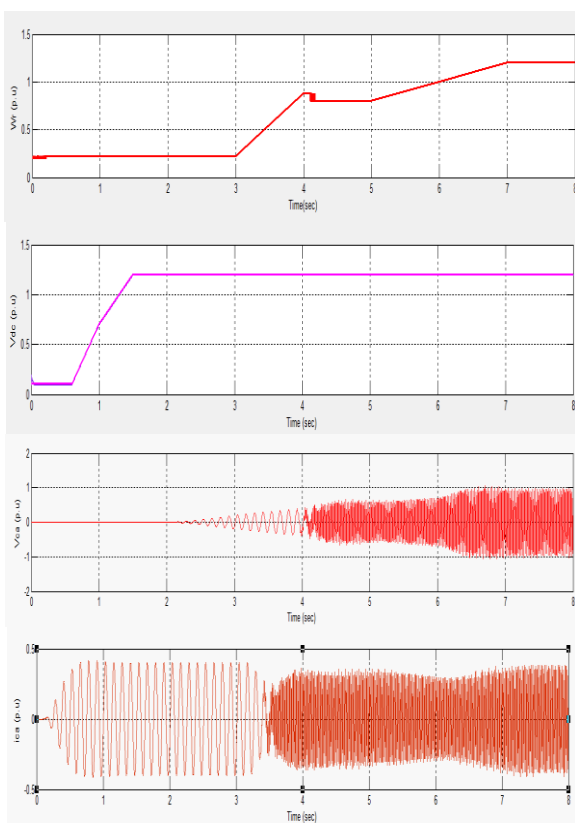


Fig.9. Simulation results of 2.3Micro grid by using Fuzzy logic controller

VII. CONCLUSION

In this paper discussing about increasing the speed range of doubly winding induction generator by using boost converter along with fuzzy logic controller. For broad speed range and MPPT a step up converter is employed, particularly at minimum-speed showed up. At minimum speed, DWIG voltage is discarded because of v/f control system and a step up converter is utilized to expand the voltage level to meet the sophisticated and consistent voltage prerequisite. In this paper by replacing fuzzy logic controller in the place of PI controller we can obtain bulk values at low speed region and at nominal speed region so that speed range is increased in the results of DWIG and boost converter. The performance of DWIG and boost converter can be evaluated by using mat lab/Simulink

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