

# Detailed Simulation of Voltage and Frequency Controller for Wind Generating System with Unbalanced Linear Load with Fixed Wind Speed

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**Abstract-** This paper deals with Voltage and frequency controller for wind generating system with unbalanced linear loads. The proposed system is modelled and simulated in MATLAB using simulink .The controller that controls both voltage and frequency of an asynchronous generator along with its improvement of power quality. The proposed controller has bidirectional active and reactive power flow capability along with battery energy storage system by which it controls the system voltage and frequency with variation of consumer load.

**Index Terms-** Battery energy storage system, isolated asynchronous generator, voltage and frequency controller, wind energy conversion system.

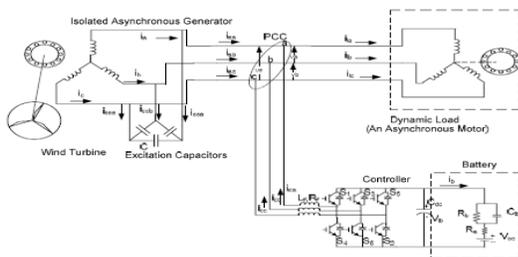
## I. INTRODUCTION

Today the need for renewable sources is increasing particularly wind .Because wind is the most prominent source of energy available. We can easily exploit by using asynchronous generator .Squirrel cage induction are low cost, robust and simple in its construction.

Here employing a voltage and frequency controller for standalone wind power generating systems in order to maintain voltage and frequency.

The proposed voltage and frequency controller is having bidirectional active and reactive power flow capability by which it controls the system voltage and frequency with variation of consumer loads and wind .The performance is demonstrated using standard MATLAB software. Here we can discuss about detailed simulation of this scheme.

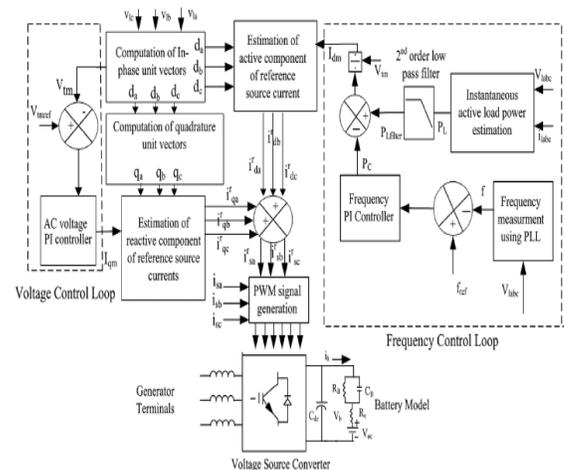
## II. SYSTEM CONFIGURATION



**Fig.1. Schematic diagram of the proposed isolated wind energy system**

The complete off grid stand alone system with asynchronous generator, wind turbine, excitation capacitor, balanced/unbalanced, linear/non-linear/dynamic consumer loads and proposed controller is shown in Fig.1. The proposed controller includes three-phase insulated gate bipolar junction transistor (IGBT) based voltage source converter (VSC) along with a battery at its dc link. The controller is connected at the point of common coupling (PCC) through the inter-facing inductor [1] . The excitation capacitor is selected to generate the rated voltage at no-load while additional demand of reactive power is met by the controller.

## III. CONTROL SCHEME



**Fig.2.Schematic diagram of the proposed control strategy for an isolated wind energy system**

Fig 2 demonstrates the control strategy of the proposed controller which is based on the generation of reference source currents. Reference source currents are having two components one is reactive component for controlling the magnitude of the generated voltage and other one is the active component for regulating the frequency of the generated voltage. The amplitude of active power component of the source current is estimated by dividing the difference of filtered load power and output of PI frequency controller to the amplitude of the terminal voltage. Multiplication of with in-phase unit templates yields the in-phase component of reference source currents. These templates are, three-phase sinusoidal functions which are derived by dividing

the ac voltages by their amplitude. To generate the reactive component of reference source currents another set of unit templates is derived from in-phase unit template and which are 90 leading from the corresponding voltages. The multiplication of these templates and output of PI (Proportional–Integral) terminal voltage controller gives the reactive component of reference source currents. The sum of instantaneous reactive and active Components of currents gives the total reference source currents and these are compared with the sensed source currents. The amplified current error signals are compared with fixed frequency (10 kHz) triangular carrier wave to generate the PWM switching signals for the devices of VSC.

#### IV. MODELING OF THE CONTROL SCHEME

Basic equations of the control scheme of the proposed controller are as follows.

##### A. Computation of Active Component of Reference Source Current

Active component of reference source current is estimated by dividing the difference of filtered instantaneous load power ( $P_{Lfilter}$ ) and output of the PI frequency controller ( $P_C$ ) to the terminal voltage ( $V_{tm}$ ). The load power ( $P_L$ ) is estimated as by taking three-phase to two-phase transform

$$v_\alpha = \left(\frac{\sqrt{2}}{3}\right)(v_{la} - \frac{1}{2}v_{lb} - \frac{1}{2}v_{lc}) \quad (1)$$

$$v_\beta = \left(\frac{\sqrt{2}}{3}\right)\left(\frac{\sqrt{3}}{2}v_{lb} - \frac{\sqrt{3}}{2}v_{lc}\right) \quad (2)$$

$$i_\alpha = \left(\frac{\sqrt{2}}{3}\right)\left(i_{la} - \frac{1}{2}i_{lb} - \frac{1}{2}i_{lc}\right) \quad (3)$$

$$i_\beta = \left(\frac{\sqrt{2}}{3}\right)\left(\frac{\sqrt{3}}{2}i_{lb} - \frac{\sqrt{3}}{2}i_{lc}\right) \quad (4)$$

Instantaneous active power is estimated as

$$P_L = v_\alpha i_\alpha + v_\beta i_\beta \quad (5)$$

It is filtered to achieve its dc component ( $P_{Lfilter}$ ).

The frequency error is defined as

$$f_{er(n)} = f_{ref(n)} - f(n) \quad (6)$$

Where  $f_{ref}$  reference frequency (50 Hz in present system) and “ $f$ ” is the frequency of the voltage of an asynchronous generator. The instantaneous value of “ $f$ ” is estimated using phase locked loop (PLL).

At the  $n$ th sampling instant the output of frequency PI controller ( $P_C$ ) is as

$$P_{C(n)} = P_{C(n-1)} + K_{pf} \{f_{er(n)} - f_{er(n-1)}\} + K_{if} f_{er(n)} \quad (7)$$

Where  $K_{pf}$  and  $K_{if}$  are the proportional and integral gain constants of the frequency proportional integral (PI) controller.

Then active component of reference source current ( $I_{dm}$ ) is calculated as

$$I_{dm} = 2 \frac{(P_{LFilter} - P_C)}{3v_{tm}} \quad (8)$$

The instantaneous line voltages at the terminals of an asynchronous generator ( $v_{la}, v_{lb}$  and  $v_{lc}$ ) are considered sinusoidal and their amplitude is computed as

$$V_{tm} = \left\{ \left(\frac{2}{3}\right)(v_{la}^2 + v_{lb}^2 + v_{lc}^2) \right\}^{\frac{1}{2}} \quad (9)$$

The unity amplitude templates are having instantaneous value in phase with instantaneous voltage ( $v_{la}, v_{lb}$  and  $v_{lc}$ ), which are derived as

$$d_a = \frac{V_{la}}{V_{tm}} \quad d_b = \frac{V_{lb}}{V_{tm}} \quad d_c = \frac{V_{lc}}{V_{tm}} \quad (10)$$

##### B. Computation of Reactive Component of Reference Source Current

Instantaneous values of in-phase components of reference source currents are estimated as

$$i_{rda} = I_{dm} d_a, \quad i_{rdb} = I_{dm} d_b, \quad i_{rdc} = I_{dm} d_c \quad (11)$$

The ac voltage error at the  $n$ th sampling instant as

$$V_{er(n)} = V_{tmref(n)} - V_{tm(n)} \quad (12)$$

Where  $V_{tmref(n)}$  is the amplitude of reference ac terminal voltage and  $V_{tm(n)}$  is the amplitude of the sensed three-phase ac voltage at the terminals of an asynchronous generator at  $n$ th instant.

The output of the PI controller ( $I_{qm(n)}$ ) for maintaining constant ac terminal voltage at the  $n$ th sampling instant is expressed as

$$I_{qm(n)} = I_{qm(n-1)} + K_{pa} \{V_{er(n)} - V_{er(n-1)} + K_{ia} V_{er(n)}\} \quad (13)$$

Where  $K_{pa}$  and  $K_{ia}$  are the proportional and integral gain constants of the voltage proportional integral (PI) controller (values are given in Appendix).  $V_{er(n)}$  and  $V_{er(n-1)}$  are the voltage errors in  $n$ th and  $(n-1)$ th instant and is the amplitude of quadrature component of the reference source current at  $(n-1)$ th instant. The instantaneous quadrature components of reference source currents are estimated as

$$I_{rqa} = I_{qm} i_{qa}, \quad I_{rqb} = I_{qm} i_{qb}, \quad I_{rqc} = I_{qm} i_{qc} \quad (14)$$

where  $q_a, q_b$  and  $q_c$  and are another set of unit vectors having a phase shift of  $90^\circ$  leading the corresponding unit vectors, and which are computed as follows:

$$q_a = -\frac{d_b}{\sqrt{3}} + \frac{d_c}{\sqrt{3}} \quad (15)$$

$$q_b = \frac{\sqrt{3}d_a}{2} + \frac{(d_b - d_c)}{2\sqrt{3}} \quad (16)$$

$$q_c = -\frac{\sqrt{3}d_a}{2} + \frac{(d_b - d_c)}{2\sqrt{3}} \quad (17)$$

### C. Computation of Reference Source Current

Total reference source currents are sum of in-phase and quadrature components of the reference source currents as

$$i_{rsa} = i_{rqa} + i_{rda} \quad (18)$$

$$i_{rsb} = i_{rqb} + i_{rdb} \quad (19)$$

$$i_{rsc} = i_{rqc} + i_{rdc} \quad (20)$$

### D. PWM Signal Generation

Reference source currents ( $i_{rsa}$ ,  $i_{rsb}$  and  $i_{rsc}$ ) are compared with sensed source currents ( $i_{sa}$ ,  $i_{sb}$  and  $i_{sc}$ ). The current errors are computed as

$$i_{rsaerr} = i_{rsa} - i_{sa} \quad (21)$$

$$i_{rsberr} = i_{rsb} - i_{sb} \quad (22)$$

$$i_{rscerr} = i_{rsc} - i_{sc} \quad (23)$$

These current errors are amplified with a gain (K) and the amplified signals are compared with fixed frequency (10 kHz) triangular carrier wave of amplitude to generate gating signals for IGBTs of VSC of the controller.

## V. ANALYSIS AND DESIGN

### A. Design Of Three Leg VFC

Parameters of VFCs are designed for a 22-kW, 415-V, 50-Hz asynchronous generator-based standalone WECS. It is reported that for feeding reactive power in the case of 0.8-pf lagging reactive loads, an IAG requires 140–160% of the reactive power of the rated generated power. Therefore, the VAR rating of the VFC required for 22 kW ( $P_A$ ) generator is around 30 kVAR.

Then, the apparent power  $SA$  is given as

$$S_A = \sqrt{(P_A)^2 + (Q_A)^2} = \sqrt{(22)^2 + (30)^2} = 37 \text{ kVA.}$$

So the current rating of VSC is  $\sqrt{3}V I_C = 37 \text{ kVA}$

$$\therefore I_C = 51.7 \text{ A.}$$

The amplitude of the current is  $I_C (pk) = 73.19 \text{ A.}$

The average current is  $I_{avg} = 0.9 \times 51.7 \text{ A}$   
 $= 46.53 \text{ A.}$

On the basis of earlier current rating, the peak-to-peak current ripple (considering 5% of the peak current) through the filter inductor can be estimated as

$$I_{Lripplepk-pk} = 0.05 * 73.19 \text{ A} = 3.6595 \text{ A.}$$

By estimating this current ripple and the average value of the current, the value of filter inductors and dc link capacitors can be estimated for various VFC topologies as follows

Here, the modulation index  $m_a$  is considered equal to value of 1. The ripple current through the inductor is taken 5% Overloading factor  $\partial$  due to transient condition varies from 120% to 180%

The switching frequency of 10 kHz is selected for IGBTs of VSCs.

The filter inductor is calculated by substituting the values of parameters as

$$L_{an} = L_{bn} = L_{cn} = \frac{\sqrt{3}m_a V_{dc}}{12 * \partial * f_s * I_{LRipple}} = 3 \text{ mH.}$$

The dc link voltage is selected as

$$V_{dc} > \frac{2\sqrt{2}}{\sqrt{3}} V = 677 \text{ V.}$$

The dc link capacitor can be estimated by considering the voltage ripple across it. The value of the capacitor can be determined by the following equation:

$$V_{dcRipple} = \frac{1}{C_{dc}} \int i_c dt = \frac{I_{avg}}{2\omega C_{dc}}$$

$I_{avg} = 46.53 \text{ A}$ , and  $\omega = 314 \text{ rad/s}$  for a 50-Hz WECS, the value of the dc bus capacitor is given as

Considering  $V_{dcRipple}$  of 2%

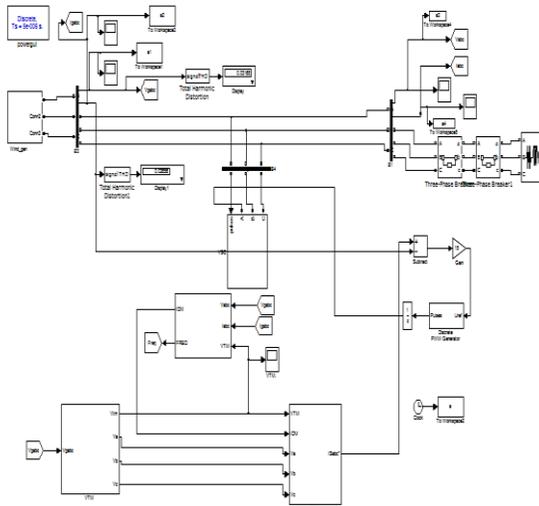
$$V_{dcRipple} = 13.54 \text{ V}$$

$$C_{dc} = \frac{I_{avg}}{\partial \omega V_{dcRipple}} = 5475.6 \mu\text{F}$$

## VI. SIMULATION, RESULTS AND DISCUSSION

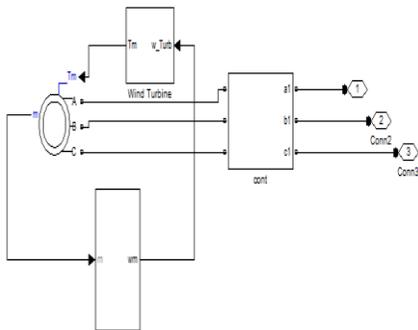
Model with voltage and frequency control is modelled using MATLAB for linear unbalanced loads. The results are given below and we can see distortion is very much reduced.

### A. Simulation of the Controller Feeding unbalanced Linear Loads



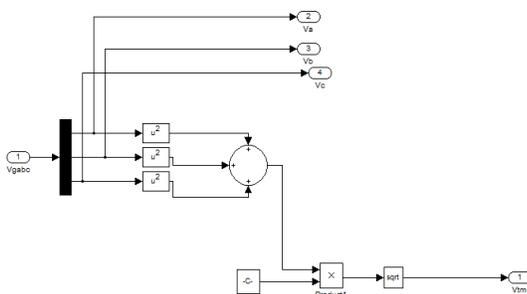
**Fig.3. Wind generator feeding unbalanced linear load**

Fig.3. Wind generator feeding unbalanced linear load. The unbalance is given using breakers. The system first started at no load, that is first breaker in open position. Then at 1s it is closed and load given. Then at 1.2 s unbalance is given by opening phase at 1.2s.

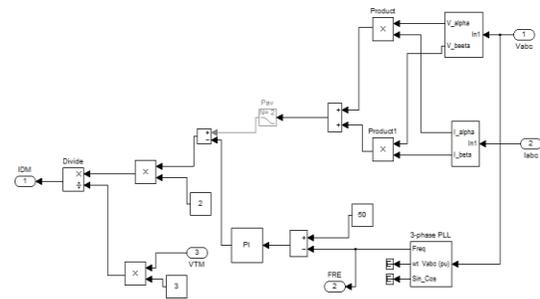


**Fig.4. Wind power generation**

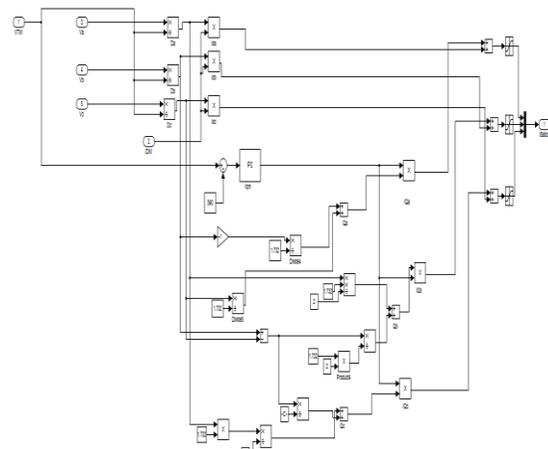
The subsystems for active, reactive power,  $v_{lm}$  generation generation re given below.



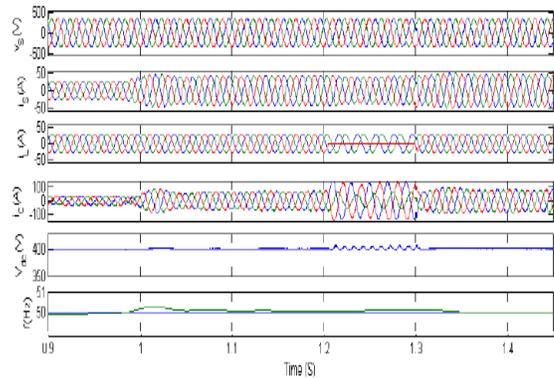
**Fig.5.  $v_{lm}$  generation**



**Fig.6. Computation of active component of reference source current**



**Fig.7. Computation of reactive component of reference source current and reference current generation**



**Fig.8. Transient waveforms during application of balanced/unbalanced 0.8 pf lagging load at fixed wind speed**

Fig.8.demonstrates the performance of the controller for feeding unbalanced linear loads. At 1 s load is given and later on at 1.2 s one phase of the load are opened using breakers and the load becomes unbalanced but voltage and current at the generator terminals remain balanced under such worst case of load

## VII. CONCLUSION

The performance of the proposed controller has been demonstrated for an isolated wind energy conversion system.

Simulation results have verified the performance of the controller under unbalanced linear load. It has been observed that the proposed controller has been found to regulate the magnitude and frequency of the generated voltage constant in isolated wind power application..

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