A

Term Paper Report

on

Voltage and Frequency Controllers for an Asynchronous Generator-Based Isolated WECS/constant speed gen. systems

Submitted

to

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INTRODUCTION

Remotely located villages, islands, military equipment, ships, etc., are some of the areas that are mainly isolated from the power system grid and require a standalone generating system. However, because of continuous depletion of fossil fuels and concern about the global warming, the importance of locally available natural sources has increased such as wind, small hydro, etc.

In isolated generating systems for harnessing renewable energy from available nonconventional energy sources, such as small hydro, wind and bio-mass, an asynchronous machine, driven by these prime movers and operated as an isolated asynchronous generator (IAG) with its excitation requirement being met by a capacitor bank connected across its terminals, has become the compatible option since last two decades because of its low cost, small size, light weight, brushless construction, and self-short-circuit protection.

However, the poor voltage and frequency regulation is a major bottleneck in its commercialization.

In wind turbine-driven IAGs, magnitude and frequency of the generated voltage vary because of varying consumer loads and wide fluctuation in wind speeds. Therefore, new types of VF controllers based on a voltage source converter along with a battery energy storage system are proposed to maintain the voltage and frequency of IAG constant at varying wind speeds and varying consumer loads.

In view of this, a number of attempts have been made to investigate voltage and frequency controllers for constant, as well as variable, power applications.

These controllers have been investigated either for a three-phase, 3-wire, or single-phase power applications of IAG.

In constant power applications, there has been a reasonable literature available on controlled or uncontrolled rectifier-based electronic load controller (ELC) for regulating the voltage and frequency of the asynchronous generator.

However, due to nonlinear behavior of such controllers they continuously inject harmonics into the asynchronous machine. These harmonics in voltage and current increase the power losses, create unequal heating and cause torque pulsation on the shaft of the generator and derate the machine.

Along with such drawbacks it is also observed that previously proposed controllers are also not having capability of feeding unbalanced loads, nonlinear loads and single-phase as well as three-phase loads simultaneously.

However, for feeding single-phase load, a separate single-phase ELC is proposed for a single-phase asynchronous generator.

In some other schemes for regulating the voltage and frequency along with harmonic elimination and load balancing a voltage-sourced converter (VSC) along with chopper and auxiliary load have been proposed but due to continuous flow of auxiliary power through the VSC it increases the rating of the controller.

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The wind energy is one of the prominent sources of the energy and it is explored tremendously in grid-connected applications using wound rotor asynchronous generators [1] – [11].

However, the standalone wind energy conversion systems (WECS) employing a squirrel-cage asynchronous generator which is recommended as a better option for such an isolated system due to its low cost, less maintenance, and self-short-circuit protection [12], [13].

The battery energy storage system (BESS) with voltage source converter (VSC)-based voltage and frequency controller (VFC) is recommended for an isolated system.

An advantage of the BESS system is that the bidirectional active power flow control can be achieved for controlling the frequency and there is no fuel consumption.

The main challenges in a squirrel-cage asynchronous generator-based isolated WECS are related to its voltage and frequency control. Therefore, need of a VFC for such an isolated system is mandatory for satisfactory operation of WECS.

These VFCs are having capability of:

- ☞ Bidirectional active and reactive powers by which they can control the system voltage and frequency under varying consumer loads and velocity of the wind.
- ☞ Harmonic elimination and load balancing [18]-[23].

CLASSIFICATION OF VFCs:

These configurations of VFCs for IAG are classified here.

- ❑ **VFCs for a Three-Phase Three-Wire IAG Systems:**
  - ✓ Three-Leg VSC-Based VFC.
  - ✓ Two-Leg VSC-Based VFC.

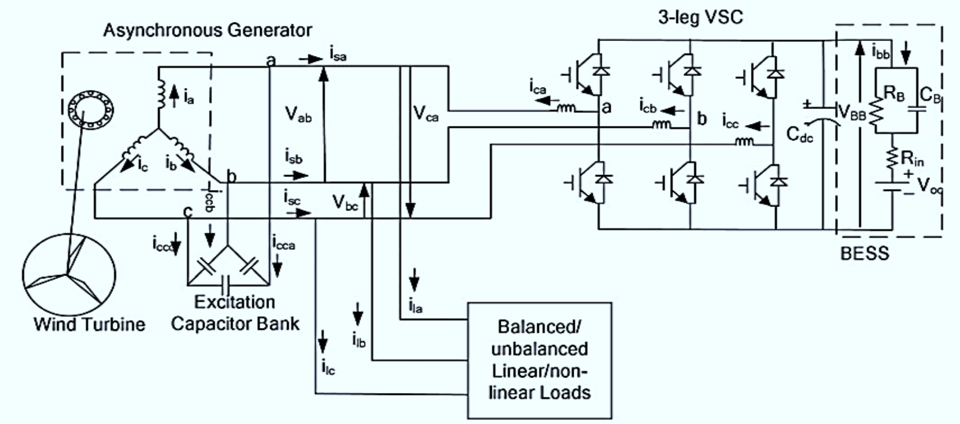


Fig. 1 . Three-leg VSC with BESS-based VFC for a three-phase three-wire IAG system.

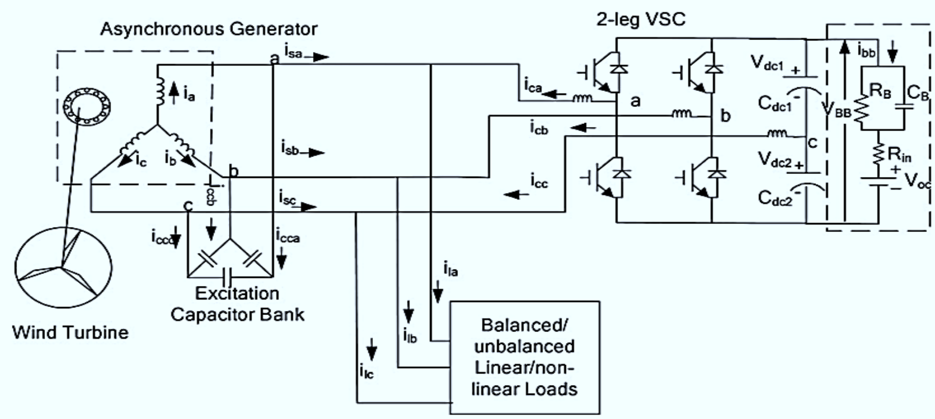


Fig. 2 . Two-leg VSC with BESS-based VFC for a three-phase three-wire IAG system.

- ❑ **VFCs for a Three-Phase Four-Wire IAG System**
  - ✓ Three-Leg VSC with Midpoint Capacitors as a VFC.

✓ Four-Leg VSC as a VFC.

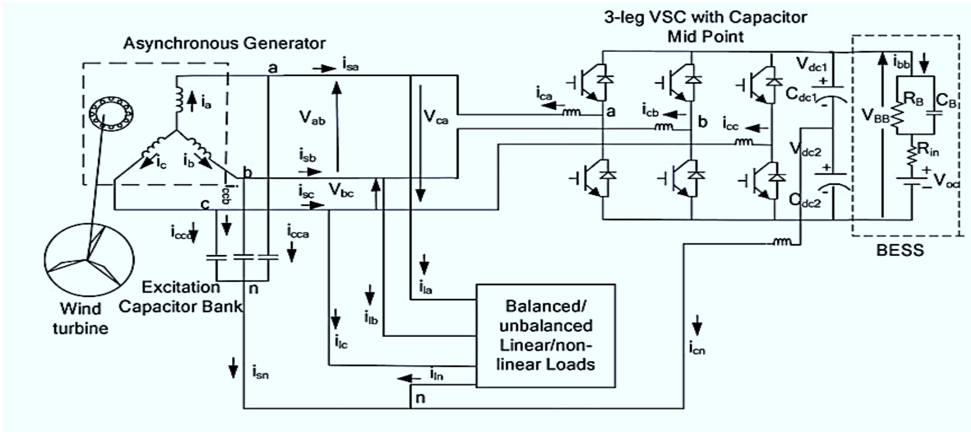


Fig. 3 . Three-leg VSC and midpoint capacitor with BESS-based VFC for a three-phase four-wire IAG system.

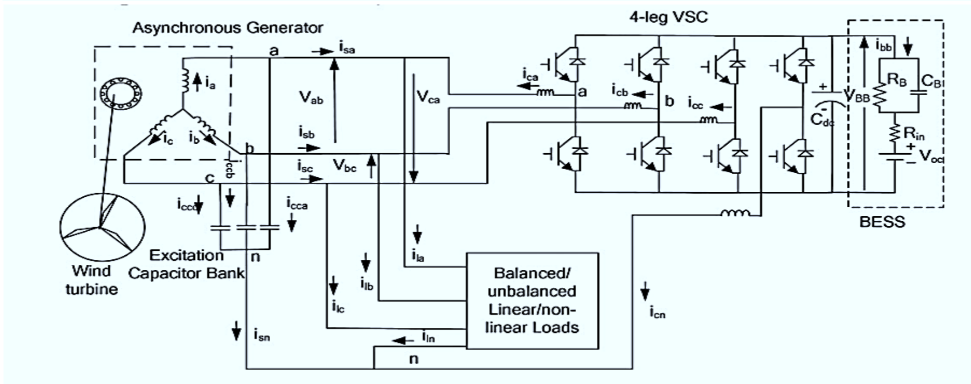


Fig.4 . Four-leg VSC and BESS-based VFC for a three-phase four-wire IAG system.

CONTROL STRATEGY:

Fig. 12 demonstrates the control strategy of the proposed VFC which is based on the generation of reference source currents ($i_{r\text{-}sa}$, $i_{r\text{-}sb}$, $i_{r\text{-}sc}$).

Reference source currents are having two components:

- one is the reactive power component ($i_{r\text{-}qa}$, $i_{r\text{-}qb}$, $i_{r\text{-}qc}$) for controlling the magnitude of the generated voltage and
- the other is the active power component ($i_{r\text{-}da}$, $i_{r\text{-}db}$, $i_{r\text{-}dc}$) for regulating the frequency of the generated voltage.
- The sum of instantaneous reactive power and active power components of the current gives the total reference source currents ($i_{r\text{-}sa}$, $i_{r\text{-}sb}$, $i_{r\text{-}sc}$) and these are compared with the sensed source currents (i_{sa}, i_{sb}, i_{sc}).
- The amplified current error signals are compared with a fixed frequency (10 kHz) triangular carrier wave to generate the pulse width modulation (PWM) switching signals for the devices of VSC of VFC.

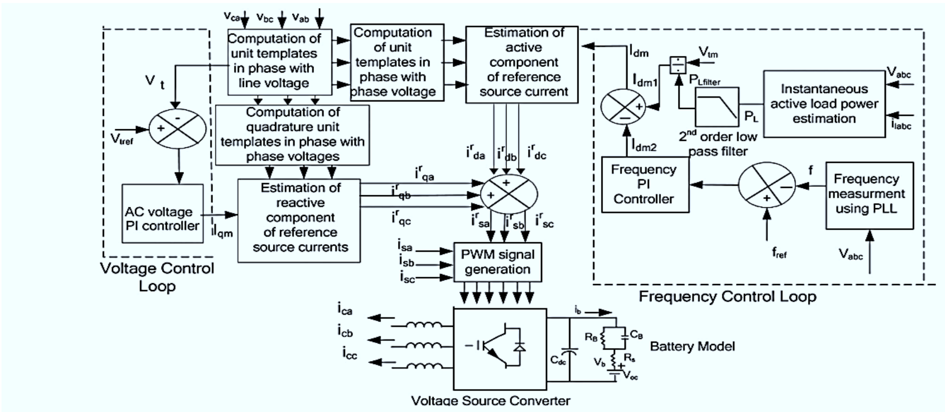


Fig.12. Control Scheme-I of VFC for the WECS.

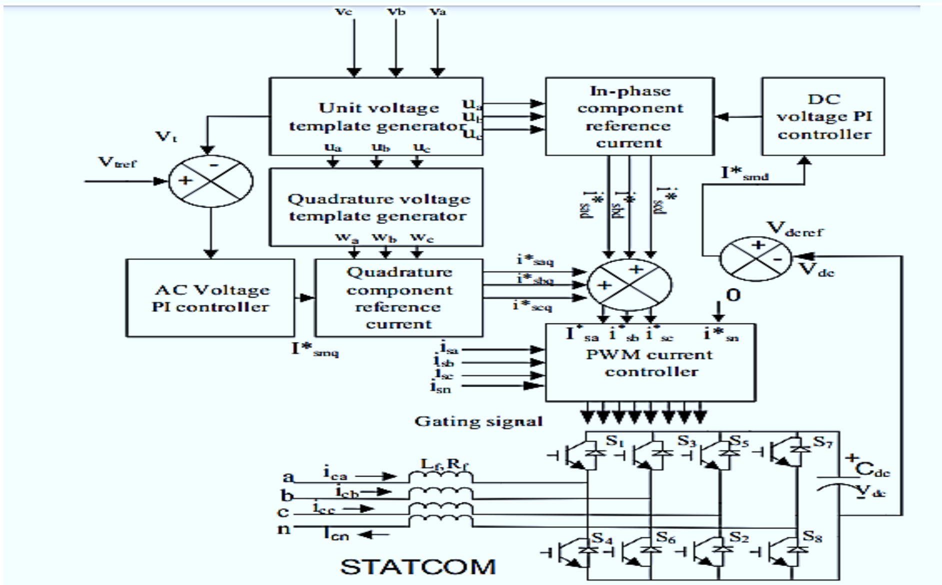


Fig. Schematic diagram of control scheme for STATCOM-SEIG

Control Algorithm for the STATCOM:

Different components of the STATCOM used in asynchronous generator-system are modeled as follows. Three-line voltages at the generator terminals (V_{ab}, V_{bc} and V_{ca}) are considered sinusoidal, and hence their amplitude is computed as:

$$V_t = \sqrt{\frac{2}{3}\{V_{ab}{}^2 + V_{bc}{}^2 + V_{ca}{}^2\}}$$

The unit template in phase with, (V_{ab}, V_{bc} and V_{ca}) are derived as:

$$u_a = \frac{V_{ab}}{V_t} \quad u_b = \frac{V_{bc}}{V_t} \quad u_c = \frac{V_{ca}}{V_t}$$

The unit template in quadrature in V_{ab}, V_{bc} and V_{ca} may be derived using quadrature transformation of the in-phase unit template as:

$$w_a = -\frac{u_b}{\sqrt{3}} + \frac{u_c}{\sqrt{3}}$$

$$w_b = \frac{\sqrt{3}u_a}{2} + \frac{u_b - u_c}{2\sqrt{3}}$$

$$w_c = -\frac{\sqrt{3}u_a}{2} + \frac{u_b - u_c}{2\sqrt{3}}$$

Quadrature Component of Reference Source Currents:

The ac voltage error $\boldsymbol{V_{er(n)}}$ at the nth sampling instant is

$$\boldsymbol{V_{er(n)} = V_{tref(n)} - V_{t(n)}}$$

where $\boldsymbol{V_{tref(n)}}$ is the amplitude of reference ac terminal voltage and $\boldsymbol{V_{t(n)}}$ is the amplitude of the sensed three-phase ac voltage at the generator terminals at nth instant.

The output of the PI controller $\left(\boldsymbol{I^*_{smq(n)}}\right)$ for maintaining the ac terminal voltage constant at the nth sampling instant is expressed as:

$$\boldsymbol{I^*_{smq(n)} = I^*_{smq(n-1)} + K_{pa}\{V_{er(n)} - V_{er(n-1)}\} + K_{ia}V_{er(n)}}$$

where $\boldsymbol{K_{pa}}$ and $\boldsymbol{K_{ia}}$ are the proportional and integral gain constants of the PI controller.

$\boldsymbol{V_{er(n)}}$ and $\boldsymbol{V_{er(n-1)}}$ are the voltage errors in $\boldsymbol{n^{th}}$ and $\boldsymbol{(n-1)^{th}}$ instants and $\boldsymbol{I^*_{smq(n-1)}}$ is the amplitude of quadrature component of the reference source current at $\boldsymbol{(n-1)^{th}}$ instant.

The quadrature components of reference source currents are computed as:

$$I^*_{saq} = I^*_{smq}w_a; \quad I^*_{sbq} = I^*_{smq}w_b; \quad I^*_{scq} = I^*_{smq}w_c;$$

In-Phase Component of Reference Source Currents:

The error in dc bus voltage of the STATCOM $V_{dcer(n)}$ at the nth sampling instant is

$$V_{dcer(n)} = V_{dcref(n)} - V_{dc(n)}$$

where $V_{dcref(n)}$ is the reference dc voltage and $V_{dc(n)}$ is the sensed dc link voltage of the STATCOM. The output of the PI controller for maintaining dc bus voltage of the STATCOM at the nth sampling instant is expressed as

$$I^*_{smd(n)} = I^*_{smd(n-1)} + K_{pd}\{V_{dcer(n)} - V_{dcer(n-1)}\} + K_{id}V_{dcer(n)}$$

where $I^*_{smd(n)}$ is considered as the amplitude of active source current.

K_{pd} and K_{id} are the proportional and integral gain constants of the dc bus PI voltage controller.

The in-phase components of reference source currents are computed as

$$I^*_{sad} = I^*_{smd}u_a; \quad I^*_{sbd} = I^*_{smd}u_b; \quad I^*_{scd} = I^*_{smd}u_c;$$

Reference Source Currents

Total reference source currents are a sum of in-phase and quadrature components of the reference source currents, as follows:

$$I^*_{sa} = I^*_{saq} + I^*_{sad}$$
$$I^*_{sb} = I^*_{sbq} + I^*_{sbd}$$
$$I^*_{sc} = I^*_{scq} + I^*_{scd}$$

Neutral Current Compensation:

The fourth leg of the VSC of the STATCOM is used to compensate the source neutral current and is controlled at the reference value (i^*_{sn}). The source neutral current (i_{sn}) which is sum of source phase currents is compared with its reference value (i^*_{sn}).

$$i^*_{sn} = 0; \qquad i_{sn} = (\, i_{sa} + i_{sb} + i_{sc}); \qquad i_{snerr} = \; i^*_{sn} - \, i_{sn}$$

The current error signal i_{snerr} is amplified and compared using a hysteresis current controller for generating the PWM signal for switching of the fourth leg of the VSC. For making source neutral current i_{sn} "zero", the compensating current i_{cn} should be equal and opposite in direction of sum of load currents.

PWM Current Controller

The reference currents (I^*_{sa}, I^*_{sb} and I^*_{sc}) are compared with the sensed source currents (i_{sa}, i_{sb} and i_{sc}). The ON/OFF switching patterns of the gate drive signals to the IGBTs are generated from the PWM current controller. The current errors are computed as:

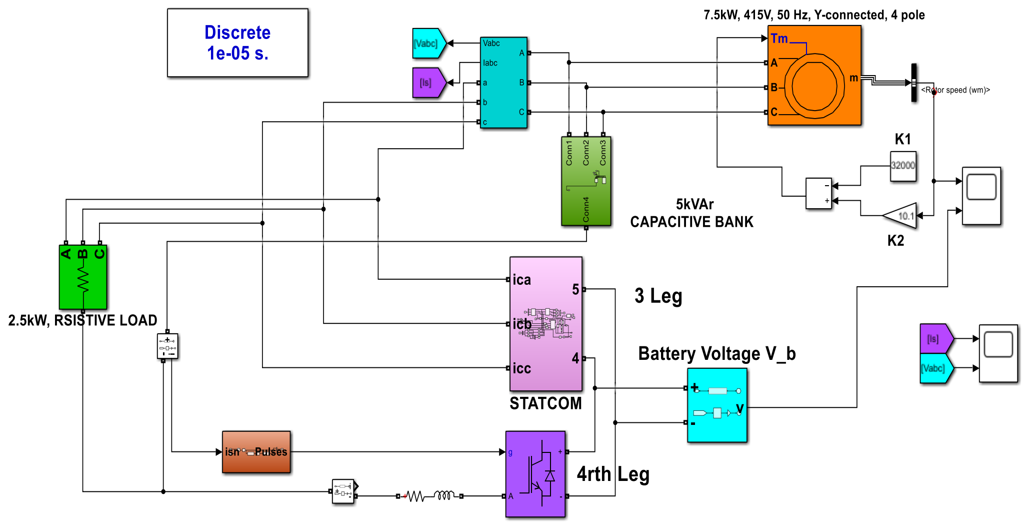
$$i_{saerr} = i^*_{sa} - i_{sa}$$
$$i_{sberr} = i^*_{sb} - i_{sb}$$
$$i_{scerr} = i^*_{sc} - i_{sc}$$

These current error signals are amplified and then compared in the PWM hysteresis controller for switching of the IGBT of the VSC (STATCOM).

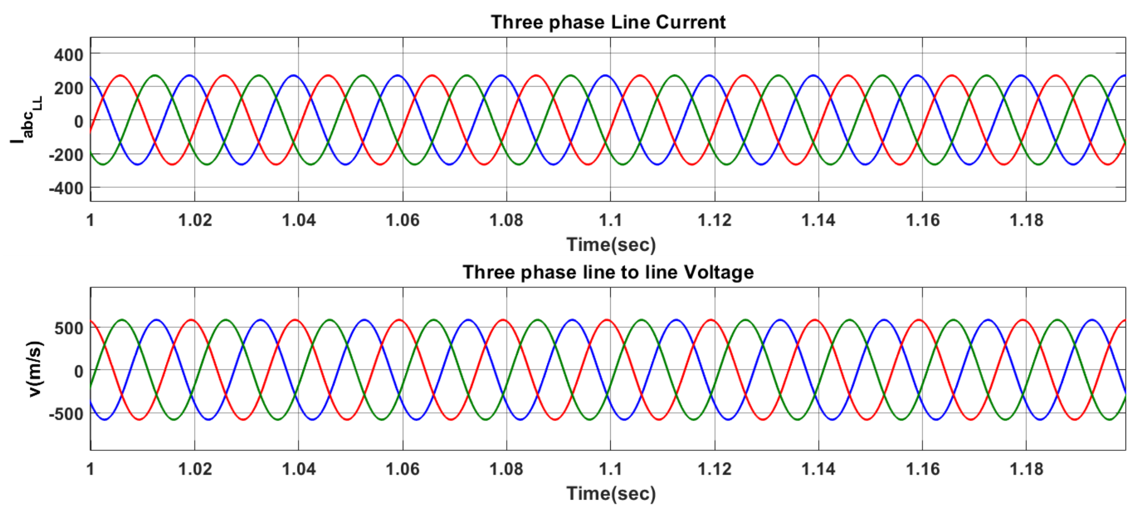
MATLAB MODELING:

- After selection of components of the VFC, such as filtering inductor and capacitor of the STATCOM, the modeling and simulation is performed in the MATLAB.
- The modeling of an asynchronous generator is carried out using 7.5 kW, 415 V, 50 Hz, 4 pole, Y-connected induction machine and 5-kVAR Y-connected excitation capacitor banks with neutral. The machine para meters are:
  $$R_s = 1\Omega,\ R_r = 0.77\Omega,\ X_{lr} = X_{ls} = 1.5\,\Omega,\ J = 0.1384\,kg - m^2, L_m = 0.134H$$
- The controller is realized with a four-legged VSC with parameters:
  $L_f = 5mH,\ R_f = 0.1\Omega,\ C_{dc} = 4000\mu F,\ K_{pa} = 0.03,\ K_{ia} = 0.001,\ K_{pd} = 0.12,\ K_{id} = 0.014,$
- linear load: 2.5kW, (Resistive)
- Prime Mover characteristics: $T_{sh} = K_1 - K_2\omega_r;\ K_1 = 3320,\ K_2 = 10.1$
- The simulation is carried out in discrete mode at 10e-6 step size with ode23tb (stiff/TR-BDF-2) solver.

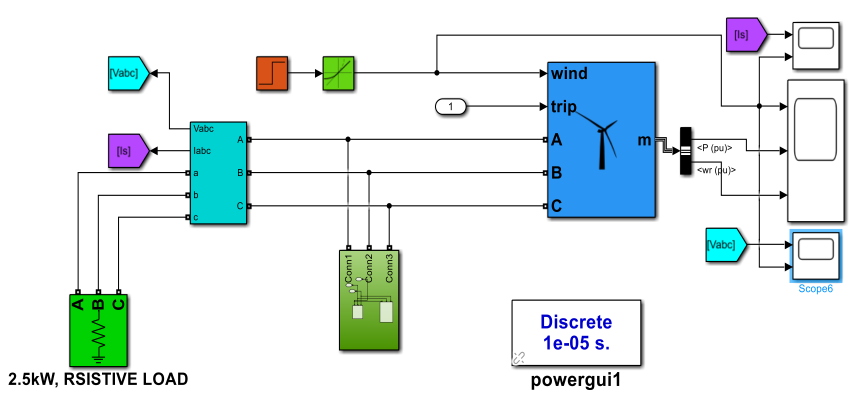
SIMULATION CIRCUIT- Constant Wind speed:



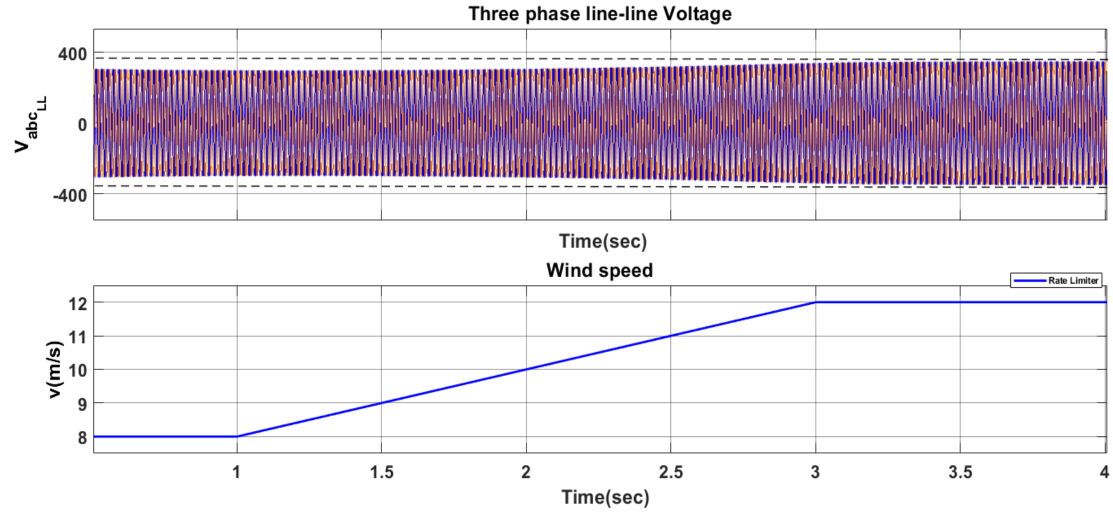
Obtained Waveform - Vabc (LL) & I_abc (line):



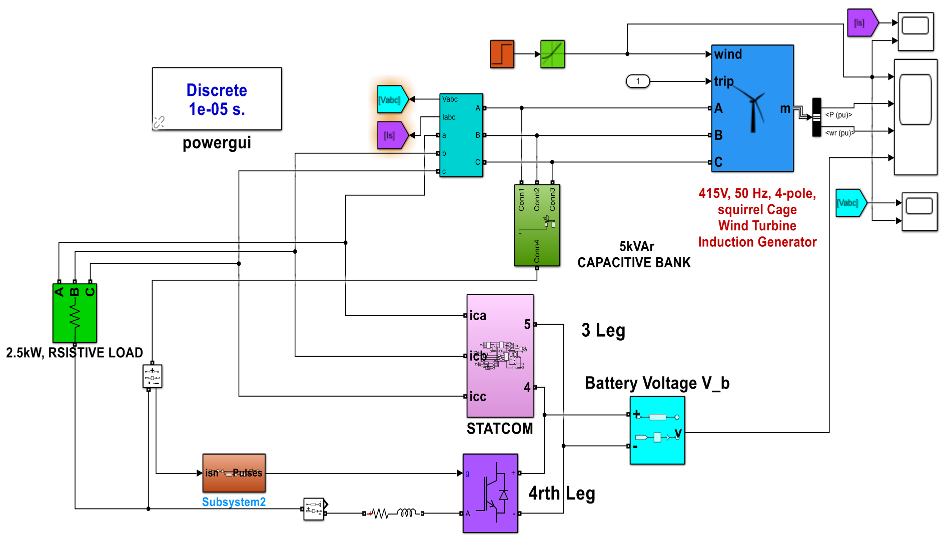
At Variable wind speed: Open Loop SIMULATION CIRCUIT:



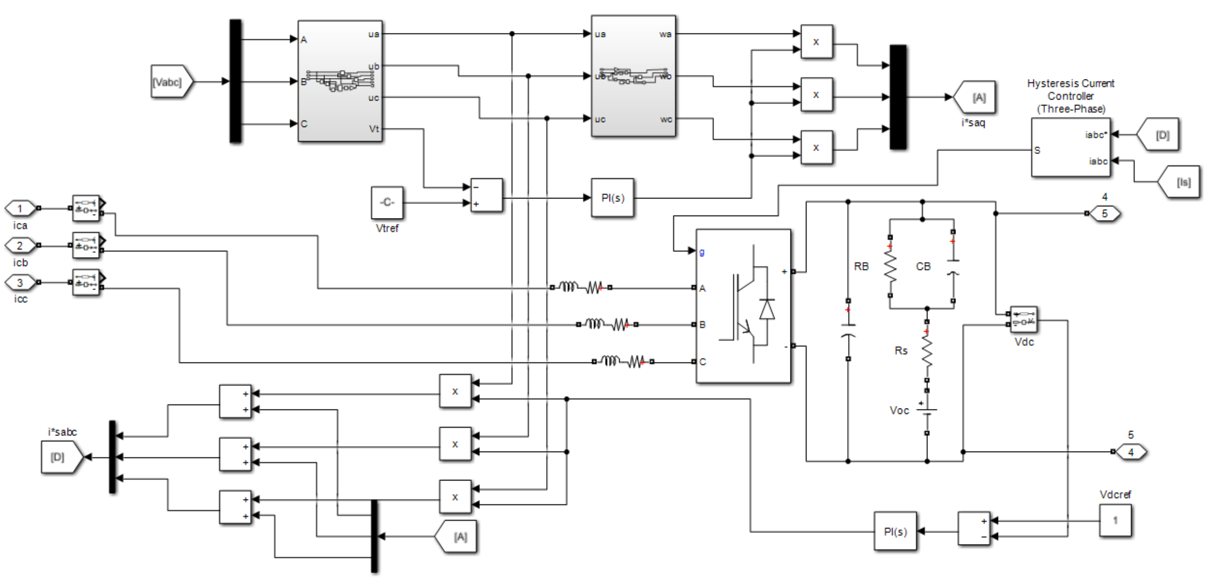
Obtained Waveform – Vabc (LL) [Open Loop]:



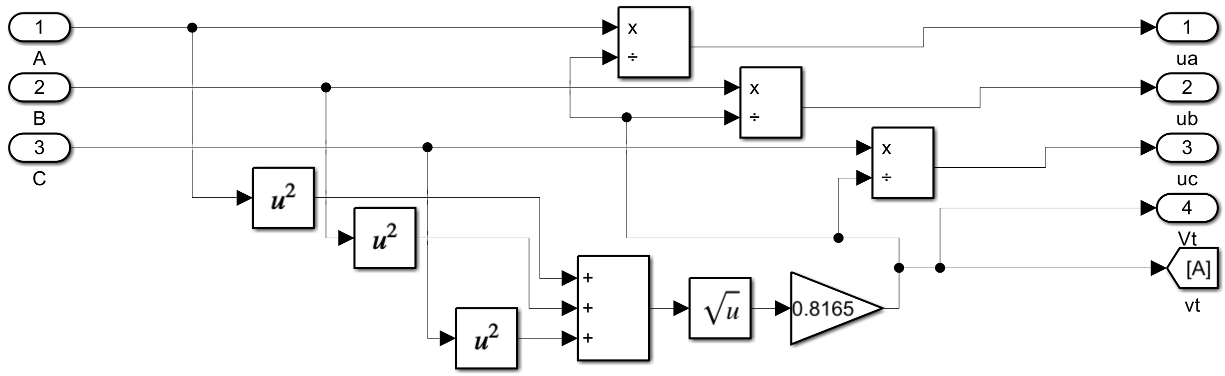
SIMULATION CIRCUIT- (Closed Loop):



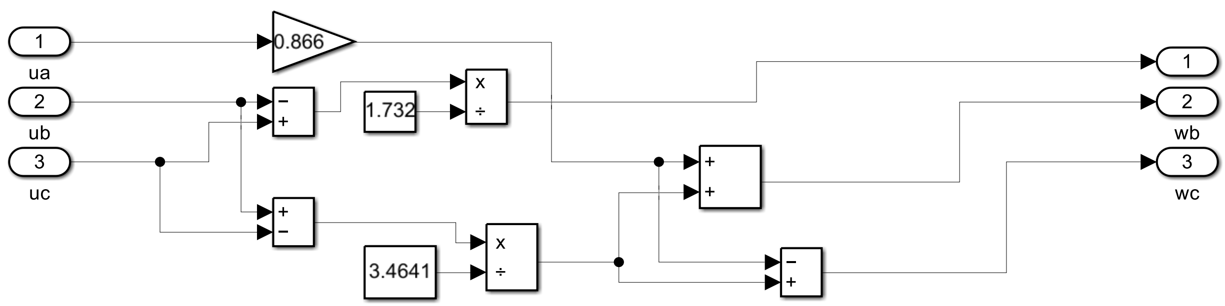
VSC (STATCOM) control loop:



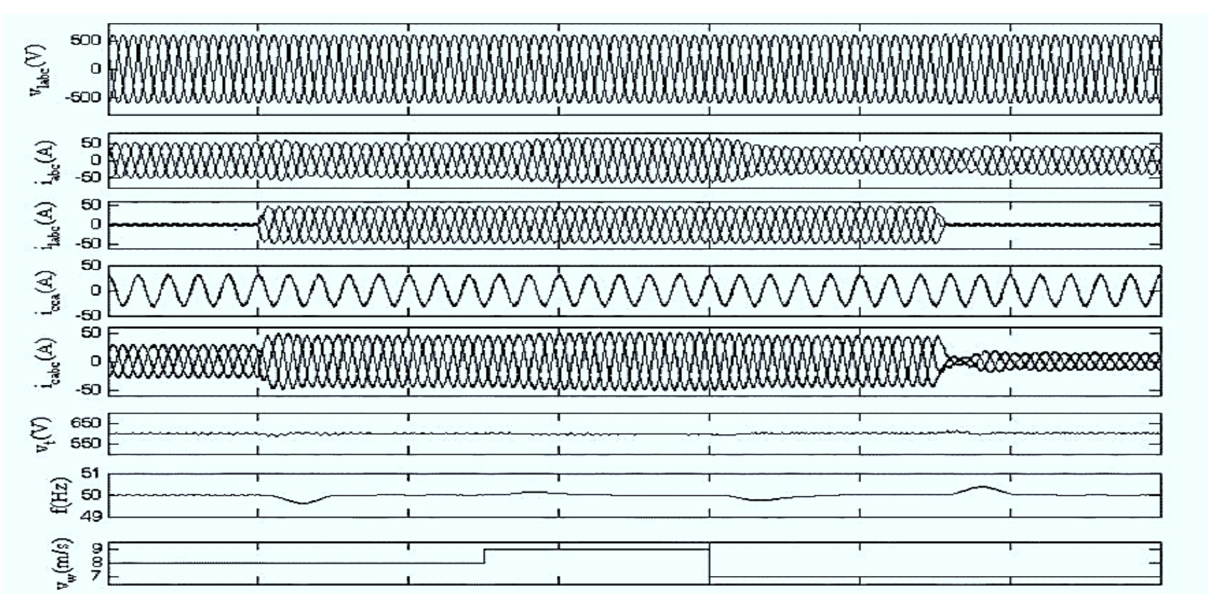
Unit voltage template:



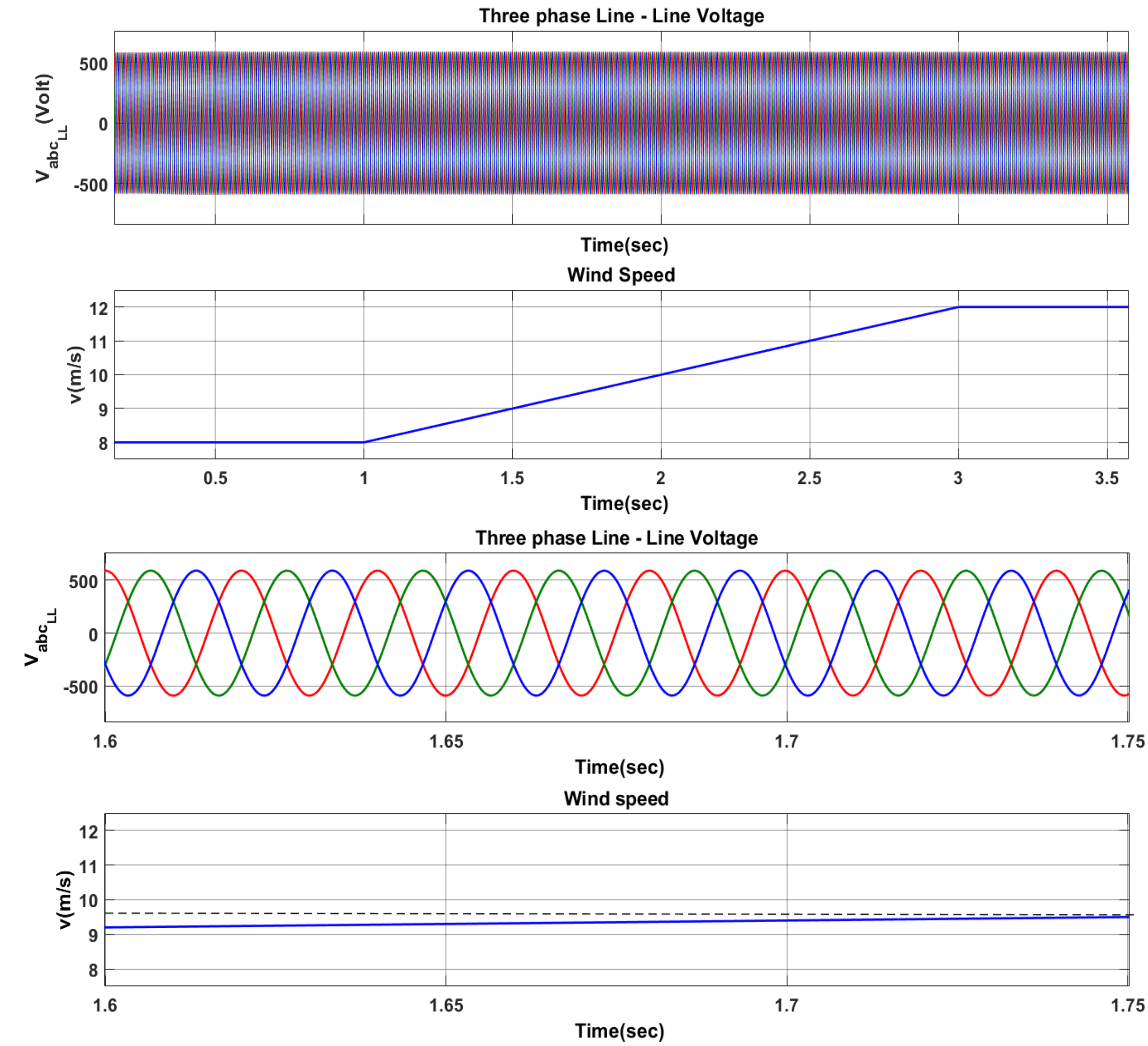
Quadrature voltage template:



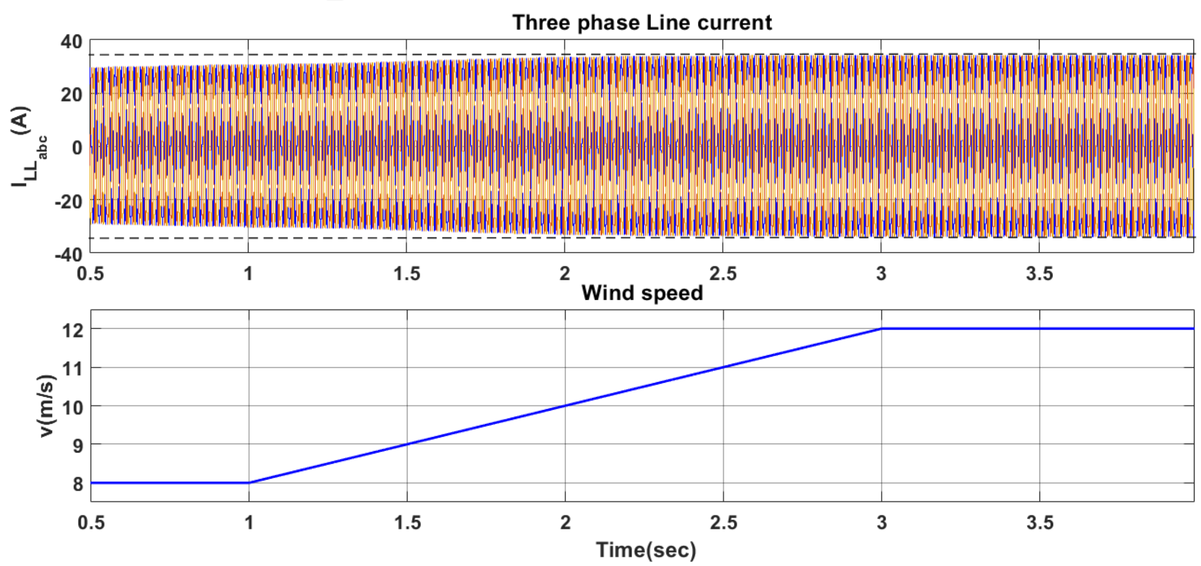
Theoretical Waveforms:

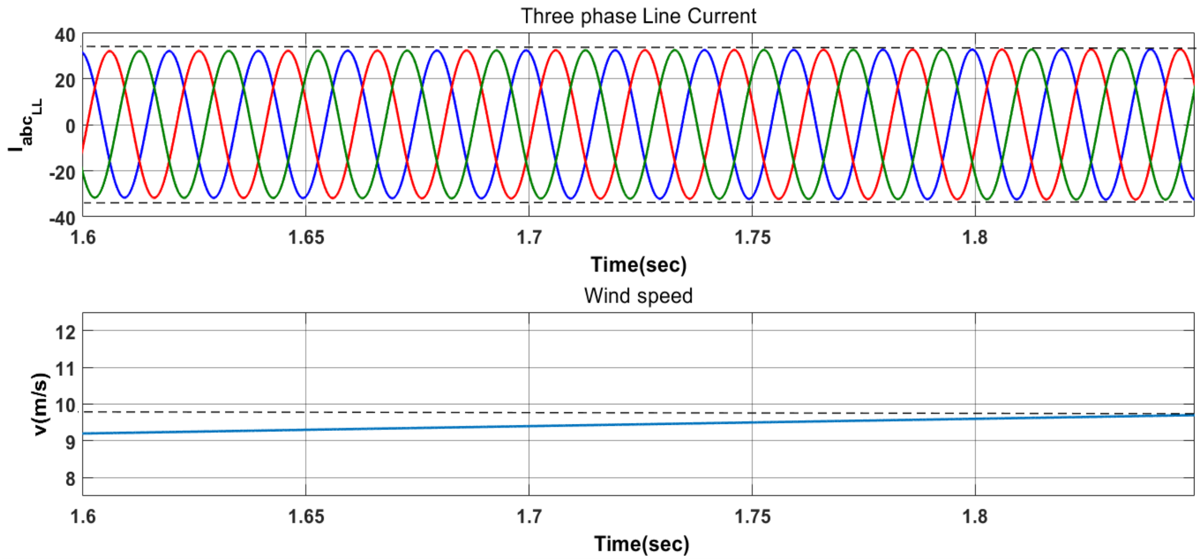


Obtained Waveform – Vabc (LL):

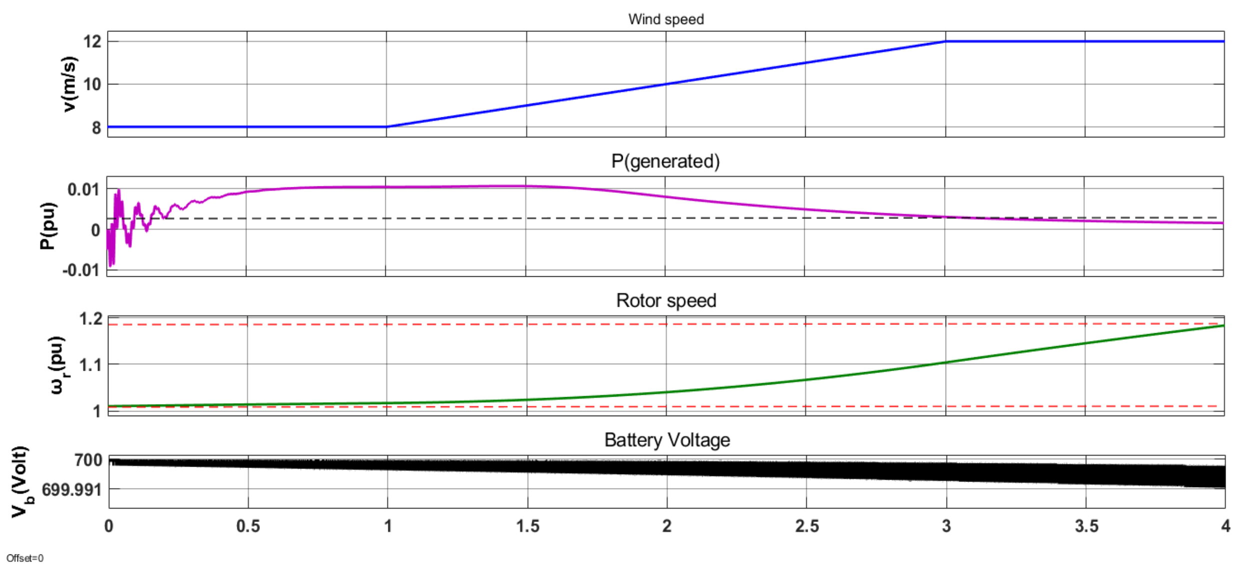


Obtained Waveform – I_abc (Line Current):





Obtained Waveform – Generator parameters:



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[1] G. K. Kasal and B. Singh, "Decoupled Voltage and Frequency Controller for Isolated Asynchronous Generators Feeding Three-Phase Four-Wire Loads," in *IEEE Transactions on Power Delivery*, vol. 23, no. 2, pp. 966-973, April 2008, doi: 10.1109/TPWRD.2008.915783.

[2] G. K. Kasal and B. Singh, "Voltage and Frequency Controllers for an Asynchronous Generator-Based Isolated Wind Energy Conversion System," in *IEEE Transactions on Energy Conversion*, vol. 26, no. 2, pp. 402-416, June 2011, doi: 10.1109/TEC.2010.2102029.

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