Synchronous Detection Method-Based Effective Power Transfer for Hybrid Wind-PV System

J. Sathya Prishma and J. Uma

Abstract The present study is the energy conversion system to attain an effective power transfer using inexhaustible energy source such as wind and PV is allied as a hybrid system. The energy is supplied from source to load through a two voltage source converter (VSC) one at wind side and other at grid side. The control algorithm proposed for wind side converter are hysteresis current controller compares the actual and reference current of VSC to create gating pulses and fuzzy logic-based voltage controller. The hysteresis current controller is utilized in grid side to create gating pulse for grid side converter. The PV array coupled to the DC interface and one of the MPPT algorithms such as P&O calculation is utilized to track greatest power from PV under different weather condition. The synchronous detection method is used to compute reference current for hysteresis controller. To evaluate the performances of proposed scheme, Matlab/Simulink model is used. From the simulation results, it is confirm that effective power transfer is achieved with minimum number of converters.

Keywords Wind energy conversion system (WECS) · Photovoltaic (PV) · Voltage source converter (VSC) · Wind side converter (WSC) · Grid side converter (GSC) · Permanent magnet synchronous generator (PMSG) · Hysteresis controller (HC)

1 Introduction

The population growth has increased the energy demand. Just now, inexhaustible energy source is mostly concentrated to diminish the energy demand. Prior, the emphasis was independently on individual energy source (or) standalone system. The distribution generation system uses two or multi-source connected in hybrid ways to increase the outcomes. The hybrid frameworks such as wind/PV/diesel experimental analysis are carried out in [1] to reveal the truth that the standalone PV cluster fails to work in winter season. In turn to progress the power outcomes at

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changeable environmental condition, the hybrid system is proposed. The renewable energy source-based energy conversion technique and feasible power transfer are explained in [2]. In [3], the micro grid system with ultra short-term power prediction and feed forward control of energy management are applied in industrial park. The arrangement of hybrid system with PV and wind-based PMSG are accounted in [4] to augment maximum output voltage from inexhaustible energy source. In [5], hybrid framework with two converters, which act as diode bridge rectifier and single phase inverter, are connected to the grid. The proposed control schemes tracking maximum power from intermitted sources and achieve active power transfer which improves the voltage regulation. The renewable energy such as wind needs PMSG to convert mechanical energy to electrical. The boost converter is in planted in this framework to enhance the performance. In [6], the complex control algorithm such as B-spline artificial neural network is used. In [7–12], current controller, which controls the current path from source to grid, is proposed as hysteresis controller. The THD is removed by servo regulating DC-link voltage and PMSG stator current. In [13], the author presents the PV cell performance under different thermal conditions using virtual instrumentation.

1.1 Hybrid Framework with Wind-PV System

The diagrammatic layout of hybrid wind-PV system organized by PMSG; two converters namely wind side converter and grid side converter. The nonlinear load is connected on either side of two converters. The three phase voltage and current are given as input to the synchronous detection method (SDM). The solar cluster is arranged at the DC interface of transmission line. One of the MPPT methods such as P&O techniques are implemented to obtain maximum power from PV cluster. The effective power transfer is achieved from fuzzy logic controller and Hysteresis current controller. In this proposed plan, synchronous detection method (SDM) is used to compute the reference grid current of VSC by calculating the difference between reference source current and nonlinear load current (Fig. 1).

1.2 Design of WSC and GSC

The design procedure for WSC and GSC includes the rate of change of stator current of PMSG (Δi_{L_s}) determined from maximum wind power minimum voltage needs for boost converter.

$$\Delta i_{L_s} = 10\% \text{ of } \frac{P_W(\text{max value})}{V_{\text{ls}}(\text{min value})}$$

where,

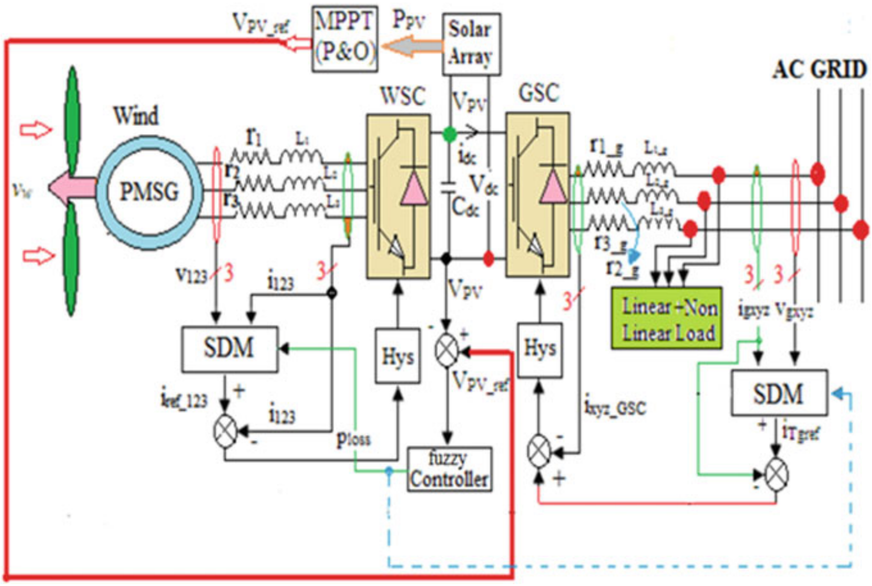

Fig. 1 Block diagram of proposed system

v_{pqr}, v_{gabc}	The instant phase voltages of the PMSG and AC grid.
i_{pqr}, i_{gabc}	Are the instant line currents of PMSG and AC grid.
$v_{dc} = v_{pv}$	Is the DC bus voltage.
I_{dc}	Is the average DC current.
$L_{11\,g} = L_{12\,g} = L_{13\,g} = L_{14\,g}$	Interface inductances.
$r_{11\,g} = r_{12\,g} = r_{13\,g} = r_{14\,g}$	Inward resistance.

For computing L_{11} (inductive filter) and DC-link capacitor, the following equations are used.

$$L_{11} = \frac{V_{\text{ls(rated value)}} \cdot \left(V_{\text{PV}} - V_{\text{ls(min value)}}\right)}{\Delta i_{L_s} \cdot f_s \cdot V_{\text{PV panel}}}$$

$$C_{\text{dc link}} = \frac{(P_{W\text{max value}} + P_{\text{PV max value}})2t_{\text{hold up}}}{V_{\text{PV panel}}^2 - V_{\text{PV(max value)}}^2}$$

The grid side inductive filter L_{g-g} is determined from

$$L_{g-g} = \frac{V_{l(\text{rated value})} \cdot \left(V_{\text{PV}} - V_{l(\text{min value})}\right)}{\Delta i_{L_{gg}} \cdot f \cdot V_{\text{PV}}}$$

to reduce the high frequency harmonics. The change of Δi_{Lsg} GSC converter grid current is given by

$$\Delta i_{L_S\,g} = 10\%\text{of}\ \frac{(P_{W\,\text{max value}} + P_{\text{PV max value}})}{\text{V}_{\text{ls(min value)}}}$$

The power at grid side converter from main inexhaustible source wind and PV is

$$P_{\text{GSC}} = \eta_{\text{GSC}}\left[P_{\text{Wind}} + P_{\text{PV panel}} + P_{\text{loss}}\right].$$

1.3 MPPT Procedure for PV

The procedure involved to track the maximum power under varying sun illumination is P&O technique-based MPPT method. The perturb and observe technique is estimating change in power ΔP_{pv} and P_{pv} from current and voltage of PV cluster. By perturbing and observing P_{s} power from PV, the precise maximum power is recognized from V-I bends of PV cluster.

1.4 Mathematical Modeling of the Proposed Hybrid System

The steady-state equation is used for modeling the wind-PV. The performance analysis of proposed system is demonstrated by using the d-q theory.

The *d–q* voltages of PMSG are:

$$V_{d\,\text{grid}} = L_{dg}\frac{\mathrm{d}i_{dg}}{\mathrm{d}t} - \omega L_{dg} i_{qg} + i_{dg} r_g$$

$$V_{q\,\text{grid}} = L_{qg}\frac{\mathrm{d}i_{qg}}{\mathrm{d}t} - \omega\left(L_{qg} i_{qg} + \Psi_{\text{PM}}\right) i_{qg} r_g$$

The mechanical power from the wind turbine is specified as

$$P_{\text{max value}} = G_p(\lambda, \beta)\frac{\rho A}{2} V_{\text{wind}}^2$$

The equation necessary to determine the DC interface voltage is

$$\begin{aligned} V_{\text{dc link}} &= V_{\text{PV panel}} \\ &\geq \frac{3\sqrt{3}V_{\text{max}}}{\prod}. \end{aligned}$$

where

V_{max} is the peak value of the PMSG stator voltage

Maximum wind speed = 12 m/s.
The DC-link current (i_{dc}) is given by

$$i_{\text{dc}} = i_{d\,\text{wind}} + i_{q\,\text{wind}} + I_{\text{PV panel}}$$

The d–q voltages and currents of the GSC in terms of DC-link voltage V_{dc} are given by

$$v_{d\,\text{grid}} = L_{dg}\frac{\text{d}i_{dg}}{\text{d}t} - \omega L_{qg} i_{qg} + i_{dg} r_{gg} + d_d V_{\text{dc link}}$$

$$v_{q\,\text{grid}} = L_{qg}\frac{\text{d}i_{dg}}{\text{d}t} - \omega L_{dg} i_{dg} + i_{qg} r_{g\,g} + d_q V_{\text{dc link}}.$$

2 Control Algorithms Description

Three control algorithm is proposed in this study, they are

- The hysteresis current controller at two converter side.
- The voltage controller such as fuzzy logic controller at PV side.
- The tracking algorithm MPPT control is implemented at PV side.

2.1 Dynamic Current Controller for WSC

The converter gating pulse is generated from the synchronous detection method (SDM) scheme. The synchronous detection method computes the reference grid current by calculating the difference between the reference source current and nonlinear load current. The HC current controller compares the output of SDM such as reference current with actual current. The hysteresis controller process the current error signal to control the current path from stator of PMSG to actual WSC input current templates. The current controller at grid side converter reduces the harmonics and achieve unity power factor.

2.2 Voltage Controller for WSC

Unlike other methods, the fuzzy logic controller is rule-based membership function. The input of the fuzzy logic controller is the error signal. It is obtained by comparing the reference voltage and the actual voltage of DC link. The fuzzy logic controller process the error by controlling the voltage (Table 1).

Table 1 Fuzzy rule table

Error	Reference						
	VVL	VL	L	LL	ML	N	H
NB	Z	Z	Z	Z	S	N	ML
NM	Z	Z	Z	S	N	ML	LL
NS	Z	Z	S	N	ML	LL	L
Z	Z	S	N	ML	LL	L	VL
PS	S	N	ML	LL	L	VL	VVL
PM	N	ML	LL	L	VL	VVL	VVL
PB	ML	LL	L	VL	VVL	VVL	VVL

2.3 Current Controller for GSC

The current controller proposed for grid side converter is hysteresis controller. From the synchronous detection method, the reference current is calculated which is given as input to the hysteresis controller. The grid side converter acts as shunt active power filter and compensate current imbalance because of nonlinear load at GSC. The synchronous detection method is utilized to determine the reference grid current

$$\begin{pmatrix} i^*_{Tgx} \\ i^*_{Tgy} \\ i^*_{Tgz} \end{pmatrix} = \frac{P_W + P_{pv} + P_{nl}}{v^2_{gx} + v^2_{gy} + v^2_{gz}} \beta \begin{pmatrix} v_{gx} + \left(v_{gy} - v_{gz}\right) \\ v_{gy} + \left(v_{gz} - v_{gx}\right) \\ v_{gz} + \left(v_{gx} - v_{gy}\right) \end{pmatrix}$$

where;

$$V_{gx} = V_m \sin wt$$

$$V_{gy} = V_m \sin(\omega t - 120°)$$

$$V_{gz} = V_m \sin(\omega t + 120°)$$

are the grid voltages. The calculated reference currents are compared with the actual AC grid current to create current error.

3 Simulink Model for the Proposed System

Figure 2 shows the arrangement of overall effective power transfer scheme of hybrid wind-PV system. The proposed system is validated on a MATLAB SIMULINK.

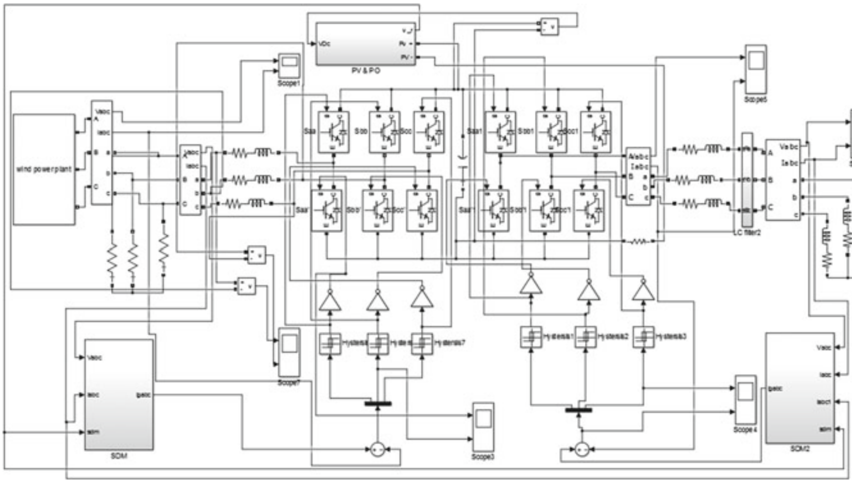

Fig. 2 Simulink model for the proposed system

In Fig. 3, the wind energy conversion system consists of wind turbine. The mechanical energy is converted into a electrical energy using permanent magnet synchronous generator. The constant wind speed is 12 m/s.

From Fig. 4, one of the MPP algorithm is P&O method that is used on PV panel to obtain the optimal power under varying weather condition of sun radiation. The investigation is conducted under a constant irradiation of 1000 W/m^2. The voltage controller for wind side converter is fuzzy logic controller. It is used to direct the yield DC voltage of WSC to MPP voltage.

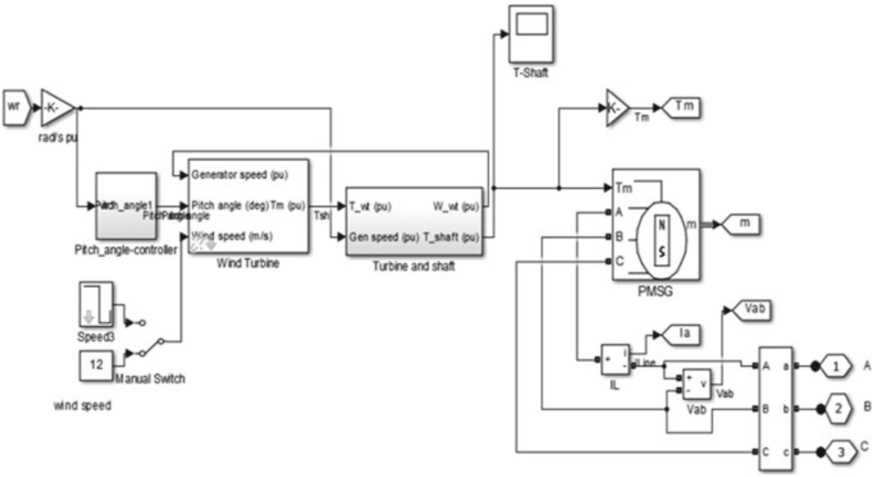

Fig. 3 Simulink model of wind energy conversion system

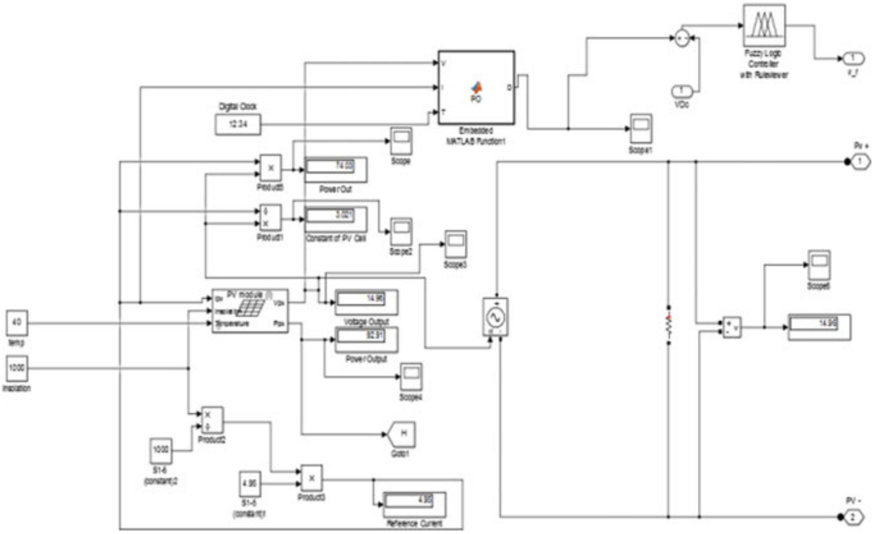

Fig. 4 Simulink model of photovoltaic system

Figure 5 shows the synchronous detection method which is used to compute the reference grid current of VSC by calculating the difference between reference source current and nonlinear load current. The hysteresis controller is used to generate gating pulses for two voltage source converter.

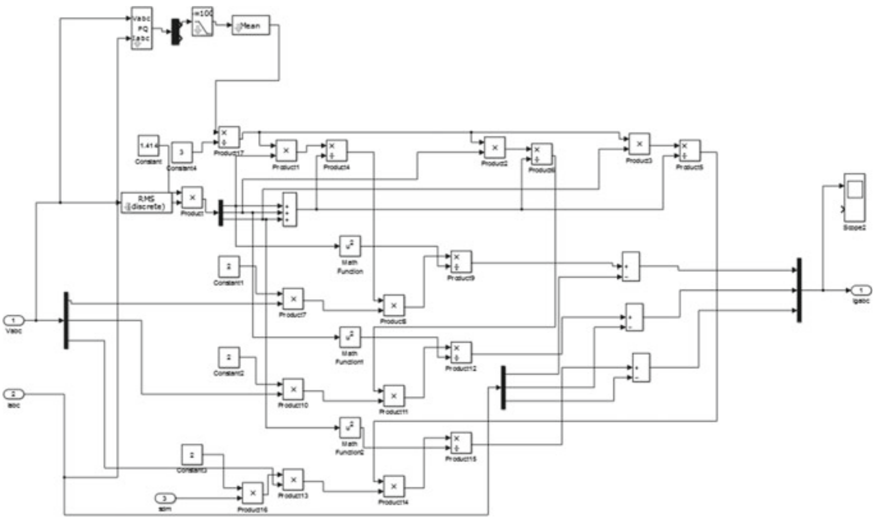

Fig. 5 Simulink design of synchronous detection method

4 Results

The simulation results are validated through MATLAB/SIMULINK for the proposed hybrid system. In Fig. 6 shows the rotor speeds, electromagnetic torque, and mechanical torque of permanent magnet synchronous generator.

Figure 7 shows the scaled down sinusoidal compensated PMSG voltage and current which is given as input to the voltage source converter.

The output voltage and output power from the PV panel under 1000 W/m^2 are shown in Fig. 8. The MPP algorithm is used to track the maximum power from the PV panel.

The reference grid current of VSC is obtained from synchronous detection method by calculating the difference between reference source current and nonlinear load current as shown in Fig. 9.

The sinusoidal waveform from output voltage and current from voltage source converter (grid side converter). The output is given to the grid through the nonlinear load (Figs. 10 and 11).

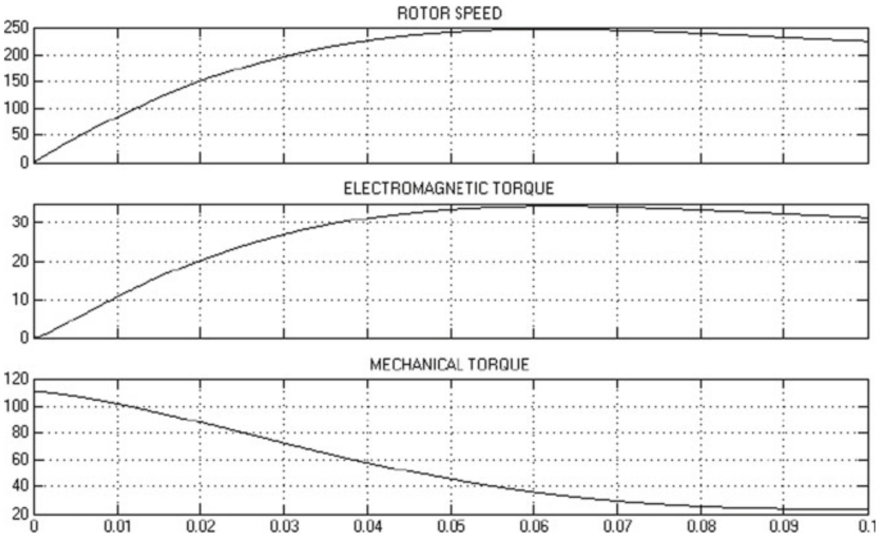

Fig. 6 Rotor speed, electromagnetic, and mechanical torque from PMSG

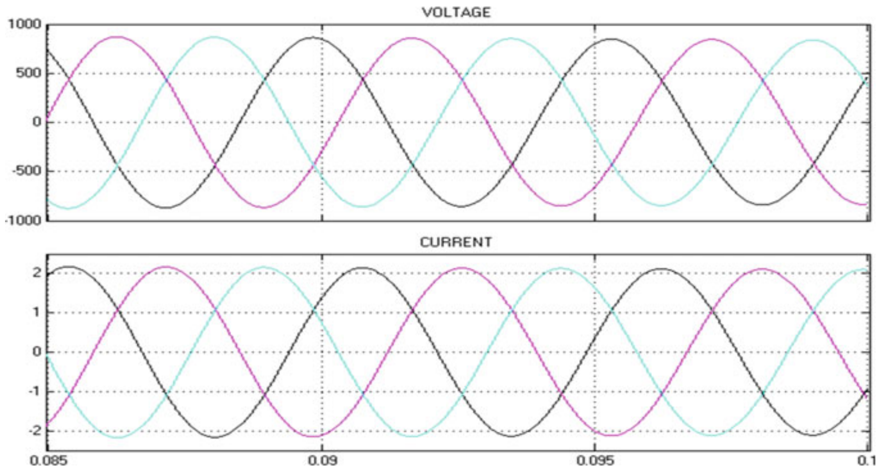

Fig. 7 Output voltage and current from PMSG

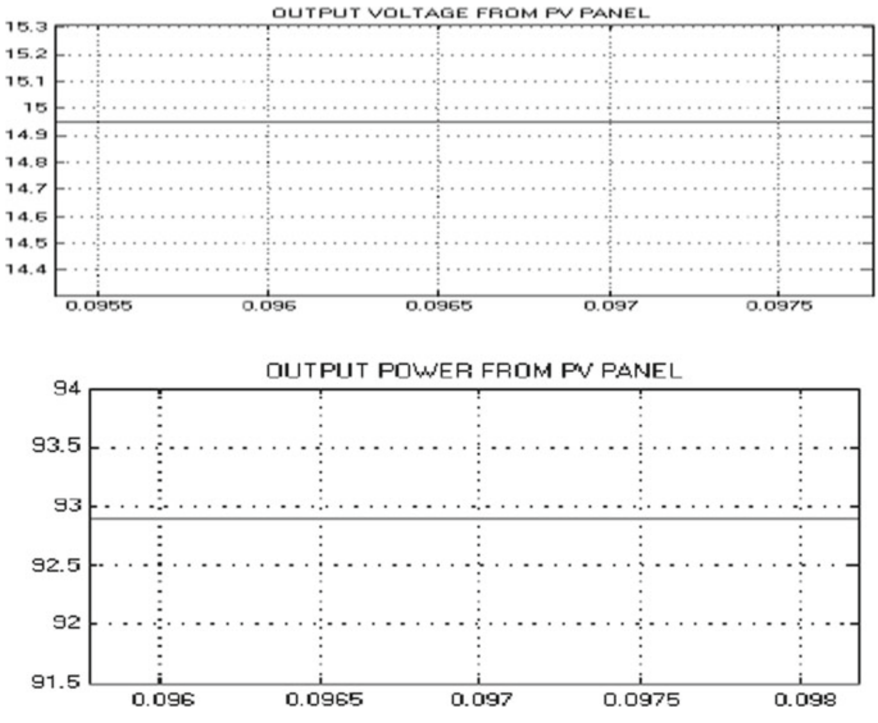

Fig. 8 Output voltage and current from PV panel

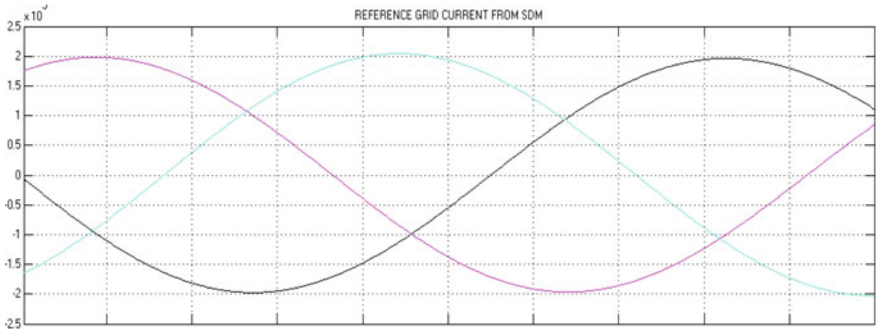

Fig. 9 Reference grid current from SRM

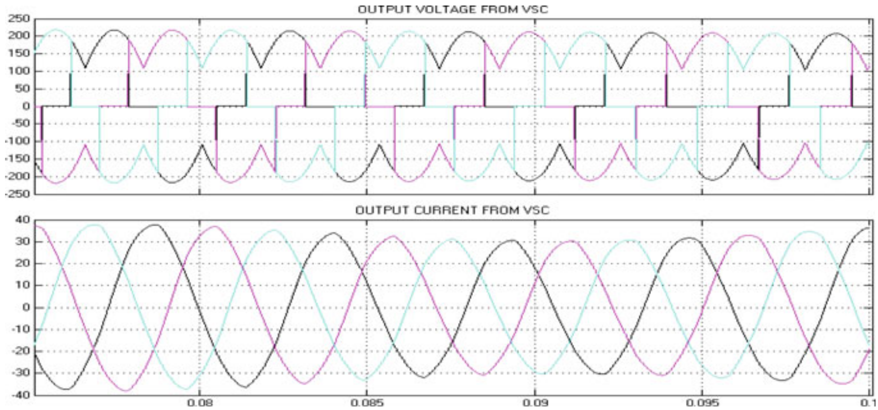

Fig. 10 Output voltage and current from VSC

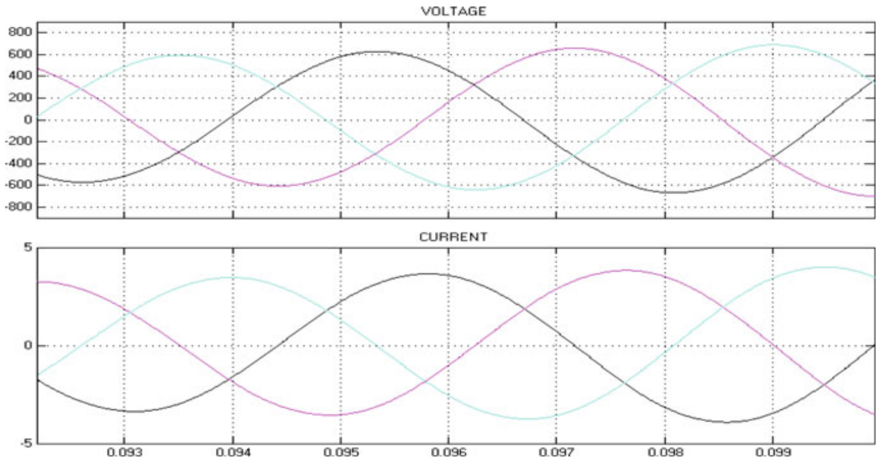

Fig. 11 Waveform of grid output voltage and current

5 Conclusion

The future expansion of this present study is feasible with parallel operation of hybrid system with PV and wind. The outcomes of the proposed study have extracted maximum power by using minimum converter and control algorithm for both PV and wind. The SDM determines the reference current utilizing maximum power from PMSG, the control algorithm proves that the effective power transfer from source to linear and nonlinear loads. The output of the proposed study is verified by using Matlab/Simulink.

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