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Synchronverter Based PWM Generation for a PEI (Power Electronic Interface)

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ABSTRACT

This paper discusses, synchronverter based voltage controlled strategy for a Power Electronic Interface (PEI), - a three phase inverter that is to be integrated between a suitable micro source and micro grid. The simulation is developed in MATLAB – SIMULINK environment and the results are validated.

Keywords: control, micro grid, parallel operation, synchronverter.

I. INTRODUCTION

Energy generation and its sustainment are two of the mandatory issues that needs proper discussions and diversified solutions. A common solution, which is gaining popularity in recent days is the integration of non - conventional energy resources i.e., solar, wind, fuel cell…. into the existing utility in the form of small Distributed Energy (DG) units. Although such an integration results in an improvement of the overall system performance, most of these sources yield intermittent, fluctuating nature of output. Hence such units can't be put in direct connection with the grid without a proper interface. In case of micro/smart grids, a suitable power electronic interface in the form of inverters are to be used. Control strategies for inverter should be selected in addition - to aid power quality improvement, seamless and smooth transition between grid connected and stand- alone modes of operation and for achieving proportional power sharing.

II. POWER FLOW CONTROL

(A) Synchronverter

Micro grid's stability and overall performance relies mainly on power flow control. Majority of the control strategies are of vector control approach in the d-q reference frame. The direct, quadrature – grid components of current and voltage are accordingly controlled for power flow. But, due to the decoupling terms used for achieving the desired field orientation, vector control techniques become sensitive to parameter variation and mismatch.Opposed to the existing vector control techniques, synchronverter technique is completely independent from the parameters of the permanent magnet synchronous generator providing significant advantages to the system performance [2]

Synchronverters are grid-friendly inverters that mimic the operation of conventional synchronous generators (SG) by designing parameters of the SG into the droop control mechanism of PEI [1] [3] – [10]. As a result, inverter based DER units can readily play the role of voltage and frequency regulator. The concept of synchronverteris based on the working principle of a synchronous generator (SG), and can simulate the electromagnetic characteristics, rotor inertia, primary frequency regulation and voltage adjustment characteristic of SG [3] [9].

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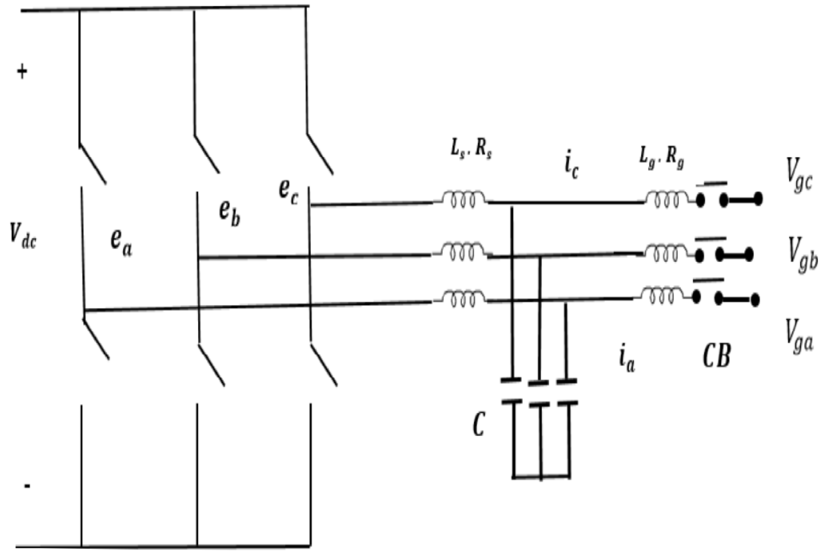
The idea of synchronverter has opened up a wide possibility of novel applications. For example, in [11], the model of synchronverter has been used to synthesize a STATCOM controller. In [9] [12] the synchronverter concept is adapted to the sending end (synchronous motor action) and receiving end (synchronous generator action) converters of a HVDC transmission.

A new self-synchronization control strategy without PLL unit is proposed for synchronverter in [13] [14]. It is proved that, with the proposed strategy - seamless reconnection can be achieved for micro grids with or without local loads. The design can be implemented with ease and high accuracy .The technique could also be extended to the pre-synchronization of inverters with droop control.

Self-synchronization inverter ("*synchronverter*") using virtual impedance without dedicated PLL synchronization unit is proposed in [15]. [16] Shows that it is possible to replicate the action of a static VAR compensator (SVC) by means of a synchronverter. It is also shown that it can enact the role of a power system stabilizer.

An improved synchronverter model to achieve secondary frequency control, active voltage feedback control for a hybrid MTDC system is proposed in [17]. The model developed unlike its traditional counterpart is capable of limiting current under fault conditions independent of PLL. A complete nonlinear model of the synchronverter is proposed [18] and its stability in the sense of boundedness is investigated. A small signal model based on signal flow graph technique is outlined in [19]. Article [10] discusses droop control based power sharing by consensus algorithm and also the transient energy function approach for system stability.



L_S . R_S — Stator Impedance,
L_g . R_g — Grid Interface Inductors,
CB – Circuit Breaker,
C – LC Filter Equivalent

Figure 1: Power Part- Synchronverter

III. SYNCHRONVERTER MODEL

The mathematical model of the synchronverter is the composition of a power part and an electronic part. The power part is the inverter, while the electronic part is an electronic controller based program which, when run on a processor controls the switching pattern. The heart of the electronic part is the mathematical model of a synchronous generator.

(A) Equations

Given below are the equations that constitute the core of the electronic part:

$$T_e = pM_f i_f \left\langle i, \widetilde{\sin\theta} \right\rangle \tag{1}$$

$$e = \dot{\theta} M_f i_f \widetilde{\sin\theta} \tag{2}$$

$$Q = \frac{3}{2}\dot{\theta} M_f i_f \sin(\theta - \varphi) \tag{3}$$

$$\ddot{\theta} = \frac{1}{J}(T_m - T_e - D_p\dot{\theta}) \tag{4}$$

Where

$$i = i_0 \sin\varphi \tag{5}$$

$$\mathrm{J} = D_p \tau_f \tag{6}$$

$$K = \dot{\theta}_n D_q \tau_v \tag{7}$$

$$\widetilde{\sin\theta} = \left| \begin{matrix} \sin\theta \\ \sin\left(\theta - \frac{2\pi}{3}\right) \\ \sin\left(\theta - \frac{4\pi}{3}\right) \end{matrix} \right| \tag{8}$$

$$i = \left| \begin{matrix} i_a \\ i_b \\ i_c \end{matrix} \right| \tag{9}$$

$$e = \left| \begin{matrix} e_a \\ e_b \\ e_c \end{matrix} \right| \tag{10}$$

T_e — Electro -magnetic torque,
T_m — Mechanical torque,
J — Moment of inertia,
K — Dual of inertia/Gain,
M_f — Mutual inductance of field coil,
i_f — Field current,
e — Back EMF,
θ – Virtual angle,
$\dot{\theta}$ — Virtual angular speed,
$\dot{\theta}_r$ — Angular frequency reference,

$\dot{\theta}_n$ — Nominal angular speed,

D_p — Damping factor
D_q — Voltage droop co efficient,
τ_f — Time constant – Speed/Frequency loop,
τ_v — Time constant – Voltage loop,
Q — Reactive power,
P — Real power,

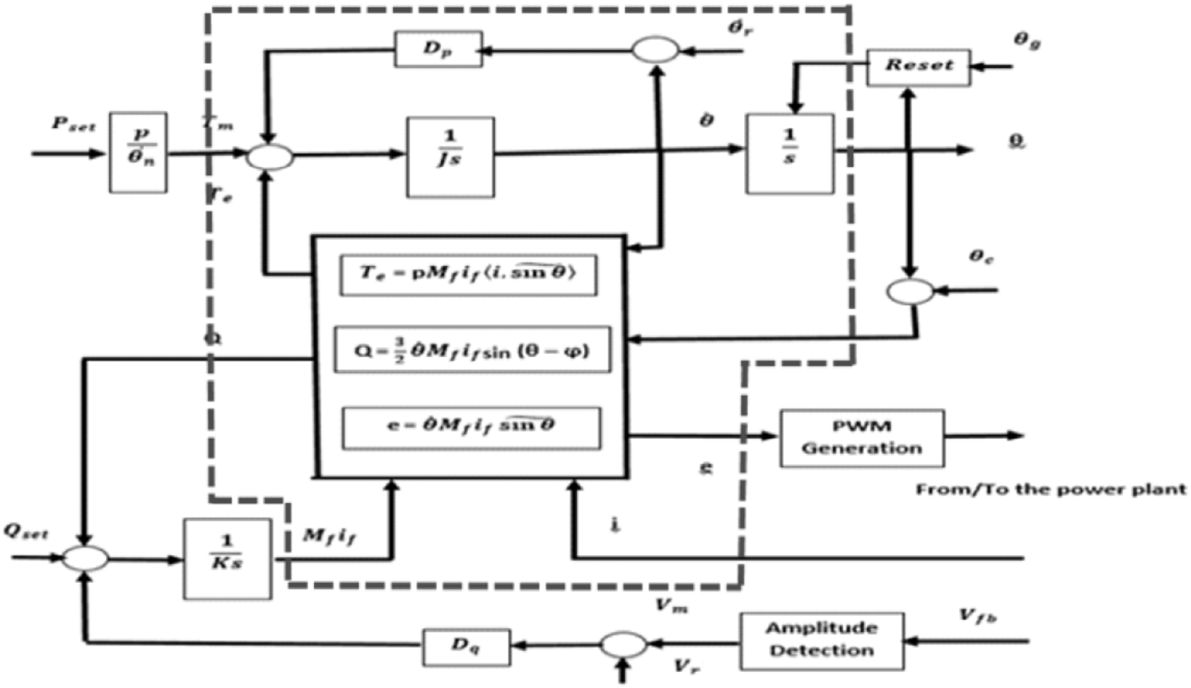


Figure 2: Electronic Part (With Control) -Synchronverter

IV. CONTROL IMPLEMENTATION

Models for electronic part of the synchronverter with and without control is simulated. The inverter (power part), filter, grid interface, control and other parameters are as listed in Table. 1. [2]

(A) Electronic Part – Without Control

The partial schematic shown inside the dashed lines of Figure 2 depicts the electronic part without control.

The model in SIMULINK is developed with the help of the equations (1), (2), (4) – (6), (8). io, is chosen to be a random sine wave signal as the system is as yet without any closed loop control. The waveforms for $'\widetilde{\sin\theta}'$ and ‘e’ are as shown in Figure 4.

(B) Electronic Part – With Control

Figure 2 as a whole is the synchronverter’s electronic part with the inclusion of voltage and frequency control function. The control inputs of the synchronverter are Tm and Mfif.

A controller should be included to generate these parameters, so that the system stability is maintained and real and reactive power regulation is achieved.

The control is a cascaded structure whose upper part regulates the real power (torque).The inner loop is the speed/frequency loop and the outer loop forms the real power/torque loop. The lower part of the control is meant for the regulation of reactive power.

Table I
Design and Control Parameters

Parameters	*Values*
J	0.0122
K	2430.1
D_p	6.0793
D_q	386.7615
$M_f i_f$	0.5
T_m	25
R_S, L_S	1.1 mH
R_g, L_g	1.1 mH
C	22
V_{DC}	500

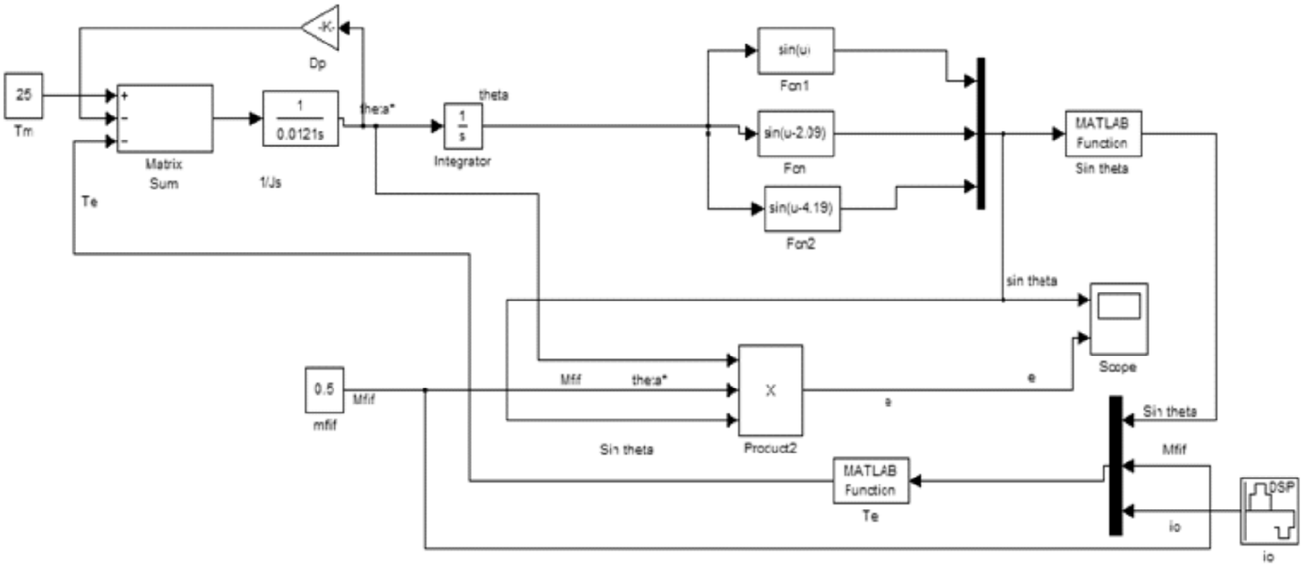


Figure 3: Electronic Part of Synchronverter (WithoutControl) SIMULINK MODEL

(C) Application of Control

Figure 5. shows synchronverter control, partially being used only for the sake of pulse width modulated gating pulse generation. The circuit is devoid of power, voltage and frequency regulation. Full use of closed loop control of synchronverter with all these features included is mandatory, when the inverter is acting as an interface between a micro source and the micro grid. As the focus of this paper is only upon how gating pulses are generated, the fullest nature of control implementation is not discussed.

The electronic part is applied to a 3 phase 3 level inverter fed from a dc voltage of 500 Volts.

The actual load current, io is used for generating the electromagnetic torque Te, and the rotor back emf, e is used as the reference wave for the PWM pulse generation of the six number of switches forming part of the inverter.

The gating pulses observed are as shown in Figure 6.

The simulation results of DC input voltage (V_{DC}), Phase to Phase voltage of inverter (V_{AB}), Load voltage are as shown in Figure 7.

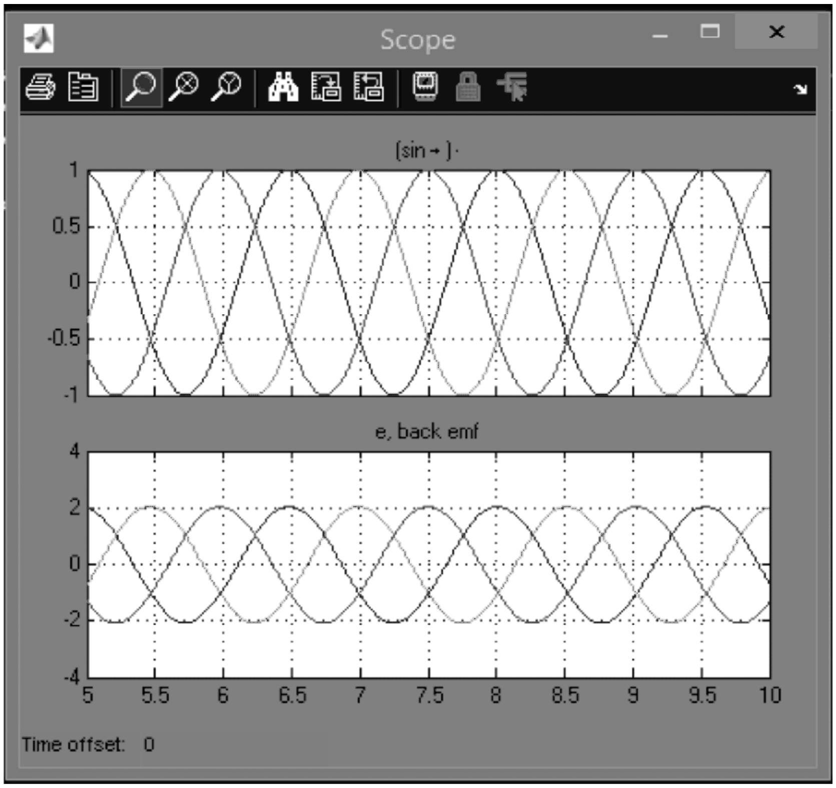


Figure 4: Simulation Waveforms – Without Control

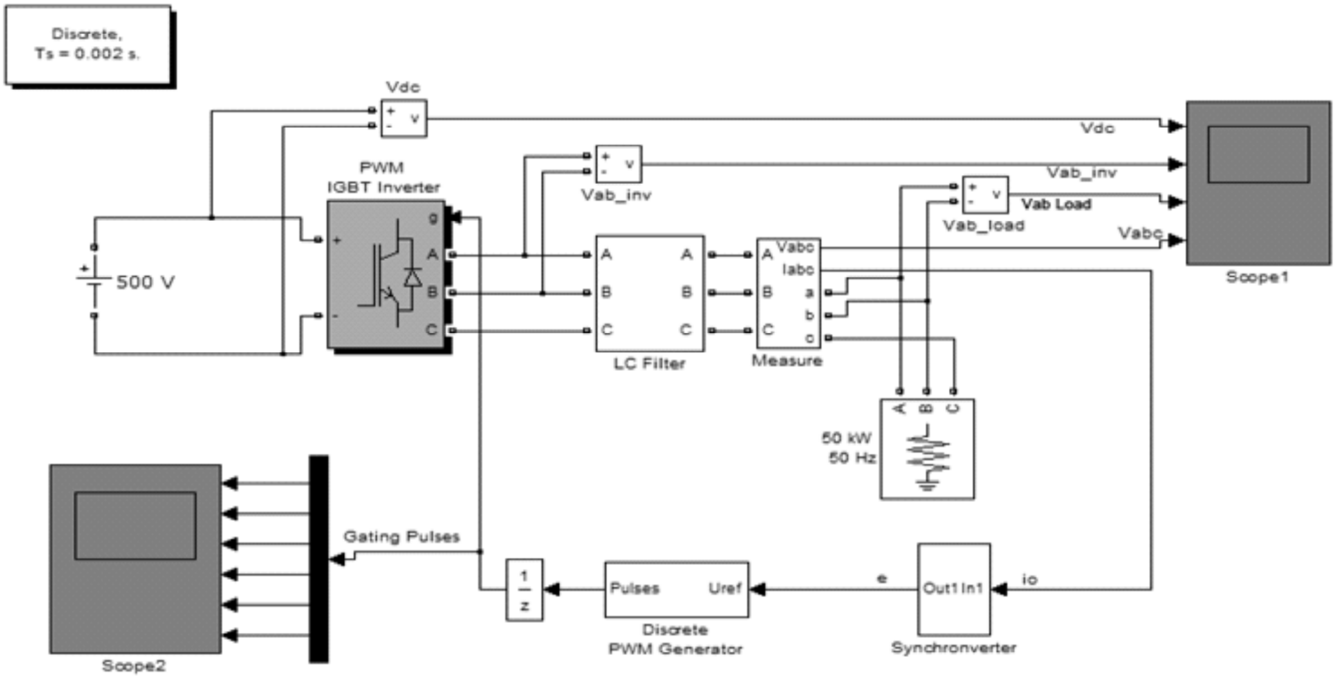


Figure 5: Electronic Part of Synchronverter (With Partial Control) SIMULINK MODEL

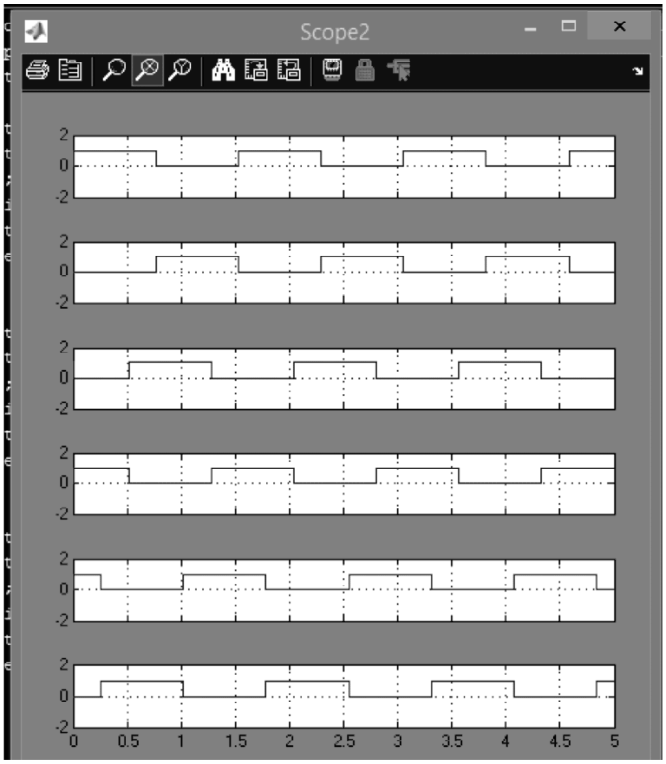


Figure 6: Simulation Waveforms – Gating Pulses

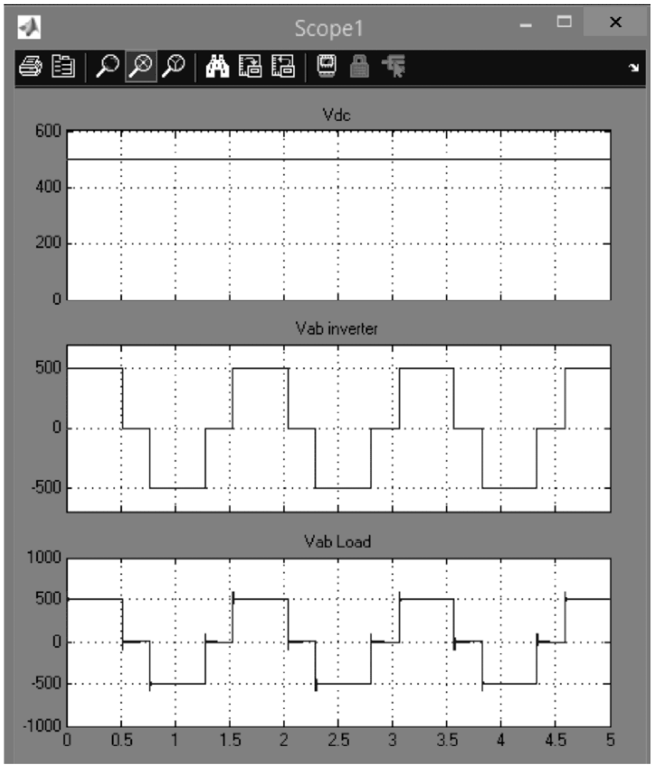


Figure 7: Simulation Waveforms – With Partial Control

V. CONCLUSION

A simple and brief explanation of how, a synchronverter model can be used to produce required PWM signals for a 3 phase inverter is presented in this paper. The future extension of this work is to

- Apply the control technique for a PV based micro grid.
- Apply the technique for control of PEI integrating multiple DC micro sources with the micro grid.

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