Fractional Order Control Of A Sinusoidal Output Inverter

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Abstract: *In this paper fractional order proportional integral derivative (FOPID) controller tuned with genetic algorithm (GA) is used to control of a novel designed sinusoidal output inverter. FOPID is used to minimize the total harmonic distortion (THD), increase efficiency and output voltage in order to obtain sinusoidal wave form. In this topology fully rectified form of a sinusoidal voltage waveform at a utility amplitude and frequency is achieved by a well-known buck-boost converter which has been converted to AC voltage. A conventional well-tuned PI controller is already applied to inverter in the previous paper [1]. The comparison of the FOPID and the PI is presented by taking into consideration their low THD, high efficiency and high output voltage at the inverter output under the same conditions. The simulation results prove that the FOPID shows better performance than the PI controller in terms of efficiency, THD level and output voltage.*

Keywords: *FOPID, PWM, inverter, sinusoidal, buck-boost.*

1. Introduction

Inverters are used to convert direct current to alternating current and therefore they used widely in industrial applications. Since the conventional inverters require the elimination of harmonics, the sinusoidal output inverter has some advantages such as results a pure sinusoidal form of output voltage and contains less harmonic distortion [1]. Several control technique is used to control the inverter output, for example, PID [2], adaptive fuzzy control [3], sliding mode control [4], H_∞ control [5], μ analysis and synthesis control [6], to name a few. Recently, in addition to this, design of the fractional order controllers (FOC) has been reported. A modulated Hysteresis current control applied to multilevel inverter with FOC to increase the stability of the grid voltage is discussed in [7]. Fractional Order PID controller is used to simulate a multi-level inverter, regarding total harmonic distortion factor of current and to remove phase shift error [8]. A control model of zero source inverter (ZSI), voltage source inverter (VSI) and four-leg inverter using fractional order control method is presented in [9]. Another FOPID controller is implemented on independent micro-grid topology including boost converter and multi-level inverter is also discussed in [10]. A new maximum power point track (MPPT) method uses fractional order extremum seeking control method for grid - connected photovoltaic (PV) systems is discussed in regards to the controlling the three phase voltages of the network which has faster speed and less THD values is presented in [11]. A controller on the basis of the current mode control and fractional order control approach is proposed for boost power converter used in solar photo-voltaic systems in [12]. The simulation results show better performance of the FOC approach as compared to that of integer order controller. A simulation based FOPID control of a boost converter by a multi objective optimization algorithm is discussed in [13]. A FOC is optimized by using particle swarm optimization to fix the voltage level of a photovoltaic (PV) system is presented in [14]. An isolated solar powered system using FOC is discussed in [15]. Behavioral analysis of a DC / DC converter including high performance source filter is realized by using a FOPID controller is presented in [16].

In this paper, a FOPID and a conventional PI controller are applied to an inverter which includes a novel method to achieve quasi-sinusoidal waveforms at the output. The simulation results obtained prove that the FOPID results in better responses than PI controller in terms of efficiency, THD level and output voltage.

2. Sinusoidal Output Inverter

The topology of the system based on the principle of a buck-boost converter [1]. This regulator gives a sinusoidal output depending on the novel duty cycle topology. The circuit of DC / DC side of the system for FOPID application and the main system are shown in Fig. 1 and Fig. 2 respectively. The related buck-boost converter equations are given by Eqs. 1 and 2 respectively.

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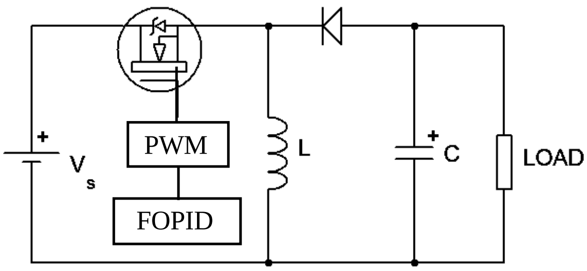


Figure 1. FOPID application of DC / DC side of the Sinusoidal Output Inverter.

$$V_0 = \frac{V_S d}{1-d} \quad (1)$$

$$I_0 = \frac{I_S d}{1-d} \quad (2)$$

V_0, V_S and I_0, I_S are the output and source average voltages and currents, respectively and d is the varying duty cycle, here.

The aim of the novel switching method proposed in the previously paper is to obtain a sinusoidal output voltage. In this switching method an appropriate duty cycle is implemented for every value of sinusoidal reference voltage to be generated within the considered switching period. As a result, the rectified sinusoidal voltage can be obtained approximately that can be seen from Eq. 1. A FOPID regulator with PWM switching method is shown in the block diagram in Fig. 2. Goal of the simulation system is to make it more stable and more applicable by FOC. The mathematic model control of system depends on capacitor current reference which related to the reference voltage which is given by Eq. 3 and 4.

$$i_C^* = \left| C\omega V_m \cos\omega t \right| \quad (3)$$

$$i^* = i_{loadmeasured} + i_C^* \quad (4)$$

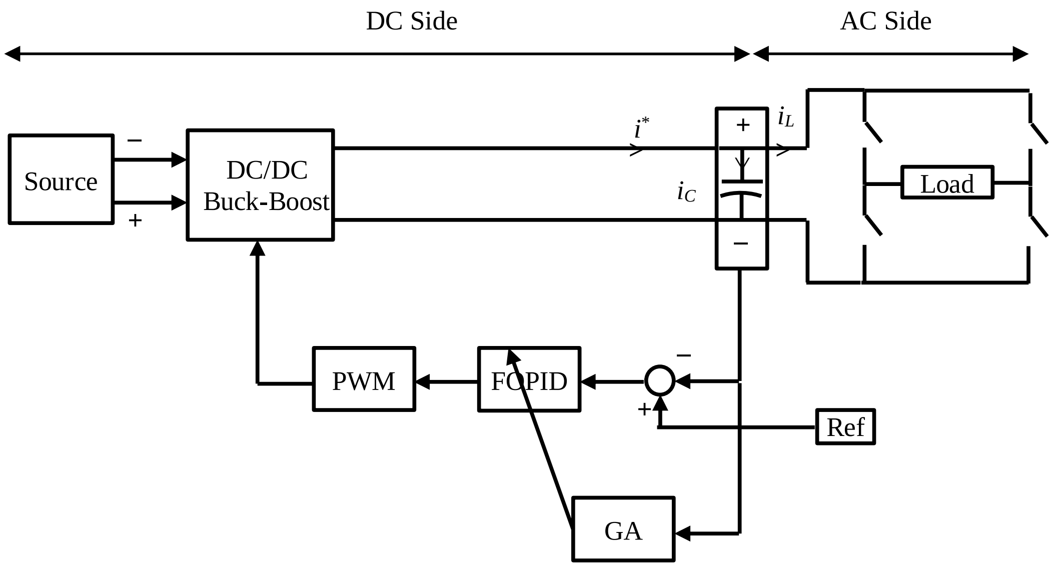


Figure 2. . Block Control Diagram the Sinusoidal Output Inverter

Figure 1. The first and subsequent pages layout of the paper

3. Fractional Order PID Controller

The fractional-order differentiator can be denoted by a general fundamental operator ${}_aD_t^r$, where a and t are the limits of operations.The fractional-order differentiator and integral are defined as follows,

$$ {}_aD_t^r = \begin{cases} \dfrac{d^r}{dt^r} & : r > 0 \\ 1 & : r = 0 \\ \displaystyle\int_a^t (d\tau)^{-r} & : r < 0 \end{cases} \quad (5)$$

where r is the fractional order which can be a complex number, however the constant r is related to initial conditions. There are several mathematical definitions for the fractional differentiation and integration. Between these definitions, here are two commonly used ones, i.e., the Grünwald–Letnikov (GL) and the Riemann–Liouville (RL). The GL definition is [17],

$$ {}_aD_t^r f(t) = \lim_{h\to 0} h^{-r} \sum_{j=0}^{\left[\frac{t-a}{h}\right]} (-1)^j \binom{r}{j} f(t-jh) \quad (6)$$

where [.] means the integer part, while the RL definition is given as,

$$ {}_aD_t^r f(t) = \frac{1}{\Gamma(n-r)} \frac{d^n}{dt^n} \int_a^t \frac{f(\tau)}{(t-\tau)^{r-n+1}} d\tau \quad (7)$$

for $(n-1<r<n)$ and where $\Gamma(.)$ is the gamma function. The general form of the fractional order PID controller is the $PI^{\lambda}D^{\mu}$ and its general transfer function is given as,

$$G_c(s) = K_p + K_i s^{-\lambda} + K_d s^{\mu} \quad (8)$$

where λ and μ are positive real numbers, K_p, K_i and K_d are the proportional gain, integration constant and differentiation constant respectively. The optimization of the five parameters K_p, K_i, K_d, λ and μ makes designing of FOPID controller more challenging than integer order PID controller. Several methods are proposed for this design by using optimization methods. In this paper the determination of the five parameters is achieved by using genetic algorithmone-line separation is needed between the author affiliation(s) and the abstract

4. Tuning of the FOPID Controller Using the Ga

Genetic Algorithm is an evolution algorithm modeling the biologic procedure, and optimizing functions. The algorithm consists of three operators: reproduction, crossover, mutation. Reproduction is to obtain a mate pool which contains individuals according to their fitness values. Then the best individuals are chosen from this pool. The next steps are crossing over and mutation. There is very strong relationship between generation number (the number of loops) and fitness value. The algorithm is highly sensitive to the initial conditions, in other words, pool mate. In addition, selection and crossing over methods are especially important parts of algorithm. GA may find local optimals with these operators, not the real extramums. To overcome this disadvantage mutation is used. The real parameter based GA is simulated in this study, and individuals of the model and population is shown in (9),

$$\begin{pmatrix} K_{P11} & K_{I12} & \lambda_{13} & K_{D14} & \mu_{15} \\ \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} \\ K_{Pn1} & K_{In2} & \lambda_{n3} & K_{Dn4} & \mu_{n5} \end{pmatrix}_{5xn} \quad (9)$$

The fitness function of the system is

$$O(t) = y_{out1}(a) + y_{out2}(a) + y_{out3}(a) \quad (10)$$

Where O(t) is objective function and $y_{out1,2,3}$ are the response of the system for different loads in the Table 2 and a is the last value of the response. Each individual contains five bits in the system and represents the chromosome. One of the important issues in GA is the bounds and listed in the Table below:

Table 1. Parameter bonds for GA.

Parameters	Lower	Upper
K_p	0,1	1,7
K_I	0,1	1,5
λ	0,3	0,9
K_D	0,1	0,7
μ	0,3	0,9

Population and sub population number of 50 and 10 individuals are selected respectively for GA. Mutation operator is %1. Weighted selection method is chosen for the paper. Crossing over dominant genotype the first chromosome of sub population between the dominant parameter of the last chromosome has an advantage of which eliminates unwanted individuals.

5. Simulation Results

The circuit parameters and semiconductor devices simulated in MATLAB (R2007b) are given in Table 2 and 3 respectively. The validation of the FOPID is achieved by comparing the THD value, efficiency and output voltage of inverter against the conventional PI results. It can be seen from the Table 2 that obtained THD value and efficiency are more valuable in FOPID results when it compared to the responses of PI for 1 kW load which equivalent to 40 Ω, while there is a slight difference for output voltage. For RLC loads FOC control has more stable results in comparison with PI. There is an apparent difference for THD values in PI, while they are approximately same for FOPID. PI control only gives best results for dynamic load, on the other hand FOC gives more efficiency. Because of high level currents effect of the circuit, the efficiency increases contrast to load.

Table 1. Circuit parameters and results..

DC supply		48 V							
Controller		PI				FOPID			
Load		40 Ω	RLC (1 kVA)	RLC (0,5 kVA)	Dynamic Load (0,9 kVA)	40 Ω	RLC (1 kVA)	RLC (0,5 kVA)	Dynamic Load (0,9 kVA)
Efficiency (%)		82	87	89	84	85,3	86,7	86,4	93,8
Output Voltage (V_{RMS})		218,4	220,4	226	221,8	216,9	216,9	217	214,4
THD (%)		5,5	4,8	11	4,75	4,05	5,03	5,18	6,75
L, C		9 µH, 28 µF							
PI / FOPID values	K_p	0,04				1,519			
	K_i	0				1,0698			
	K_d	1e-5				0,1937			
	λ	-				0,5794			
	µ	-				0,5635			

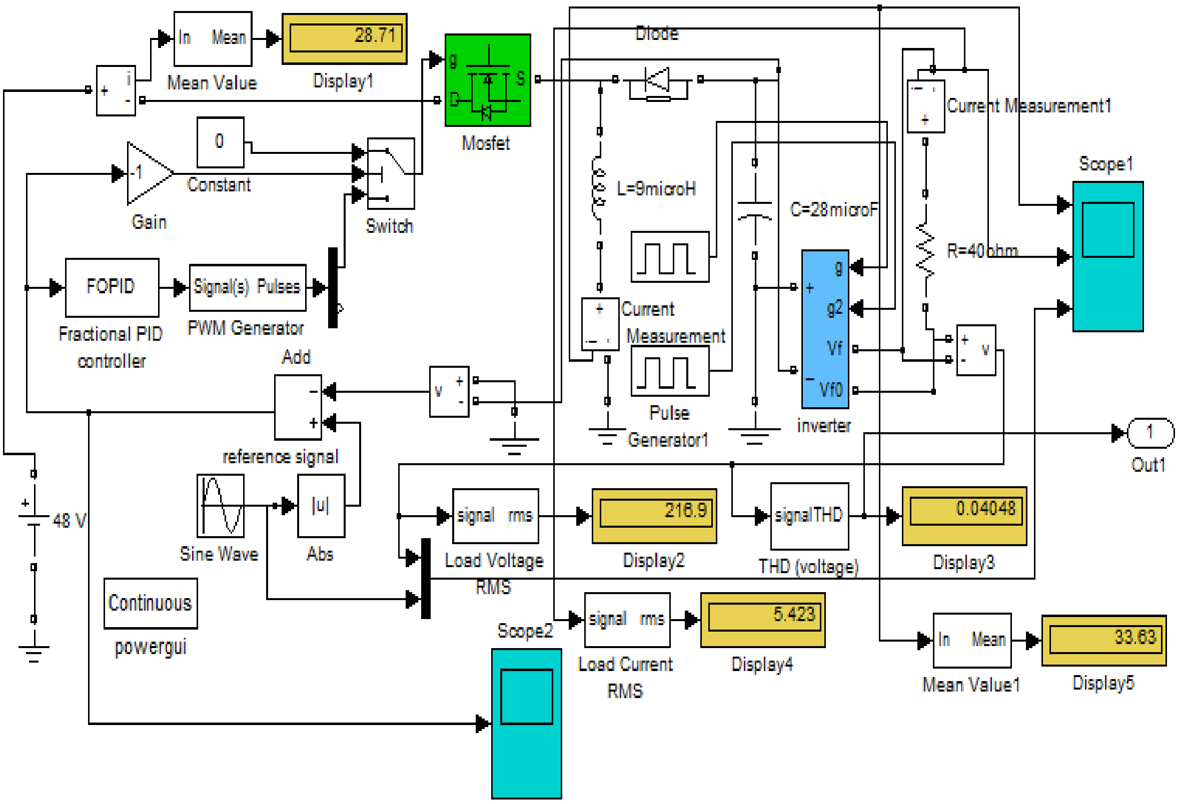


Figure 3. FOPID Buck-boost inverter SIMULINK block diagram.

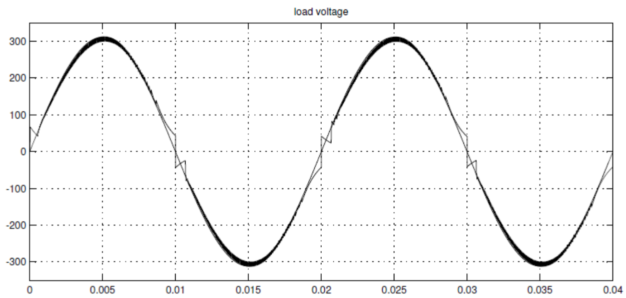
Table 1. Semiconductor specifications used in the simulation.

DC Source	48 V DC
Name of the device	AP80N30W-3
$V_{(BR)DSS}$ (volts)	300
$r_{DS(on)}$ (ohm)	0,066
I_{DSS} (amps)	88
P_D (miliwatts)	150000

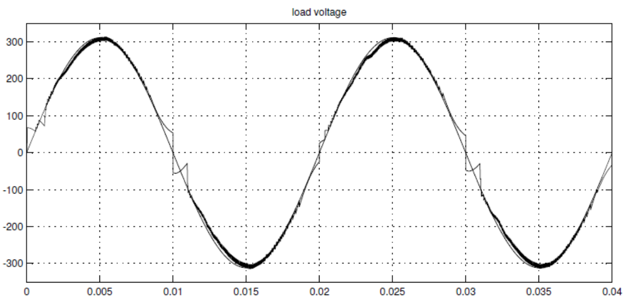
The Simulink diagram is shown in the Figure 3. The FOPID output voltages of the system are given in Figure 4 and 5 for various loads while PID results are shown in the previous study [1]. High dependency of load current causes distortion in output voltages regarding to decreasement of load values. It requires a current regulation especially in dynamic load for source side. Also it must be noted that a discharge problem occurs in zero crossings at some load levels as seen in the Figure 4. This problem causes a disturbance in the THD values. The simulation of dynamic load depends on the Eq. 11 with the parameters np = 1.3, nq = 2 and V_{min} = 0.7 pu. It can be seen that there is a transient state at first two cycles for both of two controller, but PI gives more performance after it. A circuit of damping is contributed with the system to prevent peak voltage values in short time ranges.

$$P = P_0\left(\frac{V}{V_0}\right)^{np}, Q = Q_0\left(\frac{Q}{Q_0}\right)^{nq} \qquad (11)$$

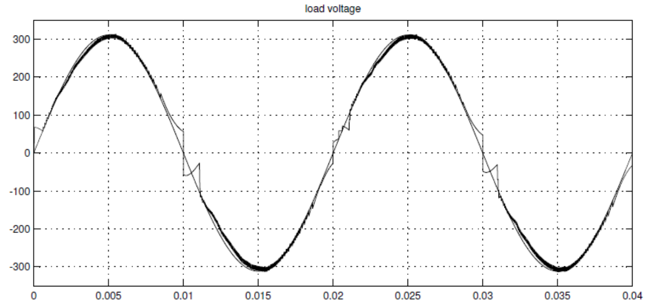
A considerable higher overall performance can be notice for FOC behind PI except dynamic load. Besides reader must be notice that THD values may be more important in some cases in inverter design.



a)

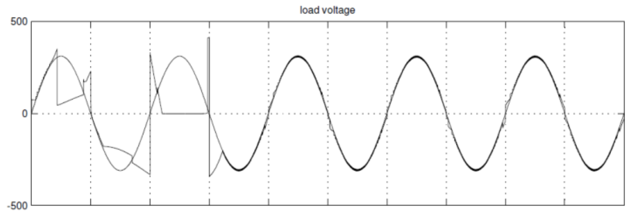


b)

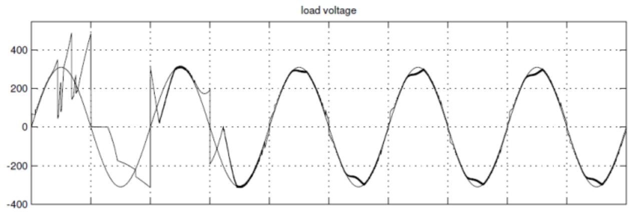


c)

Figure 4. The simulation results for FOPID of the system for various loads:
a) R (40 Ω), b) RLC (1kVA), c) RLC (0,5 kVA)



a)



b)

Figure 5. Simulations results for dynamic loads: a) PID, b) FOPID.

6. Conclusions

In this paper, two controllers are compared in a novel designed inverter [1] based on a well-known buck-boost regulator. The simulation results for alternative loads are also presented. The main goal of this design is to minimize switching complexity of conventional inverter and to obtain pure sinusoidal wave form without harmonic elimination methods. However the topology causes to highly distorted currents drawn from the DC source; application of single switching on the AC side reduces the complexity of the PWM technique. Besides, a switching frequency of 20 kHz causes to one of the main losses in the topology while no need to a transformer dominates the case. Since the circuit totally depends on how well the capacitor discharge is succeeded in zero cross points, the critical component is load current in this regulation. A considerable higher overall performance is obtained for FOC behind PI except dynamic load. However output voltages are slightly lower in FOC, THD values are more valuable which they are one of the major parameter in inverter design.

A dynamic FOPID / PID control should exactly give the best results for this system in the future. Another objective can be decrease the switching frequency of the DC side which will probably minimize the losses.

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