Design of PID Controller for Wind Power Converter with Aid of Soft Computing

Sattar Jaber Al-Isawi, Mohamed Ali Shatwan
Electromechanical Engineering Department, The College of Industrial Technology
Misurata, Libya
Shatwan57@yahoo.com

***Abstract*-The aim of this paper is to design a PID Controller for wind power converter by simulation system. The system consists of a three phase Permanent Magnet Synchronous Generators (PMSG) rotating by wind turbine system and connected with rectifier, chopper, single phase inverter and AC grid. PID controller is designed to control the modulation index (M) of the Sinusoidal Pulse Width Modulation (SPWM) of the inverter for the system. Where the inverter is single phase and driven by SPWM. The boost converter is implemented using a chopper with boost up configuration. To improve system damping over a wide range of operating conditions, it is desirable to adapt the parameters of each damping controller in the system by using soft computing. All currents, speed and DC link controller parameters which are designed and tested in MATLAB fits to the practical implementation values. This shows the assumptions and the approximations of the control loops are very close to the real system.**

Index Terms- PMSG , Wind Power, PID controller, SPWM, Converter, Genetic, neuro-fuzzy.

I. INTRODUCTION

The European Union has set a binding target of 20% of its energy supply to come from renewable resources by the year 2020[1]. The three phase permanent magnet synchronous generator with full scale converter arrangement has gained significant market share in wind energy turbine topology [2].

The development of power electronics devices and the advancement in DSP modules boomed the study and research on the multiphase machines. Multiphase machine drives has been used as in Electric Vehicles (EV), hybrid EV, aerospace, ship propulsion, and high-power applications in which the requirements are not cost oppressive when compared to the overall system [3]. Levi [4] did a thorough survey related to Multiphase drives in various subcategories including the application of Multiphase machines for power generation.

Multi phase PMSG for large power applications had not obtained much attention because of the high price and the lower quality of magnetic materials. It has now turned out with steady decrease in the price of the magnet and by the technology advancement which brings very high quality magnetic material.

In [5] parallel connection of converters to multiphase PMSG with a modular way was investigated to allow the use of classical converters. The control of multiphase PMSG for wind was also presented in [6] when the two set of three phase windings are controlled independently by using two independent converters.

II. TOPOLOGY AND PARAMETERS

The system under study consists of a permanent magnet generator, a two-level three phase active rectifier, boost converter, inverter controlled by SPWM and PID controller to keep the DC voltage across inverter at constant value, as shown in Fig(1).

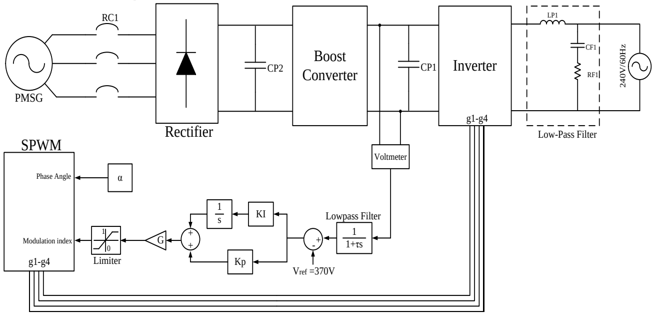

Figure 1. The system under study

III. DESIGN A PID CONTROLLER

The PID controller is the most common form of feedback. It was an essential element of early governors. PID controllers made today are based on microprocessors. This has given opportunities to provide additional features like automatic tuning, gain scheduling, and continuous adaptation. Designing and tuning a PID appears to be conceptually intuitive, but can be hard in practice. Fig.(2) shows block diagram of a PID controller.

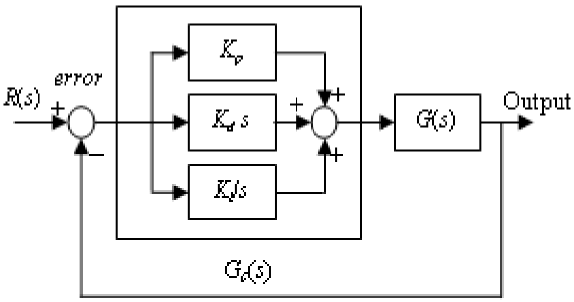

Figure 2. Block diagram of a PID controller.

The PID controller can be thought of as having a transfer function[7]:

$G_c(s) = K_p(T_i.T_d.s^2+T_is+1)/T_i.s$ ……………………….….(1)

Where: $T_i = K_p / K_i$ is the integral time constant, or 'reset time', $T_d = K_d / K_p$ is the derivative time constant.
The system under study shown in Fig(1) to keep the DC voltage across the capacitor (VCP1) at constant value of 370V, PID controller will be design for this purpose, this controller will control the modulation index (M) of the SPWM of the inverter, so by increasing the modulation index the DC voltage (VCP1) will decrease and vice versa. We will use low pass filter to filter the measured voltage (VCP1) this filter will prevent the harmonics that is existed in the DC voltage (VCP1) from moving to the output voltage of the inverter. In addition, limiter will be used to limit the output of the controller between 0 and 1; this will ensure that the output voltage of the inverter will change linearly with the input voltage. To get a stable and fast result, soft computing used to find the controller parameters[8].

IV. SOFT COMPUTING

It is now realized that complex real-world problems require intelligent systems that combine knowledge, techniques and methodologies from various sources. These intelligent systems are supposed to possess humanlike expertise within a specific domain, adapt themselves and learn to do better in changing environments, and explain how they make decisions or take actions. It is frequently advantageous to use several computing techniques synergistically rather than exclusively, resulting in construction of complementary hybrid intelligent systems. The quintessence of designing intelligent systems of this kind is neuro-fuzzy computing: neural networks that recognize patterns and adapt themselves to cope with changing environments; fuzzy inference systems that incorporate human knowledge and perform inference and decision making. The integration of these two complementary approaches, together with certain derivative-free optimization techniques, results in a novel discipline called neuro-fuzzy and soft computing [7].
Jang and Sun [9] introduced the adaptive Neuro-Fuzzy inference system (ANFIS). This system makes use of a hybrid learning rule to optimize the fuzzy system parameters of a first order Sugeno system. The ANFIS architecture consists of two training parameter set

1-The antecedent membership function parameters
2-The polynomial parameters [p, q, r]

In [7], The ANFIS training paradigm uses gradient descent algorithm to optimize the antecedent parameters and a least square algorithm to solve for the consequent parameters. Because it uses two very different algorithms to reduce the error, the training rule is called hybrid.

A. Genetic Algorithms

Genetic algorithms(GA) are derivative-free stochastic optimization method based on the concepts of natural selection and evolutionary processes. GA. Major components of GA include initial population, natural selection, mating, and the mutations and the characteristics of GA are:

1- Optimizes with continuous and discrete parameters.
2- Deals with a large number of parameters.
3- They can jump out of local minimum.
4- Simultaneously searches from a wide sampling of the fitness surface.

The flow chart in Fig.(3) provides an overview of a continuous GA[9].

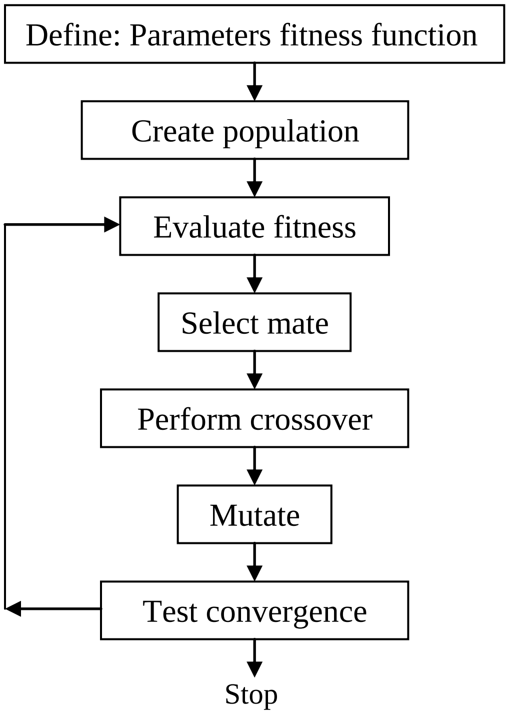

Figure 3. Flow chart of continuous GA

When the fitness function parameters are continuous, it is more logical to represent them by floating-point numbers. In addition, since the binary genetic algorithm has its precision limited by the binary representation of parameters, using real number instead easily allows representation to the machine precision. This continuous parameter genetic algorithm has the advantage of requiring less storage than the binary genetic algorithm. The other advantage is in the accurate representation of the continuous parameter, it follows that, representation of the fitness function is also more accurate.

The randomly selected initial population is sorted according to the fitness value. Selection is made randomly taking into consideration that the fittest individuals have the highest probability of being selected. If P1 and P2 are chosen to perform crossover, the resulting offspring according to the arithmetic crossover are[11]:

P`1 = r.P1 + (1-r).P2
P`2 = (1-r).P1 + r.P2

Where r is a random number between 0 and 1.

Mutation introduces new solution to the population for trial by producing spontaneous random change in various individuals. Non-uniform mutation is defined as follows, if an element Pk of a parent P is selected for mutation, the result would be:

$$P_k' = \begin{cases} P_k + (UB - P_k)\ f(gen) & if\ a\ random\ digit\ is\ 0 \\ P_k - (LB + P_k)\ f(gen) & if\ a\ random\ digit\ is\ 1 \end{cases}$$

Where UB and LB are the upper and lower bounds of the individual Pk respectively, gen is the current generation. The function f(gen) should return a value in the range [0,1] such that the probability of f(gen) being close to 0 increases as gen increases. This insures the operator to search the space uniformly initially and very locally at later generations. The following function can be used

$$f(gen) = (r.(1 - \frac{gen}{gen\max}))^b$$

Where r is a random number in the range [0,1], gen_{max} is the maximum number of generation, and b is called the shape parameter that determines the degree of non-uniformity[11].

B. Genetic controller for the System

The problem faced when designing the pole-placement damping controller for the converter is the location of the new mechanical modes. In previous analysis this location is choosed to insure good damping and not to affect the other modes, but there is no criteria to insure that the choosed location is the optimal solution. Genetic algorithm is used to tune the parameters of the PID damping controller to obtain the optimal damping ratio for the mechanical mode without affecting the others[7].

Genetic algorithm is used to tune the parameters of the PID controller previously designed by the pole-placement technique.
The fitness function of the genetic controller is to maximize damping ratio of the poorly damped modes,

$$fitnessfuction = Max(\sum_{i=1}^{n} \zeta_i)$$

Where n is the number of system modes that have a damping ratio less than 0.2 (A flow chart for the algorithm is obtaining the fitness function)[11].

With constraints:

1-Damping ratio for all modes is not less than 0.2.
2-The searching space of kp, ki and kd is between ± 5.

Floating point GA with maximum generation number of 200, population size of 20 and a shape parameter b = 3 is used. The solution converged after 120 generations to kp=-0.2421, kI = 4.4514and kd=-2.2421. System modes are shown in Table 1.

Table 1. System modes with genetic based PID damping controller

Mode	**λ**	**Damping Ratio**	**Frequency**
Exciter mode	-220.3	1	0
Electromechanical mode	-3 .35±16.45i	0.1996	2.6181
Converter controller mode	-2.69±13.17i	0.2	2.0961
Interaction mode	-0.49 ± 0.43i	0.7516	0.0684

The fitness function versus the generation number is shown in Fig(4). Because GA maximizes all system modes damping ratio not only the mechanical mode as pole-placement based damping controllers, system response with GA based damping controller is superior over that with pole-placement based damping controller.

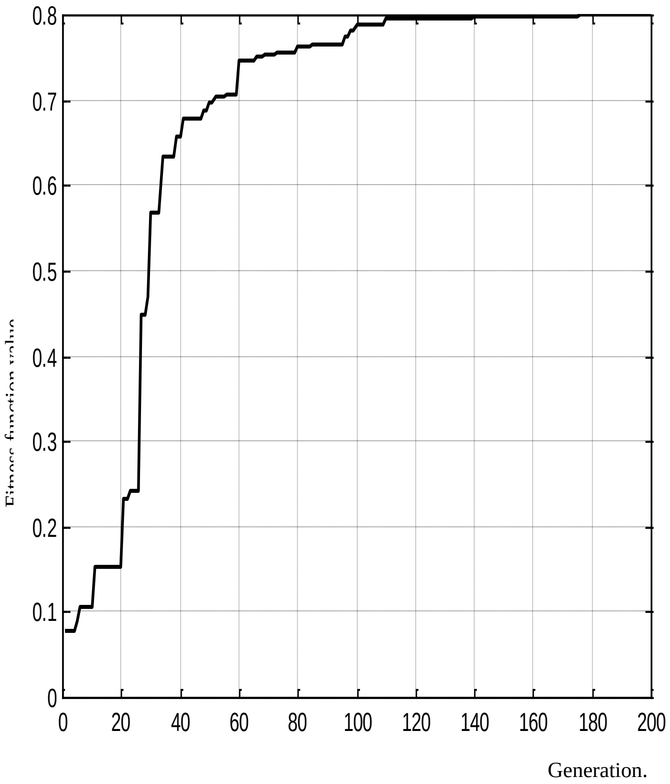

Figure 4. Variation of the fitness function

V. GENERATOR CIRCUIT

Assuming that the PMSG is cylindrical and connected Star to ground. The model of such machine can be considered as a voltage source connected in series with the inductance and resistance of the machine per phase. The following calculations are done based on the generator speed (n=135 rpm) to find the parameters of the generator model per phase[10]:

$$E_{L-L} = 1.217 * n = 1.217 * 135 = 164.295\, V$$

$$E_P = \frac{E_{L-L}}{\sqrt{3}} = \frac{164.295}{\sqrt{3}} = 94.86\, V$$

$$f = \frac{n * p}{120} = \frac{135 * 32}{120} = 36\, Hz$$

$$Ls = 0.3\, mH \quad , \quad Rs = 0.1\ \Omega$$

VI. RECTIFIER CIRCUIT

Six pulse rectifier will be used with ideal diodes. Also a capacitor (CP2) will be used to regulate the output voltage of the rectifier. The value of this capacitor is (1000µF).

VII. BOOST CONVERTER CIRCUIT

The boost converter can be implemented using a chopper with boost up configuration that has inductance (LP3=180 µH) and duty cycle of (0.5). The output voltage can be regulated using a capacitor (CP1=2000µF) [11].

VIII. THE INVERTER CIRCUIT

This inverter is single phase and driven by SPWM. The switches are ideal switches. The voltage reference of PWM has phase angle 2.30 in order to ensure a unity power factor at the output side of the inverter, and controlled modulation index to ensure that the DC voltage across the capacitor CP1 at value of 370v [10]. The purpose of the filter is to eliminate all the high order harmonics that presents in the output voltage of the inverter. So this filter is low pass filter with (LF=0.8mH, RF=0.5Ω and CF=10 µF).

IX. THE GRID CIRCUIT

If The grid can be modeled as an ideal voltage source with Vrms=240v and f=60Hz. Using the circuits parameters and elements in previous section we can draw the power circuit shown in fig(5).

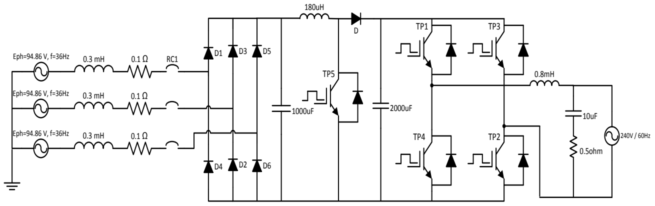

Figure 5. Power circuit of the simulation program

X. RESULTS

Using the designed simulation program with appropriate measurement devices and scope, we can obtain the needed waveforms that can be useful for our study. To see whether the controller is working as it should be or not, fig(6) shows the mean value of boost voltage (VCP1).

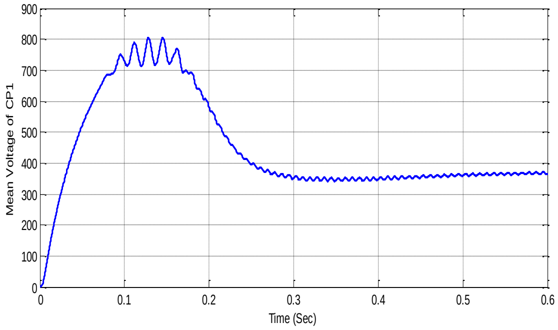

Figure 6. The changing of boost voltage mean value.

Fig(7) shows the mean value of boost voltage (VCP1) has to be at value of 370V at the steady-state.

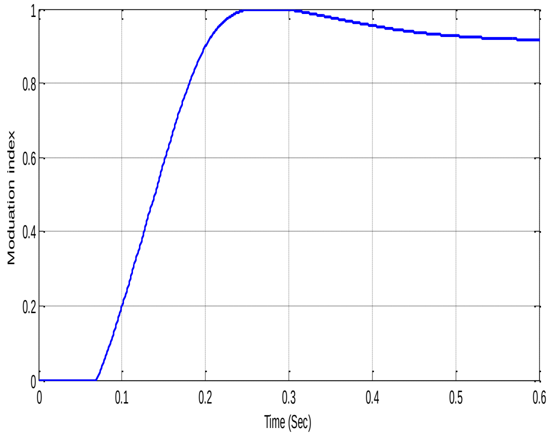

Figure 7. The changing of modulation index with time

From fig(7) we find that at the beginning the PID controller set the modulation index at zero because the boost voltage is less that 370V, and when the voltage exceeds 370V the PID controller starts to maintain the voltage to be equal to 370V. Also we note that the controller has quite slow response due to the time delay caused by the low pass filter and the controller itself.

Fig(8) shows the transient and steady-state waveforms of the generator line-line voltage and line current.

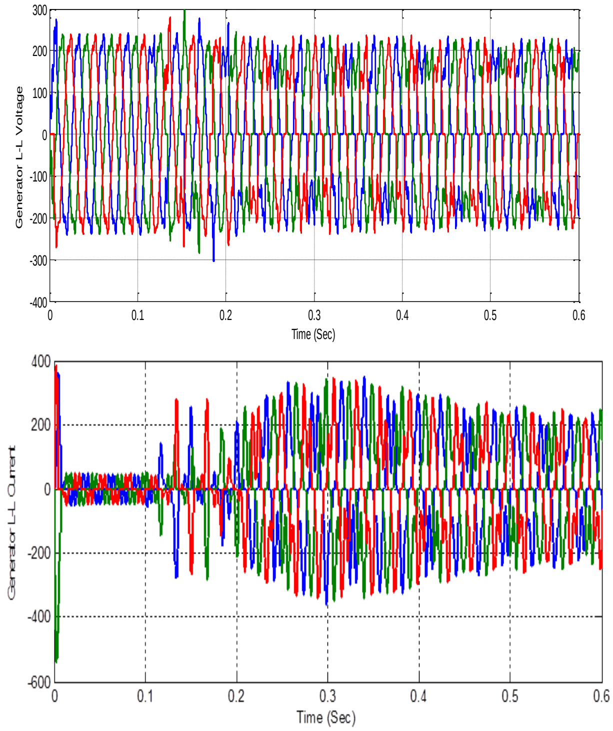

Figure 8. The transient and steady-state waveforms of the generator line-line voltage and line current

In this figures , we note that the current and the voltage waveforms have non-sinusoidal waveform due to the nonlinear load which cause to generate harmonics that distort the current and the voltage waveforms, In addition, we note that at the first half cycle there is a high pulsation current flowing in the generator even though the modulation index of the inverter is zero (open circuit), this current is charging current for the capacitors (CP1, CP2). After the first half cycle there is also a small current still flowing in the generator even though the modulation index of the inverter is zero (open circuit), this current due to the ripples that exist in the DC voltage (Vac) this voltage will cause an AC current flowing through the capacitors (CP1, CP2).

In the fig(9), we note that at the very beginning the output voltage of the inverter is zero because there are no switching pulses and the inverter is working as rectifier by its diodes that is why we find a negative current pulses at the beginning as well.

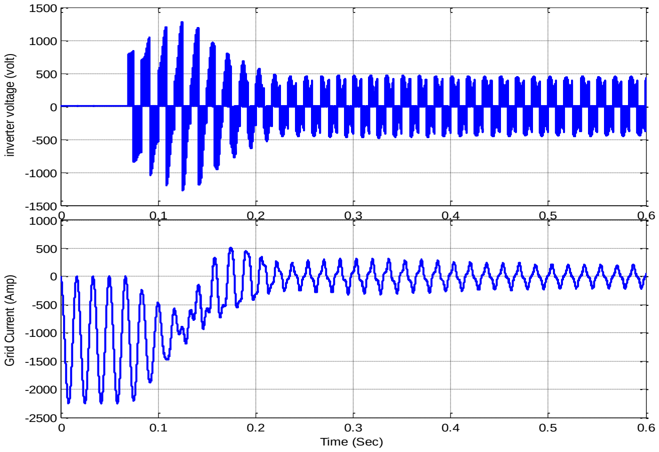

Figure 9. The transient waveforms of the inverter output voltage and the grid current.

In the fig(10), we find the current waveform of the grid has distorted by the harmonics especially the third harmonic, this harmonic moved from the boost voltage to

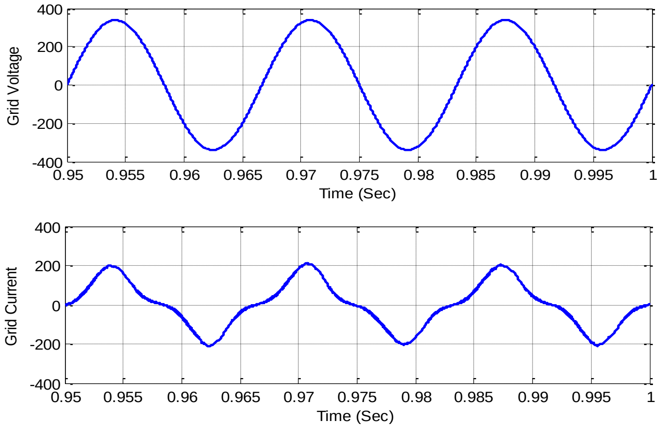

Figure 10. The voltage and current of the grid

The output voltage of the inverter and the output filter of the inverter is designed to eliminate the high order harmonics that generated at frequency of (2*fc = 20kHz). This harmonic has not been generated by the rectifier or the chopper but it has been generated by the inverter itself, the inverter works as rectifier for the grid voltage, so the voltage across the capacitor CP1 is due two sources, one of them is the boost voltage of the chopper, and the second is the rectified voltage of the grid, and because the inverter is single phase so the largest harmonic in this voltage will be the third harmonic. Table 2. shows the characteristics values of grid current responses with and without soft computing.

Table 2. Comparison of Output Response of grid current

characteristics	System without controller	System with PID controller	System with controller and soft computing
RISING TIME (tr) Sec	0.14	0.11	0.04
PEAK TIME (Sec)	0.32	0.28	0.19
SETTLING TIME(Sec)	1.6	0.72	0.31
OVERSHOOT (%)	3.2	1.62	0.91

Table 3. shows the characteristics values of grid voltage responses with and without soft computing.

Table 3. Comparison of Output Response of grid voltage

characteristics	System without controller	System with PID controller	System with controller and soft computing
RISING TIME (Sec)	0.12	0.09	0.03
PEAK TIME (Sec)	0.29	0.22	0.11
SETTLING TIME(Sec)	1.2	0.57	0.30
OVERSHOOT (%)	2.4	1.35	0.81

Table 2 shows a Comparing of Output Response of output grid current and voltage, the system has the best performance among the controllers with soft computing. In fact, all the characteristics have fulfilled the design criteria that were initially fixed.

XI. CONCLUSIONS

From the early results and analysis , it can be concluded that the PID conventional controller are capable of controlling the system under study. By using the designed simulation program with appropriate measurement devices and scope, we could obtain the needed waveforms that can be useful for our study. the system has the best performance among the controllers with soft computing. The algorithm in the laboratory and test the correct is necessary to test the theoretical performance by using the simulations. The mathematical model of the PMSM was tested in simulations, and then Field Oriented Control strategy with the sensor was implemented. In order to achieve a stable system the PID controllers have to be tuned properly. For the PID current controller the optimal criterion for adjusting the gains is the magnitude optimum while for the speed controller is symmetry optimum. Finally the entire model was tested in Matlab/Simulink and results were presented. For different test conditions the model shows good performance. Damping controllers' gains can be determined by the soft computing, which makes the proposed stabilizer relatively simple and suitable for practical on-line implementation.

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