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Reduction of Asynchronous Motor Loss by Heuristic Methods (PSO-GA)

M. Dogan, M. Dursun
Department of Electrical Education, Duzce University,
Duzce, Turkey, phone: +90 380 542 1133, e-mail: metindogan@duzce.edu.tr

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Introduction

The Electric Power Quality is of great interest to the researchers, producer and consumers of electrical energy, due to the increasing electric pollution caused by the proliferation of non-linear loads. Theses loads are considered to be the main harmonics pollution source in power distribution lines; hence the electrical power network is deeply infected causing voltage disturbances which can not be tolerated by sensitive electronics equipments. The recent developments in the field of power electronics devices make the improvement of the electrical power system utility interface possible [1].

In modern electrical distribution systems, there has been a remarkable growth in the use of nonlinear loads, such as rectifiers, converters, adjustable speed drives, arc furnaces, computer power supplies, etc. Nonlinear loads act as current sources injecting harmonic currents into the power systems. These power-electronic-based loads have caused severely distorted voltage waveforms at the point of common coupling (PCC). Other linear loads connected at the same PCC will receive a distorted supply voltage, which may lead to various unwanted effects. The overheating of motors, transformers, cables, maloperation of some protection devices, and resonance with capacitors are some of these effects [2, 3].

Induction motor for many years has been regarded as the workhorse in industrial applications. In the last few decades, the induction motor has evolved from being a constant speed motor to a variable speed, variable torque machine. Its evolution was challenged by the easiness of controlling a DC motor at low power applications. When applications required large amounts of power and torque, the induction motor became more efficient to use. With the invention of variable voltage, variable frequency drives (VVVF), the use of an induction motor has increased. Most modern variable frequency drives operate by converting a three-phase voltage source to DC using rectifier. After the power flows through the rectifiers it is stored on a dc bus. The dc bus contains capacitors to accept power from the rectifier, stores it, and later deliver that power through the inverter section. The inverter contains transistors that deliver power to the motor. The “Insulated Gate Bipolar Transistor” (IGBT) is a common choice in modern VFDs. The IGBT can switch on and off several thousand times per second and precisely control the power delivered to the motor. The IGBT uses “pulse width modulation” (PWM) technique to simulate a sine wave current at the desired frequency to the motor [4].

Harmonic analysis of SPMW consists of the main component with $Ma*Vdc/2$ (Ma: Modulation index) amplitude in the output frequency and components with wide amplitude in switching frequency. When symmetrical regular sampling and asymmetrical regular sampling is compared in the harmonic analysis results, we can say that asymmetrical regular sampling is a better representative of natural sampling [5]. Reduction of switching frequency or the rotor speed referencing causes the increase in the harmonics seen on welding currents. Also, it is seen that when selecting IGBT against sudden voltage increase or decrease in high collector emitter voltage values, collector emitter voltage parameters should be sufficiently high in the selection [6].

Harmonics seen in inverters

It is well-known that voltage and current harmonics in the power system can come from a number of sources in the network.

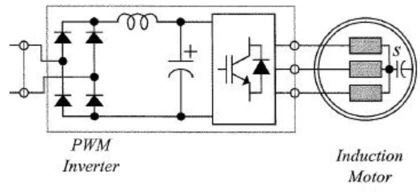

Fig. 1. Motor fed by inverter

Theoretically, any nonsinusoidal periodical waveform can be transformed into a different order harmonic waveform through Fourier analysis. Therefore, the nonsinusoidal voltage and current waveform can be expressed as:

$$v(t)=\sqrt{2}\left[V_1 \sin \omega_0 t+\sum_{k=2}^{\infty} V_k \sin(k\omega_0 t+\phi_k)\right], \quad (1)$$

$$i(t)=\sqrt{2}\left[I_1 \sin \omega_0 t+\sum_{k=2}^{\infty} I_k \sin(k\omega_0 t+\phi_k)\right], \quad (2)$$

where V_1, I_1 are the fundamental voltage and current, V_k, I_k are the k^{th} order harmonic voltage and current, ϕ_k, θ_k are the phase angles of the k^{th} order harmonic voltage and current, ω_0 is the radian frequency of the fundamental wave.

When a nonsinusoidal voltage source is supplied to a three-phase induction motor, the corresponding slip S_k to the various harmonics can be expressed as [7]

$$S_k=\frac{kN_t+(1-s)N_s}{kN_s}=\frac{k+(1-s)}{k} \quad (3)$$

The effect of harmonics on motor performance

The rice of iron and copper losses are the big problems in synchronous motors. Inverters produce harmonics and they need to be optimized. Angles obtained by GA were applied to the system so that the output voltage is higher, less current is needed for the power source which makes it possible to select lower current values for switching elements and to reduce switching losses [8]. The most important effect of harmonic voltage and currents is the increase in the rotating motor temperature by the increase in the iron and copper loss in the harmonics frequency. Hence harmonic components cause the decrease in the efficiency in the rotating motors and the moment and get the motor work more noisily compared to sinusoidal supplied motors. At the same time, due to the induction motors' production of a resultant voltage in the air gap, situations such as failure in motor start up and providing synchronous are possible.

Extreme temperatures in the rotors of electric motors are one of the most important problems in voltage distortions caused by harmonics. The losses in electric motors are related to the frequency of the applied voltage. The fact that motor temperatures rise due to harmonics reduce the life of the motor, a case which affects the single phase motors the most. Harmonic components reduce motor performance by 5-10%.

Each harmonics voltage (5,, 7., 11, ...) inducts a harmonic current in the stator of the motor and creates additional temperatures in the stator windings. Hence, the additions at the level of temperatures caused by main current component will increase the temperature of the motor [9].

The dynamic equations of induction machine can be written as [5]

$$V_i=RI_i+\frac{d\lambda_i}{dt}, \quad i=a,b,c. \quad (4)$$

In this equation V and I are voltage and currents of the 3 phase stator windings respectively. R and i are the matrices of the stator winding resistance and phase flux linkages. In normal condition motor was supplied by its rated voltage which is 170 volts peak for each phase. The voltages applied are as follows [10, 11]:

$$\begin{cases} Va1(t)=170\cos(2\pi 60t), \\ Vb1(t)=170\cos(2\pi 60t+240), \\ Vc1(t)=170\cos(2\pi 60t+120). \end{cases} \quad (5)$$

As the harmonics in the voltage source can cause excessive losses, extra noise and pulsating torque detecting harmonics in the voltage applied is important. In the case of unbalanced voltages the efficiency and average output torque of the motor would decrease and the ripple would increase significantly destructing the motor application. In case of an unbalanced voltage with harmonics these quantities still work properly towards detection purpose [11].

By overcoming all these problems, we will be able to reduce the iron and copper losses in the asynchronous motors, reduce the noise and increase moment gradients, performance and life of motors.

Particle swarm optimization

Kennedy and Eberhart developed PSO through simulation of bird flocking in a two-dimensional space. The position of each agent is represented by its x, y axis position and also its velocity is expressed by vx (the velocity of x axis) and vy (the velocity of y axis). Modification of the agent position is realized by the position and velocity information.

Bird flocking optimizes a certain objective function. Each agent knows its best value so far (*pbest*) and its x, y position. This information is an analogy of the personal experiences of each agent. Moreover, each agent knows the best value so far in the group (*gbest*) among pbests. This information is an analogy of the knowledge of how the other agents around them have performed. Each agent tries to modify its position using the following information:

- The current positions (x, y);
- The current velocities (vx, vy);
- The distance between the current position and pbest;
- The distance between the current position and gbest.

This modification can be represented by the concept of velocity (modified value for the current positions). Velocity of each agent can be modified by the following equation

$$V_i^{k+1}=wv_i^k+c_1 rand_1\times\left(pbest_i-s_i^k\right)+ \\ +c_2 rand_2\times\left(gbest-s_i^k\right), \quad (6)$$

where V_i^k is velocity of agent i at iteration k, w is weighting function, c_1 is weighting coefficients, rand is random number between 0 and 1, s_i^k is current position of agent i at iteration k, $pbest_i$ is $pbest$ of agent i, and $gbest$ is $gbest$ of the group.

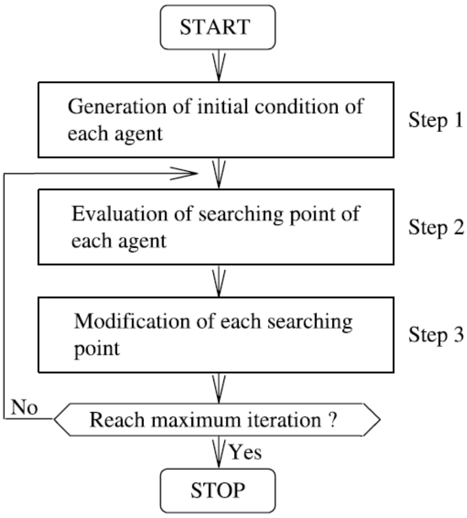

Fig. 2. A general flowchart of PSO

Fig. 2 shows the general flowchart of PSO [12].

A simple genetic algorithm

Given a clearly defined problem to be solved and a bit string representation for candidate solutions, a simple GA works as follows:

1. Start with a randomly generated population of n l–bit chromosomes (candidate solutions to a problem);
2. Calculate the fitness $f(x)$ of each chromosome x in the population;
3. Repeat the following steps until n offspring have been created:
   a. select a pair of parent chromosomes from the current population, the probability of selection being an increasing function of fitness. Selection is done "with replacement," meaning that the same chromosome can be selected more than once to become a parent,
   b. with probability pc (the "crossover probability" or "crossover rate"), cross over the pair at a randomly chosen point (chosen with uniform probability) to form two offspring. If no crossover takes place, form two offspring that are exact copies of their respective parents. (Note that here the crossover rate is defined to be the probability that two parents will cross over in a single point. There are also "multi–point crossover" versions of the GA in which the crossover rate for a pair of parents is the number of points at which a crossover takes place.),
   c. mutate the two offspring at each locus with probability pm (the mutation probability or mutation rate), and place the resulting chromosomes in the new population. If n is odd, one new population member can be discarded at random.
4. Replace the current population with the new population;
5. Go to step 2.

The simple procedure just described is the basis for most applications of GAs. There are a number of details to fill in, such as the size of the population and the probabilities of crossover and mutation, and the success of the algorithm often depends greatly on these details. There are also more complicated versions of GAs [13].

Modulation index

The output voltage is independent of the output load current since one of the two switches in a leg is always on at any instant. Therefore, the inverter output voltage is independent of the direction of the load current.

The objective in pulse-width-modulated three-phase inverters is to shape and control the three-phase output voltages in magnitude and frequency with an essentially constant input voltage V_d .

In the three-phase inverters, only the harmonics in the line-to-line voltages are of Concern. Where only the odd harmonics exist as sidebands, centered around mf and its multiples, provided mf is odd. The harmonic at mf is suppressed in the line-to-line voltage V_{AB} . The same argument applies in the suppression of harmonics at the odd multiples of mf if mf is chosen to be an odd multiple of 3 (where the reason for choosing mf to be an odd multiple of 3 is to keep mf odd and, hence, eliminate even harmonics). Thus, some of the dominant harmonics in the one-leg inverter can be eliminated from the line-to-line voltage of a three-phase inverter.

PWM considerations are summarized as follows:

1. The frequency of the triangular waveform is kept constant, whereas the frequency of Vcontrol varies, resulting in noninteger values of mf (so long as they are large);
2. For low values of mf to eliminate the even harmonics, a synchronized PWM should be used and mf should be an odd integer. Moreover, mf should be a multiple of 3 to cancel out the most dominant harmonics in the line-to-line voltage;
3. During overmodulation (ma>1.0), regardless of the value of mf, the conditions pertinent to a small mf should be observed [14].

Application of modern heuristic optimization techniques

The program based on modern heuristic optimization techniques works as follows:

1. The values and data for the following are entered: harmonics number that will be eliminated, number of population, the number of maximum generations, whether the harmonics with a value of 3 and its multiplications will be eliminated, how many more angles is required from the harmonics number that will be eliminated in order to be able to make the elimination, harmonics coefficient starting from the third harmonics, and how many harmonics want to be seen as graphics and values;

2. Separate numbers that match the number of population for the initial generation are produced randomly. These random angular values produced separately for each population are placed in the equation (7) and harmonics are calculated. Suitability and average suitability is calculated. Scaled suitability values and the copy numbers according to these values are calculated. The angular values in the initial generation are calculated according to a specific rule;

3. If the generation number is smaller than the maximum generation number it is increased one point. New harmonics and new suitability values are calculated according to these new values;

4. The population angles with the biggest suitability value are selected by comparing the previous calculations with the suitability of each population separately that are calculated as a result of crossover. Suitability averages of these populations are calculated. If the resulting suitability average is smaller or equal to the previous suitability average (if the crossover has not been successful) mutation process is started. One bite of the randomly selected last angles is mutated and new angles are created. New suitability values are calculated according to the new angles formed as a result of the mutation. If these new suitability values are bigger than the previous suitability values, the angles of each large suitability value to their populations are selected;

5. If the number of generation is bigger than the maximum generation number angles with the biggest suitability values are selected in all generations. The number of harmonics that are required to be obtained according to these angles are calculated and the amplitude spectrum is drawn [15]. In the program it is also possible to include harmonics that will be repressed. By choosing these weights, each harmonics can be repressed in the desired degree or can be kept at the desired level.

Simulation and optimization results were obtained in a computer with Intel Core2 Duo CPU E7400, 2.80GHz, 2.0GB RAM, Intel G41 Express Chipset features by using the motor parameters in Table 1 and GA, PSO optimization parameters in Table 2.

For objective function, equation number 7 which was inspired from Fourier Series was used

$$OF = \frac{f_0}{\sum_{j=1}^{n} f_1 + \varepsilon}. \tag{7}$$

Table. 1. Asynchronous machine parameters

Parameter	Value
Nominal power	180 VA
Voltage (line-line)	220 Vrms
Frequency	50 Hz
Stator resistance and Inductance	11.05 Ohm, 0.0224 H
Rotor resistance and Inductance	6.11 Ohm, 0.224 H
Pole pairs	2

Table. 2. Optimization parameters

Parameter	GA	PSO
Execution	200	200
Individual	100	100
Generation	1000	1000
Mutation rate	0.1	--
Encoding type	real	real

Simulink model

A three-phase squirrel-cage motor rated 3 HP, 220 V, 60 Hz, 1725 rpm is fed by a 3-phase IGBT inverter connected to a DC voltage source of 325 V. The 3-phase voltage between 120 ° phase difference was made with Simulink F(u) blocks to achieve the 3-phase voltage in the model. After more the three-phase switching signals produced by comparing high-frequency triangle wave, 120 ° phase different from each other with 3-phase sinusoidal signals and switched IGBTs. Controlled sinusoidal PWM obtained from inverter output was applied to the 3-phase asynchronous motor.

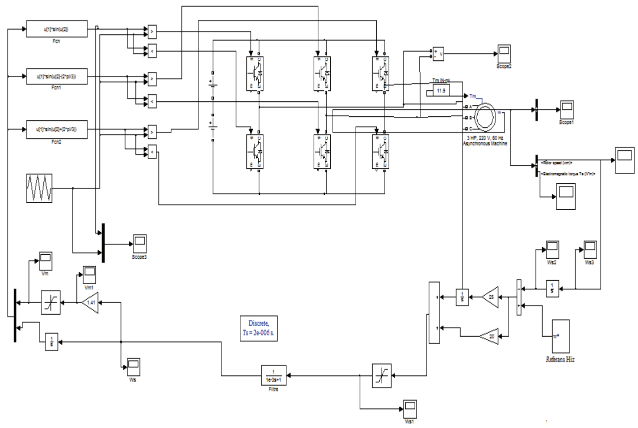

Fig. 3. Newly created simulink model

In the new model created in Matlab/Simulink environment parameters in the input and output of the asynchronous motor are calculated. Also, IGBTs are induced by the produced induction angles.

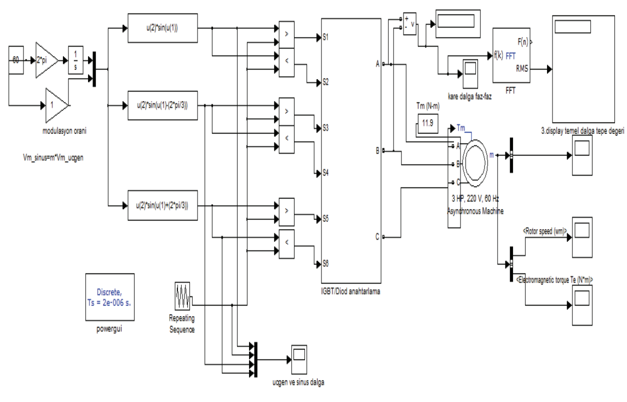

Fig. 4. Modulation index model

SPWM and modulation index was obtained in this model in a manner to support the first model.

Application of data

As can be seen from Fig. 5, measurement such as rotor speed was balanced in a 0.16 seconds. As can be seen from Fig. 6, measurement such as electromagnetic torque 0.2 was balanced in 0.19 seconds.

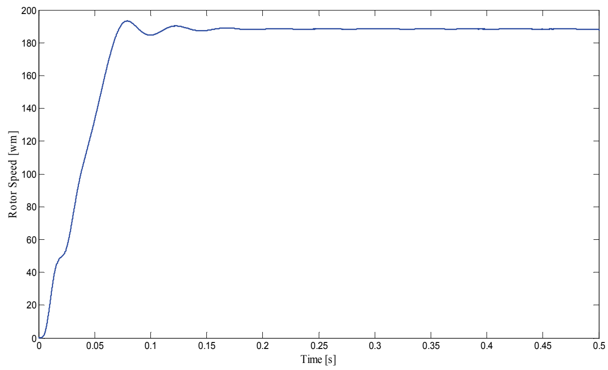

Fig. 5. System response of rotor speed

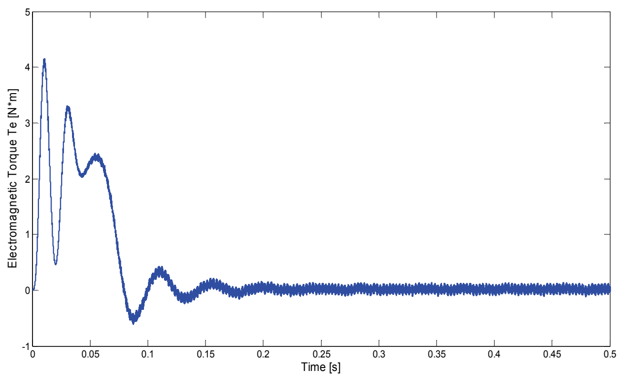

Fig. 6. System response of electromagnetic torque

According to Heuristic Methods' Optimization results, the best objection value obtained was shorter in duration and closer to the desired minimum in PSO compared to GA.

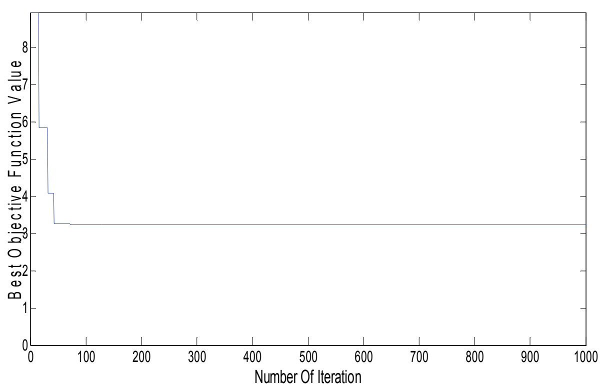

Fig. 7. Optimization with genetic algorithm

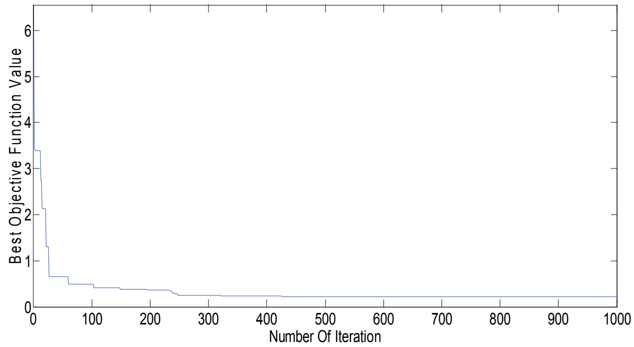

Fig. 8. Optimization with particle swarm optimization

When we look at Fig. 7 and Fig. 8, we can see that particle swarm optimization is more conducive in comparison to genetic algorithm, because during the optimization of genetic algorithm, the best objection value can be decreased up to a point as 3.2 while we can see that this value is 0.21 point during the optimization with particle swarm optimization.

Conclusions

The study identified the voltage harmonics and the rates of distortion. Induction angle values of IGBTs which are the key elements of invertors that feed the motor were optimized. The obtained angle values were fed to the system again to generate new harmonics values.

As can be seen from the figures, measurements such as rotor speed 0.16 and electromagnetic torque 0.2 were balanced in a short time. According to Genetic Algorithm and Particle Swarm Optimization results, the best objection value obtained was 14 times shorter in duration and closer to the desired minimum in PSO compared to GA. These values are highly below the values limited by IEEE and IEC standards.

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The purpose of this article is to compensate the loss of performance caused by asynchronous motor feed. It was aimed to increase inverter output quality in order to reduce voltage instability at the current output and to minimize the harmonics of the inverters used to feed the motor. Many studies have made use of various algorithms to realize the aim mentioned in the article. Particle Swarm Optimization and Genetic Algorithm methods of optimization were used in this article to increase the current output quality, to minimize harmonics and to increase motor performance. Ill. 8, bibl. 15, tabl. 2 (in English; abstracts in English and Lithuanian).

M. Dogan, M. Dursun. Asinchroninio variklio nuostolių sumažinimas euristiniais metodais // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 1(117). – P. 53–58.

Šio darbo tikslas – kompensuoti našumo praradimą dėl asinchroninio variklio maitinimo. Buvo numatyta pagerinti inverterio išėjimo kokybę, siekiant sumažinti įtampos nestabilumą išėjime ir minimizuoti inverterių, naudojamų varikliui maitinti, harmonikas. Dalelių spiečiaus optimizavimo ir genetinio algoritmo metodai buvo taikomi srovės išėjimo kokybei pagerinti, harmonikoms minimizuoti ir variklio našumui padidinti. Il. 8, bibl. 15, lent. 2 (anglų kalba; santraukos anglų ir lietuvių k.).