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Intelligent Monitoring for DC Motor Performance Based on FPGA

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ABSTRACT

This paper presents a fault monitoring of DC motors. A neural network is prepared to processes the inputs parameters “motor speed and current” collected from sensors and delivers condition states of the DC motors “good, fair or bad”. FPGA Spartan 3 kit board is used to implement the proposed monitoring network and the circuits are designed for data acquisition to makes an interface between motors analog collected data and FPGAs digitals inputs ports. The designed circuits are intended to gather analogs readings from the target motor and converting them into digitals to be compatibles with FPGAs inputs ports specifications. The neural networks which are designed based on backs propagation trainings are implemented using Xilinx Spartan-3A Starter FPGAs Kits boards.

Keywords: Conditions Monitoring, Fault Detection, FPGA, Artificial Intelligence, Neural Network.

INTRODUCTION

By allowing the earlier detections of extremely harmful faults, condition monitoring of electric equipment can significantly reduce the costs of maintenance and danger of unexpected failures. In condition based maintenance , operator does not plan maintenance or machine replacement based on statistical evaluation or past records of machine failure . Condition monitoring means using estimations taken while a machine is working, to determine the possibility of fault existence. On the other hand, one depends on the data provided by condition monitoring systems assessing the machine's status condition . Therefore, the best way for the condition based maintenance success is having an accurate means of condition assessment and fault analysis.

Soft-computing is a rising approximation to computing, which simulates the noticeable capacity of the human brain to learn and reason in situations of imprecision and uncertainty. It is, generally, a computing tools collection and procedures, shared by closely related learning rules that involve genetic algorithms, belief calculus, fuzzy logic, artificial neural networks, and some aspects of machines learning like inductive logics programming. These algorithms are utilized independently as well as mutually depending on the types of the areas of applications [12]. Great developments have been made in this area of studies in the last years. Therefore, the researchers have been interested on making advantage from this technique in the field of fault detection and diagnosis. **Nawal A. Hussein, 2010,** presented the diagnoses of different faults of certain three phase's inductions motors using Motors Currents Signatures Analysis (M.C.S.A) techniques based on neural networks technique [1]. **P. Dobra, et. al., 2011**, introduced a structure of a method for fault detection and diagnosis based on continuous time parameter estimation of a mathematical model of the DC. This work has a limitation of complex mathematical models that prevent of using this design for real time processing [2]. **Ali H. Majeed, 2012,** proposed two algorithms for fault detection and isolation in sensor based method, first neural network trained by particle swarm optimization and second adaptive neuro-

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fuzzy inference system, to improve the performance of the artificial neural network [3].

Theoretical Foundations

Fault Detection

Figure 1 shows a block-diagram of the general approach [4]. Fault detections, locations and diagnosis are fundamental to the safety and effective industrial systems operation. There is much work to devise appropriate techniques to predict the fault before major losses occurs [5].

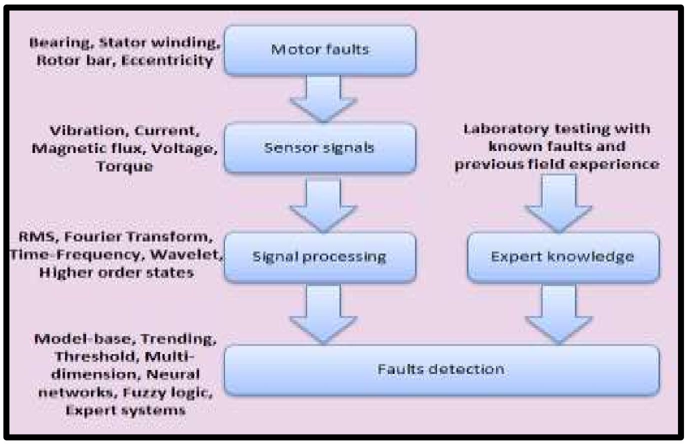


Figure (1). General structure of condition monitoring process

A fault is an unexpected change in a system or an unexpected deviation in conditions of operation that leads to decays the entire performance of the system. Fault may happen in the controls systems, actuators, components of the processes or sensors for the closed loop process. Some common modes of failure could be like failure in signal transmissions between the sensors, actuators and the data processors, faults in the procedure of data processing and errors in the A/D and D/A converters [6].

Problems of fault detection and isolation are important and critical issues for reliability, safety and performance of industrial processes. If an error occurs in the system could lead to severe economic damage, and thus reduce the overall performance, and in the worst cases, to serious risks for operators [6, 7].

In the other hand, failure is an event that causes a permanent interrupt of a functional unit's ability to execute a required operation under specific operating conditions. It results from one or more faults [8].

Faults of DC Motors

In this paper DC motor has been used to detection of faults. Faults might appear in the functioning of DC machines with permanent magnets both when starting operation and after a long times of working [9].

Faults could be mechanic or electrics, as illustrated in Table 1.

Table (1). DC motor faults

Electric Faults	Mechanic Faults
sparks at the collector	bearing support heating
Overheating	machine vibrations
Abnormal starting	
Abnormal speed	

For electric faults, it can be said, the sparks of commutator are too common. They appear because of commutation poles', wrong positioning for brushes or overloading.

The electric motors overheating is due to overvoltage or a wrong progression of the poles . Sometimes, the overheating could be attended with sparks of commutator or a higher than rated speed , or even not rotating the motor . By using a sensor for temperatures the machine temperature can be measured .

After the machine has started correctly, the abnormal speed appears. This fault could occur because of poles wrong placement on the collector , they may be outside of its neutral area . On the other hand the speed could be unstable because the brushes is behind their neutral axis .

It can be said for mechanical defects that the other type of faults can be the permanent magnet displacement in its frame . This fault could be possible in the process of manufacturing or during motor running. The machine vibrations and noises are measured in order to detect permanent magnet DC motors faults.

Field Programmable Gate Array (FPGA)

Programmable logic device (PLDs): A PLD is an integrated circuits with logics gates inside and connected through electronics path that act like fuses. When the devices is programed, those fuses will be blown along the paths that should be removed in order to get the specific arrangement of the desired logic behavior [10].

FPGAs introduced as a development of PLDs and also as simple 'glue logic' technology, giving programmable connectivity between significant components where the programmability was based on anti-fuse, Electrically Programmable Read Only Memory (**EPROM**) or Static Random Access Memory (**SRAM**) technologies [6, 11].

This methodology permits errors in design which had only been perceived at this development's late stage to be corrected, by only reprogramming the FPGA. Thereby, permitting the components interconnectivity to be changed as needed. While this new technology produced extra delays due to the software interconnect, it eliminates a time-consuming and expensive board redesigning and impressively reduced the risks in design sequences.

As theirs name demonstrate, FPGAs offers the notable advantage of being# readily programmable. They don't like the forbearers in the PLD classification; FPGAs can be programmed many times with no limit, giving designers more opportunities to modify the designs.

Artificial Neural Network ANN

The neural networks most important features are its learning, to association, and to be error tolerant abilities. Unlike traditional techniques for problem solving, neural-networks can learn to do a special task. This can be performed by presenting the system with a representative examples sets that describe the problem, in another word, samples of input and output pairs; the neural-network will then predict the mapping between input and output data. After training, the neural-network can be used to perceive information likes any of the examples demonstrated during the learning process [12].

The neural-network can even distinguish data which are uncompleted or noisy, and also it can detect an important feature that is frequently used for diagnosis, control or prediction purposes. Besides, neural-networks have the power of self-organize, therefore coarse coding or enabling segmentation of data.

Simulation results

The monitoring Neural Network is receiving digital readings (speed and armature current) in digital form and processes this data to decide the condition of the motor in use.

First back-propagation technique, then Particle Swarm Optimization (PSO) technique for network training is used and after comparing two techniques it can be decided which one is the optimum for this operation.

Implementing the network with back-propagation learning

The aim of BP algorithm is adjusting weight and bias of the network to reach the output of the network to the desired output with minimum of Mean Square Error (MSE).

After preparing the network with two inputs “speed (ω) & armature current (I)” as the readings from the DC motor, five neurons in the hidden layer and three outputs “good, fair and bad” as the condition pointers for the motor, setting the activation functions for hidden layer as Symmetric saturating linear transfer function (**satlins**) and for the output layer as Linear transfer function (**purelin**), the BP parameters are set as “momentum coefficient (α) = 1.05; learning rate (η) = 0.02; maximum number of iterations (epoch) = 3000”.

Trainlm function is used to train the neural network. **Levenberg-Marquardt** backpropagation (**trainlm**), this function manipulates weight and bias values using Levenberg-Marquardt optimization.

The inputs and targets information shown in Table 2 are given to the training function to train the neural network.

Table (2). NN training inputs

outputs	Good (100)		Fair (010)		Bad (001)	
	I (mA)	ω (rpm)	I (mA)	ω (rpm)	I (mA)	ω (rpm)
Inputs	135	129	240	60	243	52
	150	360	245	254	270	216
	165	586	270	477	297	427
	179	808	280	694	322	627
	190	1035	195	938	342	932
	203	1270	300	1165	365	1143
	213	1503	310	1422	383	1353
	225	1730	315	1661	405	1557
	235	1963	324	1893	423	1767
	248	2216	335	2118	446	1994
	253	2473	340	2382	455	2226
	261	2724	350	2614	470	2452

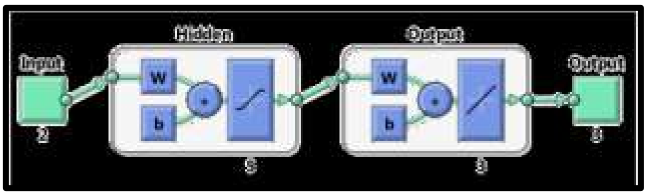


Figure (2). Neural network trained with BP

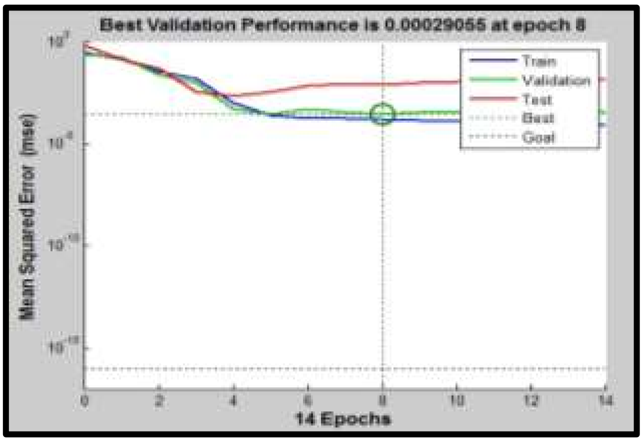
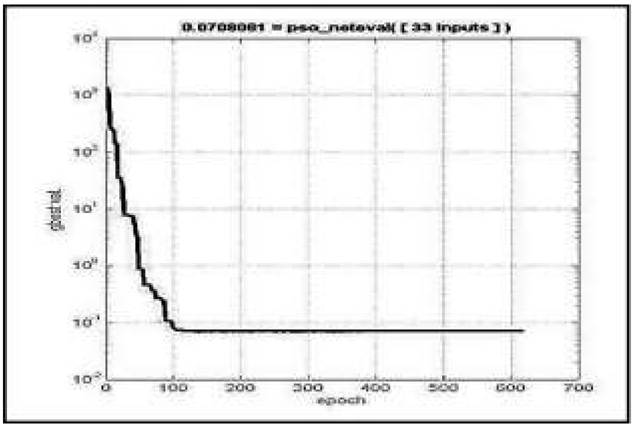


Figure (3). Neural network training performance graph

Implementing the network with particle swarm learning

The function of PSO algorithm is to find best values according to the work of an animal herd with no leader. Particle - swarm – optimization includes a swarm of particles, where particle simulates a possible solution (better - condition). The particle will move through a multi-dimensional motion space to find the best - position in that space (the best position has maximum-or-minimum-values) [13].

After preparing the same network that used in BP algorithm, the PSO parameters as “swarm size = 200 particles; the-maximum-number-of-iterations (epoch) = 1000; acceleration-constants C1 = C2 = 2; inertia weights (r1= 0.9, r2 = 0.4)”.

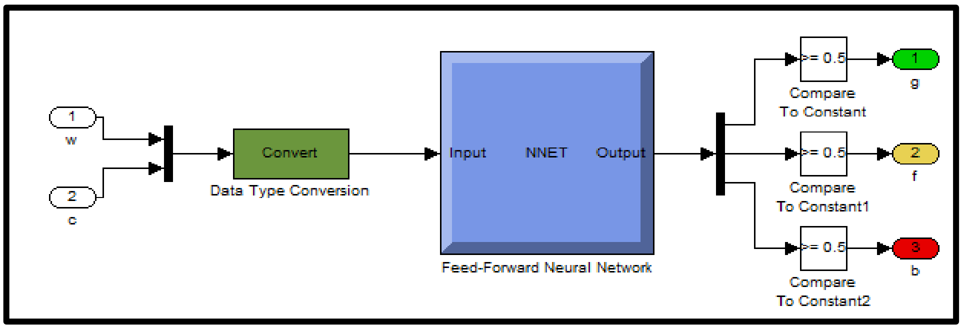


Figure(4). PSO training graph

Through the process of training neural network using two training algorithm “BP and PSO” and comparing these two algorithms it can be concluded as:

1. PSO algorithm was slow in respect to BP algorithm, in BP network after 14 iterations was trained successfully, but in PSO it took 620 iterations to be trained.
2. Bp trained network was more accurate than PSO trained network. First one has a maximum error about 14% in response of test input, while the second network has a maximum error 33%.

According to the results the BP trained network is more effective for implementation, thus it is converted into Simulink model to prepare it for using by FPGA. Figure 5 shows the digital network that will be programmed in FPGA kit.



Figure(5). Neural network simulink model

Hardware Implementation

The block diagram shown in Figure 6 will be implemented to perform DC motor performance monitoring based on FPGA and soft computing approach.

Current measurement interface circuits

Resistor can be used as a current sensor, voltage difference across resistor is proportional to the current that flows through it, by using difference amplifier circuit and Analog to Digital Converter (ADC) the input digital current data will be prepared to the FPGA.

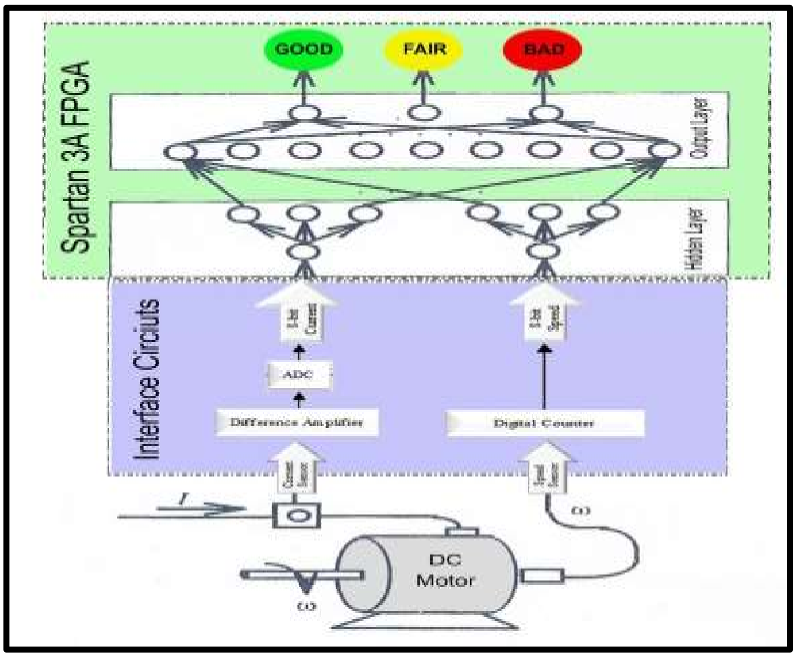


Figure (6). Monitoring system block diagram

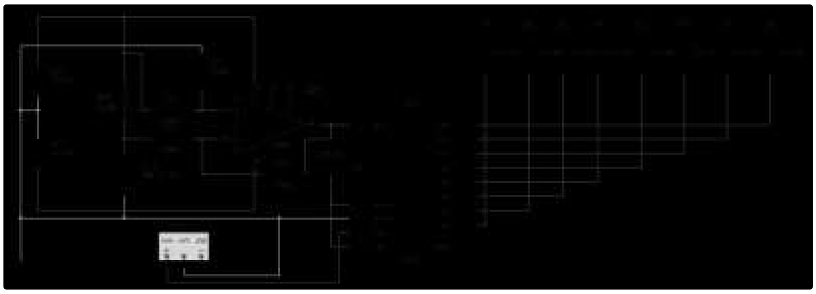


Figure (7). Current measurement interface circuit diagram

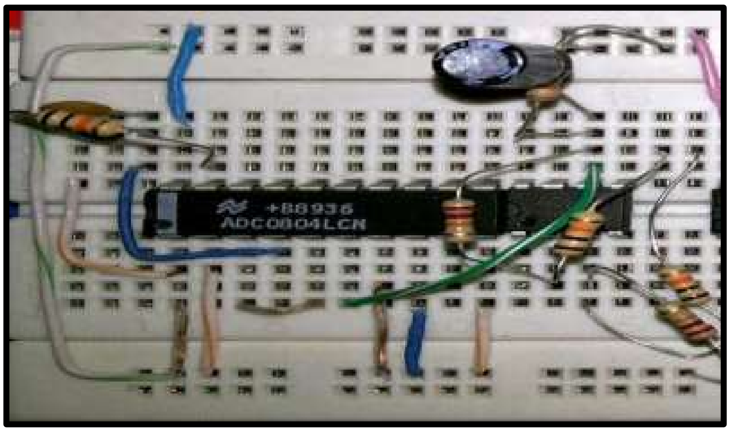


Figure (8). Current measurement interface circuit

Speed measurement interface circuits

To measure the motor speed, the **Speed Encoder** circuit is used. This is a single transistor circuit that creates a **digital-square-pulse** output that has a frequency proportional on the speed of a small DC-motor.

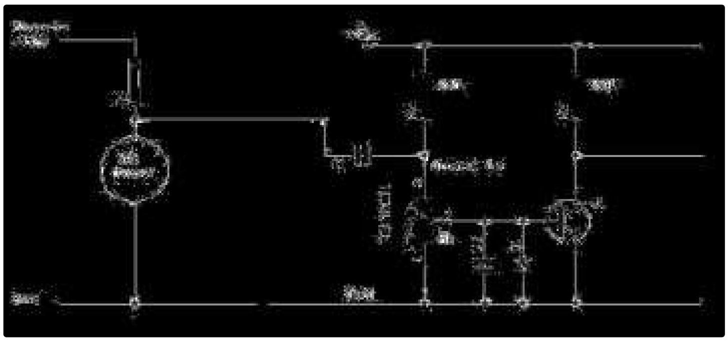


Figure (9). Motor speed encoder circuit diagram

Small DC-motors have a brass commutator, when the motor armature rotates brushes alternately are connected with the windings. When the brushes commutate through the junctions in the commutator, the current waveform drawn by the motor alternates at a frequency that defines the motor-speed, at a set number of square pulses per motor revolving.

This effect can be observed as a voltage ripple waveform on the oscilloscope when the motor runs. The ripples are more visible, and more reliable, while increasing load. Adding a small resistance like 1 Ω or 10 Ω in series with the motor drive this even more clearly.

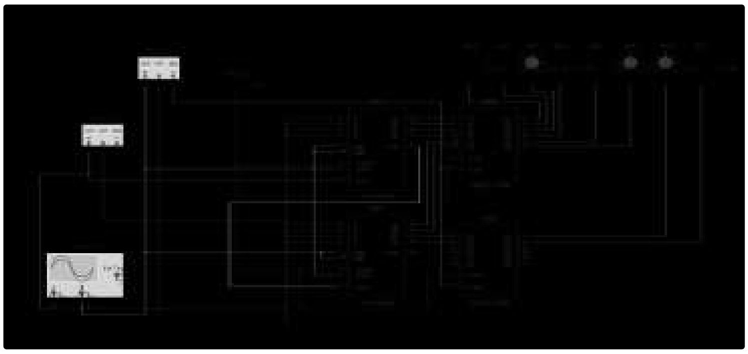


Figure (10). Speed measurement circuit diagram

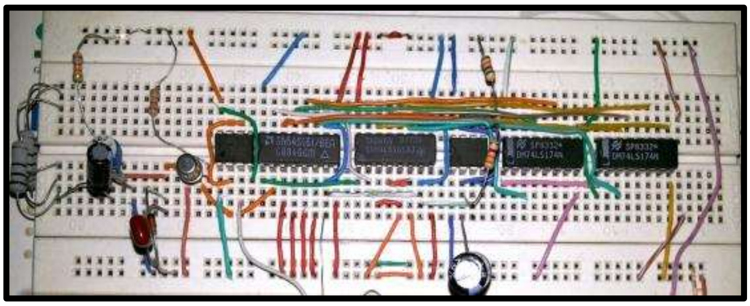


Figure (11). Speed measurement circuit

By collecting and implementing circuits shown in Figures (8 and 11), the final interface circuits as shown in Figure 12.

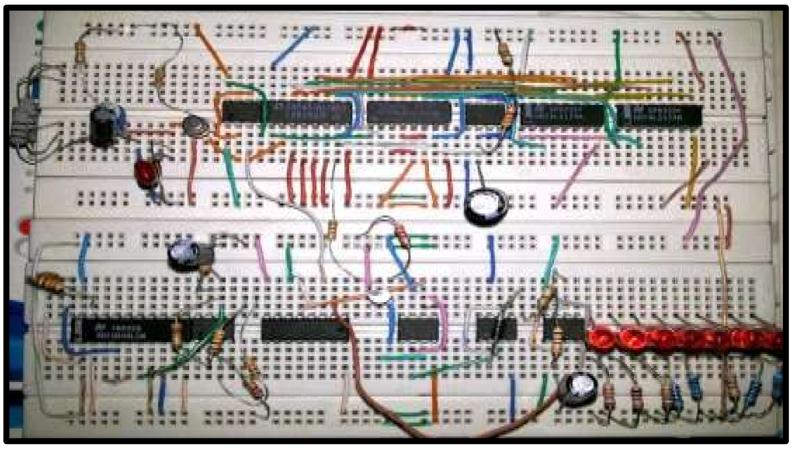


Figure (12). Interface circuits

FPGA Design and Programing

The Xilinx Spartan-3A Starter Kit board contains different I/O devices, such as serial ports and VGA display. The peripherals I/O support various output compatibilities, depending on which I/O port or display devices are in work.

The FPGA will get 16-bit as an input of the designed network from the interface circuits (8-bit for speed and 8-bit for current) through FX2 connector. The output of the network will be three LEDs from 8 discrete LEDs which included in the FPGA kit board (Good, Fair or Bad).

The designed network in Figure 5 must be converted to Verilog Hardware Description Language, **VHDL** project code. MATLAB program has this ability to convert Simulink model into VHDL code.

The FPGA card must be connected to the PC through USB connector, selecting the device and downloading the bit file generated from VHDL code.

A neural network programed and trained to perform monitoring on DC motor condition status as shown in Figure 5. This network is downloaded on FPGA kit through **Xilinx-ISE Design Suite 13.3** program. The FPGA kit now is ready to connect to DC motor through the designed interface circuits as shown in Figure 12. The implemented system is shown in Figure 13.

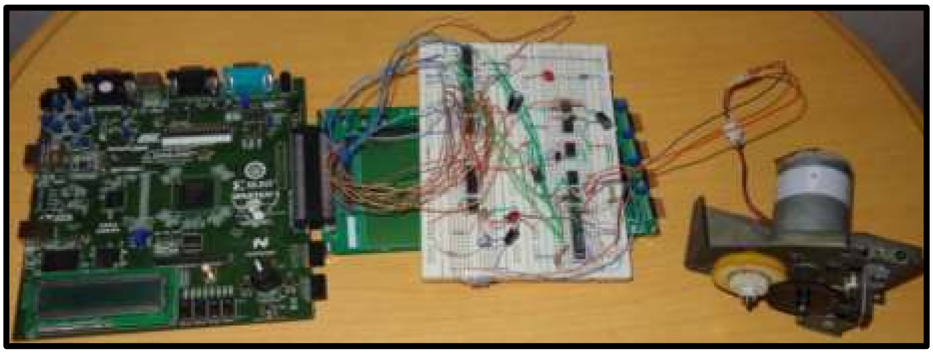


Figure (13). Implemented system

When motor runs, the current and speed readings can be obtained their sensors and processed by the interface circuits, and the digital readings are delivered through FPGA input ports to **Xilinx Spartan-3A Starter Kit board**. The programed neural network in the kit according to its training has an ability to decide the condition status of the running DC motor (**Good**, **Fair** or **Bad**) through three LEDs as shown in Figure 15.

Figure (14) Conditions of the motor

CONCLUSIONS

According to the experiments performed in this work, it can be concluded that using intelligent algorithms improves fault detection techniques by mixing the expert knowledge from laboratory testing with signal processing for on-line input data, also, the effective designs of interfaces digitals circuits is based on successfully implementations of the synchronizations which is explained in timings diagrams of digitals IC's data sheets. The two neural networks simulation results tend to choose the backs propagations trained networks for better accuracy. (Backs Propagations has a numbers of iterations (14) and maximums errors (14%), while Particles Swarms Optimizations (620 iterations and 33% maximums errors)).

FPGAs are effective's devices which implements digitals auto supervising services for industrials factories. It provides more flexibility and easy to implement digital circuits in low cost.

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