Effect of defective NPC Three level Inverter on speed artificial neural network control of Induction Motor

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Abstract— this paper proposes an artificial neural network-based speed controller model of induction motor drives. The performance of traditional feedback controllers has been found to be insufficient for speed control of induction motors due to the nonlinear structure of the system, changing environmental conditions, and the effects of disturbances. This paper investigates the neural speed control of induction motor combined with three-level NPC inverter for accurate and fast speed control and on the other hand the effect of fault in three-level NPC inverter on neural speed control of induction motor. The faults presented in this work can be classified into switching faults of the three-level NPC inverter and their effects on the physical parameters of the induction motor. The simulation results are performed using Matlab/Simulink which clearly shows the robustness of this controller.

Keywords—Induction motor; neural network; NPC three level inverter; switch fault, robustness.

I. INTRODUCTION

Today, alternating current machines can replace the direct current machine in most variable speed applications. In particular, induction motor is considered the preferred actuator in constant speed applications. It offers some advantages compared to the DC motor, such as its ease of manufacture and maintenance.

The neural network (ANN) is widely used as a universal approximates in nonlinear mapping and uncertain nonlinear control problems. Neural control is very powerful tool capable of achieving very good results in the control of complex systems. It is preferred to use neural networks (ANN) for control when requirements for precision are high and system is not identified precisely or its parameters are changing [1]-[2].

In recent years, there has been an increasing demand for the use of multi-level converters in power electronics applications. The increase in the number of voltage levels in the converter output voltage leads to a satisfactory level of total harmonic distortion (THD) while reducing the stress in each switching component by reducing their supported voltages especially in high power applications. The common neutral point clamped (NPC) inverter is one of the most used multi-level topologies in industrial applications [16] because of the several advantages offered in terms of its reduced stress across the semiconductors, less harmonic content, and lower voltage distortion.

The speed sensorless vector control of induction motors driven by three-level neutral-point clamped (TL-NPC) inverters have become a research hotspot in the field of high-power, motor drive. At present, the high-voltage high-power motor drive device often adopts a three-level neutral-point clamped structure, which has the advantages of small loss, high efficiency, and small harmonics compared with a conventional two-level inverter.

The power electronics part is considered as the weakest component in the drive system and about 38% of the induction motor faults are due to switching faults. In this section the causes and effects of various switching faults in the induction motor performance are described. Switching faults may occur due to many reasons, which include electrical stress due to stored charge carriers, maximum reverse current, faulty base drive system, manufacturing defects, ageing on the capacitor, loose connections, abnormal transients, etc. It can result in reduced performance of the motor, increase in temperature that resulting an increase in stator current or may even result in shutdown of the motor [12]-[15].

Multilevel inverter offers interesting advantages such as possibility of operation in medium, high voltage and high power applications, providing a better voltage waveform with low total harmonic distortion for electric machine applications. However, the number of switches needed in the topology increases with the number of levels and, although the switches may be highly reliable, a system's fault probability will become increasing. An unbalanced voltage is generated when a fault occurs which can produce permanent damage to the load or complete system failure [7]-[8].

This paper presents two studies: the first one is about the use of a neural speed controller for an induction motor combined with a variable speed drive which is a three-level NPC PWM inverter without application of fault. In this study, the principle of artificial neural network and three-level NPC PWM inverter are combined for better robustness, minimized ripples and higher operating performance. It is also found in this study that the neural network speed controller provides high efficiency and good resistance to speed reference variation.

The second study is to test the robustness of the neural speed controlled by applying a switching fault in the three-level NPC inverter and show there effect on physical parameters of the induction motor.

Result simulation using Matlab shows the effect of switching fault NPC three level inverter on physical parameters of the induction motor and show the performance and robustness given by neural speed controller.

II. MATHMATICAL MODEL OF INDUCTION MOTOR

The mathematical model of the induction motor is used for analyzing the dynamic behaviour of the motor. The change in the dynamic behavior of the motor affects the motor parameters such as speed, torque, resistance, flux analyzing the change in performance of the induction motor. Dynamic model of the induction motor is derived by transforming the three-phase quantities into two phases direct and quadrature axes quantities (Park transforms). Mathematical equation of the induction motor is given below (dq rotating) wish rewritten in rotation reference frame [12]:

$$\frac{d\Omega}{dt} = \frac{n_p L_m}{J L_r}\left(\varphi_{rd} I_{sq} - \varphi_{rq} I_{sd}\right) - \frac{1}{J} C_r - \frac{1}{J} f\Omega \quad (1)$$

$$\frac{dI_{sd}}{dt} = -\lambda\, I_{sd} + w_s I_{sq} + \frac{K}{\tau_r}\varphi_{rq} + w_r\, K\varphi_{rd} + \frac{1}{\sigma L_s} v_{sd} \quad (2)$$

$$\frac{dI_{sq}}{dt} = -w_s I_{sd} - \lambda\, I_{sq} - w_r\, K\varphi_{rd} - \frac{K}{\tau_r}\varphi_{rq} + \frac{1}{\sigma L_s} v_{sq} \quad (3)$$

$$\frac{d\varphi_{rd}}{dt} = \frac{L_m}{\tau_r} I_{sd} - \frac{1}{\tau_r}\varphi_{rd} + (w_s - w_r)\varphi_{rq} \quad (4)$$

$$\frac{d\varphi_{rq}}{dt} = \frac{L_m}{\tau_r} I_{sq} - (w_s - w_r)\varphi_{rd} - \frac{1}{\tau_r}\varphi_{rq} \quad (5)$$

With: $\tau_r = \frac{L_r}{R_r}$, $\sigma = 1 - \frac{L_m^2}{L_s\ L_r}$

σ: Scattering coefficient Blondel

$$landa = \lambda = \frac{1}{\tau_s\ \sigma} + \frac{1}{\tau_r}\left(\frac{1-\sigma}{\sigma}\right)$$

$$K = \frac{L_m}{\sigma L_s\ L_r}$$

III. SPEED ARTIFICIAL NEURAL CONTROL

The Artificial Neural Network (ANN) is widely used in many fields of technology application and scientific research. This technique can be used in cases of difficult problems that cannot be described by precise mathematical approaches where they are very complicated to manipulate [1]-[6]

The induction motor can be controlled using artificial intelligence techniques; however, Fig. 1 is depicting the control system based on artificial neural network. Mainly, two functions need to be performed in such control system, reference speed and musered speed.

However, ANN controller is required to be trained for reference speed and speed musered emulation. In this control paradigm, that, we got two inputs to ANNA in return, speed data may resource during working conditions of induction motor and feed into ANN for training purpose. [3]- [4]-[5]:

Number of layers is implemented depending on the real-world requirements, nodes are propagating in each layer, every node is performing a function on reception of data from the preceding node, so that, each node is yielding an output that differs from their input. Nodes are connected with each other by logical connections called neurons. [17]

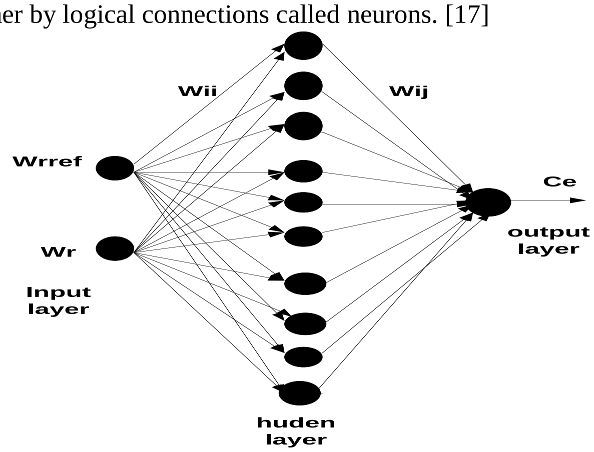


Fig. 1. Structure of ANN controller

The inputs to the network are sampled from the reference speed 'Wrref' and the musered speed 'Wr' data.

The network is trained with Levenberg-Marquardt back-propagation algorithm (LM) [14]. The structure of the neural network controller of speed was a neural network with one linear input node, 10 neurons in the hidden layer, and one neuron in the output layer [3]-[6]. The ANN algorithm is elaborated in the following steps:

Step 1: Firstly, reference speed and the musered speed are given as inputs to the network. The input vector matrix is given by [X] 2*1 with two inputs.

Step 2: Subsequently, the targets are chosen in order to attain the desired variables of the network. The target vector matrix is given by [t] 1*1 with one output.

Step 3: The weights and biases are then initialized and are updated corresponding to Levenberg–Marquardt optimization algorithm. The output vector matrix is given by [y] where [w] and [b] are the weights and biases row matrices, respectively.

Step 4: The ANN is trained by using the data provided in Step 1 and Step 2, respectively, and by fixing the goal parameter to a minimum. The error data in the form of an error vector matrix (E) is generated to confirm that the desired convergence of the specified goal parameters or epochs during training has been met then training stops.

$$E = \frac{\sum_{i=1}^{n}(t_i - y_i)^2}{I} \quad (6)$$

Where "E" is the error data matrix obtained using a mean squared error as the objective function, "n" is the total number of outputs and "I" is the number of iterations.

Step 5: After the training the network, the optimized value of the steady state error as the output is yielded.

The structure of a developed ANN controller is 2, 10, 1, which means that the network has two neurons in the input layer, 10 neurons in the hidden layer and one neuron in the output layer. The fig.2 show model of layer of ANN in Matlab

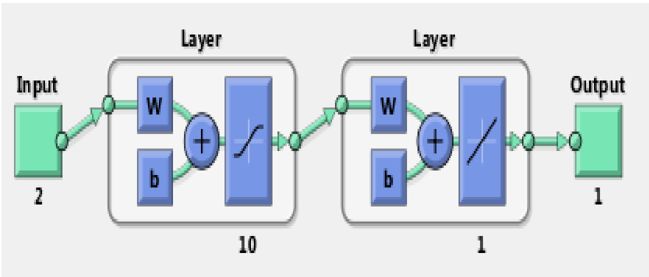


Fig. 2. Matlab model of layer1 and layer 2 off ANN controller

The Fig.3 shows the subsystem of Neural Network, It is a network with two layers: layer1 is the hidden layer and layer 2 is output layer.

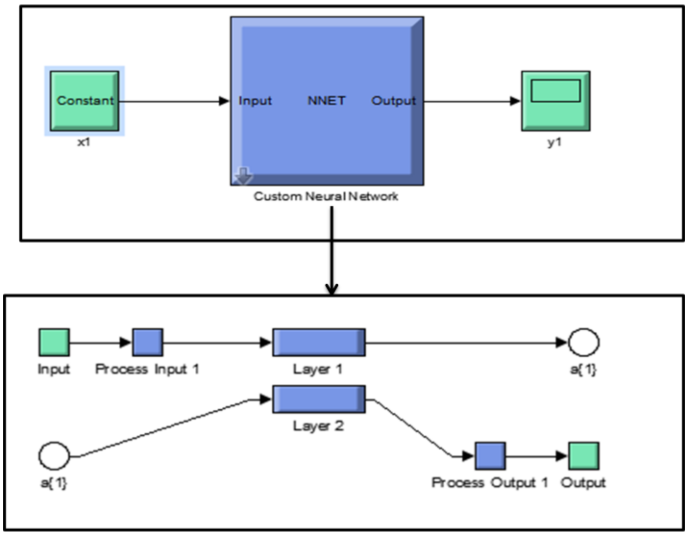


Fig. 3. Subsystem of layer1 and layer 2 off ANN controller

Fig.4 shows the command of induction motor using speed neural network control. It is a network with two neurons in the input layer, whose inputs are: reference speed W_{rref}, musered speed W_r while the output is the electromagnetic torque C_e.

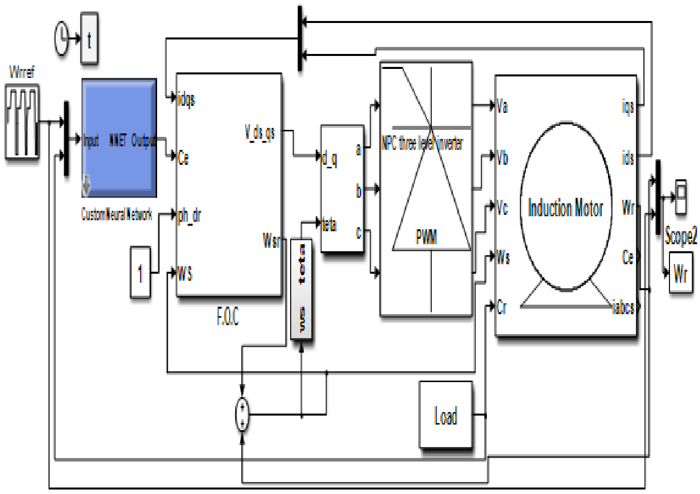


Fig. 4. Speed neural network control of induction motor associated with NPC three level inverter.

IV. NPC THREE LEVEL INVERTER STRUCTURE

A three-phase three-level NPC converter is shown in Figure4. The three phases have a common DC bus, divided by two capacitors into three levels. The voltage across each capacitor is $V_{DC}/2$; and the voltage stress across each switching device is limited to $V_{DC}/2$ through the clamping diodes. A three-level NPC converter is able to produce five levels of line to line voltage and three levels of phase voltage. This NPC converter reduces harmonics in both voltage and current output [7]-[8]-[16].

Inverter power switch faults are subdivided into short circuit and open circuit [13]-[14]-[19].

Short circuits, in most cases, that can lead to brutal damages on the switch itself or even on the drive. These faults usually cause the tripping of fuses and, in tolerant structures (conservative design), the turn-on of spare power switches [11] - [12].

Open-Switch Faults that have less immediate negative effect. However, the cumulative effect may lead to non-reversible degradations [9]-[10].

Open-Circuit Fault in K_1: To generate switching positive state, $K_1$and K_2 should be turned on, and positive currents will pass through these switching devices. While, when K_1fault occurs, another current path is formed, from $D_1$and K_2. Output current decreases to 0. When K_1 fault occurs, the switching positive state can't work as normal. [18]

Without application of fault the output voltage is equal to the reference value (200V) and the output current reaches to 1.4 A in the full-load condition, and all capacitors have the same voltage value (100 V). The voltage of capacitors is equal to half of the DC-link voltage because of their serial connection.

Our study based on the application of three switches defected in three arms (K_1"first arms", K_7 "second arms" and K_{10}"third arms") to see the influence of this switch fault on physical parameter of squirrel cage motor by used of speed sliding and speed sliding neural controllers.

The Fig.5 shows the application of the switch fault K1, K7and K10 of three level NPC inverter.

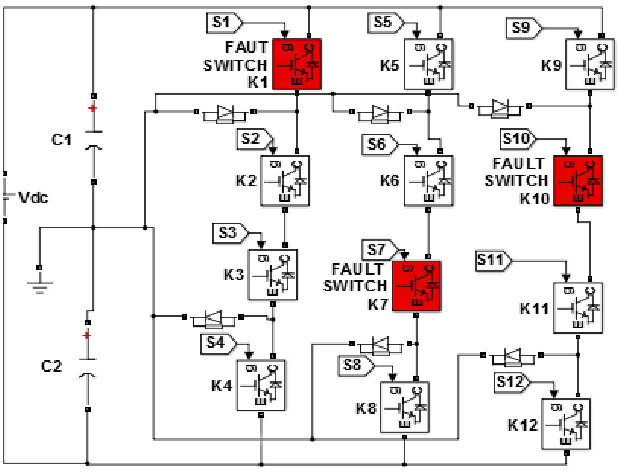


Fig. 5. NPC three level inverter with application of K_1,K_7, K_{10} switch fault

The Fig.7 show during the switch fault K1, K7and K10 at t= [0.2s 0.7s] the output filtering current decreases to 0.32A, the increase in switches faults defect on the current value which is observed by their reduction or cancellation.

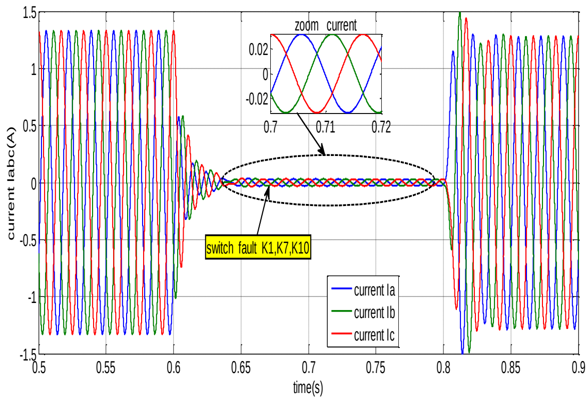


Fig. 6. Output current response of NPC three level inverter with application of K_1,K_7, K_{10} switch fault

The Fig.7 show simulation results of three levels NPC inverter outputs line-line voltages with three states. The system is operating normally before 0.6s. When the switch fault K_1, $K_7$and K_{10} occurs at t= [0.6s 08s], the output voltage of three level inverter NPC is distorted and the level of the output voltage is reduced.

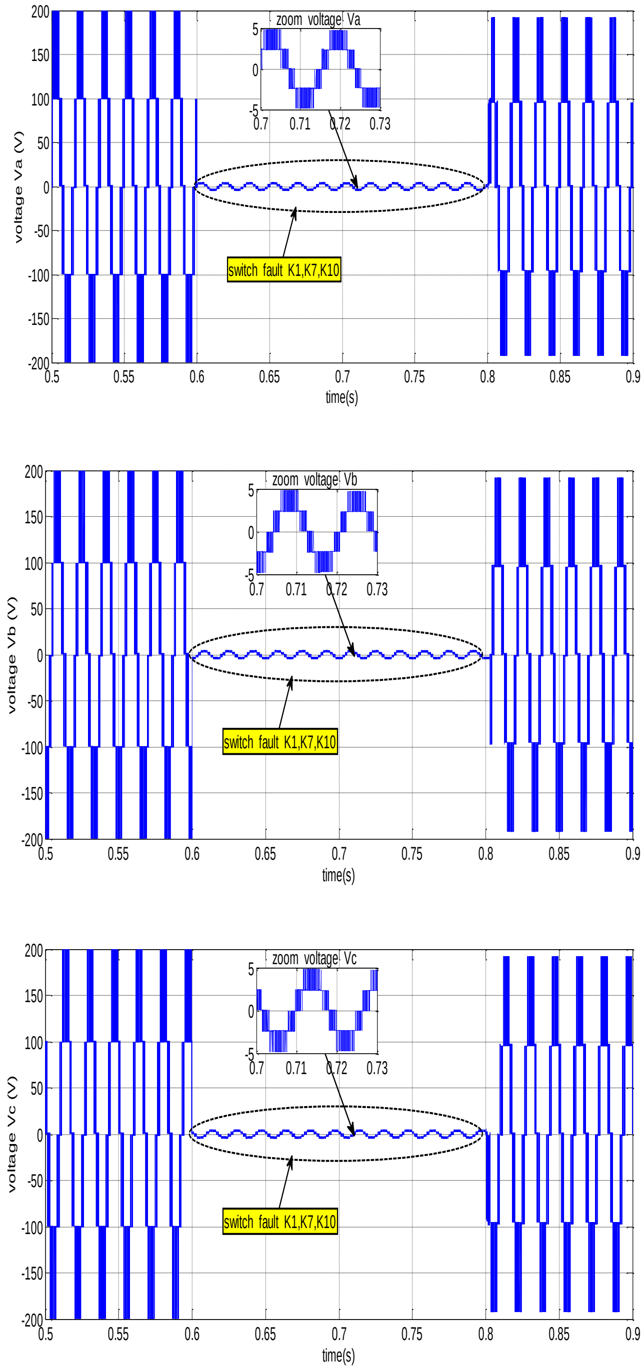


Fig. 7. Output voltaget response of NPC three level inverter with application of K_1,K_7, K_{10} switch fault

The Fig. 8 shows the filtered output voltage which is equal to the reference voltage before the fault (200v) but during the application of a switch fault K_1, K_7 and K_{10} notice a significant decrease in the output filtering voltage (5v).

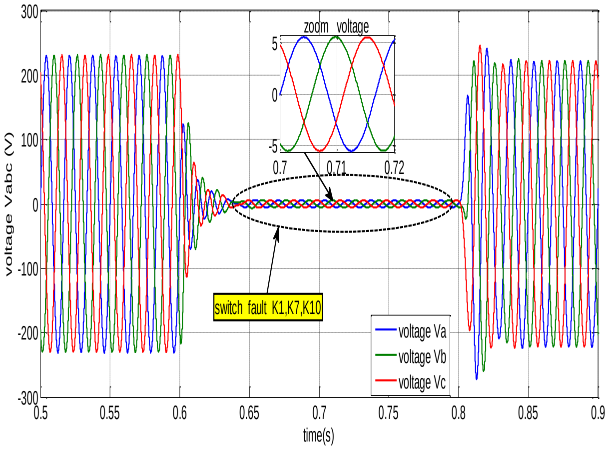


Fig. 8. Output voltage response of NPC three level inverter with application of K_1,K_7, K_{10} switch fault

V. SIMULATION RESULT

The results presents firstly the use of a neural speed controller for an induction motor combined with NPC three-level inverter without application of fault, and secondly the existence of this controller with the defects of switch fault.

The simulation results given by Fig.9 show that the speed artificial neural network control without application of switch fault is robust with respect to the variation of the reference speed, since the speed measured without fault track the reference speed at start up as at the reversal of direction of rotation, in a very satisfactory, it can be observed also that the measured speed does not influence by the application of load at time t=0.2s. Concerning the torque response, we can observe that it follows the load value, as we can notice the effect of the speed increase and the rotation direction reversal on their response. From these results, it can be concluded that the neural speed controller gives satisfactory results.

The application of switches fault K1, k7 and K10 at time t= [0.6s 0.8s] in the three-levels NPC inverter associated with the induction motor by the use of speed artificial neural network control, we can see that this type of defect causes a disturbed and unstable operation of the system due to the change in the mode of operation during the application of the defect.

During the application of defect K1, k7 and K10 of NPC three level inverter with application of speed artificial neural network control shows a very significant decrease in the speed, as it can also notice the torque rate also have very strong undulations during a fault. We result that the presence of this type of inverter defect can damage other components and endanger the operation of the system.

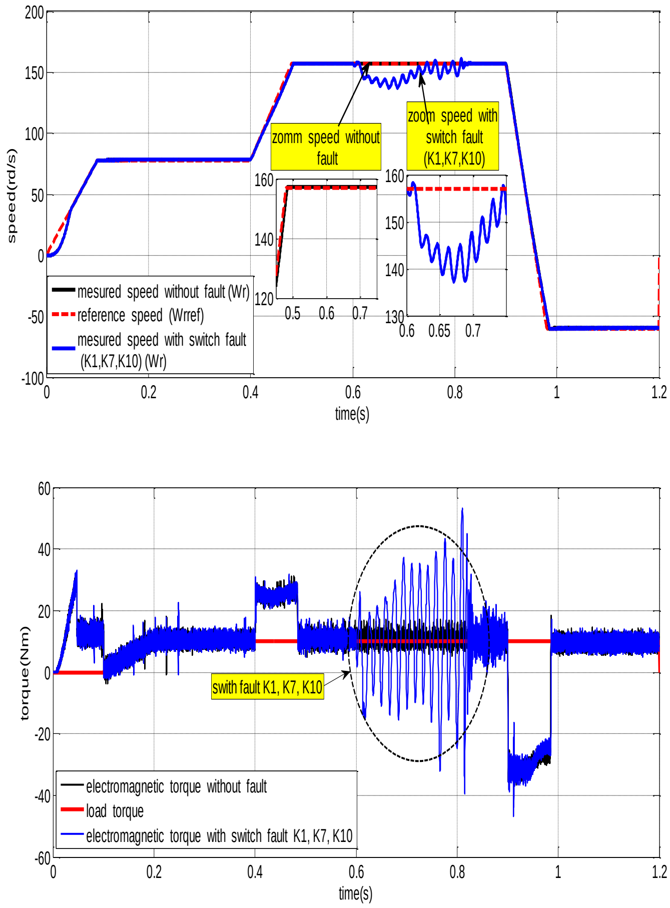
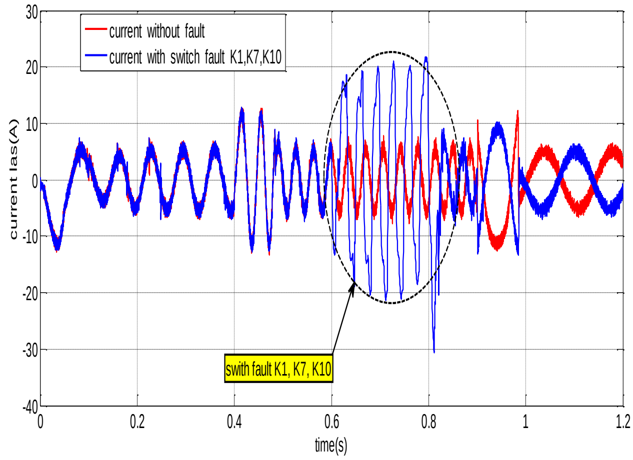


Fig. 9. Speed and torque response for speed artificial neural control with application of K_1,K_7, K_{10} switch fault of NPC three level inverter.

The Fig.10 shows that during the switches fault K_1, K_7, K_{10} at the time t= [0.6s 0.8s] we can see a strong increase in the rotor and stator current and huge imbalance is noticed in this two phase currents, where they magnitude reaching a very high value which leads to the degradation of the system and damaging of the motor.



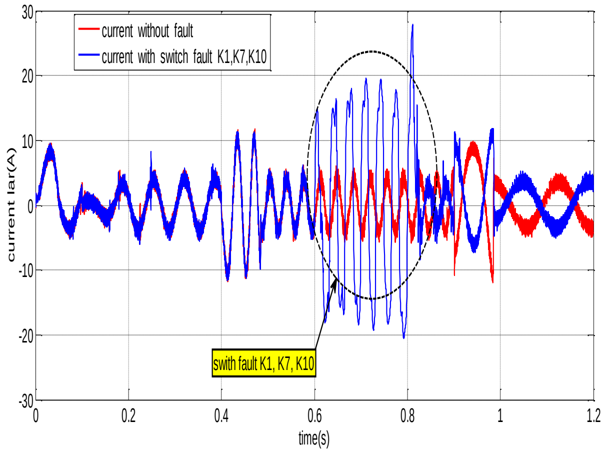


Fig. 10. stator and rotor current response for speed artificial neural control with application of K_1,K_7, K_{10} switch fault of NPC three level inverter.

VI. CONCLUSION

This work is presenting firstly a straight forward approach to synthesis the strength of artificial intelligence controller for induction motor speed control combined with NPC three levels inverter without fault. Results proved that ANN controller is drawing enhanced performance, is found quick and accurate in induction motor speed control, from the stability point of view, ANN controller is more reliable due to accurate and quick speed.

Concerning the second part that presented speed artificial neural network controller with the existence of switch fault for the NPC three levels inverter gives performance result. So the regulator enables us to have the influence of the existence of a defect on the physical parameters of the induction motor (speed, electromagnetic torque, stator and rotor currents) which is in the undulation and the oscillation which disturbed various signals. The simulation study indicates clearly the superior performance of controller speed neural network control. It appears from the response properties that it has a high performance in presence of defects.

It results that the proposed intelligent controller had a good dynamic stability without application of defective NPC three level inverter, as it gives satisfactory results with faults.

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