Choice Of Input Data Type Of Artificial Neural Network To Detect Faults In Alternative Current Systems

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Abstract: This paper present a study on different input data types of ANN used to detect faults such as over-voltage in AC systems (AC network , induction motor). The input data of ANN are AC voltage and current. In no fault condition, voltage and current are sinusoidal. The input data of the ANN may be the instantaneous values of voltage and current, their RMS values or their average values after been rectified. In this paper we presented different characteristics of each one of these data. A digital software C++ simulation program was developed and simulation results were presented.

Keywords: Diagnosis, Learning Data type, AC voltage and current, instantaneous value, RMS value, Average value.

INTRODUCTION

AC systems (AC network , induction motor) may be exposed to different kinds of faults (over-voltage, single phasing, under-voltage, unbalance state). These faults need to be detected and identified rapidly in order to take the appropriate procedure to protect the AC system. That is possible by using the artificial neural network. This former need input data in its conception and to be used after that. The input data must be significantly sensible to all faults that happen.

Choice of data type (mathematical models and simulation results)

The simulation is done by using the software programmation language C++ with following parameters:
Vrms = 115.45 V & 220 V , 50 Hz ,
Sample time T=0.0001 seconds.

Sinusoidal instantaneous value of voltage and current

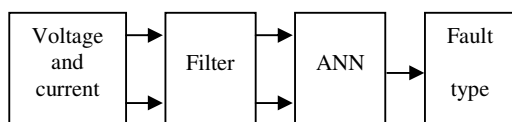AC systems diagnosis may be presented by the following scheme :

Fig. 1 Schematic diagram of fault detection in AC system

In the following part, we will simulate the over-voltage and thus we will consider only the voltage signal as an input of the ANN. Voltage is acquired in sample time of T (fig. 2). Then, It is filtered to get the sinusoidal fundamental component which will be introduced to the ANN to detect the fault type.

In this case, if Ts is the signal period and T is the simple time, there will be ((Ts/T)+1) per period value that will be introduced to faults detection ANN to conceive it. By the other hand, when the ANN model is completed, the fault detection (for example over-voltage) is done

instantaneously (without delay time). This data type is sensible to all kinds of faults even very short time ones (pulses).
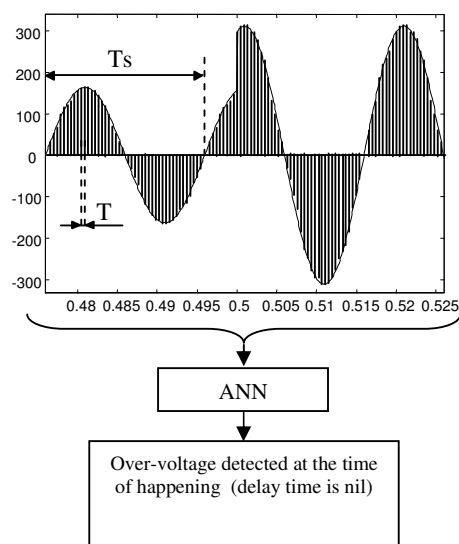

Fig. 2 Schematic diagram of over-voltage detection by using instantaneous values of voltage

RMS value of Sinusoidal voltage
RMS value per period
Numerical integration

In this case, RMS value of sinusoidal voltage is calculated and introduced to the ANN to detect the faults.
RMS value of sinusoidal signal of Ts as period can be calculated as follow:

$$Vrms^2 = \frac{1}{Ts} \int_0^{Ts} V^2(t) \, dt \qquad (1)$$

Numerically, RMS value can be calculated by:

$$Vrms^2 = \frac{1}{Ts} \sum_{i=1}^{N} Vi^2 \, T \qquad (2)$$

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where:

V_i is the voltage at time t=i,

T is the sampling time,

N is the number of sample voltage values taken per period:
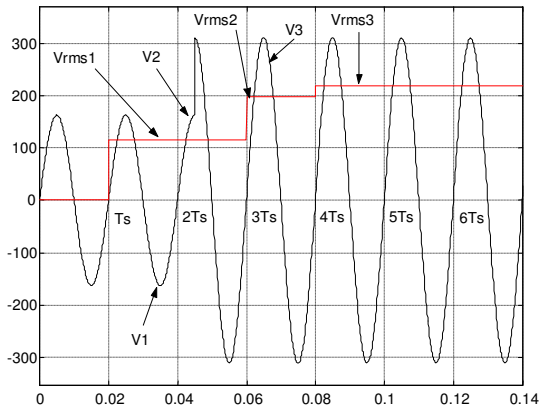
$$N = \frac{Ts}{T} + 1 \qquad (3)$$

Fig. 3 Simulation result of over-voltage influence on RMS value of voltage calculated by numerical integration method
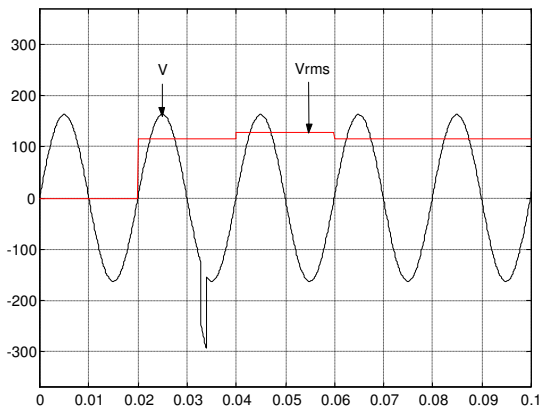

Fig. 4 Simulation result of sensibility of RMS value of voltage calculated by numerical integration method

The RMS value of sinusoidal voltage is always given at the end of each period (fig 3). The voltage V is defined like follow:

$$V = \begin{cases} V1 & 0<t<2Ts \\ V2 & 2Ts<t<3Ts \\ V3 & 3Ts<t<6Ts \end{cases} \qquad (4)$$

After calculating its RMS value using this method, we get:

$$Vrms = \begin{cases} 0 & 0<t<Ts \\ Vrms1 & Ts<t<2Ts \\ Vrms1 & 2Ts<t<3Ts \\ Vrms2 & 3Ts<t<4Ts \\ Vrms3 & 4Ts<t<5Ts \\ Vrms3 & 5Ts<t<6Ts \end{cases} \qquad (5)$$

As said before, it is clear that the RMS value of the voltage is always got at the end of each period. When an over-

voltage occurs at a any time between nTs and (n+1)Ts, there will be an increase in the RMS value that is recovered at (n+1)Ts with a varying delay time between 0 and Ts. This delay time, wasted in calculation of RMS value, added to the time of execution of the ANN program increase the time between the fault and its detection.

This data type is sensible to all kinds of faults but more the fault is shorter in time (pulses) more its influence is limited and so its detection is difficult (fig. 4).

Discrete Fourier Transform (DFT)

As the precedent method, the RMS value of sinusoidal voltage is calculated in one period (Ts). Discrete Fourier Transform(DFT) algorithm is used to calculate peak values from sampled voltage. 8 samples per cycle (period) are taken for the calculation It is calculated like follow [1]:

Sampled values of voltage = V1, V2, ... V8.

Real coefficients for 8 samples (Ri) = 0 , .707 , 1 , 0.707 , 0 , -0.707 , -1 , -0.707.

Imaginary coefficients for 8samples (Ii) = 1, 0.707 , 0 , -0.707 , -1 , -0.707 , 0 , 0.707.

Real part of the voltage:

$$VR = ¼ \sum_{i=1}^{8} Ri\ Vi. \qquad (6)$$

$$= ¼\ (0*V1 + 0.707*V2 + \ldots - 0.707*V8).$$

Imaginary part of the voltage:

$$VI = ¼ \sum_{i=1}^{8} Ii\ Vi. \qquad (7)$$

$$= ¼\ (1*V1 + 0.707*V2 + \ldots + 0.707*V8).$$

Peak value is given by:

$$Vpeak = \sqrt{V_R^2 + V_I^2} \qquad (8)$$

RMS values of voltage is calculated by:

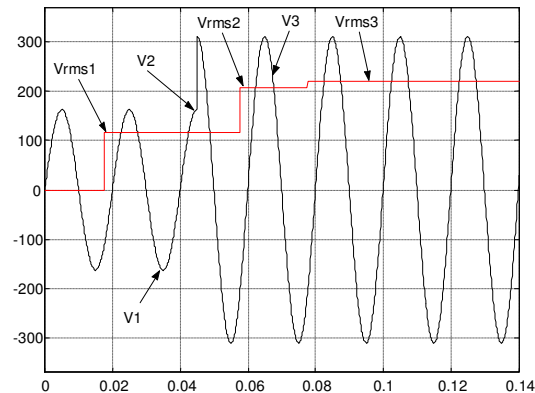$$Vrms\ \frac{\sqrt{2}}{2}\ Vpeak = 0.707\ Vpeak \qquad (9)$$

Fig. 5 Simulation result of over-voltage influence on RMS value of voltage calculated by Discrete Fourier Transform method (DFT)

The voltage V is defined like follow:

$$V = \begin{cases} V1 & 0<t<0.04 \\ V2 & 0.04<t<0.06 \\ V3 & 0.06<t<0.12 \end{cases} \qquad (10)$$

After calculating its RMS value using this method, we get:

$$Vrms = \begin{cases} 0 & 0<t<7*Ts/8 \\ Vrms1 & 7*Ts/8<t<7*Ts/8+2Ts \\ Vrms2 & 7*Ts/8+2Ts<t<7*Ts/8+3Ts \\ Vrms3 & 7*Ts/8+3Ts<t<7*Ts/8+4Ts \\ Vrms3 & 7*Ts/8+4Ts<t<7*Ts/8+5Ts \end{cases} \quad (11)$$

It is clear that the RMS value of the voltage is always got at $((7*Ts/8)+(n*Ts))$ (fig. 5). When an over-voltage occurs at a any time between $((7*Ts/8)+(n*Ts))$ and $((7*Ts/8)+((n+1)*Ts))$, there will be an increase in the RMS value that is recovered at $((7*Ts/8)+((n+1)*Ts))$ with a varying delay time between 0 and Ts. This delay time, wasted in calculation of RMS value, added to the time of execution of the ANN program increase the time between the fault and its detection.

This data type is sensible to all kinds of faults unless very short time ones (pulses) that occurs between $(n*Ts/8)$ and $((n+1)*Ts/8)$ because there will be no influence on the RMS value of the voltage calculated by DFT method (fig. 6).
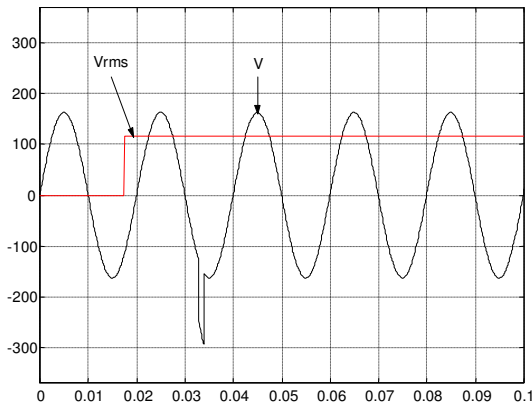

Fig. 6 Simulation result of sensibility of RMS value of voltage calculated by Discrete Fourier Transform method (DFT)

RMS value per half period

By replacing Vi^2 by Vicar in the expression (2) we get:

$$Vrms^2 = \frac{1}{Ts} \sum_{i=1}^{N} Vicar \; T = Vcarave \quad (12)$$

Since Vicar is always positive (Vicar=Vi^2) and according to last mathematical expression (12), it can be said that $Vrms^2$ is the square of average value of the function Vicar that is the square of the function Vi. Hence, it is possible to calculate Vrms by calculating the average value of the function Vicar which has Ts/2 as period (Vicar=Vi^2). So instead of calculation of RMS value of Vi along one period (Ts), it is preferable to calculate the average value of Vi^2 along its period (Ts/2) and then we calculate its square root (fig. 7).
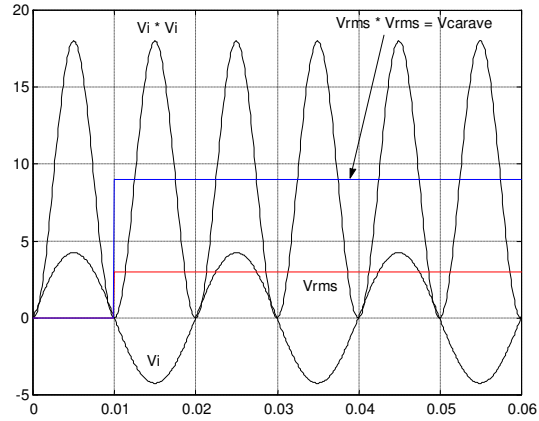

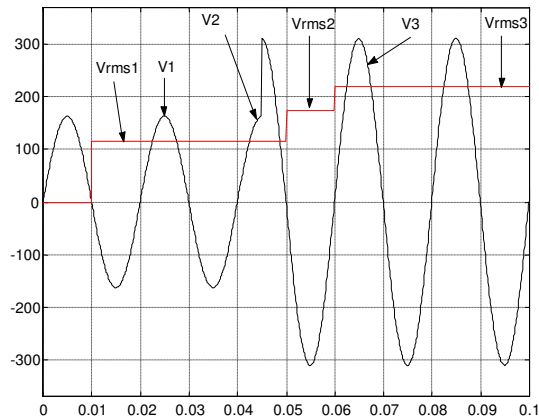Fig. 7 Simulation result of RMS value of voltage Vi and average value of Vi^2

Fig. 8 Simulation result of over-voltage influence on RMS value of voltage based on the average value of its square calculated by numerical integration method

The voltage V is defined like follow:

$$V = \begin{cases} V1 & 0<t<0.04 \\ V2 & 0.04<t<0.05 \\ V3 & 0.05<t<0.10 \end{cases} \quad (13)$$

After calculating its RMS value using this method, we get:

$$Vrms = \begin{cases} 0 & 0<t<0.01 \\ Vrms1 & 0.01<t<0.05 \\ Vrms2 & 0.05<t<0.06 \\ Vrms3 & 0.06<t<0.1 \end{cases} \quad (14)$$

As said before, it is clear that the RMS value of the voltage is always got at the end of each half period of V (Ts/2) (fig. 8). When an over-voltage occurs at a any time between $(nTs/2)$ and $((n+1)Ts/2)$, there will be an increase in the RMS value that is recovered at $((n+1)Ts/2)$ with a varying delay time between 0 and Ts/2.

This data type is sensible to all kinds of faults but more the fault is shorter in time (pulses) more its influence is limited and so its detection is difficult (fig. 9).
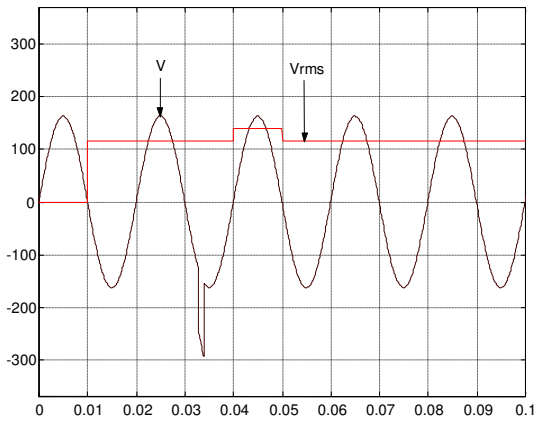
RMS value of voltage calculated by DFT method (Vrms (DFT)) is the least sensible to short time variations.

Average value of rectified voltage
In this case, voltage is filtered and rectified. The average value of output signal of the rectifier is calculated and introduced to the ANN to detect the fault (fig. 12) [2].
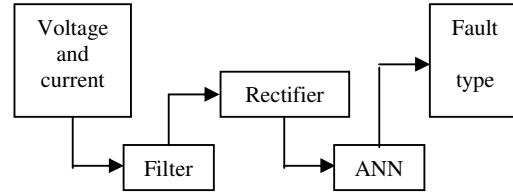
Fig. 12 Schematic diagram of fault detection in AC system based on average value of rectified voltage

The rectifier may be realized hardly or softly.
The mathematical expression that allows the calculation of the average value of rectified voltage is:

$$Vave = \frac{1}{Ts/2} \int_{0}^{Ts/2} V(t) \, dt \qquad (15)$$

Numerically, this average value can be calculated by:

$$Vave = \frac{1}{Ts/2} \sum_{i=1}^{N'} Vi \, T \qquad (16)$$

where :
Vi is the voltage at time $t=i$,
T is the sampling time,
N' is the number of sample voltage values taken per half period:

$$N' = \frac{Ts/2}{T} + 1 \qquad (17)$$

The mathematical expression linking this average value to the maximal value is:

$$Vave = 2 \frac{Vmax}{\pi} \qquad (18)$$

Fig. 9 Simulation result of sensibility of RMS value of voltage based on the average value of its square calculated by numerical integration method
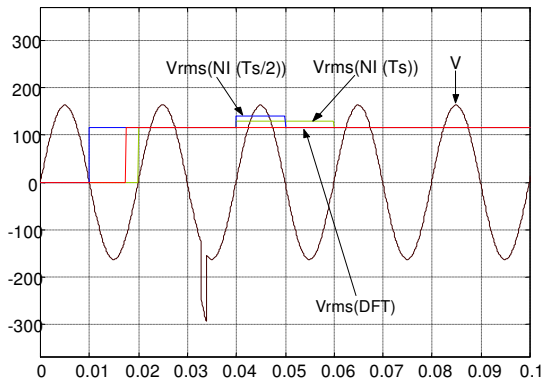

Fig. 10 Simulation result of comparison of sensibilities of RMS values of voltage calculated by different methods
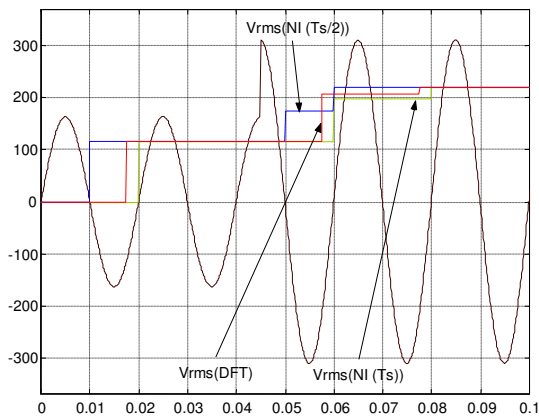

Fig. 11 Simulation result of comparison of over-voltage influence on RMS values of voltage calculated by different methods

Fig. 13 Simulation result of over-voltage influence on average value of rectified voltage

In figure 10 are compared the sensibilities of RMS values of voltage calculated by different methods. It's cleat that the RMS value of voltage based on the average value of its square calculated by numerical integration method (Vrms NI(Ts/2)) is the most sensible to short variations. While the RMS value of voltage calculated by numerical integration method (Vrms NI(Ts)) is less sensible and the

CONCLUSION

In this paper, are presented the different data inputs of ANN used to detect faults (over-voltage) in AC systems. These data are compared at different levels such as sensibility to fault and delay time of influence of fault on the data. The ANN input data is selected according to the application.

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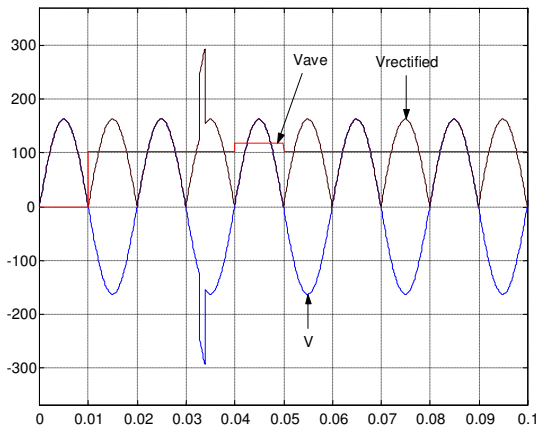

Fig. 14 Simulation result of sensibility of average value of rectified voltage calculated by numerical integration method

As said before, it is clear that the average value of the rectified voltage is always got at the end of each half period of V (Ts/2) (fig. 13). When an over-voltage occurs at a any time between (nTs/2) and ((n+1)Ts/2), there will be an increase in the average value that is recovered at ((n+1)Ts/2) with a varying delay time between 0 and Ts/2. This data type is sensible to all kinds of faults but more the fault is shorter in time (pulses) more its influence is limited and so its detection is difficult (fig. 14).

The following table, recapitulate the performances of each one of the data types mentioned before.

Table 1: Performances of the different data types

Input data type	Sensibility data to short time fault	Delay time (between fault happening time and data calculation time)
Instantaneous value	Very high	0
RMS value by numerical integration	Average	between 0 and Ts
RMS value by DFT	Low	between 0 and Ts
RMS value based on the average value of square of voltage by numerical integration	High	between 0 and Ts/2
Average value of rectified voltage by numerical integration	High	between 0 and Ts/2