Detecting the Triple Resistance Fault in Twisted Pair Telephone Lines

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ABSTRACT

Telecom Egypt Company (TE) is the unique copper fixed line network operator in Egypt and its primary aim is to improve the efficiency of this network to face the increasing demand for high data rates communications. The severe fault affects the copper network is the resistance fault. The most commonly used testing and measuring instrument in TE is "Dynatel 965DSP" which has some drawbacks.

This paper introduces a new methodology for the determination of Resistance Fault locations of a three resistance faults twisted pair telephone line. This method is based on the three voltmeter method and automated by using NI USB-6281 Data Acquisition Card (DAQ). The simulation results accuracy of one of the faults does not exceed 1.63% for faults up to 100 KΩ and 350 m length cable.

General Terms

A new methodology for determination of resistance fault locations, three voltmeter method, Data Acquisition System

Keywords

Telecom Egypt Company; Dynatel 965DSP; Three voltmeter method; Resistance Fault Location (RFL); Data Acquisition Card

1. INTRODUCTION

The demand on high data rates across the telephone copper network in Egypt increases dramatically. The public telephone network in Egypt must be of high performance to satisfy the requirements of this demand. To improve the network performance, the telephone cable faults have to be accurately determined and repaired to achieve this target. The new trend in TE is to replace the primary copper network with fiber cables without replacing the secondary copper network [1, 2]. As the secondary network is susceptible to different types of faults, the determination of ground resistance faults locations represents the real challenge to engineers and technicians [3-7]. In TE, "Dynatel 965DSP" is the most commonly used instrument to determine such faults. This instrument is expensive in addition, it cannot measure some types of resistance faults; low insulation resistance for both wires of a telephone line with ground.

In this work, a new reliable, cheap and sufficiently accurate automatic measurement method used in measuring the telephone line electrical parameters with sufficient accuracy is introduced to determine the fault locations of a three resistance faults twisted pair telephone line [8]. This method is based on the adaptive three voltmeter method [9-11] with NI USB-6281 Data Acquisition Card (DAQ) [12-14] and a Personal Computer (PC).

The paper is organized as follows: section 2 contains the three voltmeter method principle; section 3 introduces RFL using the three voltmeter method including the simulation results for different cases; section 4 shows the experimental results. Finally, the conclusions are presented.

2. THREE VOLTMETER METHOD PRINCIPLE

The three voltmeter method is primarily suited for power and energy measurements, but it is also well suited for impedance measurements provided that suitable reference impedance and three highly-accurate voltmeters are available [9-11]. Recently, the three voltmeter method has been found very convenient for routine calibration of standards of self-inductance, inductor losses, and it has also been applied to calibration of the mutual inductance. The basic arrangement of the measurement method is shown in Figure 1, where $Z_x = R_x + jX_x$ is the Device Under Test (DUT) and $Z_s = R_s + jX_s$ is the reference impedance standard. Referring to [9-11], the three voltmeter method is explained in details.

In our work, the RFL determination depends on the measurement of the wire DC resistance, and thus the unknown impedance Z_x will be of resistive part only; R_x. The voltages V_x, V_s and V_T can be measured across R_x, R_s and the DC signal source respectively. In this case, the value of the unknown resistance is calculated using equation (1).

$$R_x = \frac{V_x}{V_s} R_s \qquad (1)$$

Figure 2 illustrates the RFL measurement circuit. There is no need for the peak detectors illustrated in Figure 1.
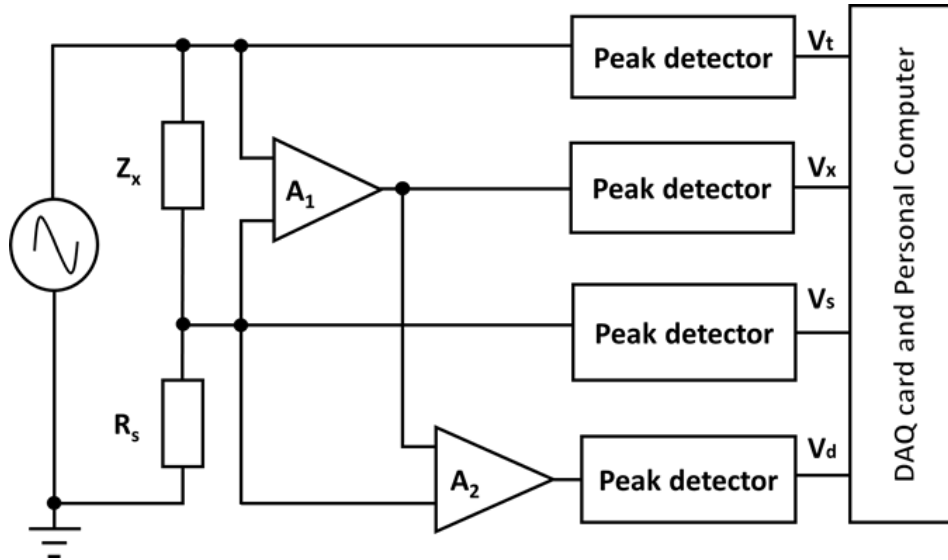
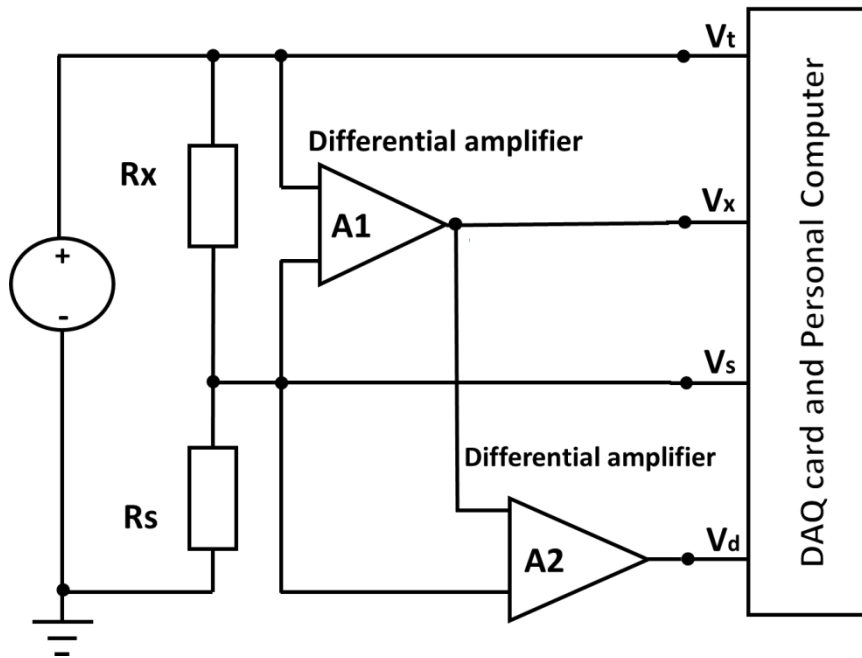**Fig 1: The modified three voltmeter method measuring circuit**

Fig 2: Reduced three voltmeter method RFL measuring circuit

3. RFL OF A THREE RESISTANCE FAULTS TELEPHONE LINE

The RFL test purpose is to determine the location of the fault (usually a splice) from both near and far ends with the highest accuracy. The engineer should check the continuity of the line, and then the insulation resistance measurement of the two conductors with the ground have to be performed. Assuming that we have a transmission line that is continuous along its path and has three resistance faults as shown in Figure 3.

In the Figure, A and B are the near end terminals and C and D are the far end terminals. The two terminals A and ground are connected in the circuit as the unknown resistance while the two terminals C and D are still open. The measured unknown resistance R_e is described by equation (2)
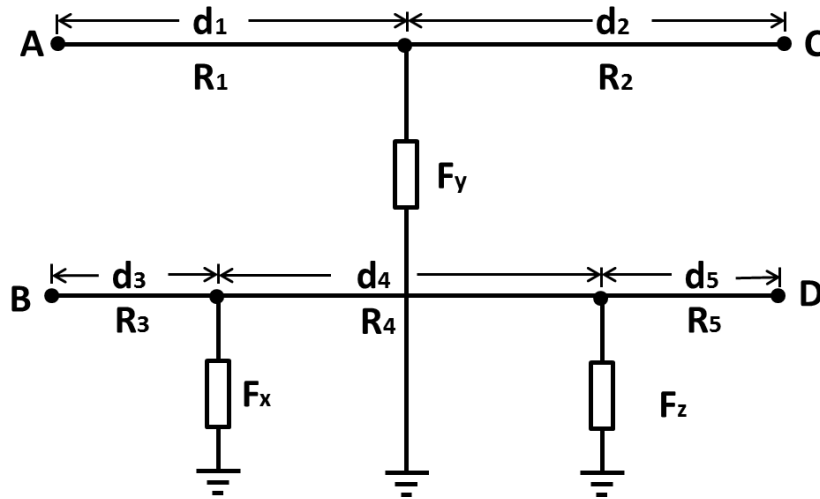
Fig 3: Three resistance faults telephone line

$$R_e = R_1 + F_y + 0.211\, d_1 \qquad (2)$$

Where R_1 is the wire DC resistance from terminal A to the location of the fault F_y and d_1 is the distance between terminal A and the fault F_y. The DC resistance of the ground wire is 0.211 Ω/m.

Applying the above mentioned sequence for terminals A and ground as the unknown resistance when the two terminals C and D are strapped (S.C.). By neglecting the value of the copper and the ground wires resistances with respect to the faults values, the measured unknown resistance R_f is described by equation (3)

$$R_f \cong R_1 + \left(\frac{F_x F_y F_z}{F_x F_y + F_y F_z + F_x F_z}\right) + 0.211 d_3 \qquad (3)$$

Where F_x and F_z are two ground faults. d_3 is distance between terminal B and the fault F_x. R_3 is wire the DC resistance from terminal B to the fault F_x.

By connecting B and ground as the unknown resistance and neglecting the value of R_4 and the ground wire resistance with respect to the faults values, the measured unknown resistance R_k is described by equation (4)

$$R_k \cong R_3 + \left(\frac{F_x F_z}{F_x + F_z}\right) + 0.211 d_3 \qquad (4)$$

By using terminals C and ground as the unknown resistance, the measured unknown resistance R_c is described by equation (5)

$$R_c = R_2 + F_y + 0.211 d_2 \qquad (5)$$

Where R_2 is the wire DC resistance from terminal C to the fault F_y and d_2 is the distance from terminal C to the fault F_y.

If the two terminals C and ground are used to represent the unknown resistance terminals when terminals A and B are strapped, the measured unknown resistance is R_d. By neglecting the value of the copper and ground wires resistances with respect to the faults values, R_d is described by equation (6).

$$R_d \cong R_2 + \left(\frac{F_x F_y F_z}{F_x F_y + F_y F_z + F_x F_z}\right) + 0.211 d_5 \qquad (6)$$

Where d_5 is the distance from terminal D to the fault F_z. The wire DC resistance from terminal D to the fault F_z is R_5.

Finally, repeating the previous sequence for terminals D and ground and neglecting the value of R_4 and the ground wire resistance with respect to the faults values, the measured unknown resistance R_j is described by equation (7)

$$R_j \cong R_5 + \left(\frac{F_x F_z}{F_x + F_z}\right) + 0.211 d_5 \qquad (7)$$

Equations (2) to (7) are solved simultaneously to determine the fault locations and the fault resistance F_y.

3.1 Three Resistance Faults Telephone Line Simulation Results

Assuming a twisted pair of three resistance faults of length 350 m is simulated. The fault F_y is 100 m away from the near end terminal A, d_1 and 250 m away from the far end terminal C, d_2. Also, assuming that the fault F_x is 50 m away from the near end terminal B, d_3 and the fault F_z is 180 m away from the far end terminal D, d_5. The distance between the faults F_x and F_z, d_4 is 120 m. Referring to [12-14], NI USB-6281 DAQ card specifications are used in the simulation process. The simulation figures illustrate the error percentage of fault locations for fault resistances starting from 1 KΩ up to 100 KΩ using a DC voltage source of 10 V taking into account the DAQ card absolute accuracy and resolution in DC measurement processes. The faults values are considered equal at every simulation process. The distances errors are illustrated for different cases of reference (known) resistances. Figures 4, 5, 6, 7 and 8 demonstrates the error in distances d_1, d_2, d_3, d_4 and d_5 respectively using adaptive resistance R_s as the known resistance in the case of 18 bit resolution (5.5 digits) DAQ card (NI USB-6281) and 16 bit resolution (4.5 digits) DAQ card (NI USB-6210). Adaptive resistance measurement depends on using a potentiometer to change the known (variable) resistance value until reaching the point at which both V_x and V_s are nearly equal. This is because the three voltmeter method exhibits the best accuracy when both the known and unknown resistances are nearly equal.
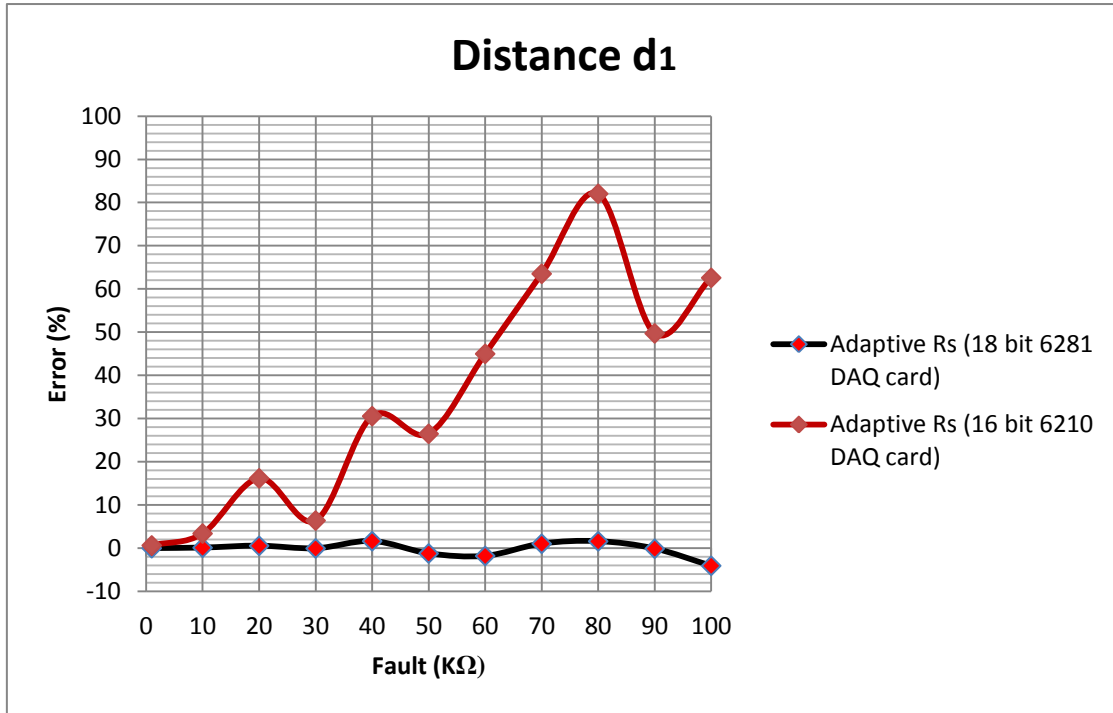
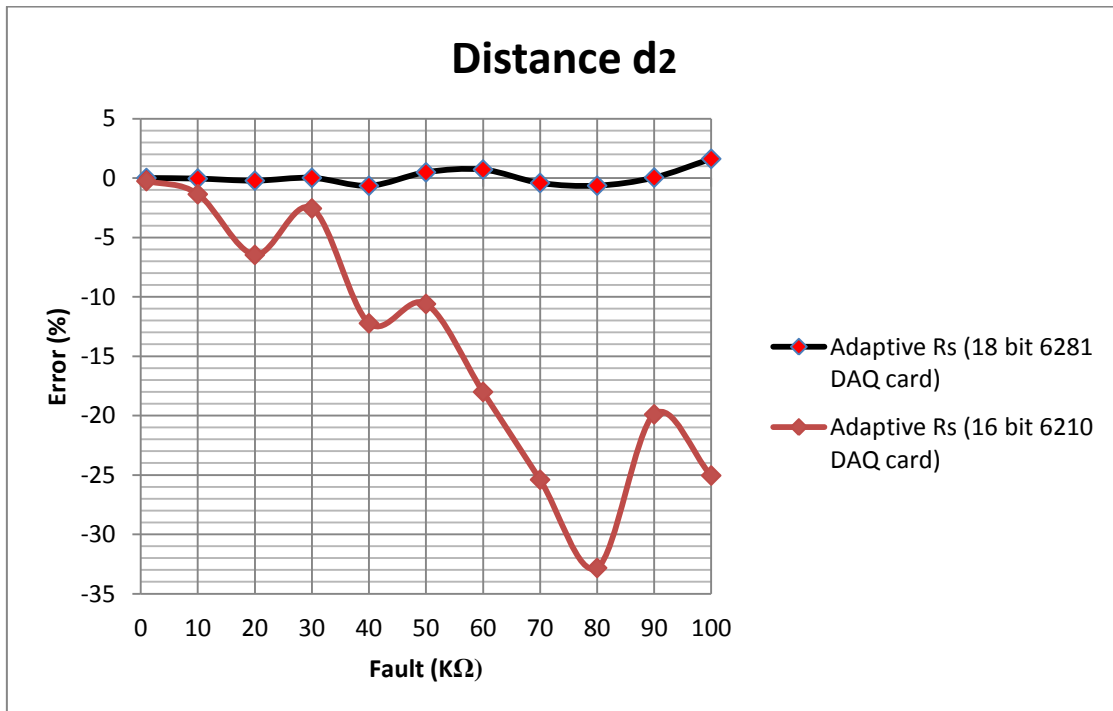**Fig 4: Distance d$_1$ simulation error at different known resistance values**

Fig 5: Distance d$_2$ simulation error at different known resistance values
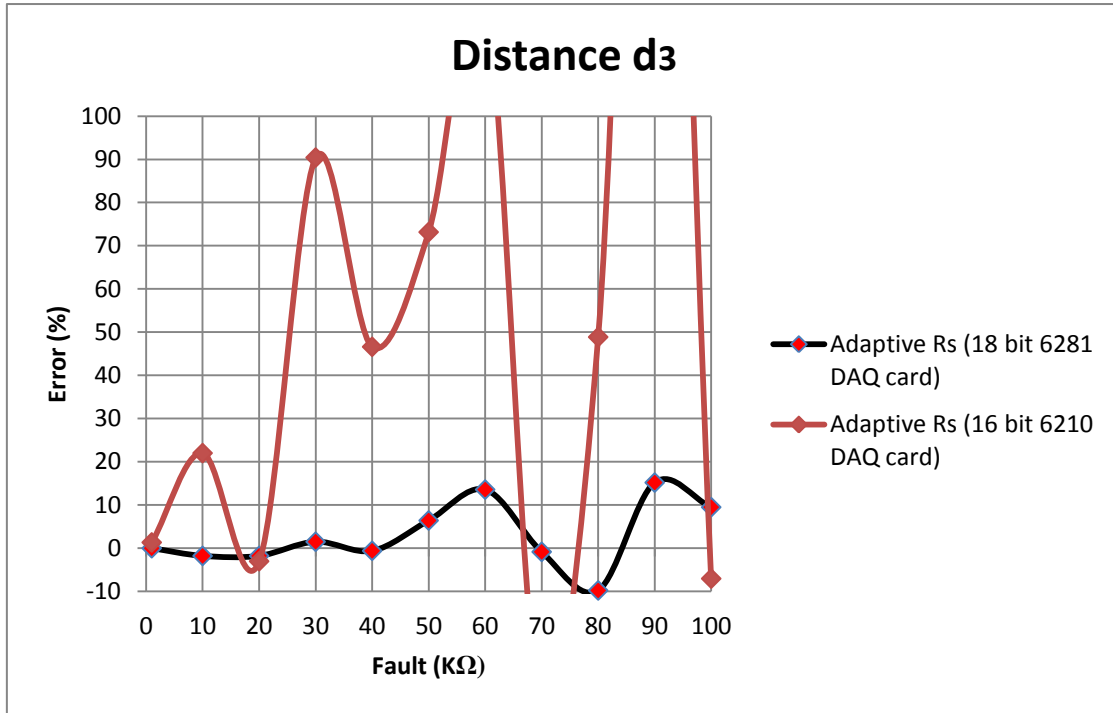
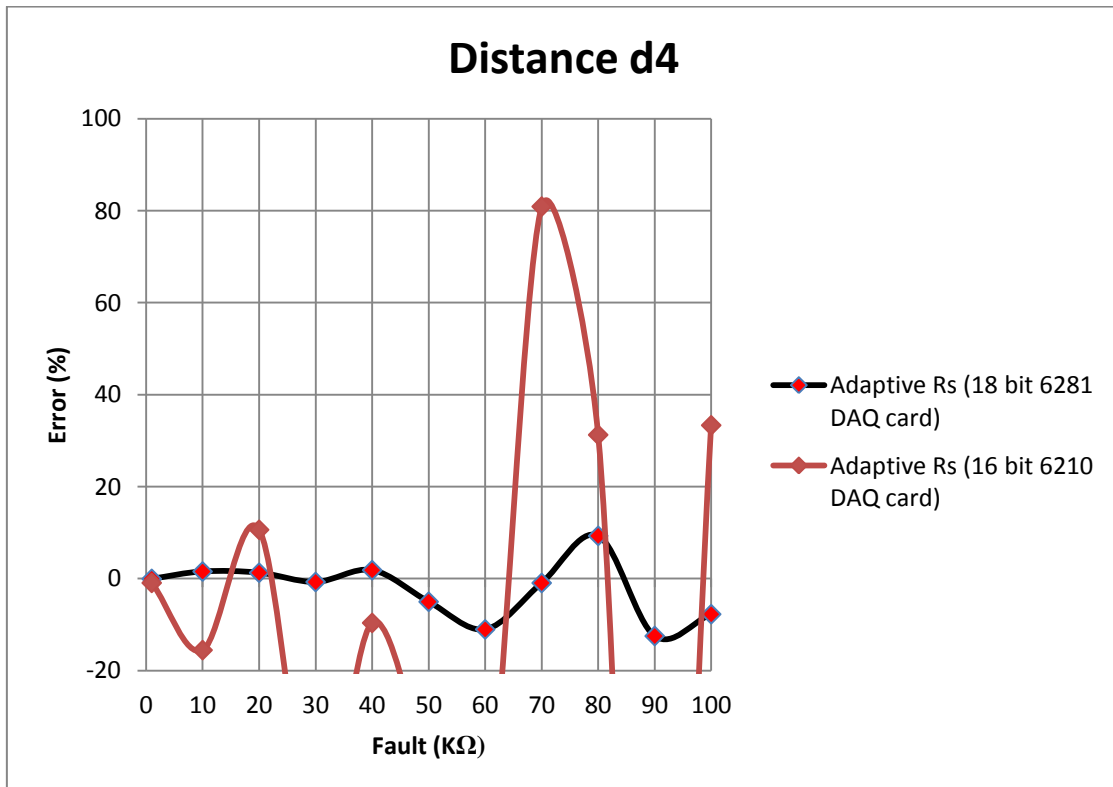**Fig 6: Distance d₃ simulation error at different known resistance values**

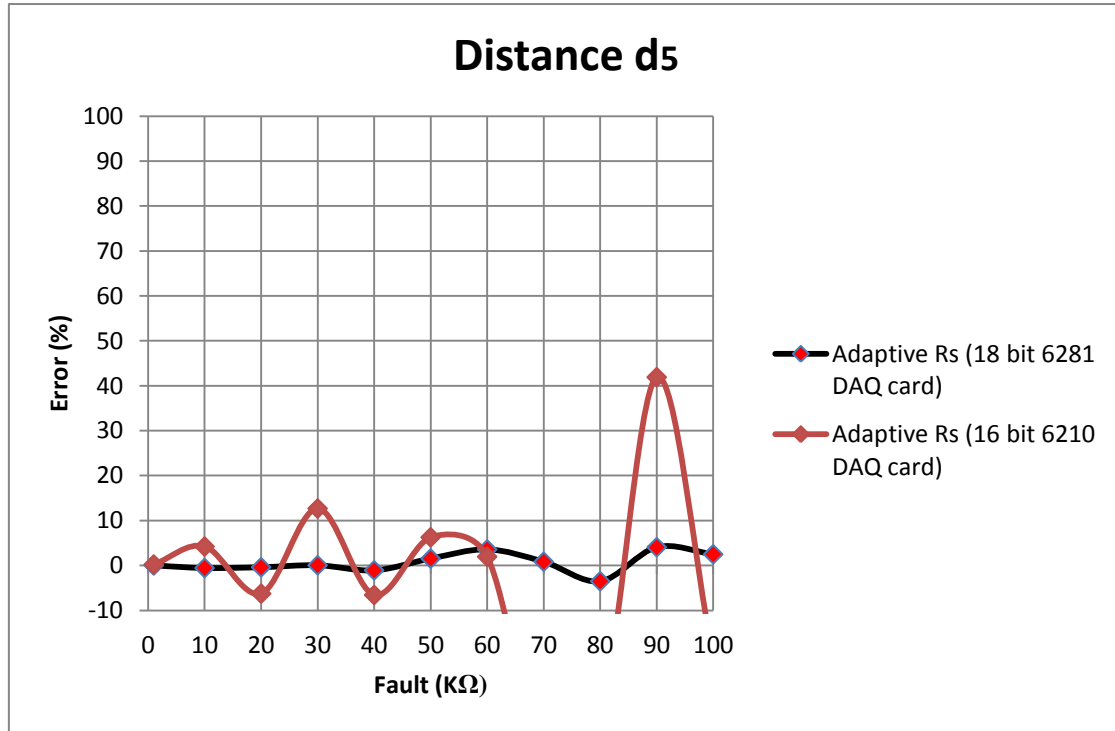**Fig 7: Distance d₄ simulation error at different known resistance values**

Fig 8: Distance d_5 simulation error at different known resistance values

3.2 Analysis of Simulation Results

The simulation distance is chosen to be 350 m which is the average length of the secondary telephone cable of Multi-Service Access Node (MSAN) new cabinet in TE. The simulation process was performed using adaptive resistance R_s as the known resistance and for two cases of DAQ resolution; 18 bit and 16 bit resolution DAQ card. The concept of adaptive resistance is illustrated before. In our simulation, it is assumed that F_x, F_y and F_z have equal values. The simulation results for distance d_1 error show that they have acceptable accuracy (<10% error) in the case of 18 bit resolution DAQ card for all values of faults. The results obtained 16 bit resolution DAQ card have acceptable accuracy for faults up to 30 KΩ except at value of 20 KΩ. For faults higher than 30 KΩ, the accuracy is not acceptable.

For the distance d_2, the simulation results using 18 bit resolution DAQ card (NI USB-6281) have acceptable accuracy for all values of faults and does not exceed 1.63% for all fault values. The results obtained using adaptive known resistance in the case of 16 bit resolution DAQ card have acceptable accuracy for faults up to 30 KΩ and suffer from large error values for faults greater than this value.

For distance d_3 simulation error, the results obtained using adaptive known resistance in the case of 18 bit resolution DAQ card (NI USB-6281) are not acceptable for fault values of 60 KΩ and 90 KΩ. For other fault values, the results are acceptable. The results obtained using adaptive known resistance in the case of 16 bit resolution DAQ card have acceptable accuracy for faults of values 1 KΩ, 20 KΩ and 100 KΩ only.

For distance d_5 simulation error, the results obtained using adaptive known resistance in the case of 18 bit resolution DAQ card (NI USB-6281) are acceptable for all fault values. The results obtained using adaptive known resistance in the

case of 16 bit resolution DAQ card have acceptable accuracy for fault values up to 60 KΩ except at the value of 30 KΩ. For faults greater than 60 KΩ, the accuracy is not acceptable.

Distance d_4 is calculated using equation (10)

$$d_4 = d - d_3 - d_5 \tag{8}$$

Where d is the twisted pair telephone line length starting from the near end to the far end terminals. The error in d_4 is due to the errors in d_3 and d_5 as illustrated in equation (8).

The accuracy of measurement using the three voltmeter method is improved when the value of both the known and unknown resistances are nearly equal. From the previous discussion, it is noticeable that the results using 18 bit resolution DAQ card are better than those obtained using 16 bit resolution DAQ card. In spite of using adaptive resistance, equations (2) to (7) show that the faults values are greater than the copper wire and ground wire resistances which yields to measurements errors. Equations (3), (4), (6) and (7) are based on the assumption that the copper and ground wire resistances are negligible with respect to the faults values in determination of parallel resistances equivalent value which affects the results accuracy.

Another reason for the obtained error is the absolute accuracy of the used DAQ card as it is not negligible because the voltages across the DC wires resistances are very small. Thus, adding it to the actual voltages causes fault location error. The absolute accuracy of 18 bit DAQ card is better than the absolute accuracy of 16 bit DAQ card.

4. EXPERIMENTAL RESULTS

The keyword of measurements accuracy is the DAQ card resolution; as the DAQ card resolution increases, the measurements accuracy increases. An experiment is performed using (NI USB-6008) low cost DAQ card on a single faulty wire jelly-filled cable of length 16.7 m and

different fault resistance F_x values at distance of 8.8 m from the near end port as shown in Figure 9. The used DAQ card in this experiment has a resolution of 12 bit. The adaptive R_S results emphasizes that the accuracy of the results are acceptable for fault values less than or equal to 100 Ω. Table 1 illustrates the obtained experimental results.
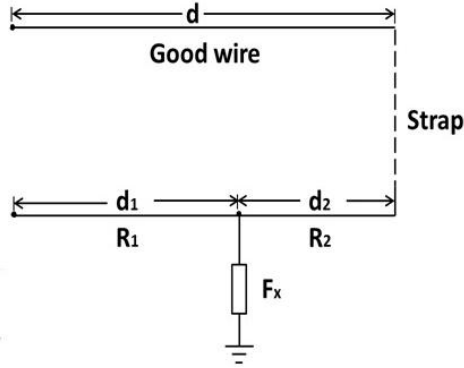

Fig 9: Single faulty wire telephone pair

As the reference resistance is nearly equal to the unknown resistance (the fault resistance plus the wire resistance), the measurement accuracy shows acceptable performance. More accurate results can be obtained in this case if the line length is longer than the length used in the experiment. The accuracy depends on the DAQ card resolution; as the DAQ card resolution increases, the result accuracy increases and vice versa.

Table 1. NI USB-6008 experimental results

F_x (Ω)	d_1 (experiment)	Error (%)
12	9.259	5.21
100	9.376	6.54
1000	16.7	89.77

5. CONCLUSIONS

The simulation results show that the error in distance d_1 does not exceed -4.09% for all faults values using adaptive known resistance in the case of 18 bit DAQ card (NI USB-6281). In the case of 16 bit DAQ card using adaptive known resistance, the error does not exceed 6.37% for faults up to 30 KΩ except at the value 20 KΩ and is not acceptable for fault value greater than 30 KΩ. Distance d_2 location error has the same results as d_1 using adaptive known resistance and 18 bit DAQ card, the results accuracy is acceptable for all fault values and the error does not exceed 1.63%. In the case of adaptive known resistance with 16 bit DAQ card, the results are acceptable for faults up to 30 KΩ and does not exceed 6.46% error. For distance d_3, the results obtained using adaptive known resistance with 18 bit DAQ card are acceptable for all fault values and does not exceed -9.8% except at the value of 60 KΩ and 90 KΩ. In the case of 16 bit resolution DAQ card, the results accuracy is not acceptable for most values of the faults.

For distance d_5, the results obtained using adaptive known resistance with 18 bit DAQ card do not exceed 4.09% error for all fault values. The results obtained using adaptive known resistance with 16 bit DAQ card have acceptable accuracy for fault values up to 60 KΩ and does not exceed -6.54% error

except at the value of 30 KΩ. For faults greater than 60 KΩ, the results accuracy is not acceptable.

The experimental results accuracy depends on the DAQ card resolution; the higher DAQ card resolution, the better results accuracy.

"Dynatel 965DSP" can measure only one resistance fault for one wire of the twisted pair line and the other wire must not have any faults. The measurement results using "Dynatel 965DSP" illustrate that the error is 7.16% or higher for different fault values.

The determination of resistance fault location using the three voltmeter method has many advantages. First, the three voltmeter circuit is simple and cheap. Second, many cases of resistance faults can be measured on the contrary to "Dynatel 965DSP". Third, the program is simple to be used by engineers and technicians. Finally, the fault locations can be determined easily.

The main disadvantage of the three voltmeter method is that its accuracy depends on the accuracy of the measured voltages and the used DAQ card.

As a future work, we will improve the resistance fault location by using the four voltmeter method in addition to using high accuracy DAQ card. Using numerical methods in solving the equations can yield to more accurate results.

6. ACKNOWLEDGMENTS

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