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Research Article

KVL and KCL verification by cotton conductive yarn resistor instead of carbon resistor fixation with Ag nanoparticles for sustainable e-textiles application

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Abstract

This paper parades the effectiveness of conductive yarn resistor instead of carbon resistor by verifying the Kirchhoff's voltage (KVL) & current (KCL) law. This research work enlightens about the sustainability of e-textiles on account of presenting characteristics of this conductive yarn resistor. Resistor is one of the most useful materials in the electrical laboratories. Generally resistor is made by carbon. Using carbon resistor is pernicious for our environment, society & cost. It is known that sustainability is the concerned area at present. Sustainable e-textile is one of the major need in material science .This quest indicates that point to boggle sustainable e-textile by inventing conductive yarn resistor verifying with most orthodox theory of Kirchhoff's voltage & current laws. KVL and KCL are the most prominent theory in electrical science. Summation of KVL and KCL will be zero in any closed loop in this theory. The summation of KVL is also zero here and summation of KCL is also zero here. It can justify Kirchoff's KVL & KCL theory.

Keywords

conductive, sustainability, nanoparticles, resistor, e-textile.

1. Introduction

It is perceived that conductive yarn is the premier ingredient of e-textiles or smart textiles. According to the definition of electrical conductivity from IEEE "*the degree to which a specified material conducts electrically , calculated as the ratio of the current density in the material to the electric field which causes the flow of current*" [1]. On the other hand resistor is that element which resists the current flow. From the demarcation of textile institute "*Yarn is a long continuous length of interlocked fibers*, *suitable for using in the production of textiles*, *sewing*, *crocheting*, *knitting*, *weaving*, *embroidery or rope making*" [2, 3]. Generally conductive fabric which can be recognized as application of smart textiles. The resistance of jute fabrics with variation of different gauge length was analyzed [3]. It was observed that decay of electrical conductivity of wool textiles . It was explained that decay of electrical conductivity by *in situ* oxidization of poly-pyroole with giving stress [1, 4]. Silver nanoparticle preparation is very important to generate the conductive yarn resistor [5]. PET conductive yarn were produced from silver and copper nanoparticles. The surface morphology of silver and copper nanoparticles based conductive yarn was investigated there. The experimental theory of Kirchhoff's voltage **(KVL)** & current

(KCL) law were analyzed. It was gone through by analyzing circuit from KVL & KCL [6, 7]. Economical, environmental & social sustainability concept were generated from numerous design of sustainable projects [8]. The main problem of the conductive materials are lacking of green resources [9]. Synthetic materials show good quality of conductive performance but they are not eco-friendly [10]. There are many ways to make conductive yarns. Polymerization techniques and deposition of nanoparticles are one of them [11]. Conductive yarn resistor was produced by depositing silver nanoparticles. From these background studies, it was wanted to generate an idea to experiment KVL & KCL through sustainable cotton conductive yarn resistor due to electrical application. In this experiment, conductive yarn resistor is made instead of carbon resistor. The resistance of carbon resistor varies from 1 to 2 kOhm [12]. In this study, 1–2 kOhm based conductive yarn resistor is timbered due to the sustainability issue. Carbon is not a biodegradable material. It volleys CO_2 when it towards the water or environment [13–15]. It is also a heavy material. From sustainability concept, it has been proved that conductive yarn resistor is better than carbon resistor. Besides with this most convenient theory of Kirchhoff's voltage & current law are proved by conductive yarn resistor. The research of new program for manufacturing conductive yarns for electromagnetic shielding purposes in various operations of medical textiles, health care, defense and electronic industries. Electronic textiles can be originated from conductive fibers. Conductive fibers are classified into two sections. One of them is naturally conductive and another one is specially treated to create conductivity [16]. Specially treated fibers portrays metal coated fibers, fibers filled or loaded with carbon or metallic salts [16]. The work view of nanomaterials can deal with more feature able textile materials. It can develop new properties like antibacterial activity, flame retardant properties, UV-protection, super hydrophobicity, and others. The resistivity of many insulating fibers are 10^{12} Ohm/cm^2 [7]. For shielding fibers it can lower than 10^2 Ohm/cm^2 [7].

2. Experimental

2.1. Materials and methods

Four ring spun cotton yarns which are 30 tex & each of their length is 10 mm recognized as samples. At first, yarns are scoured in 10% aqueous solution at room temperature for 10 min. Then the yarns are rinsed with distilled water for 5 min. After rinsing, the yarns are dried in the electrical oven machine for 3 min. Silver nanoparticles are used here due to its conductive behavior. In the meantime, 0.3M $AgNO_3$ solution is produced. In this case, $AgNO_3$ is a solid substance. 2.54 g $AgNO_3$ is taken in digital balance &it puts into the 50 ml distilled water. The molecular weight of $AgNO_3$ is 169.87 g [17]. Theory of Malvern Zetasizer (Malvern Instruments Ltd, United Kingdom), the Synthesized nanoparticles had a size range of 10–15 nm which was determined by the nano series based on the light scattering principle of the Brownian motions of particles [1]. After completing nanoparticle preparation, 28% aqua ammonia is dropped into the $AgNO_3$ solution to make it transparent. Then a beaker is used to dip the yarn. Two clips are used to the top of yarn to remain it parallel position. Finally the dipping & curing processes are started. 5 min dipping & 5 min curing are taken in each cycle. Curing is done at 100 °C. Dipping & curing are continuing at a constant process. A cycle is completed after one dipping & curing. After fulfilling 150 cycle, 0.1 M glucose solution are put into the remaining $AgNO_3$ solution. As a result, maximum silver nanoparticles are associated with the fiber axis of yarn [1]. The schematic diagram of the overall procedure is shown in Fig. 1.

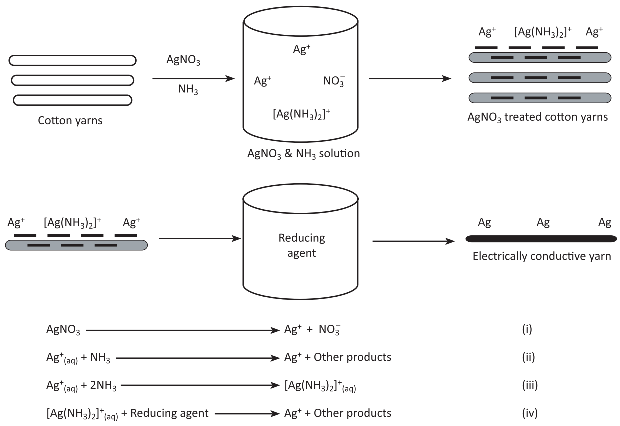

Figure 1. Process flow of sliver nanoparticle deposition on cotton yarns.

Finally conductive yarn resistor is produced. 1 cm stick is bound the yarn to rehash the conductive yarn resistor. A laptop source is used as voltage source & bread board is used for verifying KVL & KCL theory (Fig. 2) [18].

Figure 2. Conductive ring spun cotton yarn resistor.

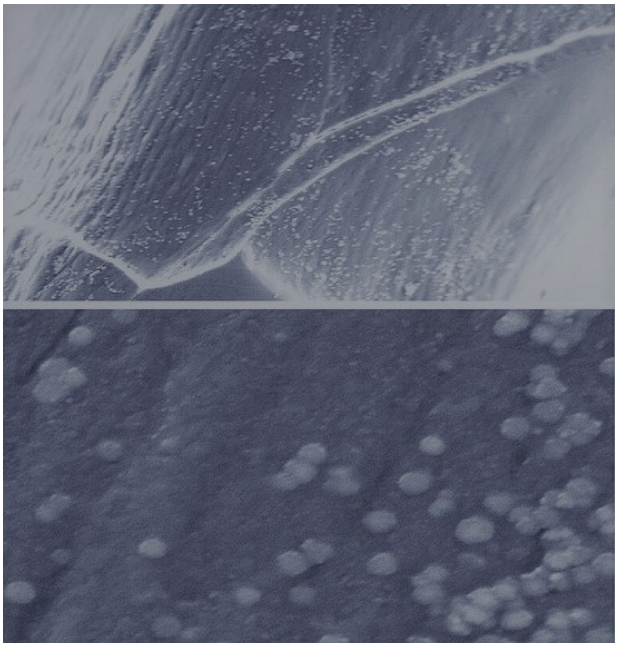

Figure 3. SEM image of ring spun cotton conductive yarn resistor.

Figure 3 shows the SEM picture of cotton conductive yarn resistor.

Nanoparticles are deposited on conductive yarn. Here, top image of 1 μm and bottom image is 100 nm ranges silver particles are deposited on conductive yarn. Two types of magnification are available here which are micrometer range and nanometer range.

3. Results and discussion

At first, resistance & electrical conductivity are measured by UT 33 A+ Multi-meter. For the convenience of calculation the resistance of the material is kOhm level and voltage of the material is taken into kilo voltage level. The values are in Table 1.

The graphical representation of resistance & conductivity is shown in Fig. 4.

It was measured by multimeter which model number was UT33A+. It can measure resistance up to kOhm level and measure current up to mA level.

It is shown that electrical conductivity is decreasing when resistance is increasing.

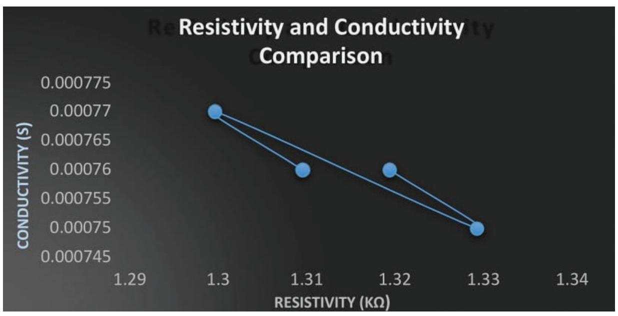

Figure 4. Horizontal line shows resistance & vertical line shows electrical conductivity.

Table 1. Four conductive yarn resistors resistance & their electrical conductivity.

Sample number	Concentration	Cycle	Resistance (kOhm)	Electrical conductivity (S)
1	0.3M	150	1.31	0.763
2	0.3M	150	1.30	0.769
3	0.3M	150	1.33	0.751
4	0.3M	150	1.32	0.000757

Here, unit of conductivity is Siemens.

3.1. Kirchhoff's voltage law verification.

Kirchhoff's voltage law is: **"***In any closed loop network, the total voltage around the loop is equal to the sum of all the voltage drops within the same loop*" [19]. The algebraic sum of all voltage value is zero in this theory. At first bread board is used to make circuit. Then the laptop computer source gives voltage flow and multi-meter is used to determine voltage value (Fig. 5).

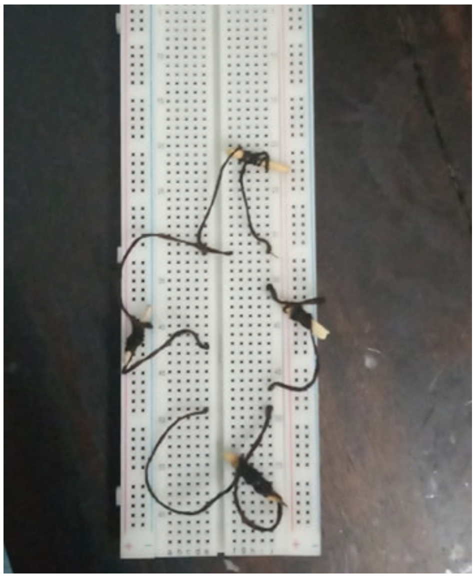

Figure 5. Conductive yarn resistor circuit in bread board.

The voltage values are originated from multi-meter. The circuit diagram of conductive yarn resistor is shown in Fig. 6.

The data of voltages are in Table 2.

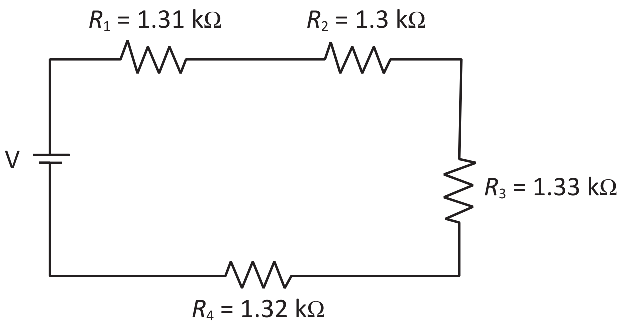

Figure 6. Circuit diagram of conductive yarn resistor.

Table 2. Voltage values of four conductive yarn resistor.

Sample number	Concentration	Cycle	Voltage value (kV)
1	0.3M	150	–0.21
2	0.3M	150	+0.20
3	0.3M	150	+0.33
4	0.3M	150	–0.32

Loop 1: voltage values are: -0.21kV + 0.20kV; (1)

Loop 2: voltage values are: +0.33kV – 0.32kV. (2)

The sum of voltages are: –0.21kV + 0.20kV + 0.33kV – 0.32kV = 0.

The Kirchhoff's voltage law is proved by conductive yarn resistor (Fig. 7).

From the Fig. 7, it is shown that concentration & cycle remain unchanged in the graph as it is going parallel. For that reason total values of voltage are zero.

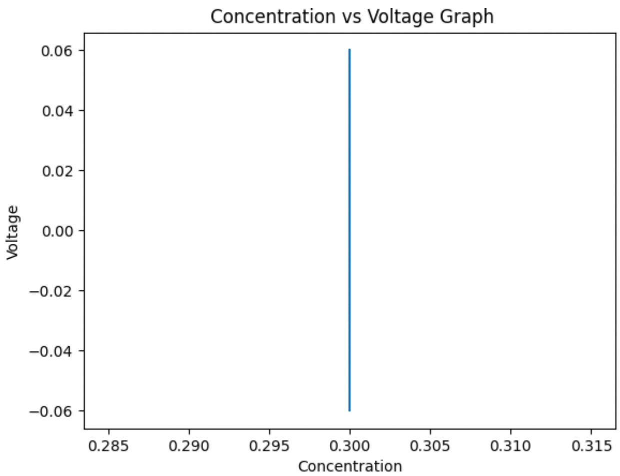

Figure 7. Graphical representation of voltage values of four conductive yarn samples.

According to Kirchhoff's voltage law, the graph is going to make a closed loop, because the values are at first in negative slope & then positive slope. So, finally it will create a closed loop.

3.2. Kirchhoff's current law verification.

The theory of Kirchhoff's current law is one of the fundamental laws in electrical engineering. It states that total current which enters a circuit junction exactly identical to the total current leaving the same junction [19]. This paper verifies Kirchhoff's current law by using conductive yarn resistor.

The data of current values are in Table 3.

Table 3. Current values of four conductive yarn resistor.

Sample number	Concentration	Cycle	Current value (Amp)
1	0.3M	150	–0.03
2	0.3M	150	+0.03
3	0.3M	150	+0.06
4	0.3M	150	–0.06

Loop 1: Current values are: -0.03A + 0.03A; (3)

Loop 2: Current values are: +0.06A – 0.06A. (4)

The sum of current values are: –0.03A + 0.03A + 0.06A – 0.06A = 0.

Kirchhoff's current law is proved by conductive yarn resistor (Fig. 8).

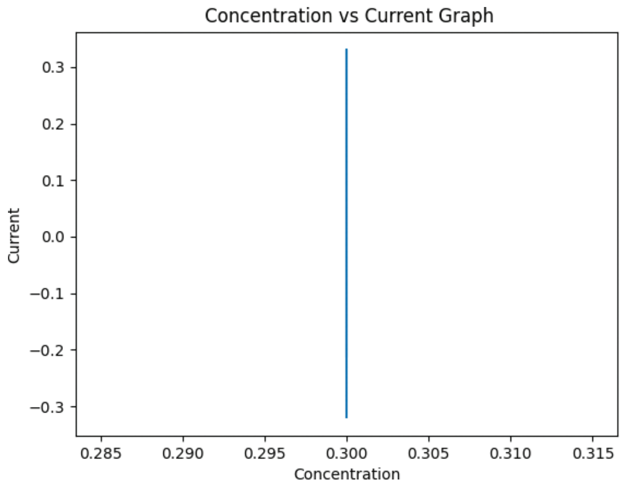

Figure 8. Graphical representation of current values of four conductive yarn samples.

From the Fig. 8, it is asserted that concentration & cycle remain unchanged in this graph , but consequences of Kirchhoff current law this graph is going to make a closed loop as it is going parallel. The total values of current are zero. It is going through negative & positive slope based sequence. So, this graph will create a closed loop from the law of Kirchhoff's current.

3.3. Heat durability test of cotton conductive yarn.

As here cotton conductive yarn is used as resistor, there is a relation between resistance & temperature. If the conductive yarn is not absorbed particular amount of temperature it will be burnt [20]. So heating durability test is important for cotton conductive yarn resistor. Temperature is given from 25 to 200 °C, then electrical resistance & conductivity are measured (Table 4).

Table 4. Heating durability of cotton conductive yarn.

Cycle number	Temperature (°C)	Conductivity (S)	Resistance (kOhm)	Time (min)
1	25	0.0076	1.3	5
2	50	0.0073	1.37	5
3	75	0.0069	1.44	5
4	100	0.0067	1.51	5
5	125	0.0063	1.58	5
6	150	0.006	1.65	5
7	200	0.0058	1.72	5

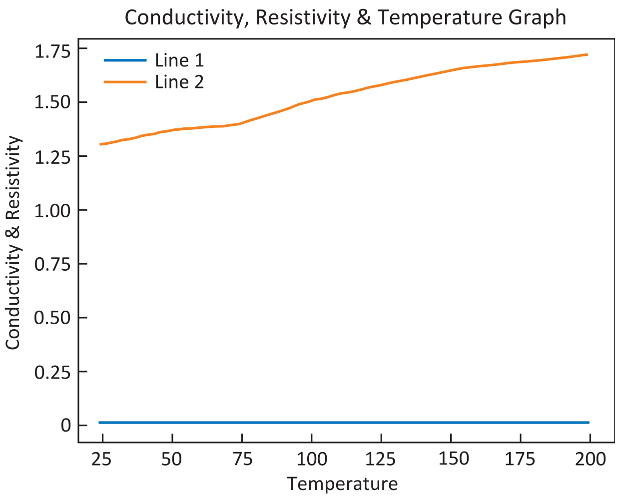

Figure 9. Graphical representation of heating durability of cotton conductive yarn.

The chart shows that when temperature is increased electrical conductivity is decreased & resistance is increased. In every cycle, time is remained in 5 minutes. Graphical representation of heating durability (Fig. 9).

From the Fig. 9 it can be said that, there is a disproportional relation between conductivity & resistance. It is acknowledged that metal shows this characteristics. So it is proved that after depositing silver nanoparticles insulator cotton yarn turns into conductive cotton yarn & it shows its conductivity through increasing temperature. Finally it is asserted that this conductive yarn is a heat durable conductive yarn. It is asserted that the resistor is using in KVL & KCL verification so that it is harmful to use in free hand without wearing gloves. Gloves should be taken of when experimental procedure is running.

3.4. Color fastness to perspiration test of cotton conductive yarn.

The textile material which come in contact with skin where perspiration can generate serious discoloration. The test is designed to determine the resistance of color of dyed textile to the action of acidic and alkaline perspiration.

Needed reagent to make perspiration test:

1. 0.5 g sodium hydroxide 5 gm sodium chloride and 2.5 gm di sodium hydrogen phosphate are needed. PH is remained 5.5 at 0.1 N sodium hydroxide solution.
2. Four cotton conductive yarns are recognized as samples. Specimens are placed between the two pieces of white cloth and sew along one side to boggle a composite sample.

Working Process:

1. Thoroughly a wet composite sample in a solution of pH 8.00 at the liquor ratio of 20:1 and it is remained in room temperature for 20 min. Pour off the solution and placing the sample between two glasses plates measuring about 7.5× 6.5 cm^2 under 4 kg weight in force.
2. Treat the other samples in the same way but with the PH of 5.5. Placing the apparatus containing the samples in the oven for 3 h at 37 °C.
3. Separate the samples from white cloth and dry them apart in the air at the temperature not exceeding at 65 °C. Access the change in color of the objects and the staining of the white cloth in grey scale.

The result of grey scale is listed in Table 5.

Table 5. Color fastness to perspiration test of cotton conductive yarn.

Specimens type	Color change in alkaline solution	Color staining on white cloth	Color change in acid solution	Color staining on white cloth
1	2–3	2	3–4	2
2	3–4	1–2	1–2	1–2
3	4	1	2	1
4	4–5	2	3	1

From the table, it is cleared that color staining on white cloth is generated only 1–2 times. It will not create any harmful effect in human skin [6]. Finally authors experimented the conductivity of four yarns according to normal, dry, wet and room temperature.

In Fig. 10, due to convenience of drawing graph average values of fours yarns are taken. The values are seized according to different temperature. The Fig. 10 shows exponential relation between temperature and conductivity. Conductive yarn behaves like a conductive material. Here, temperature is increasing when conductivity is decreasing. Again temperature is decreasing when conductivity is increasing.

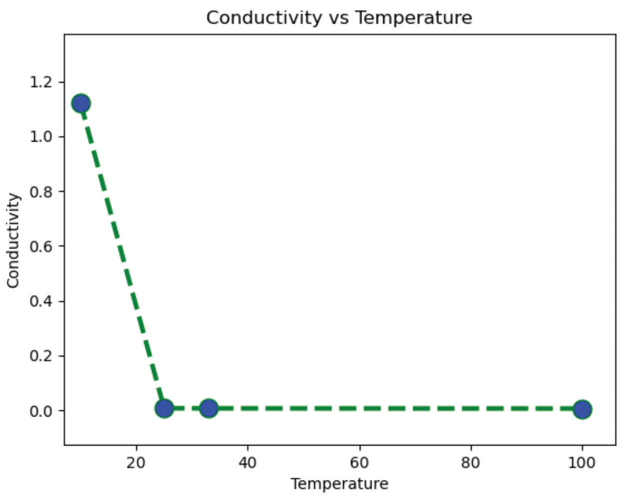

Figure 10. Graphical representation of temperature vs conductivity.

3.5. Point of view from sustainability concept.

It is recognized that business sustainability concept is put in three pillars. Economical environmental & social

Table 6. Electrical conductivity of different yarns according to different temperature condition.

Samples number	Normal temperature (33 °C)	Dry condition (100 °C)	Wet condition (10 °C)	Room temperature (25 °C)
1	0.0072S	0.0067S	1.2S	0.0076S
2	0.0070S	0.0065S	1.0S	0.0078S
3	0.0073S	0.0068S	1.00S	0.0075S
4	0.0071S	0.0064S	0.98S	0.0074S

(light weight). Single morsel of carbon resistors weight is 0.001375 kg. On the other hand conductive yarn resistor weight is 0.0005 kg. Conductive yarn resistor is 0.000875 kg which is lighter than carbon resistor. People can use this resistor very easily. Now in case of economical position, from the India mart website & local market in Bangladesh, 2000 kg cone package of yarns price are 160 Tk (1 USD = 85.01 Tk). So, 0.0005 kg conductive yarn price is 0.00004 Tk. The additional cost is only chemical cost. $AgNO_3$ is used only 2.54 gm for four sample yarns. $AgNO_3$ cost is 1.40 Tk per yarn. Glucose cost is 0.25 Tk per yarn. Other costs are ammonia & distilled water. Ammonia is required one drop to transparent the solution. One solution is made for four conductive yarns so that the costing part of ammonia is very negligible. Distilled water cost is 0.25 Tk per yarn. Total cost is 1.9 Tk per yarn. In market, each carbon resistor price is 2tk per piece [21]. 10 cent is very much cost effective for bulk production. In 1 lot, at least 5000 pieces of carbon resistor exists. If it can be made commercially, it takes profit 1500 Tk from one lot of carbon resistor. Conductive yarn resistor is made from natural cotton fiber. Cotton is a cellulosic fiber [22]. It is one of the abundant natural fibers in the world. The qualitative properties of cotton fiber are biodegradable. It is disposed in the soil. But carbon is not biodegradable [23]. It emits CO_2 when it is closed at nature. From this perception, cotton conductive yarn resistor is environment friendly. So, it can be said that cotton conductive yarn resistor is a sustainable material. Apparently, silver is not as cheap as carbon. Carbon is an available material to make resistor. But In chemical processing cost of per yarn & costing of per yarn are lower than carbon resistor. The main advantage of conductive yarn resistor are its lite weight and flexibility.

In Fig. 11, category 1 is the conductive yarn resistor weight, category 2 is the conductive yarn resistor making cost, category 3 is the conductive yarn resistor profit from one lot of resistor & category four is the biodegradability which will hatch prosperous environment impact.

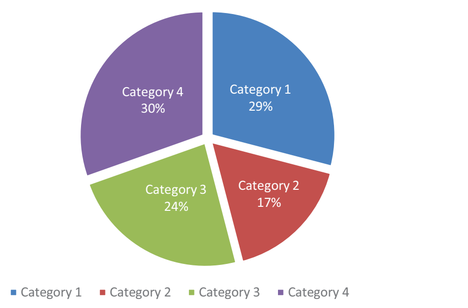

Figure 11. Impact of sustainability from cotton conductive yarn resistor.

4. Conclusion

This study proves that using conductive yarn resistor is better than carbon resistor. As, conductive yarn resistor is more flexible than carbon resistor, it is helpful for using electrical laboratories. Besides using electrical laboratories conductive yarn can be used in making cardiac supporting device & high performance based electrical apparel. Every electrical equipment, resistor is used to make that product. The requirement of resistor is increasing day by day. Most of the cases carbon resistor is availed as a resistor. This experiment prospects that cotton conductive yarn resistor is a sustainable material. It gives more effective result than carbon resistor. In this research, most implant theory of KVL & KCL are proved by cotton conductive yarn resistor to ascertain its working ability.

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Each of the author do their responsibilities regarding this research work. Redwanul Hasan is a corresponding author and first author of this research work. Minhazul Islam Minhaz draws the figure and simulation of the results and discussion. Sazid Hossain Shipan helps to manage references.

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