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An approach to Health Index Estimation using Dissolved Gas Analysis (DGA)

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ABSTRACT: The transformer condition monitoring is very essential for the efficient functioning of the overall electrical power system. Health index (HI) calculation of transformer proves to be a useful technique to analyse the remnant life period of the asset and assists to take required measures. This paper presents a methodology to prognosticate the health index by utilizing diagnostic oil measures like transformer oil dissolved gas analysis (DGA) and creating fuzzy sub models. The integrated fuzzy model proposal helps in reducing complexity in the appraisal of HI. Thus the health index emerges out to be a very helpful tool for forecasting the maintenance of transformers and guides to take appropriate actions in time. Techniques of conventional DGA interpretation are used to analyse the conclusions and then the performance from present proposed model were cross referred with results of the fuzzy model output.

KEYWORDS: Transformer, Health index, DGA, Fuzzy logic, Membership function.

I.INTRODUCTION

In today's modern world the top concern of the power utilities is the effective working of all the assets at a minimal cost over their lifetime. The transformers are the key assets that represent a notable expenditure in the power distribution network. They are the fundamental elements of the grid network that are introduced at every level from generation to transmission to distribution and hence their breakdown can result in a severe catastrophe. Hence its consistency of operation cannot be compromised as it may result to severe economic as well as social loss to the utilities and consumers respectively. Failure of these assets may lead to adverse effects on the industrial and commercial sectors and hence leaving behind a negative impact on the residential sector which are the end users of electricity.

Transformer comprises a major part in the electrical grid network and so from the entire installed appliances in the electrical power system, transformers comprises the highest cost of installation incorporating nearly about 60% of the entire installation cost thus resulting in an expensive asset in terms of reinvestment. Hence it becomes quite essential to monitor the health of the transformer at regular intervals of time for its lifelong working experience.

Transformer life span is directly proportional to its insulation condition. The degradation of its insulation results in the decrease in the life span of the asset. Significant information is provided from the solid and liquid insulations condition which helps in the health assessment of the transformer. Various stresses act on the transformer during its working such as thermal, mechanical, electrical, environmental and climatic which weakens the insulation. As a consequence the withstand capability of the transformer decrease with respect to system disturbances like high voltages and short circuit failures. The frequently occurring faults include arcing, corona, sparking, overheating.

Transformer condition monitoring is very essential for its practical maintenance which helps the power system to operate reliably. Health index acts as a good technique for assessing the state of the transformer; as it also assists to identify for its predictive maintenance. The interconnection between the different criticalities is not taken into account in conventional condition monitoring strategies, whereas the health index introduces the overall health of the transformer by considering the interaction between different measures. Thus, the health index indicates the proximity of the transformer to the end of life. With this data the utilities can identify which transformers require an immediate replacement and what precautionary measures needed to be taken.

Because of the electrical and thermal stresses and the occurrence of faults, oil and paper decomposes and evolves certain gases which reduces the dielectric strength of oil. The gases that evolve as a result of oil decomposition are H_2, CH_4, C_2H_6, C_2H_4, C_2H_2. Similarly paper decomposition emits CO and CO_2. The dissolved gas analysis (DGA) is the report of the dissolved gases in transformer oil. The gases in the oil are extracted and analysed in a DGA test to determine the amount of gases in a given volume of oil. In accordance with IEC 599, which is the DGA Oil

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Interpretation Guide for Mineral Oil, oil is considered as natural if the values of the 7 key gases extracted from DGA outcomes are lower than those given in the table below.

Table 1
Normal DGA values in Mineral oil

Gas	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	CO_2
Ppm	100	120	65	50	35	350	2500

II.CAUSES OF TRANSFORMER DEGRADATION AND FAILURE

There are several parameters which lead to the deterioration and failure of transformer over its lifetime operation. In order to create a proper health index model it is also necessary to identify these deterioration mechanisms and list them out.

a) *Transformer Core :*

The core of the transformer performs the role of leading the magnetic flux with minimum losses from one winding to another. In order to do that it should have high permeability and low magnetic reluctance so as to resist losses due to eddy current. To minimize the eddy current losses the core is laminated and coated with an insulating agent. During transportation or due to construction error, the insulating layers between the laminations can undergo damage resulting in short circuit in the middle of the laminations and causing circulating eddy currents and production of heat.

b) *Transformer Winding :*

Windings are the fundamental part of a transformer. Their failure is known to be one of the most severe failure a transformer may encounter. In case of distribution transformer there is a continuous flow of low and high currents through primary and secondary windings respectively. These windings tolerate thermal, dielectric and mechanical stresses during this process. These stresses lead to the occurring of faults in the windings resulting in the breaking of winding or their burn-out.

1) Winding are generally made up of copper. Thermal losses occur due to the copper line resistance, and hotspots are formed in the winding. This results in a decrease in physical strength upto the breaking point of winding and causes wear and tear as well.

2) Windings result in the deterioration of the insulation when exposed to high currents and voltages greater than the rated values. The breakdown of insulation contributes to the flashover between the turns of the winding and causes short circuits. The impulse lightning attack and fault voltages are the key factors for high scores.

3) Mechanical stress occur due to the distortion, loosening or displacement of the windings. The main reasons that cause mechanical faults are the defects during manufacturing process, improper repair and vibrational conditions.

c*) Oil :*

In transformers, mineral oil is used as insulation. It serves as an agent for cooling and also allows the heat of the transformer to dissipate. The gas and chemical compound content of oil acts as a vital source of knowledge relating to the internal state of the transformer. The issue of corrosive sulphur in oil has emerged in recent years. Corrosive sulphur in the oil reacts with metals like copper to form partially-conducting compounds that can accumulate in the transformer tank's internal surfaces, arising chances of short circuit failure. The oil which is used in transformer undergoes oxidation, as a result of which acid and sludge formation takes place. The acids stimulate the age of the paper insulation while the generated sludge is not soluble in the oil and precipitates at the base of the tank and obstructs the cooling mechanism of the transformer. Naphtha based transformer oil has less sludge formation as compared to paraffin based transformer oil.

d) *Tank and Auxiliary appliances:*

The transformer tank functions as a container for the oil and also plays vital function in safeguarding active parts and insulation systems from external damages like mechanical damage and moisture content. Further it enables the expansion and contraction of the oil without an explosion and adds up to cooling through its design. Because of environmental stresses, high moisture content and corrosion, cracks and leakages occur inside tank walls. Oil leaks

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from the tank resulting in oil reduction from these cracks. This oil reduction leads to two causes:(1) Reduction in transformer insulation (2) Overheating, as cooling function is reduced on account of less oil.

III.PROPOSED METHOD

The evaluation of health index of transformer is based on the concept of fuzzy logic. Here, thermal and electrical criticalities are taken into consideration for the analysis of health index. For the thermal and electrical conditions assessment the test sample values of key gases detected from the DGA test were taken into account from (5). Further this data was utilized as input for determining the health index.

The present work is carried out using MATLAB's graphical user interface (GUI) tool. The scores obtained from transformer attributes like individual DGA analysis are employed as inputs in the suggested fuzzy model. The architecture is arranged in accordance with the following block diagram as presented in fig(1). The input quantities of the model are the 7 key gases in parts per million (ppm). The output of the model gives ranking of the transformer.

IV.BLOCK DIAGRAM

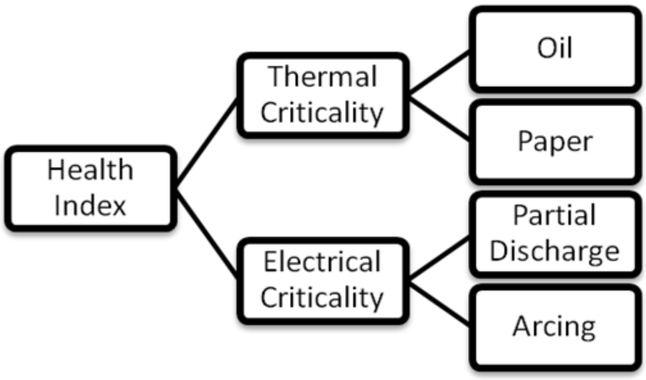

Fig 1. Block diagram representation of Health Index

V. STUDY OF FUZZY

Fuzzy logic can be viewed as a methodology for computing with words rather than numbers. Here, a set of fuzzy membership functions (MFs) and rules are used rather than mathematical or Boolean logic for evaluation of the data. In current work trapezoidal type membership functions are being used to interpret the inputs. The trapezoidal shaped MFs are more fitting to reflect the differences in various distinctive test outcomes of the transformer insulation compared to gaussian and triangular shaped MFs(4).

For the representation of diagnostic facts, a collection of fuzzy logic rules are generated similar to IF-THEN type statements that connect the input quantities to the output that helps to accurately evaluate HI. In the fuzzy logic system, the rules are basically in the form as follows : If a is less and b is more then c=moderate where a and b are input quantities and c is an output quantity. Here less, high and moderate are the membership functions specified on a, b and c respectively. Individual fuzzy logic sub-models are developed for the electrical and thermal criticalities and later on they are integrated to formulate the HI of the transformers.

VI.TRANSFORMER CRITICALITIES

Transformer criticalities are categorised depending upon the various criterion and functions it may face during its working duration. Here some of the criticalities are listed in the table shown below which helps to interpret the health assessment. The gases which are involved in the particular sub criticality and their indicating parameter are elaborated in the given table.

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Table 2
Criticalities of transformer and their indicating factors

Sr. No	Transformer criticalities	Indicating Parameters
I.	Thermal Criticality	
	Oil	DGA - Ethane & Ethylene
	Paper	DGA - Carbon Monoxide & Carbon Dioxide
II.	Electrical Criticality	
	Partial Discharge	DGA - Hydrogen & Methane
	Arcing	DGA - Hydrogen & Acetylene

A. Thermal criticality oil

The main gases that are emitted as a result of oil decomposition are ethane C_2H_6 and ethylene C_2H_4. With the aid of DGA, these gases are detected. A fuzzified sub model is created to evaluate the thermal criticality of oil. These gases are fed to the fuzzy oil thermal criticality model as an input. Ethane and ethylene membership functions (MFs) are configured considering a range of 0-150ppm and 0-220ppm respectively. The output of oil thermal criticality is scaled from 0-1 considering severe while approaching to 1.

B. Thermal criticality paper

The gases which are evolved due to the degradation of paper are CO and CO_2. The values of these gases in ppm are fed as inputs to the paper thermal model. A range of 0-1800ppm for CO and 0-1500ppm for CO_2 is selected from IEEE standard. The output MF is taken from 0-1.(normal to significant).

C. Overall thermal criticality

The combined thermal criticality can be obtained by uniting the separate models of oil and thermal criticalities. The outputs of these separate models are fed as inputs to the overall combined thermal model. The output is ranged from 0 to 1.

D. Electrical criticality (PD)

The partial discharge operation in transformer creates a peak H_2 level and a significant CH_4 gas level. Hydrogen and methane MFs are considered in the scale of 0-2000ppm and 0-1200ppm respectively. The output MFs are computed on a scale 0-1.

E. Electrical criticality (Arcing)

Arcing is a serious concern in transformer. It is a type of electrical criticality which should not remain for a longer duration. The principal gases which evolve during arcing are H_2 and C_2H_2. The MFs used for these gases are in the range 0-1800ppm for H_2 and 0-80ppm for C_2H_2 an output ranges from 0-1.

F. Overall electrical

The electrical overall criticality is evaluated by combining the partial discharge model and arcing criticality model. The outputs of these individual models are provided to the combined model and the output MF is ranged from 0-1 for the overall model.

G. Overall criticality DGA

The final overall model for the DGA criticality is gained by considering all the 7 key gases obtained from various criticalities and integrating them in the overall fuzzy model of health index as demonstrated in fig. 3. The resultant result is measured in the range from 0 to 1.

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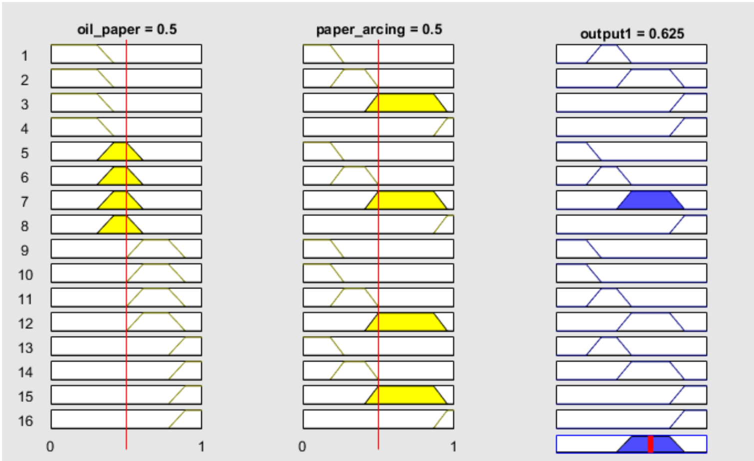

Fig 2. Rule viewer of the fuzzy system

VII.RESULT AND DISCUSSION

The evaluation of health index is carried out using the different criticality models and later integrating them to find the overall health index. Thermal condition which includes oil and paper criticalities and electrical condition which includes partial discharge and arcing criticality are used to find the health index with minimal data available. The sample values from the DGA data given in [5] are utilized and used for estimation of health index using different rule base system. Results show that the proposed system values are approximate near to some samples while in contrast to some other. There are 3 transformers that are in good condition whereas samples 1,2,5,9 and 10 are under poor conditions. Samples 6 and 8 are ranged under normal conditions.

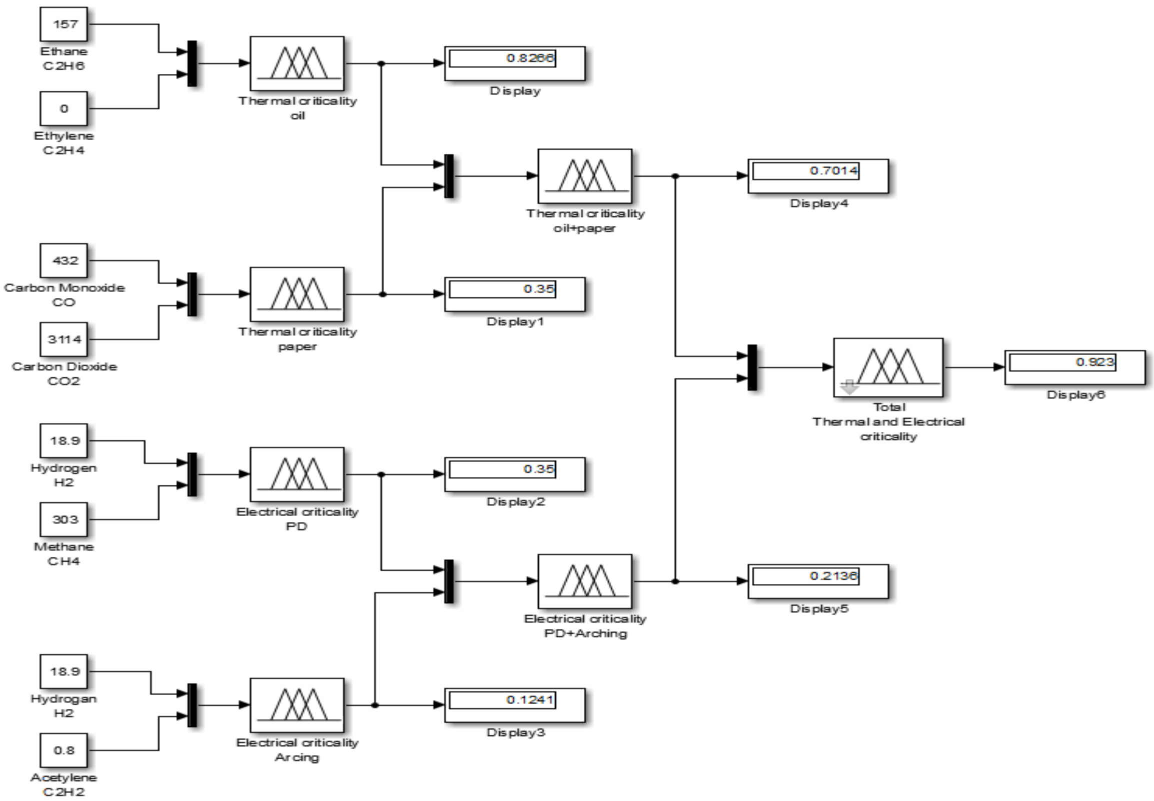

Fig 3. Health Index fuzzy model

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Table 3
Proposed model output with DGA values

Sample	C_2H_6 (ppm)	C_2H_4 (ppm)	CO (ppm)	CO_2 (ppm)	H_2 (ppm)	CH_4 (ppm)	C_2H_2 (ppm)	Combined Thermal and Electrical Fuzzy model Output [5]	Proposed Fuzzy Model Output
1	514	2824	748	6021	53	49.2	31	0.9837	**0.942**
2	2.9	0	11.8	787	12	325	108.5	0.832	**0.8894**
3	0.6	0.7	33.6	322	0	2.2	0	0.207	**0.09227**
4	57.2	0	140	1879	0	19.3	0	0.35	**0.135**
5	157	0	432	3114	18.9	303	0.8	0.83	**0.923**
6	16.4	6.02	219.2	9909	0	46.3	0	0.829	**0.6792**
7	0.6	0.7	33.7	327	0	2.08	0	0.215	**0.09227**
8	60	47	159	3303	0	18.8	0	0.61	**0.4893**
9	4834	11990	317	2959	12	8778	18.7	0.988	**0.9505**
10	88.2	0	123.7	66260.6	0	73.4	0	0.837	**0.905**

VIII.CONCLUSIONS

This paper introduces a procedure for calculating health index based on the DGA data collected. Here fuzzy logic approach is used considering criticalities like thermal and electrical to interpret the result from minimum data. The prominent gases which evolve during DGA is given priority to analyse the overall criticality. Results show that the fuzzy model extracts and interprets information and provides effective logical conclusions. The accuracy can be increased if the number of membership functions and rules are increased.

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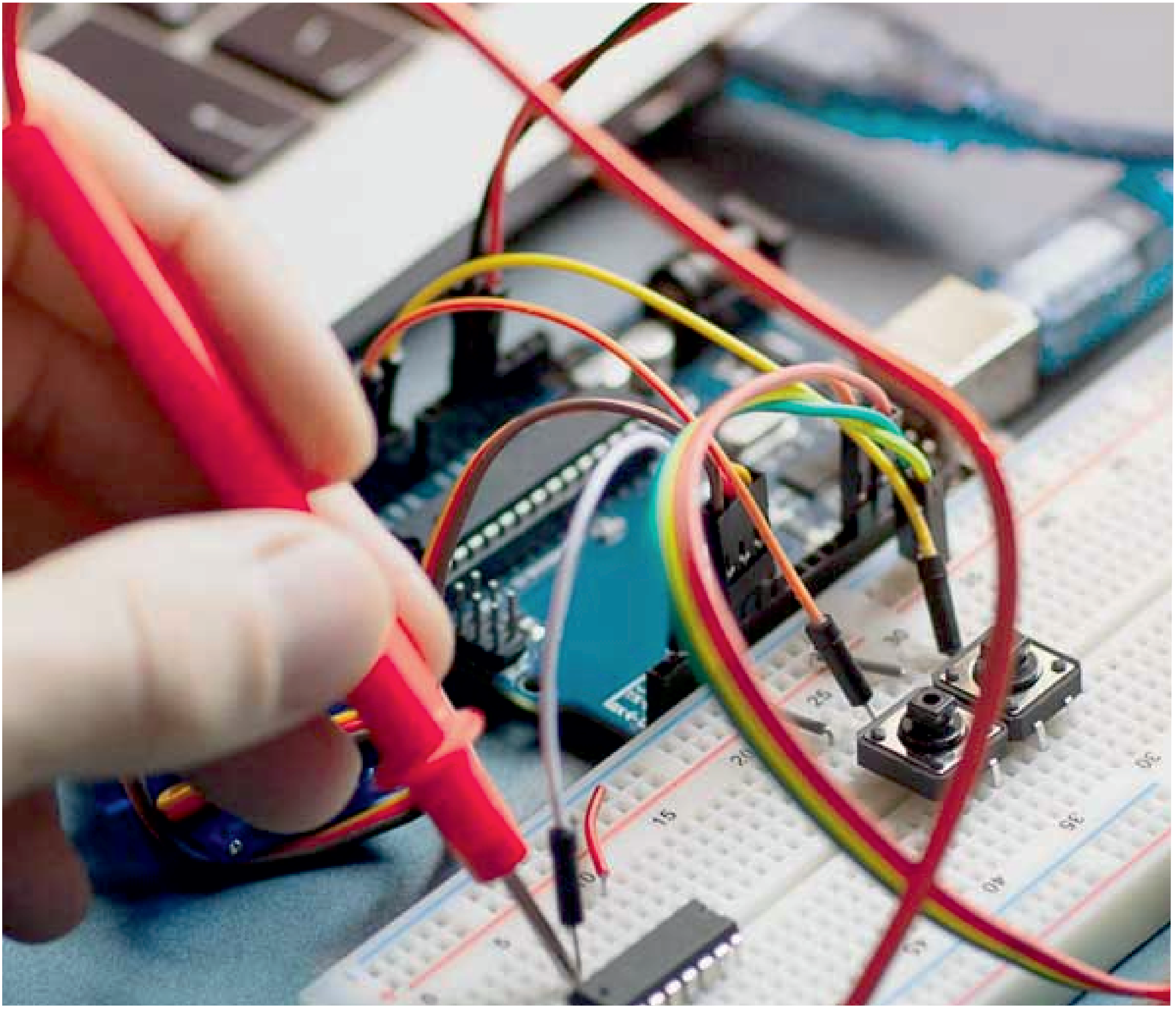

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