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Modern Trend of Power System Components Coordination Using Static Load Model

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ABSTRACT: Power system components coordination is a representation of an overview of the power system from the generator to the customer with a deliberate attempt to allow for an efficient power flow. This study was a carefully prepared solution based method for the establishment of a well coordinated typical power system. Static load model was used to accomplish and profer solution to the problem of power system components coordination. Relevant data such as static load in KVA, transmission and distribution route lengths, generator rating, step-up transformer ratings, step-down transformer ratings, injection substation transformer ratings, distribution transformer ratings, system frequency, generation voltage, transmission voltage and distribution/customer voltage were collected from National Control Center, Transmission Company of Nigeria. The data collected coupled with the static load model developed were analysed in ETAP and it showed that the voltage magnitudes for buses 1, 2, 3, 4, 5 and 6 were 1p.u, 0.9973p.u, 0.9977p.u, 0.9975p.u, 0.9972p.u and 0.9980p.u respectively. The total load in the system became 1.67MW on load buses (buses 2,3,4,5 and 6) and 1.672MW on the generator bus being bus 1 (slack bus) with a difference of 0.002MW in the system.The study showed a method capable of providing a quick solution based approach to power system components coordination.

KEY WORDS: Power System, Static Load Model, Load Bus, Generator Bus, Transmission Lines.

I. INTRODUCTION

The major parts of a power system consist of generating station, step-up transformers, transmission lines, step-down transformers, distribution lines, distribution transformers and customer load. Most power systems generate power at a frequency of either 50HZ or 60HZ AC, and most residential single phase voltages are either 120V or 240V [1]. Power systems with improper components coordination will always develop active and reactive powers mismatch. Load flow in poorly coordinated power system is usually difficult to define.

An electric power system is comprised of generating units which produces electricity, high voltage transmission lines for transportation of electricity over a long distance and distribution lines for delivering of electricity to customers-substations that interconnect all stations and energy control centres obliged to coordinate the operation of the various system components [2].According to Aditya et al. [3], power is generated in generating station, transported via transmission line and distributed to customers. According to Dharamjit & Tanti [4], load flow studies are essential because they allow for electric power transfer from generators to customers via the grid system to be stable, reliable and economic.

Based on the above professional hints, it is pertinent to use static load model that is solution based capable of identifying input and output of the power system. This is adequately necessary because load flow may be halted if the components are not properly linked to each order.

II. RELATED WORKS

A generating station also known as power plant is usually a facility where electric power is produced. The two major parts of a generating station are the turbine that converts the prime mover into mechanical power that turns the generator and the generator itself that converts the mechanical power into electrical power. The prime mover is usually in the form of steam, water, wind or a combustion engine. The majority of the generators today use steam as the prime mover which is produced by the burning of fossil fuels such as coal, oil, or natural gas or by nuclear reactors. These types of stations are normally referred to as thermal generating station. Where nuclear reaction is used to make steam it is referred to as a nuclear generating station while stations that harness the power of water are referred to as hydroelectric generating stations. Wind generators usually do not have stations, but have several generators in an area

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that are referred to as wind farms [1]. The prime mover must be able to turn the turbine, which is connected to the shaft of the generator, to convert the energy in the steam, wind or combustion engine into work. Steam turbines, gas turbins, water turbines and wind turbines are all specially designed to convert the prime mover in the most efficient manner into work, and they are all very different in size, shape, and design. A generator converts mechanical power from the turbine to electrical power by a rotating magnetic field inducing a voltage by electromagnetic induction. Using the same principles as an alternating current motor which converts electrical energy into mechanical energy, an alternating current generator converts mechanical energy into electrical energy. The AC motor needs an electrical connection to make it turn, and the mechanical output is used to turn a pump or a fan etc [1].

Power utility generators can range from 1MW to 1000MW with voltage ranges from 0.6kV to 24kV. A small 1.5MVA wind gerator would be normally operated at 0.6kV where a large gerator such as in a nuclear power plant would operate at 24kV. Most electrical power systems operate at 50HZ or 60HZ AC frequency. One cycle of alternating current is produced each time a pair of field poles passes over a point on the stationery winding. Thermal generators are powered by burning a fossil fuel (such as coal, gas, oil, diesel or natural gas) to heat a boiler. Water pipes pass through the boiler that turns the water into steam. The steam is used to turn the turbine, which is connected to the generator. Coal burning generating stations are the most common type of generator worldwide. The coal handling is quite complex as the coal blown into the boiler. Coal burning stations still rely on gas or oil to light off the boiler before the coal is used. Hydro generators are powered by falling water turning a turbine or water wheel [1]. The difference in height between the water at the intake of the power dam, called the forebay and the place where the water disdischarged, called the tailrace, provide the energy to turn the turbine. The differenc in elevation between the forebay and tailrace is called the head and is one of the factors that determine the potential for generating power. The other factor is the volume of water available. Some Hydro plants are run of river, which means there is no water storage and the plant passes whatever the river flow is to generate power. Other plants have a natural or man-made lake in which water can be stored and discharged when needed. Nuclear generators have a uranium fuel source. By the splitting of atoms, called fission, heat is produced in the reactor core. There are basically two types of reactors, heavy water reactors and light water reactors. Heavy water reactors have two water systems where the heavy water passes the heat from the nuclear reactor core to the boiler. There is a second independent water system that is converted to steam which turns the steam turbine. Light water reactors have only one water cycle and the same water that is in contact with the reactor core goes on to produce steam which turns the steam turbine [1].

Gas turbines or combustion turbines are made up of a compressor that brings the air to a high pressure and temperature. A combustion chamber isusually available for the fuel source is added. Next is the turbine where the heated energy is converted to mechanical energy where there is the generator where the mechanical energy is converted to electrical energy. These types of turbines are approximately 30% efficient. Combined cycle gas turbines or combustion turbines were developed to make the gas turbine or combustion turbine generators more efficient. The first part of combined cycle gas turbines work the same way as a gas turbine. The difference is the heat from the gas turbine's exhaust still has a lot of energy left in it, and a combined cycle utilizes that energy. The heat of 1 to 4 gas turbines is collected in a recovery system and is used to boil water and create steam. This steam is then used to turn a system turbine which turns a generator. Combined cycle gas turbines are approximately 60% efficient compared to the 30% of a gas turbine. Wind generators range from 1.5 to 5MW and are most often built in groups called a wind farm. The wind farms are further grouped as on shore and off shore. Many power companies have built the generators off shore in large bodies of water. The main factor is to construct a wind farm in an area that has consistent and high winds. The two basic systems are PhotoVoltaic Parks and Concentrated Solar Power. The main factor is to construct a solar farm in an area that has sunny days [1]. The electric power system has many circuit breakers between the generator and the customer. The electric power system has high voltage circuit breakers capable of connecting and disconnecting electrical equipment such as generators, transformers, lines and associated equipment. Circuit breakers are normally commanded to open or close by the Dispatchers or are operated by protection systems. There are many types of circuit breakers and interrupting medium with examples as air blast, bulk oil, minimum oil, gas, mixed gas and vacuum [1].

The generator always produce a voltage that is at or near most distribution voltages. When the generator and load have some distance between them, it is not practical to transmit the generator voltage a long distance. Most generators have step transformers to match the generator voltage to the transmission line voltage. These transformer usually have off load taps meaning that the taps can be moved only when the transformeris de-energized while some have on load tap changers which can be adjusted with the transformer energized [1]. As one of the major elements or components of an electric network, power transformers have been considered a major focus of a great number of studies with regards to various issues involving diagnostic methods, fault detection and the effects of loads in them [5].Transmission lines

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consist of tower footings, tower, insulators and the line conductors. High voltage transmission lines are the most effective way of getting the power from the generating station to the load and to interconnected power stations. Overhead lines and cables differ in design, costs, environmental impact, and appearance. Overhead lines may have up to 80 years life span while underground cable may last up to 40 years. Overhead lines have insulator at every tower and can dissipate heat by the surrounding air while the underground cable is coated with insulator [1]. The moment transmission line has delivered the power from the generator, the voltage is reduced to distribution/customer value. The distribution voltage is further reduced to usable level for residential and commercial customers as every customer is supplied from a distribution transformer.

According to Ujjavala & Rajni [6], the aim of power flow computations remains to establish the steady state operating characteristics of a power generation/transmission system for a given set of loads. Static load models have become very important because in load flow studies they present active and reactive power as functions of the bus voltages [7]. According to Murthy et al. (2014), a static load model is a model in which power cannot vary with variations in voltage magnitude and can be referred to as constant MVA load model. After the generation of electricity in power plants it is delivered through the transmission network to distribution network for customer use [9]. Load flow can be seen as the procedure used to obtain the steady state voltages of electric power systems basically at fundamental frequency [10]. Power flow analysis reveals the electrical performance and power flows which are essentially real and reactive for known conditions provided the system is operating at a steady state [11]. It is very imperative to conduct load flow study as it is geared towards finding the magnitude of voltage, phase angle, real power and reactive power of the system [3]. Load flow analysis using software is accurate and gives high reliable results [12].

III. MATERIALS AND METHOD

Major part of the data desired to provide adequate insight for this study were sourced from National Control Center, Transmission Company of Nigeria. The method and procedure adopted in this study are shown accordingly.

To establish a comprehensive power system components coordination that will guarrntee uniterrupted load flow and zero power mismatch, a power system comprising of a single generator through the transmission segment down to the customer was designed and considered appropriate as a test case. In the course of doing this, appropriate measures were taken in relation with network spcifications as provided by National Control Center, Transmission Company of Nigeria.

Data collected in conjunction with the ones generated served as input data to model and run load flow analysis using ETAP 12.6 software to ascertain the load flow of the network. Static load model approach was used to calculate the bus loads to be embedded in ETAP software to ascertain total load consumed at the generator point devoid of power mismatch. Bus 1 (generator bus) was considered the slack bus while buses 2, 3, 4, 5 and 6 were considered load buses.

Table 1 Data Considerations Made in Software

S/N	**Parameter**	**Unit/Dimension**
1	Static load (Total)	1670KVA
2	Transmission line route length	15km
3	Total distribution lines route length	35km
4	Step Up transformer rating (generator side)	168.2MVA
5	Step Up transformer % impedance	13%
6	Inter-bus transformer rating (generator side)	150MVA
7	Step Down transformer % impedance	12.27%
8	Step Down transformer rating (transmission)	60MVA
9	Injection substation transformer rating	15MVA
10	Injection substation transformer % impedance	11.10%
11	System type	3-phase AC
12	Generation voltage	11kV

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13	Transmission voltage	132kV
14	Distribution voltages	33kV and 11kV
15	Distribution transformers	500KVA
16	System frequency	50HZ

In a polynomial configuration

$$P = P_0(a_0 + a_1V + a_2V^2)$$
$$Q = Q_0(b_0 + b_1V + b_2V^2)$$

Where
V is the p.u value of the bus voltage.
P_0 and Q_0 are the real power and reactive power consumed at the specific bus under the reference voltage.
For all the loads, equations (1) and (2) are modelled as:
$a_0 + a_1 + a_2 = 1$ (1)
$b_0 + b_1 + b_2 = 1$ (2)
a_0 and b_0 are the parameters for constant power load component where

$$a_0 = b_0 = 1$$

and
$a_i = b_i = 0$ for $i = 1, 2, 3.$
a_1 and b_1 are the parameters for constant current (1) load component where

$$a_1 = b_1 = 1$$

and
$a_i = b_i = 0$ for $i = 0, 2, 3.$
a_2 and b_2 are the parameters for constant impedance load component where

$$a_2 = b_2 = 1$$

and
$a_i = b_i = 0$ for $i = 0, 1, 3.$
For the purpose of this case at hand, the network is modelled using static load model approach such that:
$P = P_0\left(\frac{V}{V_0}\right)^{np}$ (3)
and
$Q = Q_0\left(\frac{V}{V_0}\right)^{nq}$ (4)
Where
np and nq are the parameters while P_0 and Q_0 are active and reactive powers at unity voltage conditions.
Following that
$P = P_0\left(\frac{V}{V_0}\right)^{np}$
Where
np =1
and
$V = V_0$at unity pf
If $V = 0.415$kV then P in the load buses become:
Bus 2 = 330kw, Bus 3 = 330kw, Bus 4 = 340kw, Bus 5 = 335kw and Bus 6 = 335kw

From the static loads so far realized coupled with the network parameters, the network components are linked and load flow analysis was performed in the following way.

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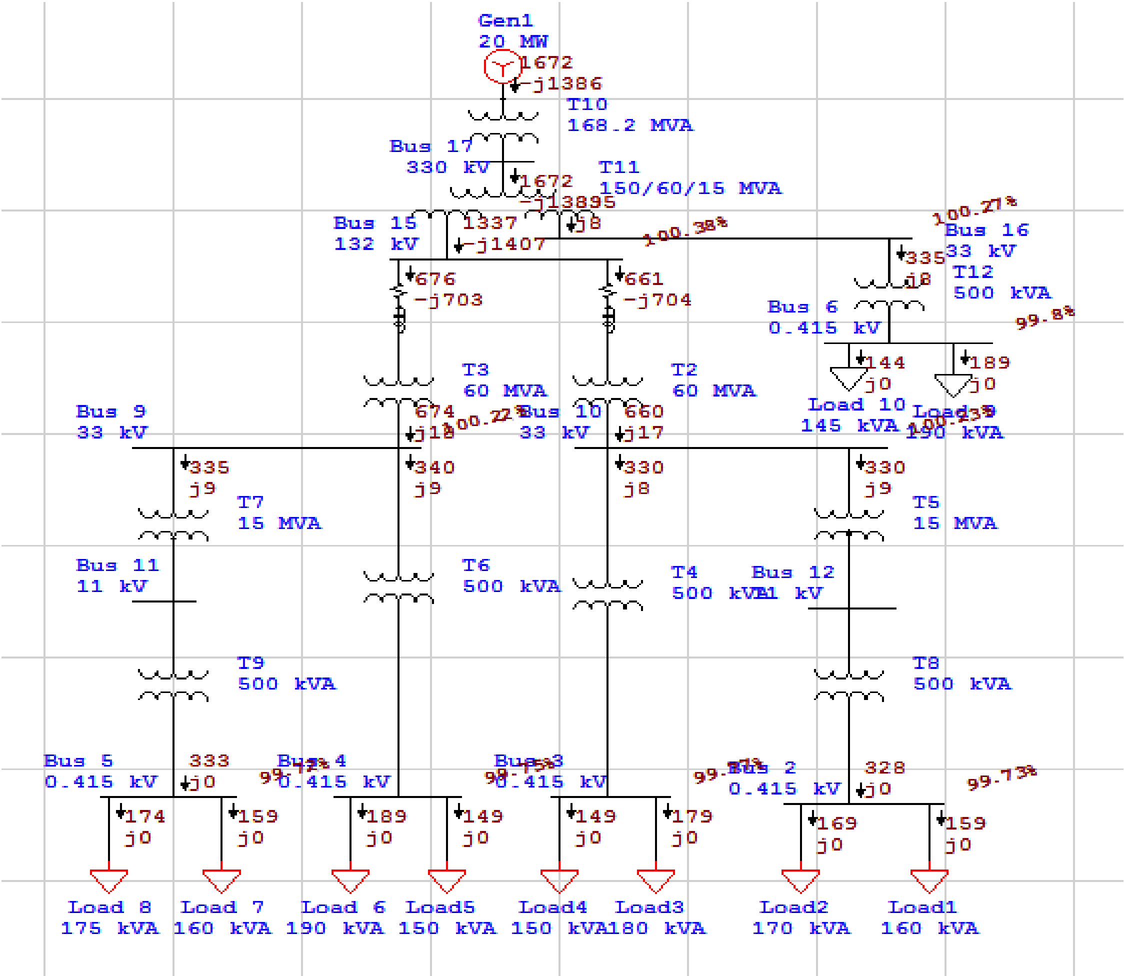

Fig. 1 Load Flow Analysis of a Power System with a Generator and 5 Load Buses in ETAP 12.6 Software

IV. RESULTS AND DISCUSSION

The results obtained from the power system load flow analysis with regard to voltage profile and load in the system are shown in tables 2 and 3 and figs. 2 and 3 respectively.

Table 2 Voltage Profile of the Power System

BUS NUMBER						
	BUS 1	BUS 2	BUS 3	BUS 4	BUS 5	BUS 6
VOLTAGE MAGNITUDE (P.U)	1	0.9973	0.9977	0.9975	0.9972	0.9980

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Table 3 Comparing Load Flow, Bus Loads and Load on Generator Bus

LOAD IN THE SYSTEM	LOAD BUS	GENERATOR BUS
TOTAL LOAD DEMAND (MW)	1.67	1.672

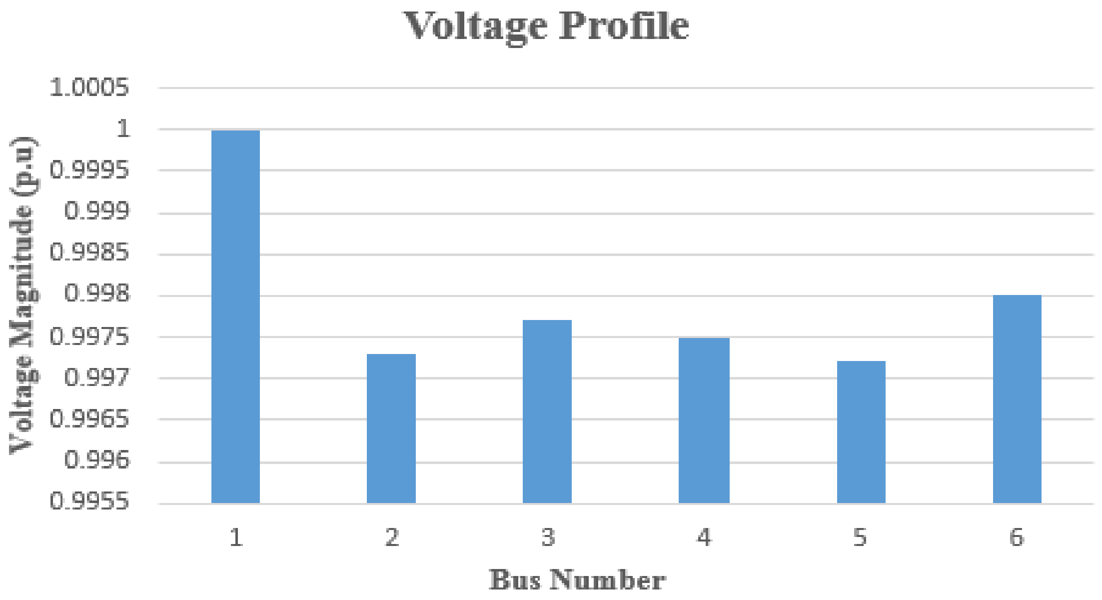

Fig. 2 Converged Voltage Magnitudes

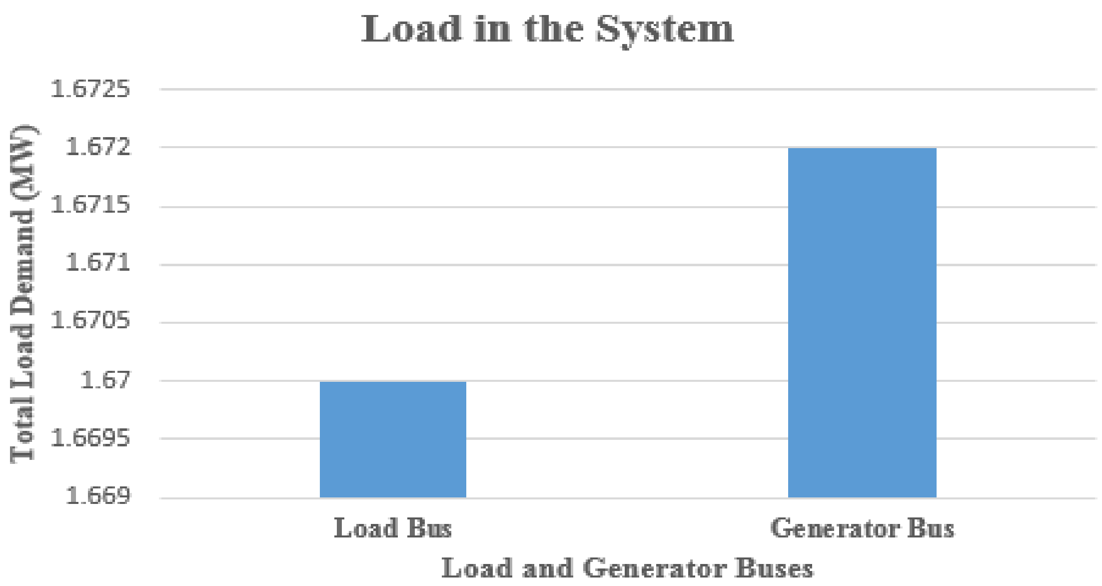

Fig. 3 Comparing Load Flow, Bus Loads and Load on Generator bus

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V.CONCLUSION

Static load model as used in this study, a model inwhich power cannot vary with variations in voltage magnitude has proved to be very efficient in determination of the system overall load demand in relation to input and output conditions. The voltage magnitudes for buses 1, 2, 3, 4, 5 and 6 were 1p.u, 0.9973p.u, 0.9977p.u, 0.9975p.u, 0.9972p.u and 0.9980p.u respectively. Also of very important was the total load in the system where the load buses (buses 2, 3, 4, 5 and 6) when put together were carrying 1.67MW while the generator bus being bus 1 (slack bus) was having a total of 1.672MW with a difference of 0.002MW in the system.

The study has shown proof that the power system components coordination can be used for general power system illustrations. This is in agreement with the assertion of Aditya et al. [3], who opined that it is imperative to conduct load flow study to find the magnitude of voltage, phase angle, real power and reactive power of the system.

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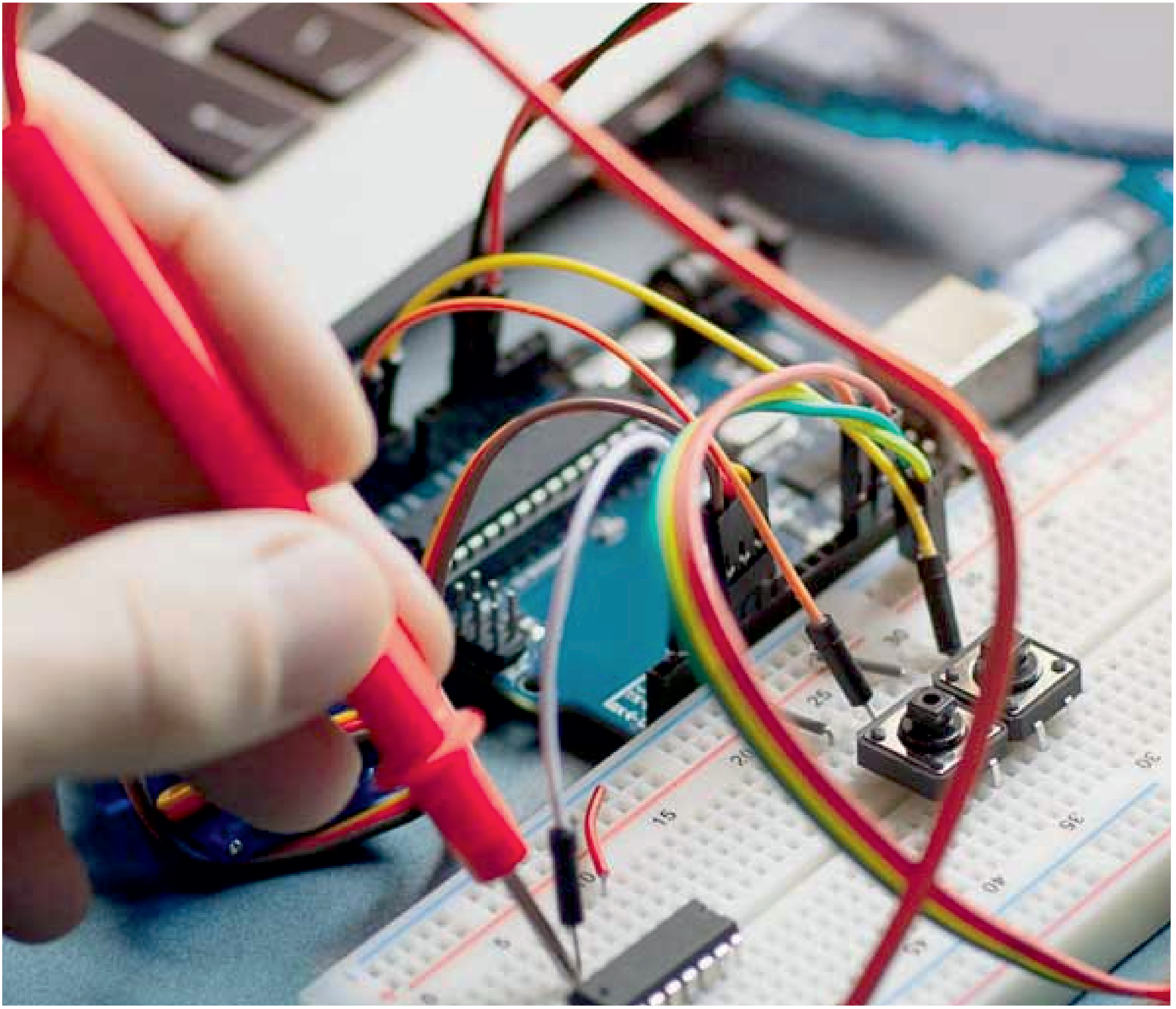

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