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Modelling of Load Frequency Control in a Hybrid Two Area System

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ABSTRACT: This work proposes a decentralized control technique for Load Frequency Control in a two-area power system while appreciating the performance of the methods in a single area power system. A variety of sophisticated control approaches are used to provide a dependable stabilizing controller. A genuine endeavour has been made to investigate the load frequency management problem in a power system composed of two power producing units and many variable load units.. Various control schemes (loop frequency control-LFC and automatic generation control-AGC) are examined through simulations. For interconnection of two or more areas in a power system, frequency should be kept within the specified range. The major goal is to reduce frequency oscillations or damping, as well as fluctuations in tie-line power. In this study, PI and PID controllers are employed to optimize both frequency and tie-line power responses for a multi-area linked power system (which includes a hydrothermal generation system). Initially, only a single area thermal power system is examined. PID provides the best dynamic response for frequency and tie-line powers. In order to achieve more control over time domain specifications, fuzzy logic controller was implemented. To provide better control over steady state response, pole placement techniques was applied.

KEYWORDS: LFC, AGC, PI, PID, Fuzzy, Pole Placement Technique, Optimal Control Systems.

I.INTRODUCTION

For extensive power systems consisting of interconnected control regions, the need for satisfactory operation of power stations running in parallel and relationship between frequency of system and speed of motors has given us a way to provide regulation of system frequency. The input mechanical power is utilized to control the frequency of the generators and the variation in the frequency and tie-line power are detected, which causes a change in rotor angle. It is also capable of providing appropriate levels of power quality by keeping the frequency and voltage sizes as close to the middle as possible.

Because the loads in a power system varies, the system's controllers must be designed to ensure excellent service. AGC effectively regulates the power flow and frequency in an interconnected system. The primary function of the AGC is to keep the system frequency stable and nearly inert to any disturbances. In general, AGC controls two parameters: voltage and frequency. Both have separate control loops that operate independently of one another [1].

Aside from managing the frequency, the secondary key goal is to maintain a zero steady state error and provide excellent transient behavior within the interconnected areas. The major goal is to create a controller that understands optimal power flow and frequency in multi-area power networks.

The following causes are the reasons for limiting power system frequency in any area

1. Electric clocks are powered by synchronous motors. The accuracy of clocks is not only reliant on frequency, but it is also a function of frequency error.
2. If the typical frequency is 50 Hertz and the system frequency is below 47.5 Hertz or over 52.5 Hertz, the turbine blades may be damaged, preventing the generator from stalling.
3. The most serious effect of subnormal frequency operation is seen in thermal power plants. Because of the subnormal frequency operation, the blast of the ID and FD fans in the power stations is lowered, lowering the generation power in the thermal plants.

There have been many experiments and studies on the frequency control of interconnected power systems. Several articles describe a number of management strategies that focus on line management theory. For some authors, the frequency stability of the system is maintained by the power of the simple sequence system. However, we need some data about system conditions that we cannot fully access. In context to [3], first of all, LFC studies are carried out without any controller. Here the system gets settled to an Offset frequency which is different than that of the system's nominal frequency. Hence, to achieve zero steady state error, conventional P, PI and PID control systems are implemented. But the transient response may be uneven because of controller action in the system parameters. Then in context to ref [7], Fuzzy methods were used for control of load-frequency in power systems. For both the areas, some fuzzy rules are established and implemented. By this, the overshoots and settling time were a bit efficient. To make the system to settle faster with less overshoots and undershoots, we implemented pole placement feedback technique and optimal control system theory as referred from [2] and [6].

In this paper, it proposes an efficient model to reduce the frequency error through conventional methods with the help of PI and PID controllers and much more reduced time domain specifications as per the fuzzy logic controller and providing a better stability with the help of pole placement techniques and Optimal Control Systems.

II. MATHEMATICAL MODELLING OF POWER SYSTEM EQUIPMENTS

1. Modelling of Generator

With the use of swing equation of a synchronous machine to small perturbation, we have

$$\frac{2H}{\omega}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e \;\ldots\ldots\ldots\ldots\ldots(1)$$

Now By applying Laplace transform, we get

$$\Delta\delta(s) = \frac{1}{2Hs}(\Delta P_m - \Delta P_e) \;\ldots\ldots\ldots\ldots\ldots(2)$$

The system can be represented as shown below

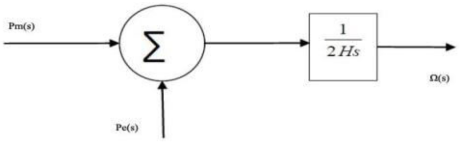

Fig 1: Mathematical Modelling of Generator

2. Modelling of Load

The load on a power system consists of variety of electrical drives. The load speed characteristic of the load is given by:

$$\Delta P_e = \Delta P_L + D\Delta\omega \;\ldots\ldots\ldots\ldots(3)$$

Where ΔP_L is the non-frequency sensitive change in load.
$D\Delta\omega$ is the load change that depends on frequency.
D is represented as percentage change in load divided by percentage change in frequency.

The Block diagram of the Load is as shown

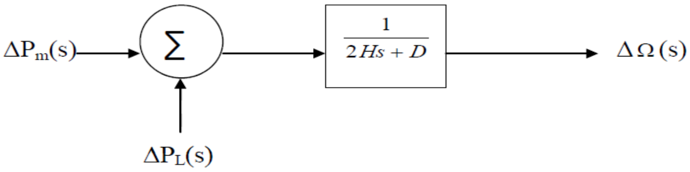

Fig 2: Mathematical modelling of Load

3. Modelling of Prime Mover

The source of power generation is the prime mover. It can be hydraulic turbines near waterfalls, steam turbine whose energy comes from burning of coal, gas and other fuels. The model of turbine relates the changes in mechanical power output (ΔP_m) and the changes in the steam valve position (ΔP_v).

Mathematically,

$$G_T(s) = \frac{\Delta P_v(s)}{\Delta P_m(s)} = \frac{1}{1 + s\tau_T} \quad \dots\dots\dots(4)$$

Where τ_T is the time constant of prime mover which lies between 0.2 seconds to 2 seconds.

4. Modelling of Governor

When the electrical load suddenly increases, the electrical power exceeds the mechanical electrical input. As a result, the power loss on the load side is reduced from the rotational power of the turbine. For this reason, when the power of the turbine decreases, that is, the power of the engine, the governor tells the first engine to increase its speed by sending more water, steam or wind to compensate for the lack of speed.

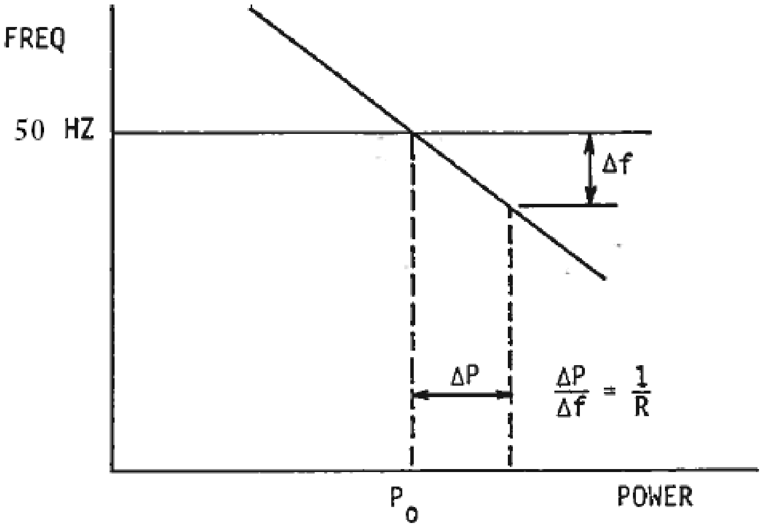

Fig 3: Governor drooping characteristics

The slope of the curve represents speed regulation R. Governors typically have a speed regulation of 5-6 % from no load to full load.

Mathematically,

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta f \quad \dots\dots(5)$$

The command ΔP_g is transformed through hydraulic amplifier to the steam valve position command ΔP_V. We assume a linear relationship and consider simple time constant we have the following s-domain relation as

$$\Delta P_v(s) = \frac{1}{1 + s\tau_g}\Delta P_g(s) \quad \dots\dots(6)$$

Where τ_g is the governor time constant.

Combining all the block diagrams from earlier block diagrams for a single are system we get the following:

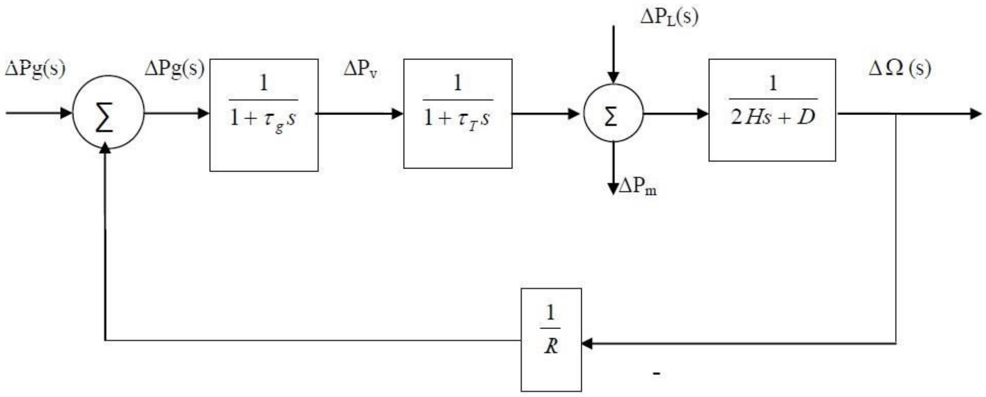

Fig 4: Mathematical Modelling of Block Diagram of single system consisting of Generator, Load, Prime Mover and Governor.

5. Automatic Generation Control
If the system load suddenly increases, the turbine speed decreases and then the governor can adjust the steam input to this new load. As the change in speed value decreases, the margin for error decreases and the position of the governor is closer to where it is needed to maintain the speed rather than the fly ball. One way to return the speed or frequency to its original value is to add input to the path. The participant monitors the average error over time and wins the split.

III. FEEDBACK CONTROL TECHNIQUES

Automatic generation control is carried out using two loops. One is primary loop in which only governor action regulates the input to the turbine which is fed to the alternators to produce electric power. Another one is called the secondary loop which uses some feedback to bring the system frequency back to its nominal value. In other words, it helps in achieving zero steady state error. It provides slower response than the primary loop's response.

1. Conventional Controllers
Most common controllers available commercially are the integral(I) controller, the proportional integral (PI) and proportional integral derivative (PID) controller. The I controllers are used to improve the steady state response i.e. they help in reducing the steady state error. The PI controllers are used to improve the steady state response by reducing the steady state error. PID is made up of three main components i.e. proportional, integral and derivative. It not only improves the steady state response but also help in improving the transient behaviour.

a) Conventional PI Controller
This controller is one of the foremost well known in industry. The relative pick up gives steadiness and tall recurrence reaction. The indispensably term guarantees that the normal mistake is driven to zero. Preferences of PI incorporate that as it were two picks up must be tuned, that there's no long-term blunder, which the strategy regularly gives profoundly responsive systems.

Be that as it may, incorporation of the PI control activity within the framework increments the sort number of the compensated framework by 1, and this causes the compensated framework to be less steady or indeed makes the framework unsteady. Hence, the values of Kp and Ti must be chosen carefully to ensure a legitimate transitory reaction. By appropriately planning the PI controller, it is conceivable to form the transitory reaction to a step input show moderately little or no overshoot. The speed of reaction, be that as it may, gets to be much slower.

b) Conventional PID Controller
A Conventional PID controller is most widely used in industry due to ease in design and inexpensive cost. The PID formulas are simple and can be easily adopted to corresponding to different controlled plants but it can"t yield a good control performance if controlled system is highly order and nonlinear. The PID controller is a combination of the PI and PD controllers.

Usually, the PID controller is a fixed parametric controller and the power system is dynamic and its configuration changes as its expansion takes place. Hence, fixed parametric PI or PID controllers are unable to give their best responses. To cope up with this complex, dynamic and fuzzy situations, fuzzy logic was proposed in literature by many researchers.

2. Fuzzy Logic Controller

Fuzzy logic was initiated in 1965 by Lotfi A. Zadeh, professor in Department of Computer Science at the University of California in Berkeley. Fuzzy set theory and fuzzy logic establish the rules of a nonlinear mapping. The use of fuzzy sets provides a basis for a systematic way for the application of uncertain and indefinite models. Fuzzy control is based on a logical system called fuzzy logic which is much closer in spirit to human thinking and natural language than classical logical systems. Now a days fuzzy logic is used in almost all sectors of industry and science.

The idea behind the Fuzzy Logic Controller (FLC) is to fuzzify the controller inputs, and then infer the proper fuzzy control decision based on defined rules. The FLC output is then produced by defuzzifying this inferred fuzzy control decision. Thus, the FLC processes contain following main components:

- Fuzzification
- Fuzzy rule base
- Defuzzification

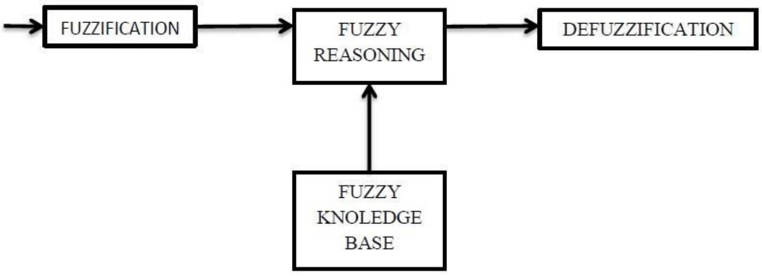

Fig 5: Block diagram of fuzzy logic model

3. Pole Placement Technique

Pole placement method is a controller design method in which you determine the places of the closed loop system poles on the complex plane by setting a controller gain K.

Poles describe the behaviour of linear dynamical systems. Through use of feedback, we are attempting to change that behaviour in a way that is more favourable for our system. Thus, we can decide on where the closed loop poles should be, then force them to be there by designing a feedback control system via pole placement method where you choose a controller gain K that places the poles at any desired locations. For this, the system must be completely state controllable.

Consider the system in the state variable form:

$$X\,(t) = Ax(t)\,+\,Bu(t)\ \ldots\ldots(7)$$
$$Y\,(t) = Cx(t)\ \ldots\ldots(8)$$

The pole placement design allows all the roots of the system characteristic equation to be placed in desired location, which eventually results in a regulator with constant gain vector K.

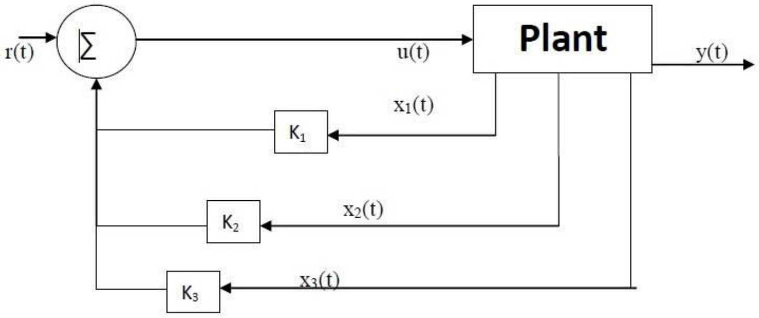

Fig 6: Control design via Pole placement

Let U (t) be the input to the system

$$U\ (t) = -K * x(t) \ldots..(9)$$

Where K is a 1×n vector of constant feedback gain.

The control system input r(t) is assumed to be zero. The purpose of the method is to reduce all the values of the state variables to be zero when the states have been perturbed. Substituting equation (3) in equation (1) the compensated system state variable representation becomes

$$X(t) = (A - BK)\,X(t) = A_f X(t) \ldots\ldots (10)$$
$$\text{Where } A_f = A - BK$$

The compensated system characteristic equation is

$$|\mathrm{sI} - \mathrm{A} + \mathrm{BK}| = 0 \ \ldots\ldots (11)$$

The function $[\mathrm{K}, \mathrm{Af}] = \mathrm{placepol}(\mathrm{A}, \mathrm{B}, \mathrm{C}, \mathrm{p})$ is developed for the pole placement design. The matrices A,B,C are the system matrices and P is row matrix containing the desired closed-loop poles. The function returns the gain matrix K and the closed-loop matrix Af. For a multi-input system $\mathrm{K} = \mathrm{place}\ (\mathrm{A}, \mathrm{B}, \mathrm{P})$, which uses a more reliable algorithm.

IV. RESULT AND DISCUSSION

The following parameters are taken for consideration of two areas
Standard values used in Area1(hydro system) are (i) R=2.4 HZ/MW P.u, (ii) KT=KG=1, KP=120, (iii) TG1=41.6 sec, Tt1=0.5 sec, TP=5 Sec, Tw=1 sec, (iv) B1=0.5
Standard values used in Area2(Thermal System) are (i) R=2.4 HZ/MW P.u, (ii) KT=KG=1; KP=120, (iii) TG1=0.08sec, Tt2=0.08sec, TP=5 Sec, (iv) B2=0.5
When a sudden load change of 0.2 p.u. occurs in one of the control areas. The fig. 7 and 8, shows the frequency response of the Thermal-Hydro System with PI and PID Controllers

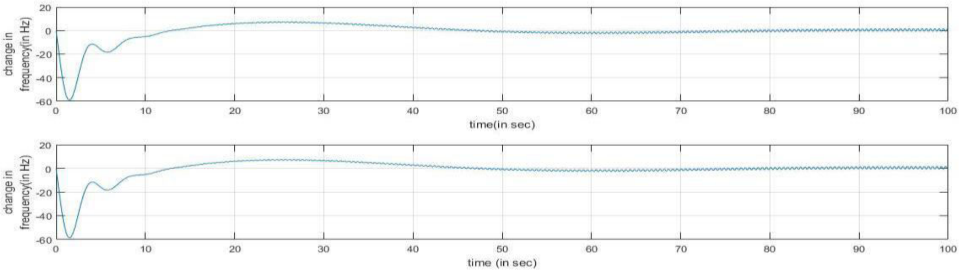

Fig 7: frequency response of Thermal-Hydro System with PI controller

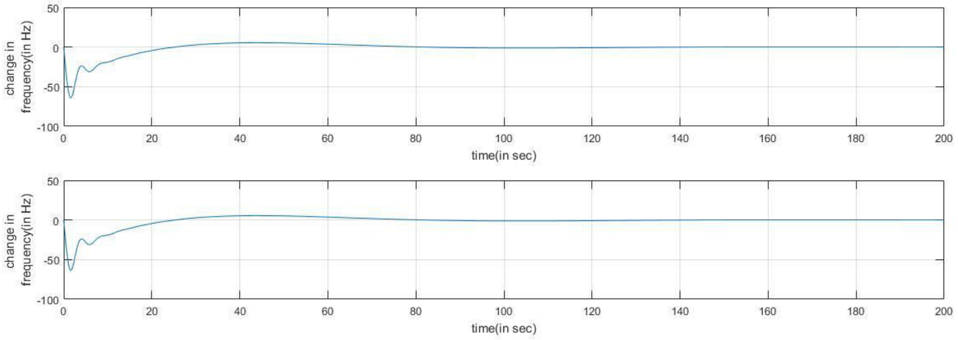

Fig 8: frequency response of Thermal-hydro system with PID controller

In fig. 9 and 10, the response under fuzzy inference system is found out for the two area Hydro-Thermal System for area 1 and area 2 respectively.

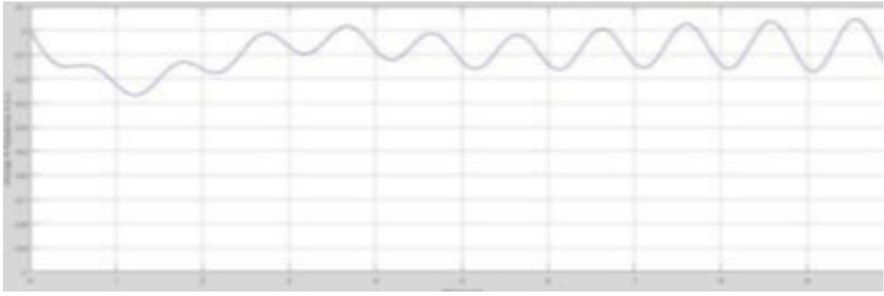

Fig 9: frequency response of area 1 of Hydro-Thermal System with fuzzy controller

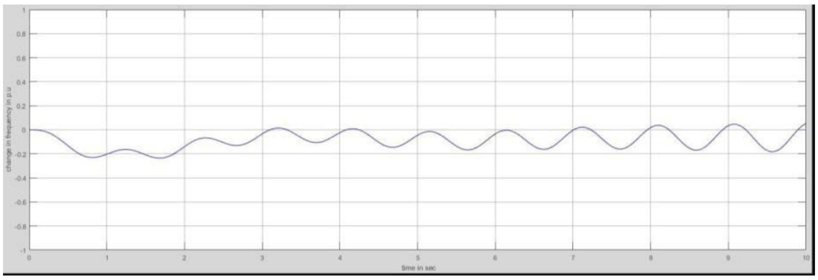

Fig 10: frequency response of area 2 of Hydro-Thermal System with fuzzy controller

In the fig 11 and 12, the pole placement technique is implemented to find out the frequency response under the pole placement Technique of the hydro-Thermal System.

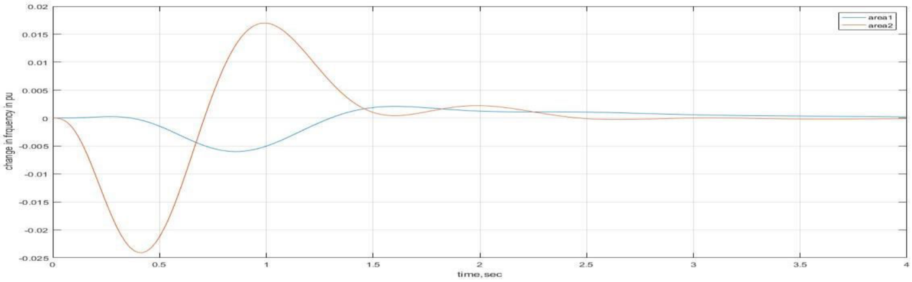

Fig 11: frequency response when area 1 input is varied with pole placement technique

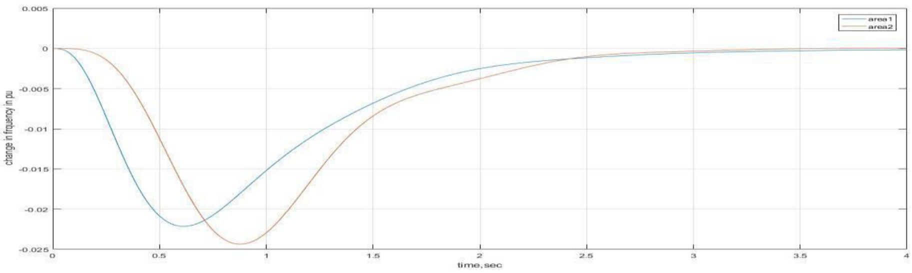

Fig 12: frequency response when area 2 input is varied with pole placement technique

The following comparison can be made for different techniques and is shown in Table 1.

Table 1 Comparison of Different methods on frequency response of Hydro-Thermal System

Sl. No.	Method Implemented	Δf_{ss} (in p.u.)	Settling Time (s)
1	PI controller	0	40
2	PID Controller	0	28
3	Fuzzy Logic Controller	0	8
4	Pole Placement Technique	0.0015	3.5

V.CONCLUSION

Hence, from these results, it has been clear that feedback control techniques are of utmost need for smooth operation of power system at the system frequency. Initially, Conventional controllers are used which help in achieving zero steady state error. But due to the controller action, the system observed some oscillations as well as overshoots. Hence, to reduce it we implemented fuzzy logic control technique. It also provided a zero steady state error response. Though overshoots decreased, the system suffed oscillation phenomenon. Hence, to achieve better control over time domain specifications, we implemented some control system techniques like Pole placement technique and optimal control system technique. Due to it, the system settled faster and steady state frequency deviation was nearly equal to zero.

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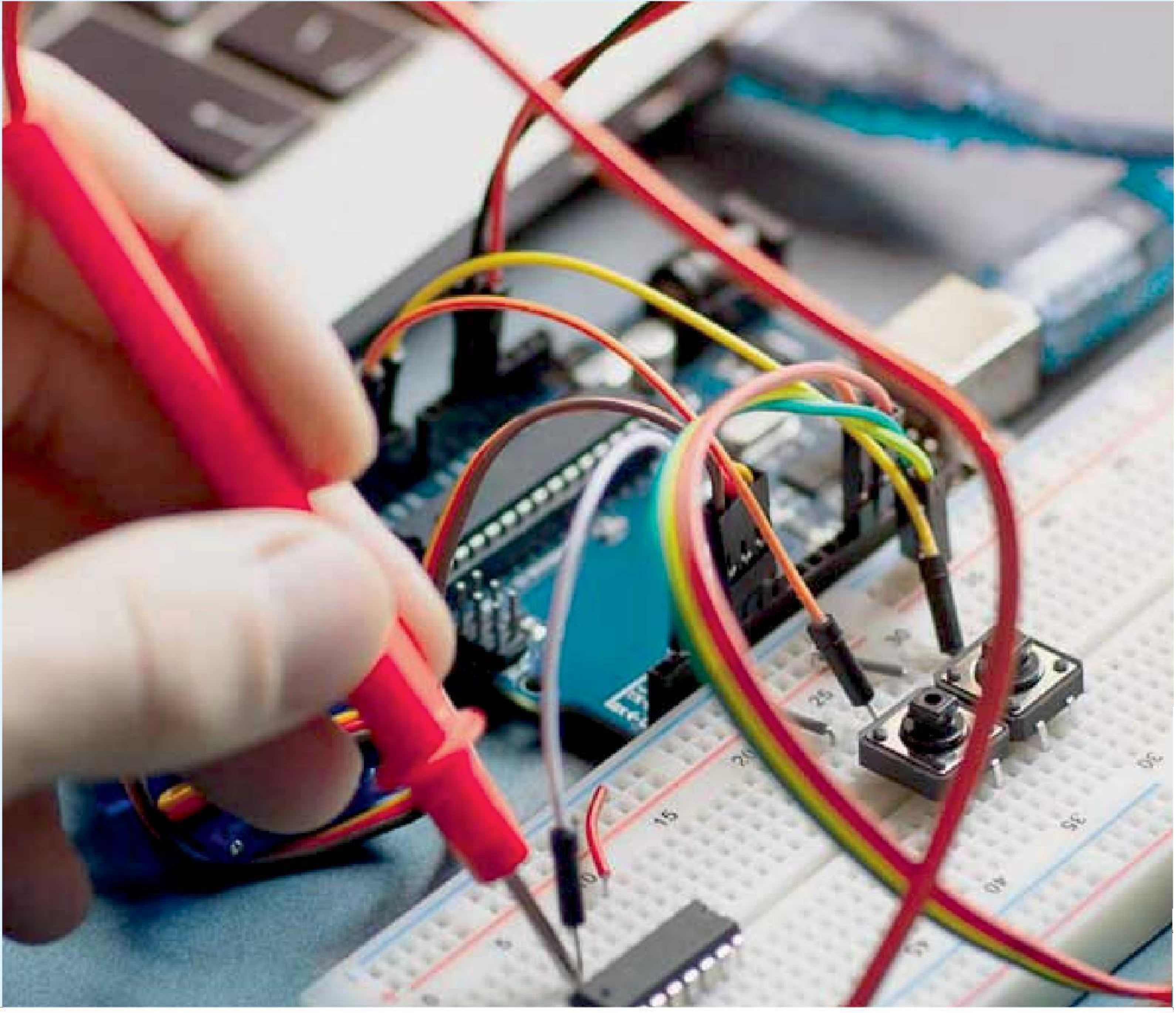

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