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Advanced Control Strategies for Enhanced Performance of PMDC Motors in Wind Turbines using a Robust H-Infinity Approach and Genetic Algorithm Optimization

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ABSTRACT This project proposes the robust H∞ controller design of the speed control of Permanent Magnet Direct Current (PMDC) motor. In modern robust control applications, the design of fixed structure H-loop shaping control depends on minimizing the H∞ norm of the closed loop control system. The core idea is to formulate the H∞ norm i.e., condition for the disturbance rejection and H∞ controller is designed by means of global optimization technique such as Genetic Algorithm (GA) such that it should satisfy the maximizing the disturbance rejection constraint and the PID controller design based on minimizing the integral of time weighted squared error (ITSE) performance index using another Genetic Algorithm in order to meet the desired requirements. As the results the robust H∞ controller provides good dynamic performance of system and robustness to uncertain disturbances. The robustness of the H∞ controller design is assessed and applied in controlling the speed of Permanent Magnet DC motor with the aid of computer simulation, thereby analysing the behaviour of the step response of the proposed controller and the closed loop is course tracked with perturbed parameters. This proposed model is found to be robust for arbitrary disturbances (simultaneous AC & DC) along with significant time response**.**

KEYWORDS: Robust H∞ controller, Permanent Magnet Direct Current motor, Genetic Algorithm, integral of time weighted error (ISTE).

I. INTRODUCTION

Wind energy is a key component of sustainable energy solutions due to its abundance and minimal environmental impact. Optimizing wind turbine performance involves challenges such as improving efficiency, stabilizing power output, maximizing energy production, and mitigating structural fatigue and vibrations. Wind turbines are an alternative energy source for regions without conventional electrical grids and are classified into vertical axis wind turbines (VAWTs) and horizontal axis wind turbines (HAWTs). VAWTs feature rotors that rotate along a vertical axis and offer advantages such as lower acoustic noise, operation in any wind direction, easier maintenance due to ground-level components, and reduced gravitational disturbances. Advanced control techniques, such as robust H∞ controllers and Genetic Algorithms (GA), play a critical role in enhancing turbine performance. The robust H∞ controller improves the speed control of Permanent Magnet Direct Current (PMDC) motors by minimizing the H∞ norm of the closed-loop system, which ensures effective disturbance rejection. GAs optimize the controller design to meet constraints like maximizing disturbance rejection. Additionally, PID controllers are optimized using GAs to minimize the integral of time-weighted squared error (ITSE) for better performance. The robust H∞ controller demonstrates superior dynamic performance and robustness against disturbances. Simulations assess the step response behavior of the PMDC motor under this controller, showcasing its effectiveness in achieving reliable speed control and stability in wind turbine applications.

II. METHODOLOGY

This study proposes a robust control strategy for speed regulation of a Permanent Magnet Direct Current (PMDC) motor using H-infinity (H∞) control, with performance optimization carried out through Genetic Algorithms (GA). The methodology consists of four key stages: dynamic modeling of the motor, formulation of the H∞ control problem,

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development of a performance index based on system behavior, and implementation of a GA-based optimization framework to identify optimal controller parameters.

The process begins with the derivation of a mathematical model of the PMDC motor. The motor is modeled using its electrical and mechanical characteristics, including armature resistance and inductance, back electromotive force (emf) constant, torque constant, rotor inertia, and viscous friction. These parameters are used to develop a second-order transfer function representing the motor's speed response to input voltage. This transfer function forms the nominal plant model, denoted as , which is used in the controller design phase.
To achieve robust disturbance rejection and maintain system stability under uncertainty, the H∞ control framework is adopted. The core objective is to limit the impact of external disturbances on the output signal. This is mathematically formulated by minimizing the H∞ norm of the weighted sensitivity function, , where is the sensitivity function and is a weighting function that shapes the desired frequency response. The disturbance attenuation level is quantified by a scalar , and the design constraint is set such that the norm does not exceed this bound. The controller is chosen in a fixed-structure form resembling a PID controller, expressed as , where represents the set of gain parameters to be optimized.

The performance of the controller is evaluated using the Integral of Time-weighted Squared Error (ITSE) as the optimization criterion. ITSE is a time-domain performance index that emphasizes error reduction over longer durations by integrating the product of time and squared error. This ensures a smooth transient response with minimal overshoot and acceptable settling time. To address the dual goals of minimizing ITSE and satisfying the H∞ constraint, a constrained optimization problem is formulated.

A two-stage Genetic Algorithm approach is employed to solve this optimization problem. In the first stage, GA-1 minimizes the ITSE performance index over a predefined parameter space. In the second stage, GA-2 checks whether the controller meets the disturbance rejection constraint. If the maximum value of the weighted sensitivity function exceeds , the process iteratively restarts, refining the controller parameters until a satisfactory solution is found. The GA operates using tournament selection, arithmetic crossover, and uniform mutation, with parameters such as population size, crossover and mutation probabilities, and search bounds carefully tuned for performance.

The methodology is implemented using a case study involving a Maxon RE 35 PMDC motor. MATLAB/Simulink simulations are used to validate the proposed control design. The step response of the motor is evaluated with and without the controller under nominal and perturbed conditions. The results demonstrate that the H∞ controller significantly improves the transient behavior, reducing overshoot and settling time, and effectively mitigates the influence of arbitrary disturbances, thereby confirming its robustness and practical applicability.

III. H∞CONTROLLER USING GA FOR PMDC MOTOR

The Genetic Algorithm (GA) operates on principles derived from natural selection and genetic evolution. In this study, two distinct Genetic Algorithms are utilized to solve a constrained optimization problem. The first algorithm (GA-1) is developed to reduce the performance index in terms of , optimizing controller parameters within a defined search range. The second algorithm (GA-2) focuses on designing an controller that maximizes the disturbance rejection criterion , beginning with an initial variable frequency . The optimized controller parameters from GA-1 are provided to GA-2, aiming to enhance the disturbance rejection metric over a fixed number of generations. If the peak value of this metric remains below , the controller design is deemed acceptable. However, if it exceeds , the search for suitable controller parameters recommences until the constraint is satisfied.The Genetic Algorithm employs three primary operations: tournament selection, arithmetic crossover, and mutation.

Selection: This step involves choosing the most suitable individuals from the current population to proceed to the next generation. Tournament selection evaluates the fitness of individuals by grouping them into random subpopulations. Within each group, the individual with the highest fitness level is selected to advance.

Crossover: In this phase, selected individuals exchange genetic material to produce new offspring. Two parents are chosen and crossed to generate offspring that inherit traits from both. These offspring then replace the parents in the new generation, contributing to the evolution of a better solution.

Mutation: Mutation refers to the occasional random changes in the genetic code of an individual. Though inherently random, when combined with crossover, it helps maintain genetic diversity and avoids premature convergence. This process is governed by a predefined mutation probability , where for each gene, a random value between 0 and 1 is

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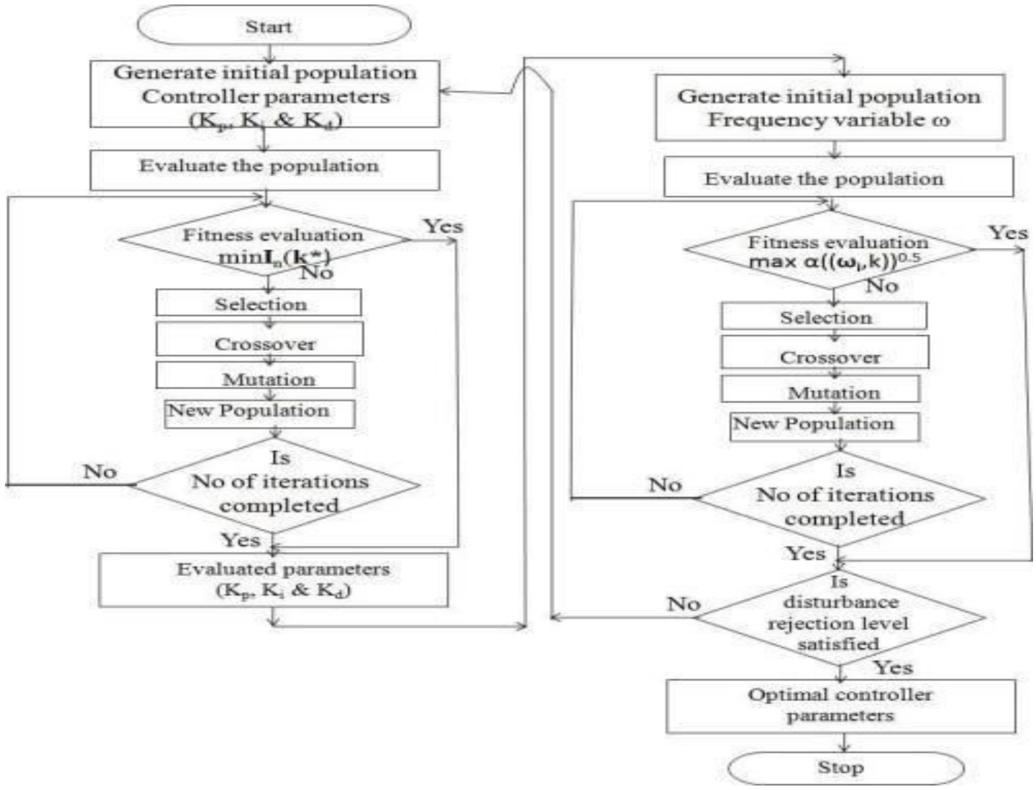
generated and compared to to determine if mutation should occur.

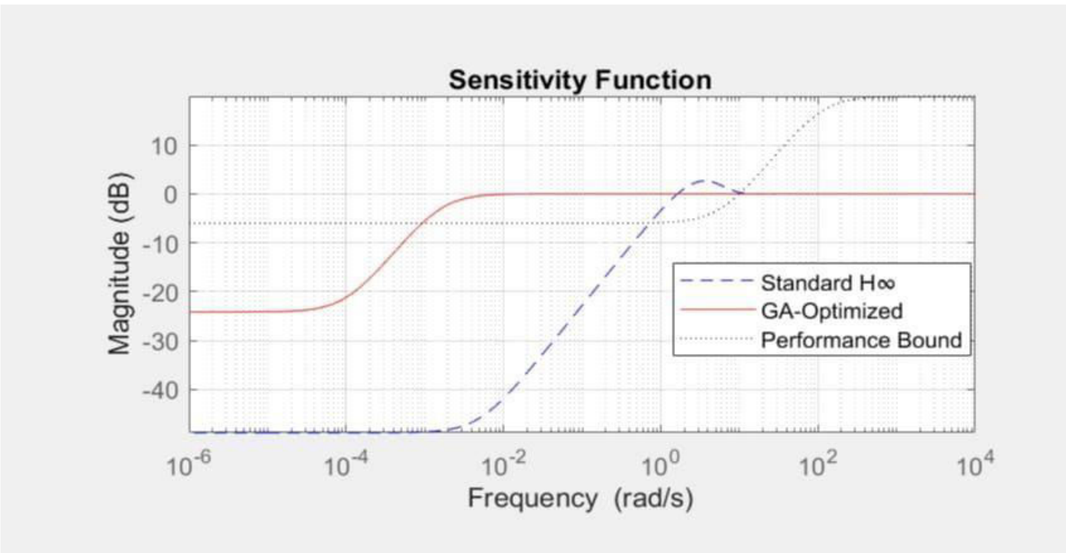


IV. RESULT AND DISCUSSION

This provides a comparative evaluation of the standard (H-infinity) controller and a version enhanced through Genetic Algorithm (GA) optimization for controlling the speed of a PMDC motor. Performance assessment is conducted through various frequency response plots, focusing on factors such as system stability, disturbance rejection, control effort, and transient behavior.

In the fig 1, This graph evaluates how effectively the system handles disturbances across a range of frequencies. A lower magnitude in decibels (dB) corresponds to improved disturbance rejection, particularly at lower frequencies.

Fig. 1 Waveform of sensitivity function



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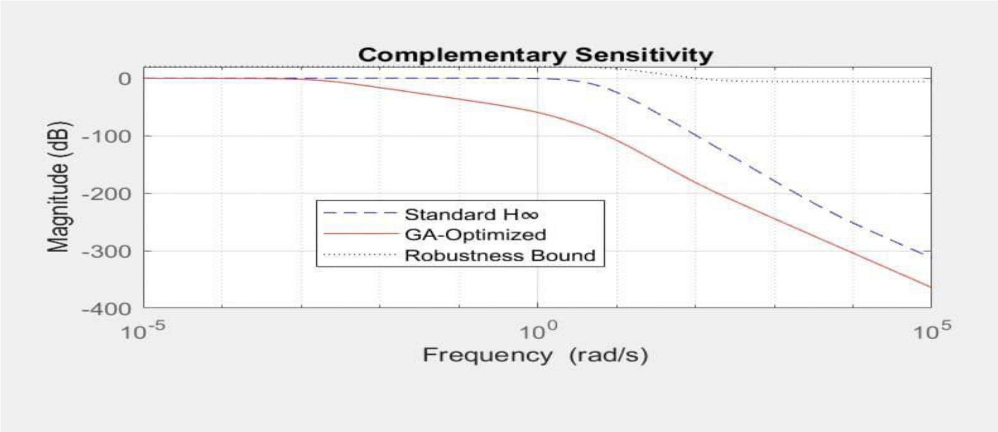
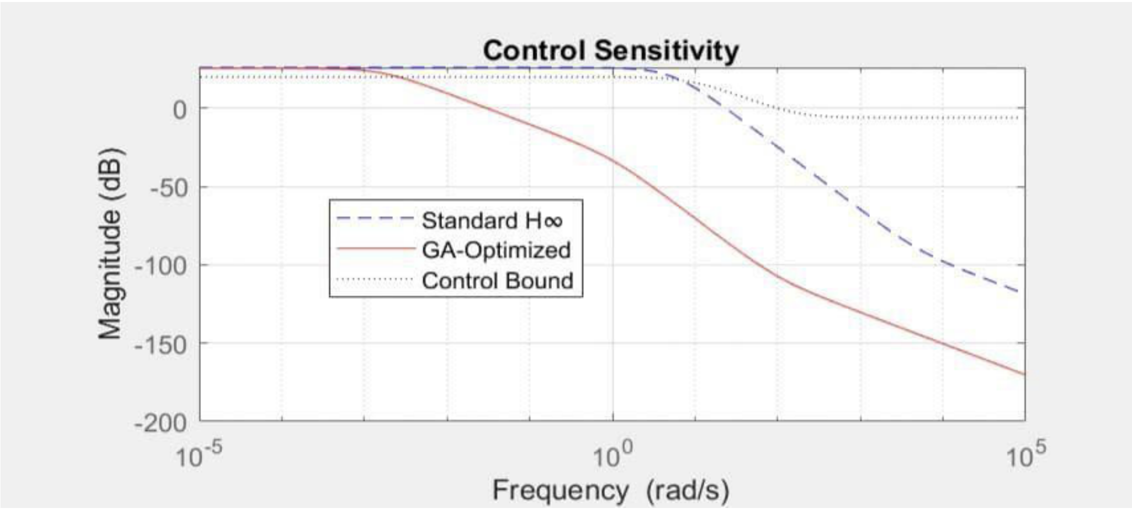


Fig. 2 waveform of complementary sensitivity

In the fig 2, This plot reflects the system's robustness to high-frequency disturbances and noise. Ideally, the complementary sensitivity should be low at higher frequencies to ensure robust performance.

Fig .3 waveform of control sensitivity



In Fig 3, This figure assesses the control effort needed by the system. A lower curve indicates a more energy-efficient controller that demands less from the actuators.

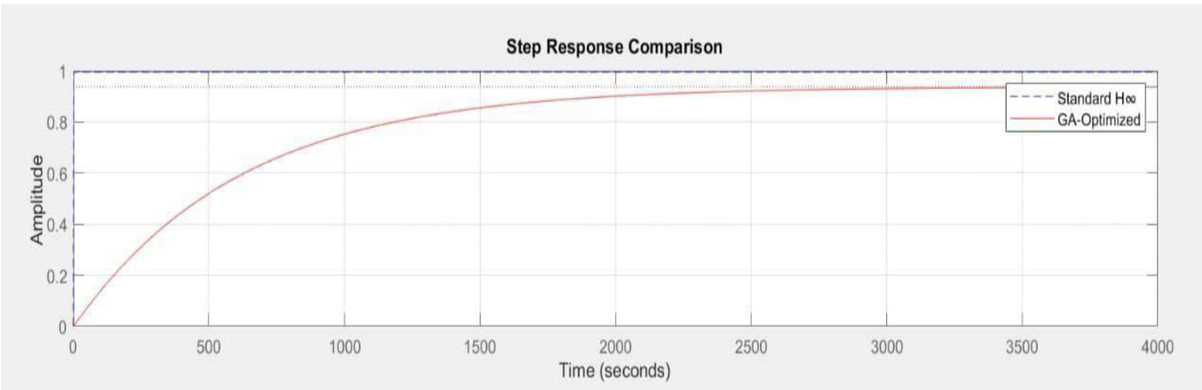


Fig 4 waveform of step response comparison

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In Fig 4 This plot measures the system's response to a step input, reflecting parameters such as overshoot, rise time, settling time, and final value.

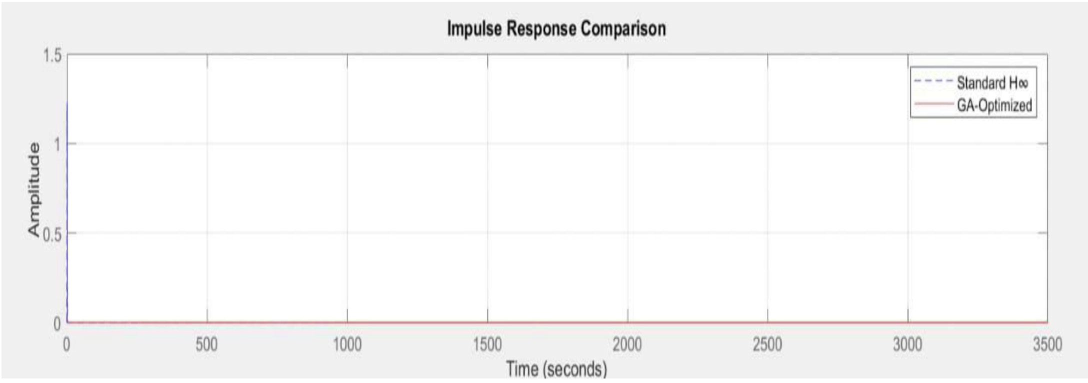

Fig 5 waveform of impulse response comparison

In Fig 5 Impulse response reveals how the system reacts to sudden disturbances.

V. CONCLUSION

Integrating a Genetic Algorithm with the H-Infinity controller for PMDC motor speed control. While the standalone H-Infinity controller struggles to regulate motor speed effectively, the optimized version achieves faster and more robust control. However, the slight overshoot indicates room for further refinement. This study highlights the effectiveness of combining classical control methods with modern optimization techniques like GA for complex dynamic systems such as PMDC motors.

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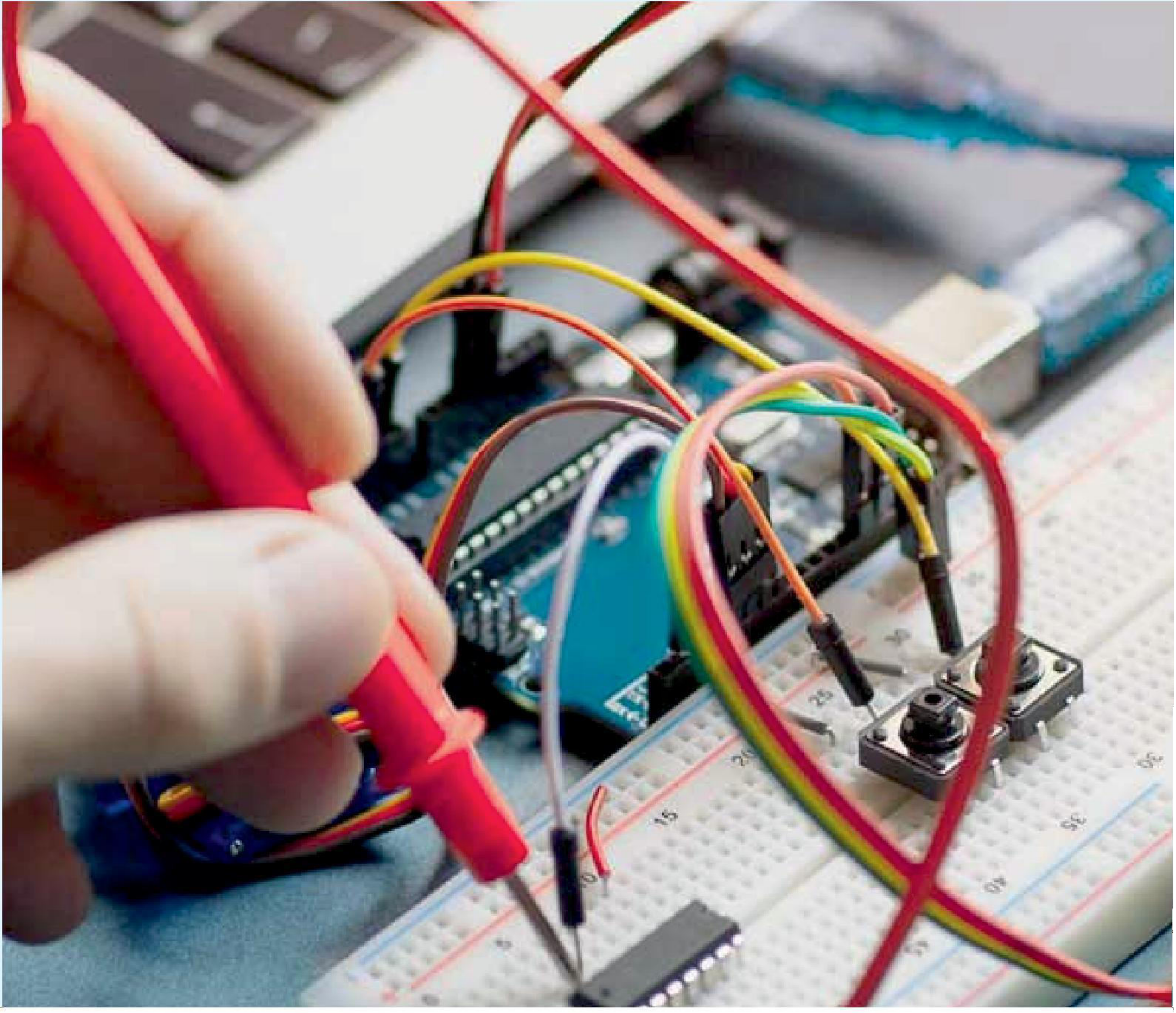

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