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Solving Combined Economic Emission Dispatch Problem using Modified and Improved Grey Wolf Optimizer

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ABSTRACT:A new technique miGWO (modified and improved Grey Wolf Optimizer) is being formulated to solve Combined Economic Emission Load Dispatch (CEED) Problem. The CEED problem in power system is to minimize the operational cost and the emission of pollutant. The development of Grey Wolf Optimizer algorithm is the modification of a value and the addition of variable weight. The results have been compared with various techniques like GWO, mGWO, iGWO, ALO and PSO for six-generator test system. Furthermore, the proposed technique obtains competitive and satisfying results compared to other proposed techniques.

KEYWORDS:modified and improved Grey Wolf Optimizer; Combined Economic Emission Load Dispatch.

I.INTRODUCTION

Operational economics in power generation which is dealing with minimum cost of power production called Economic Dispatch [1]. The gaseous pollutants from fossil power plants cause harmful effect to human beings and environment [2]. Minimizing fuel cost and minimizing emission are two controversial bi-objective are transform into single objective problem named Combined Economic Emission Dispatch (CEED) [3].

A number of techniques have been successfully used to solve CEED problems such as Artificial Bee Colony (ABC) [4], Gravitational Search Algorithm (GSA) [5], Particle Swarm Optimization (PSO) [6], Differential Evolution (DE) [3], Dynamic Particle Swarm Optimization (DPSO) [2], Simulated Annealing (SA) [7], Flower Pollination Algorithm (FPA[8] and Ant Lion Optimization (ALO) [9].

Grey Wolf Optimizer (GWO) has been proposed by Sayedali Mirjalili, Sayed Mohammad Mirjalili and Andrew Lewis in 2014 [10]. The technique inspired by the leadership hierarchy and hunting mechanism of grey wolves (Canis Lupus) in nature.GWO is applied to solve CEED problem. The study result show that the proposed approach is more efficient in minimizing fuel cost and emission compare with reviewed paper [11,12].

A modified GWO (mGWO) is proposed by Nitin Mittal, Urvinder Singh and Balwinder Singh Sohi which focuses on proper balance between exploration and exploitation that leads to an optimal performance [13]. An improved GWO with variable weight (VW-GWO) is proposed by Zheng-Ming Gao and Juan Zhao which follows social hierarchy of the grey wolves [14]. Results show that the VW-GWO works better than the standard GWO and other reviewed algorithm.

This paper introduces a miGWO technique to solve CEED problem for six-generator test system with considering transmission loss. The miGWO technique combines both the mGWO which is proposed by Mittal et al. and the VW-GWO which is proposed by Gao and Zhao. The results obtained with the miGWO technique were analyzed and compared with other optimization results such as GWO, ALO, and PSO. Due to excellent exploration and exploitation behavior of the proposed miGWO technique, solution do not to stick to local optimum points and has better convergence in the optimization problem like CEED problem. The study investigates the mGWO and VW-GWO to analyzes contribution of this two technique in the miGWO.

II.LITERATURE SURVEY

2. 1. CEED Problem

The formulation treats CEED problem whose objective is to minimize both fuel cost and emission while satisfying various constrains in order to allocate optimal generation among the power generation units. Therefore, CEED combines two objective function. The CEED problem can be formulated as follow [5,7,8] :

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1. Fuel cost minimization:
   Total fuel cost function can be formulated as quadratic equation as follows:
   $$F_t = \sum_{i=1}^{n}(a_i P_i^2 + b_i P_i + c_i) \quad (1)$$
   Where F_t is the total fuel cost, P_i is the power generated unit i and a_i, b_i, c_i are coefficients of i^th unit.
2. Emission minimization:
   Total emission of atmospheric pollutant from thermal generating unit can be modeled as the sum of quadratic function of active power output of generating units as follows:
   $$E_t = \sum_{i=1}^{n}(\alpha_i P_i^2 + \beta_i P_i + \gamma_i) \quad (2)$$
   Where E_t is the total fuel cost, P_i is the power generated unit i and α_i, β_i, γ_i are coefficients of i^th unit.
3. Combined Economic Emission Dispatch (CEED)
   The bi-objective CEED problem is converted to a signal objective form as follows:
   $$Minimize\ F = F_t + h * E_t \quad (3)$$
   Price penalty factor h ($/ton) to reflect the different ranges of value of each objective. The price penalty factor h, which is the ratio :
   $$h_i = \frac{F_t(P_i^{max})}{E_t(P_i^{max})} = \frac{a_i P_{imax}^2 + b_i P_{imax} + c_i}{\alpha_i P_{imax}^2 + \beta_i P_{imax} + \gamma_i} \quad (4)$$
4. Weighted Sum Method (WSM)
   The WSM transform each objective to have portion. Weighting factor *w* can be any number between 0 and 1.
   $$F = wF_t + (1 - w)hE_t \quad (5)$$

There are two constraints in CEED problem, such as generation capacity constraints and power balance constraint. [8]
Generation Capacity Constraints

$$P_{i\,min} < P_i < P_{i\,max} \qquad i = 1,2,\dots n \quad (6)$$

where, $P_{i\,min}$: Minimum power generated
$P_{i\,max}$: Maximum power generated

Power Balance Constraint

$$\sum_{i=1}^{N} P_i = P_D + P_L \quad (7)$$

where, P_D : Minimum power generated
P_L : Maximum power generated

Transmission Losses
To calculate total transmission loss using kron's loss formula is give in equation below,

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n}(P_i B_{ij} P_j) + \sum_{i=1}^{n} B_{0i} P_i + B_{00} \quad (8)$$

B_{ij} constants are called B coefficients or loss coefficients. It is assumed with small error, these coefficients are constant.

2. 2. Grey Wolf Optimizer

GWO algorithm was mainly proposed by Sayedali Mirjalili [10] which mimic the leadership hierarchy and hunting mechanism of grey wolf in nature. GWO algorithm involves four models which are as follows:

1. Social Hierarchy
   Grey wolves have social dominant hierarchy as alpha (α), beta (β), delta (δ) and omega (ω). in the hierarchy of GWO, alpha is considered the most dominating member among the group. the rest of the subordinates to α are β and δ which help to control the majority of wolves in the hierarchy that are considered as ω

2. Encircling Prey
   The mathematical modeling involve in encircling prey can be represented by following equation :
   $$\vec{D} = |\vec{C}.\vec{X}_p(t) - \vec{X}(t)| \quad (9)$$
   $$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A}.\vec{D} \quad (10)$$
   where Vektor $\vec{A}$ dan $\vec{C}$ are coefficients vector given by:
   $$\vec{A} = 2\vec{a}.\vec{r}_1 - \vec{a} \quad (11)$$
   $$\vec{C} = 2.\vec{r}_2 \quad (12)$$

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where: "t" is the current iteration, X is the position vector of a wolf, r1 and r2 are random vectors [0,1] and "a" linearly decreases from 2 to 0.

3. Hunting
The mechanism of hunting of grey wolves involves the following main steps:
- Tracking, chasing and approaching the prey
- pursuing, encircling and troubling the prey until it stops moving.
- Lastly, attacking the prey

To mathematically simulate the hunting behavior, the assumption is made that the alpha, beta and delta have better information about the potential location of the prey as follows:

$$\vec{D}_\alpha = |\vec{C}_1.\vec{X}_\alpha - \vec{X}|$$
$$\vec{D}_\beta = |\vec{C}_2.\vec{X}_\beta - \vec{X}| \quad (13)$$
$$\vec{D}_\delta = |\vec{C}_1.\vec{X}_\delta - \vec{X}|$$
$$\vec{X}_1 = \vec{X}_\alpha - \vec{A}_1.(\vec{D}_\alpha)$$
$$\vec{X}_2 = \vec{X}_\beta - \vec{A}_2.(\vec{D}_\beta) \quad (14)$$
$$\vec{X}_3 = \vec{X}_\delta - \vec{A}_3.(\vec{D}_\delta)$$
$$\vec{X}(t+1) = \frac{\vec{X}_1+\vec{X}_2+\vec{X}_3}{3} \quad (15)$$

where is the current iteration and $\vec{X}_\alpha, \vec{X}_\beta$and $\vec{X}_\delta$are the position vector of grey wolves α, β and δ.

4. Attacking Prey (Exploitatation and Search for Prey (Exploration)
The ability of the grey wolves may result in the global optima. that's is the exploitation ability. though the value of a decreases from 2 to 0. A is also decreased at the same time. A is a random value in the interval [-2a,2a]. If |A|<1, the grey wolves are forced to attack the prey. The value of "A" are utilized arbitrarily for indulging the search agent so as to diverge from the prey. When |A|>1, the grey wolves are forced to diverge from the prey.

2. 3. Grey wolf optimizer with value "a" modification

Modified Grey Wolf Optimizer (mGWO) developed by Mittal [13], which focuses on proper balance between exploration and exploitation. In GWO, the transition between exploration and exploitation is generated by the adaptive value of *a* and A. In this, half of the iterations are devoted to exploration ($|A| \geq 1$) and the other half are used for exploitation ($|A| < 1$). The value of "*a*" decreases linearly from 2 to 0 using this following equation:

$$a = 2\left(1 - \frac{t}{T}\right) \quad (16)$$

In mGWO employs exponential function for the decay of "*a*" over the course of iterations. The number of iteration used for exploration and exploitation are 70% and 30%, respectively. The equation as follows:

$$a = 2\left(1 - \frac{t^2}{T^2}\right) \quad (17)$$

In the proposed mGWO, exponential number will be varied to search the best result.

2. 4. Grey wolf optimizer with variable weight

An Improved Grey Wolf Optimization with Variable Weight (VW-GWO) is designed by Gao and Zhao [14]. VW-GWO is used variable weight as the portion of social hierarchy. So equation (15) is changed as follows:

$$\vec{X}(t+1) = \omega_1\vec{X}_1 + \omega_2\vec{X}_2 + \omega_3\vec{X}_3 \quad (18)$$
$$\omega_1 + \omega_2 + \omega_3 = 1$$

where $\omega_1, \omega_2$and ω_3 are variable weight for alpha, beta and delta, respectively. According to Gao, all the variable weight must be fulfilled criteria $\omega_1 \geq \omega_2 \geq \omega_3$ during iteration. the variable weight is showed as follows:

$$\omega_1 = \cos\theta$$
$$\omega_2 = \frac{1}{2}\sin\theta \,.\cos\varphi \quad (19)$$
$$\omega_3 = 1 - \omega_1 - \omega_2$$

The angular parameter was introduced as follows: $\theta = [0, \arccos(1/3)]$ and $\varphi = \frac{1}{2}\arctan(it)$. Where it is cumulative iteration number or current iteration.

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III.Modified And Improved Grey Wolf Optimizer (miGWO)

Modified and Improved Grey Wolf Optimizer (miGWO) is a new technique to upgrade the GWO algorithm. It is combine the modified the value of "*a*" and improved the position of search agent with variable weight.

3.1. Aplicationof miGWO insolving CEED Problem

The algorithm steps of the miGWO algorithm for solving CEED problems are listed below:

Step 1 : Population size (number of search agents), number of iteration, coefficients of generation cost and emission, upper & lower limit generation, transmission loss coefficient and load demand are needed to be fixed. The random initialization of active power of all generating unit except the first unit within their lower and upper active power limits. If there are "ng" number of generators, represent position of search agents in vector and there are "sa" numbers of search agents, so initial position matrix P is created which is given in Equation (20)

$$\text{Positions} = \begin{bmatrix} P_{11} & P_{12} & \cdots & P_{1ng} \\ P_{21} & P_{22} & \cdots & P_{2ng} \\ \cdots & \cdots & P_{ij} & \cdots \\ P_{sa1} & P_{sa2} & \cdots & P_{sang} \end{bmatrix} \quad (20)$$

Step 2 : Calculate fitness value of each search agents which represents fuel cost and emission of each solution of the current population

Step 3 : Update value and position search agent alpha, beta and delta

- if fitness < alpha score, alpha score = fitness, update alpha position
- if fitness > alpha score and fitness < beta score, beta score = fitness, update beta position
- if fitness > alpha score fitness > beta score and fitness < delta score, delta score = fitness, update delta position

Step 4 : Initialization a, A and C value.

The a value decreases from 2 to 0 during iterations based on equation (21) and exponential number (n) will be varied.

$$a = 2\left(1 - \frac{t^n}{T^n}\right) \quad (21)$$

Calculate A and C vectors as equation (11) and (12).

Step 5 : For each search agents, update position search agent include omega, as follows:

- Calculate D_α D_β D_δ coefficient vectors as equation (13)
- Calculate X_1 X_2 X_3 coefficient vectors as equation (14)

Update position X_{t+1} using variable weight based on equation (18)

Step 6 : Repeat Step 2 to Step 5 until iteration ended

Step 7 : Display Xα value as representation of each generating unit. Display fitness as representation total cost.

IV.SIMULATION RESULTS AND DISCUSSION

The proposed techniques have been applied over standard IEEE 30-bus 6-generator test system at 900 MW power demand. The parameters of fuel cost & emission coefficients and limiting value of active power of various generator are presented in Table 1, followed by B-loss coefficient [7]. Simulations were performed in MATLAB R2016a environment on a PC with a 2.4 GHz processor.

Table 1 Generator capacity limits, fuel cost and emission coefficients for IEEE 30-bus test system

Unit	a_i $/(MW)²h	b_i ($/MWh)	c_i ($/h)	α_i (lb/(MW)²h)	β_i (lb/MWh)	γ_i (lb/h)	$P_i min$ (MW)	$P_i max$ (MW)
1	0.15247	38.53973	756.79886	0.00419	0.32767	13.85932	10	125
2	0.10587	46.15916	451.32513	0.00419	0.32767	13.85932	10	150
3	0.02803	40.39655	1049.9977	0.00683	-0.54551	40.26690	35	225
4	0.03546	38.30553	1243.5311	0.00683	-0.54551	40.26690	35	210
5	0.02111	36.32782	1658.5696	0.00461	-0.51116	42.89553	130	325
6	0.01799	38.27041	1356.6592	0.00461	-0.51116	42.89553	125	315

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$$B_{ij} = \begin{bmatrix} 0.002022 & -0.000286 & -0.000534 & -0.000565 & -0.000454 & -0.000103 \\ -0.000286 & 0.003243 & 0.000016 & -0.000307 & -0.000422 & -0.000147 \\ -0.000534 & 0.000016 & 0.002085 & 0.000831 & 0.000023 & -0.000270 \\ -0.000565 & -0.000307 & 0.000831 & 0.001129 & 0.000113 & -0.000295 \\ -0.000454 & -0.000422 & 0.000023 & 0.000113 & 0.000460 & -0.000153 \\ -0.000103 & -0.000147 & -0.000270 & -0.000295 & -0.000153 & 0.000898 \end{bmatrix}$$

The proposed technique is applied for CEED problem with modified "a" value exponentially as equation (21). This simulation aims to get the best number exponential (n) in minimized fuel cost and emission. In order to check the robustness, the simulations are carried out for 20 trials. The result simulations are presented in Table 2. So we can conclude that the best (n) is 1/100.

Table 2 Statistical result of various number exponential (n)

n	Mean Cost ($/h)	Best Cost ($/h)	Worst Cost ($/h)	Interval	Standard Deviation
3	42062.14341	42060.07016	42066.99931	6.92915	1.784167312
2	42060.82903	42060.28334	42061.83556	1.55222	0.450715962
1	42060.45973	42060.01926	42061.31121	1.29195	0.321318704
1/2	42060.19243	42059.98506	42060.47175	0.48669	0.13138559
1/3	42060.10369	42060.00395	42060.27292	0.26897	0.085001656
1/10	42060.00586	42059.97062	42060.05776	0.08714	0.024525898
1/100	**42059.96022**	42059.95636	**42059.9657**	**0.00934**	**0.002723754**
1/500	42075.57572	**42059.95625**	42194.6957	134.73945	36.84936207
1/1000	42139.78583	42060.75232	42437.82206	377.06974	104.7804376

To judge the superiority of the conventional GWO and the proposed miGWO methods, the result are compared with the results obtained by other algorithms such as modified GWO (mGWO), improved GWO (iGWO), Ant Lion Optimization (ALO) and Particle Swarm Optimization (PSO).
The comparative results of active power generation, fuel cost, emission and combined cost using the miGWO method along with other methods are given in Table 3. The results show that the miGWO succeeds in finding the best solution.

Table 3 Simulation result using various algorithm of IEEE 30-bus 6-generator test system at 900 MW power demand.

	GWO	mGWO	iGWO	miGWO	ALO	PSO
Elapsed Time (seconds)	5.672524	6.821681	5.827677	5.631813	23.469914	5.875537
Unit #1 (MW)	124.994	125	124.995	125	125	125
Unit #2 (MW)	93.7617	93.599	94.0216	93.6055	93.5598	93.5557
Unit #3 (MW)	98.9678	99.1449	99.0561	99.1169	99.0729	99.1633
Unit #4 (MW)	139.881	139.789	139.779	139.806	139.748	139.737
Unit #5 (MW)	267.391	267.346	267.318	267.373	267.461	267.378
Unit #6 (MW)	229.3	229.465	229.161	229.43	229.46	229.506
Total Generation (MW)	954.295	954.344	954.331	954.333	954.301	954.34
Losses (MW)	54.2955	54.3436	54.3311	54.3326	54.3013	54.3398
Fuel Cost ($/h)	50243.81783	50242.76229	50250.28335	50242.45323	50240.13199	50241.68203
Emission (lb/h)	756.36824	756.389	756.22628	756.39589	756.4479	756.4132
Combined Cost ($/h)	42060.01926	42059.95636	42060.07308	42059.95622	42059.96043	42059.95823

Moreover, in order to check the robustness, the simulations are carried out for 20 trials with miGWO method. It is found from the statistical result, listed in Table 4, that the worst, average, and best values of the combined costs and standard deviation as well as success rate achieved by miGWO are much better than those of GWO and other methods

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mentioned before. These results clearly indicate the highest robustness of the solutions obtained by miGWO method.

Table 4 Comparison of statistical result of various algorithm of IEEE 30-bus 6-generator test system at 900 MW power demand.

Algorithms	Average Cost ($/h)	Best Cost ($/h)	Worst Cost ($/h)	Interval	Std Deviation	Average Computation Time (seconds)
ALO	42060.07133	42059.96043	42060.36575	0.40532	0.119292317	23.4563
PSO	42059.96766	42059.95823	42059.99946	0.04123	0.009680505	5.9820
GWO	42060.45973	42060.01926	42061.31121	1.29195	0.321318704	5.9368
miGWO	**42059.96028**	**42059.95622**	**42059.96485**	**0.00863**	**0.002902422**	**5.9332**

The convergence characteristics of the IEEE 30-bus 6-generator test system with miGWO, GWO, PSO, ALO algorithms for combined cost minimization with iteration cycles are shown in Fig 1. In the Fig. 1, itsshows the cost function value converges smoothly to the optimum value without any abrupt oscillations, thus ensuring convergence reliability of the proposed miGWO algorithm.

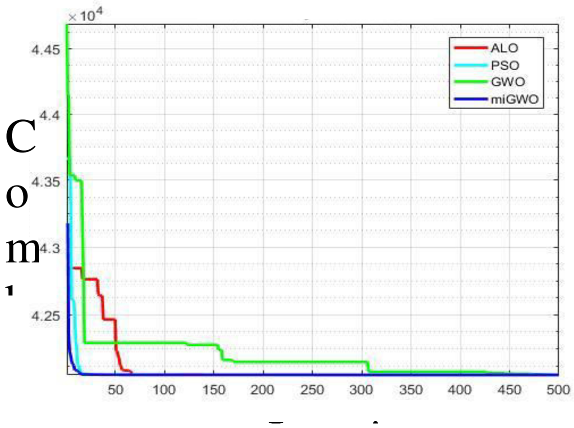

Fig. 1 Comparative convergence behavior of ALO, PSO, GWO and tne proposed miGWO strategies for 6-generator test system at 900 MW power demand.

V. CONCLUSION AND FUTURE WORK

In this paper, the miGWO method has been proposed and successfully applied to solve the CEED problem. The combined mGWO and iGWO algorithms become miGWO algorithm is capable to finding better solutions in terms combined cost, robustness, convergence and computational time over several other algorithm. To show the feasibility and effectiveness of the proposed miGWO method, this method may be implemented in other areas of the optimization problems.

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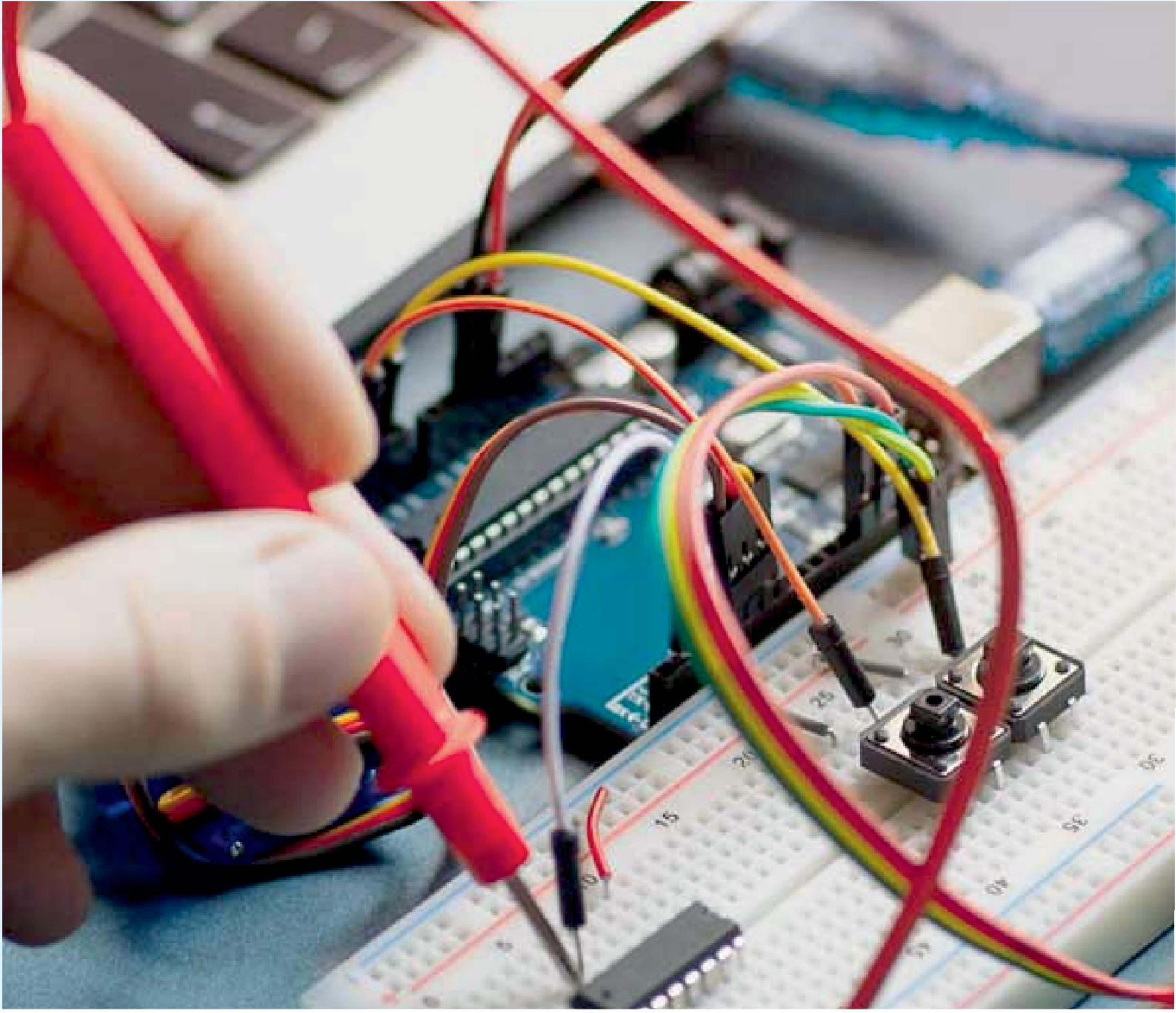

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