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Capacity & Design Optimisation of Industrial UPS system on kVA, kW, power factor & Harmonics parameters

Amit Sinha[1], Sridhar Alegatwar[2], Mohan Ramaratnam[3]

Area Lead- Electrical, Fluor Daniel Pvt Ltd, Gurgaon, Haryana, India[1]

Design Engineer- Electrical, Fluor Daniel Pvt Ltd, Gurgaon, Haryana, India[2]

Head - Business Development, Borri Power India Pvt Ltd, Bangalore, Karnataka, India [3]

ABSTRACT: The paper highlights the optimal sizing of the industrial grade UPS system and battery, with respect to its actual load power factor and output kW/kVA. The paper also attempts to outline the rationale behind the selection of a “fit to purpose” based 6 pulse or 12 pulse or Thyristor based or IGBT based UPS system. It also briefly includes the applicability of line interactive UPS, delta conversion and transformer-less UPS. The paper also discusses some ways to mitigate the over-designing of the UPS in oil & gas and petrochemical industry.

With the target audience being the EPC consultants in electrical as well as clients who are the owners of refineries and petrochemical facilities, the implementation of this paper in EPC execution is most pertinent during the material requisition stage of the UPS equipment and other non-linear electronic equipment like VFDs, DC Chargers, soft starters.

KEYWORDS:PCC- Point of common coupling, IGBT- insulated gate bi-polar transistor, SCR – silicon-controlled rectifier, Switch mode power supply (SMPS), THD- total harmonic distortion, TDD-total demand distortion, PFC-power factor corrected, VFD- Variable frequency drive

I.INTRODUCTION

Modern days SMPS & instrumentation loads have evolved on power factor from the olden day’s lows of 0.80-0.85 to present day highs of around 0.90-0.95. Despite this, the characteristics of the “uninterrupted power Supply” as required in numerous project specifications in various industries might not have been updated to reflect advancement in the technology of the load. Also, the instrument specifications might not have been revisited to mention the need of higher power factor of around 0.90-0.95.

This can culminate in either numerous industrial UPS getting undersized to cater the increased real power demand of the present-day loads or can result in oversizing of the UPS due to over-compensated and over conservative design. These do lead to wastage of organization money. Also, this happens in absence of near to real instrumentation load data and parameters while performing the UPS sizing calculation during the early stage in any project.

In addition to the power factor, the harmonic containment also leads to a similar scenario. The harmonic requirement on the source side of the UPS as interpreted from the application of IEEE 519 may sometimes result in the selection of overdesigned UPS, especially in industries with large power source, typically in oil, gas and petrochemical facilities. Also, it at times leads to inclusion of too superior designed non-linear equipment like VFDs, DC charger, soft starters, etc., thus leading to an overall increase in the total installed cost (TIC) in EPC project execution of such industrial facility.

In any kind of industry like Oil and Gas, power, metals, cement, life sciences, FMCG etc, the Electrical discipline is responsible for sizing and procuring the industrial UPS. Generally, this UPS is to cater the control system or telecommunication loads such as DCS, field instruments, PLC, workstations, fire and gas systems, public address & communication system etc. Sometimes, they also feed to ballast type lighting circuits. As most of these loads are

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instrumentation or SMPS based loads, Electrical discipline is able to size the UPS based on estimated loads furnished by the Control System or the telecommunication discipline. This paper will present how imperative is to consider the appropriate power factor and harmonic corrections while the UPS sizing, selection and ordering are done based on the received load information.

II.EFFECT OF LOAD POWER FACTOR ON KVA RATING OF UPS

Now a days all instrumentation and SMPS based loads are more efficient and advanced and also have a low distortion factor. Their power factor is generally found more than 0.95. The distortion power factor plays the prime role in improving and pushing the power factor towards close to unity in these loads. Therefore, at the outset, it is to be understood that by considering or assuming the UPS end load power factor as 0.8, the UPS and its internal components increase in size, that subsequently increases the overall UPS cost.

There are two components of power factor, first one is displacement power factor which is the power factor that is due to the phase shift between the voltage and the current at the fundamental frequency. For linear loads such as motors, compressors etc, generally the displacement power factor is equal to the true power factor. The second one is the distortion power factor which is the power factor that includes the effect of harmonics present in the system.

$$\boldsymbol{Distortion\ PF} = \frac{\mathbf{1}}{\sqrt{\mathbf{1} + \%\boldsymbol{iTHD}^{2}}}$$

Distortion factor depends on the total current harmonic distortion of that specific equipment. If THD is high, the distortion power factor will be lower and therefore poorer. Hence to improve distortion factor, the harmonic content of the load equipment shall be less. This distortion factor comes into picture for non-linear loads, such as VFD, UPS, Power convertors, SMPS loads etc.The displacement and distortion factors together combine to form the true power factor.

True power factor = Displacement power factor x Distortion power factor

For linear loads, as distortion power factor is absent, the true power factor equals the displacement power factor. For SMPS based loads, the displacement power factor is negligible, so the true power factor equals the distortion power factor.

As UPS itself feeds the non-linear Loads like SMPS, LAN, PLC, instrumentation systems and digital loads, the UPS should be sized by considering appropriate distortion factors of these loads.Further to this, as already mentioned, nowadays, SMPS and instrumentation loads are advanced and they generally have high distortion power factor that leads to high true power factor, typically around 0.95. Vendor furnished data of these loads can be assessed to check their power factor. Also, it is a well-known fact that keeping the power factor as close to 1 as possible saves money.In any UPS system, to cater to the end load requirement, the battery produces active power, and the inverter produces the reactive power.

Table-1 depicts a comparative case study of UPS system design with end loads as 108kW and 120kVA vis-a-vis with 0.8 pf & 0.9 pf. It is noticeable from the table-1 that for a fixed kW end load (here 108kW), if 0.8pf is considered, the internal components of UPS such as bypass transformer, voltage stabilizer, static switches and the rating of the associated equipment in the ACDB are increased.

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Table – 1

		Case1: End load requirement - 108kW		Case2: End load requirement - 96 kW
Sr. No	**UPS component/ equipment**	**0.9pf 120kVA UPS**	**0.8pf 135kVA UPS**	**0.8 pf 120kVA UPS**
1	Output Rating (kW)	108	108	**96**
2	Output Rating (kVA)	120	135	120
3	Output Voltage (V)	110	110	110
4	Output Power factor	**0.9**	**0.8**	**0.8**
5	Isolation transformer (kVA)	223.45	223.45	**212.45**
6	Input MCCB rating (A)	310.87	310.87	**294**
7	Bypass Transformer(kVA)	120	**135**	120
8	Rectifier rating (kW)	139.79	139.79	**125**
9	Battery AH	315AH	315AH	**290AH**
10	Static Switch Ratings (A)	1090.91	**1227.27**	1090.91
11	ACDB Incomer Rating(A)	1309.09	**1472.73**	1309.09
12	ACDB Bus Rating (A)	1309.09	**1472.73**	1309.09
13	Voltage Stabilizer	120kVA	**135kVA**	120kVA

3 important points that can be concluded from the table-1 are

1. By considering actual "true power factor" of the UPS end kW load , the UPS can be sized economically.
2. If the UPS end load requirement is estimated in kW and if 0.8 pf is considered, the battery gets appropriately sized (as the source of active power), but UPS components get oversized, as they get designed for higher current, that would actually never flow in the system.
3. If the UPS end load requirement is estimated in kVA instead of kW and 0.8 pf is considered, the battery & rectifier gets undersized. And it subsequently leads to
   (i) Either reduction in actual back-up time when the UPS is loaded with end loads with higher power factor than 0.8. Remember, a similar issue must have been noticed in UPS for personal computers that are designed for 600VA, 0.6pf, 15 minutes, but gives only 10 minutes or lesser back up, when actually loaded with those computer loads.
   (ii) UPS overloading & transfer from mains to by-pass
   (iii) Maxing out the kW without even reaching max kVA. This kW overloading in UPS is unforgiving, it produces heat & its components start degrading soon owing to the heat.

This illustrates how the power factor plays an important role in sizing of UPS. And specially in high capacity UPS, by raising the rated power factor of UPS towards unity from 0.8, the technical and commercial gain achieved can be really impressive.

III.EFFECT OF HARMONICS ON THE SELECTION OF UPS

The harmonics play a very dominant role while designing any power electronic equipment such as UPS, VFD, DC Chargers etc. Harmonics are defined as the component of periodic wave whose frequency is integral multiple of the fundamental frequency. Non-linear loads such as static power convertors (rectifiers, inverters), variable speed drives, furnaces, electronic ballasts, SMPS etcetera create harmonics. The current drawn by these loads consist of a fundamental frequency component rated at 50 Hz, plus a series of overlapping currents, with frequencies that are multiples of the fundamental frequency. These current distortions further cause voltage distortion in the system.

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As UPS is itself a harmonic generating equipment, considerable care should be taken while selecting the UPS type such as 6 Pulse, 12 Pulse, IGBT based etc. The same consideration is also needed during the selection of DC Chargers and VFD.

While selecting the above, sometimes misinterpretation of IEEE-519 recommendation about THD and TDD leads to selection of higher than required no of pulse type UPS/VFD/Charger. This ends up in a higher cost to the facility owner, unless there is an over-riding process requirement of higher pulse/ advanced technology in the aforesaid electronics equipment. This mis-selection is more pronounced in a typical petrochemical or power plant set up, where generators and grid power sources are large in capacities as compared to the electronic equipment rating.
THD is the Total Harmonic Distortion (Current/Voltage) and is the ratio of the root mean square of the harmonic content, considering harmonic components up to the 50th order & the fundamental harmonic component, and is expressed as a percentage.

TDD is the Total Demand Distortion (Current) and is the ratio of the root mean square of the harmonic content, considering harmonic components up to the 50th order and the maximum demand load current, and is expressed as a percentage. Total demand distortion is also known as "Total current distortion".
As per IEEE 519, the Total Demand Distortion/ Total Current Distortion is recommended to be evaluated at the point of exchange between owner, user and other users. In an industrial plant, PCC can be the point between linear and non-linear loads or as specified in the client specification. But it is important to consider that PCC is applicable on the full load demand level of the electrical system at the point feeding to linear plus non-linear loads, and not on the individual non-linear equipment.

Refer IEEE 519, table 2 appended below

Table 2—Current distortion limits for systems rated 120 V through 69 kV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)[a, b]						
I_{SC}/I_L	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
$< 20^c$	4.0	2.0	1.5	0.6	0.3	5.0
$20 < 50$	7.0	3.5	2.5	1.0	0.5	8.0
$50 < 100$	10.0	4.5	4.0	1.5	0.7	12.0
$100 < 1000$	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

Isc = Maximum Short circuit current at PCC
IL = Maximum load demand current at PCC under normal load operating conditions. It is calculated as the average current of maximum demands for the previous 12 months

PCC = Point of common coupling
TDD at the PCC i.e., current distortion limits are dependent on the

1. *Stiffness of the source (Isc /IL): lower the impedance, higher the stiffness.*
2. *Amount of total linear load in the user-1 system*
3. *Amount of total non-linear load in the user-1 system*

Here the TDD should not be misinterpreted as THD, because it then leads to unnecessary implementation of stringent TDD percentage on each individual non-linear equipment. During the misinterpretation, the consideration of the above 3 factors is missed. These factors when considered, gives leeway for the selection of cheaper 6 pulse or 12 pulse-based UPS/VFD/DC Chargers without reaching the current distortion limits and without deviating from IEEE 519 Table 2.

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The selection of 6 pulse UPS assists in building a fit-to-purpose design and optimises the cost of procurement. It brings saving in cost of real estate and construction owing to the smaller footprint of 6 pulse-based equipment because superior ones have additional set of rectifiers/inverters and 3 winding transformers with 30-degree phase shift along with increased quantity of internal components. Also, the servicing and maintenance cost during the life cycle is reduced. The same also applies on 6/12 pulse VFD vs 18 pulse VFD.

Note that superior 18 pulse/IGBT based systems are available in the market and are excellent products, very apt for facilities that have different nature of the 3 factors listed above. Generally, facilities like commercial buildings, data centres and smaller industries that have low MVA rating of power source or higher impedance and have an exorbitantly high percentage of non-linear loads are in dire need of these superior products. In oil, gas and petrochemical industries, that generally have high MVA rating of power sources, the implementation of 18 pulse/ IGBT based equipment should be technically evaluated with respect to specific process requirement in individual projects, as the harmonic requirement might not be an over-riding factor.

The below mentioned table-3 is comparison of 6 pulse, 12 pulse and IGBT based UPS systems on various parameters

Table- 3: Comparison Between 6 Pulse, 12 Pulse and IGBT based UPS

	6-pulse	12-pulse	PFC (IGBT)
Current rating	**High**	**High**	Medium
Efficiency	Up to 93%	Up to 93%	**Up to 96%**
Input current distortion (THDi)	≈ 27-30%	≈ 10-12%	**< 5%**
Input power factor	Up to 0,8	Up to 0,9	**> 0,99**
Response	Medium	Medium	**Fast**
Complexity	**Low**	Medium	High
Ruggedness	**High**	**High**	Medium
Reliability	**Very high**	**Very high**	High
Cost	**Low**	Medium	High

Cost Comparison matrix for VFD			
	6 pulse	**12 Pulse**	**18 Pulse**
Diode	A	A x 1.35	A x 2.5
Thyristor	A x 1.08	(A x 1.08) x 1.35	(A x1.08) x 2.5
IGBT	A x 2	(A x 2) X 1.35	(A x 2) x 2.5

EPC consulting engineers are suggested to perform a basic calculation or preliminary study to assess the TDD at the point of common coupling (described earlier as PCC), before floating the RFQ or performing the bid evaluation. Generally, for large projects, this study requirement is mentioned in the client specification, but where the same is not mentioned as a contract requirement, proactively this study can be done. This would facilitate to comprehend whether the facility needs 6 pulse-based UPS /VFD/Charger or 12 pulse-based UPS/VFD/Charger or 18 pulse/IGBT based.

Some more types of UPS with advanced technologies are also explained below

Transformer-less UPS are those in which the thyristor-based rectifier is replaced with PWM IGBT based 3 phase power factor corrected & current waveform rectifier. These UPS are still double conversion type (AC to DC & DC to AC) and have IGBT both in rectifier and inverter.But as these UPS do not have primary input transformers, it makes them unsuitable for industrial applications, where apart from harmonics, EMC/EMI noise picked up from long distance cables feeding to end loads are feared to be injected from the UPS to the source. But in commercial applications like datacentres, commercial buildings, infrastructure, where end loads are quite near to the UPS, the vulnerability to the aforesaid noise is very less and hence these are extensively used. These UPS do bring in numerous

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advantages like high-power factor over a wide range of loads, low footprint and low weight owing to lower magnetic package, better harmonic control, faster transition/ change-over time, low cooling requirement and less all-round clearances requisites.

Line interactive UPS and Delta conversion UPS are UPS with no dual conversion mode under normal conditions. The dual conversion and battery mode is applicable only during the outage of the main source, thereby increasing the battery life. While line interactive UPS are in single phase, those that are applicable in three phase applications are called delta conversion UPS. These typically are available in low ratings, up to 5-10kVA, hence apt for low rated critical applications, like healthcare.

IV. CASE STUDIES

Coming back to oil and gas industry, section IV consists of case studies for TDD calculation at PCC (point of common coupling) for a facility with a switchboard (EPMCC) powered by 2.5MVA distribution transformer and feeding to numerous other linear and non-linear loads along with the UPS system (6 pulse-based vis-à-vis 12 pulse based).

- **i) Case Study by considering 6 pulse-based UPS system.**
- **ii) Case Study by considering 12 Pulse based UPS system**

In both the cases studies, it is considered that the emergency switchboard (EPMCC) is the point of common coupling and is also directly connected to the utility (owner).

Analysis from the case studies: It is evident that even a 6 pulse-based UPS fed from a source (EPMCC) that is feeding to majority of linear loads is enough to meet the IEEE 519 requirement of harmonics at the point of common coupling. It is also understood that the variables on which the above fulfilment actually depended as per the below tables are

1. *The actual short circuit capacity and not the designed short circuit capacity of EPMCC*
2. *The actual demand load and not the transformer rated load current of EPMCC*
3. *The THD% of other non-linear loads, like VFDs in this case*
4. *The percentage of other linear loads connected*

It is to be noted that other non-linear loads like VFDs also can also be assessed through similar case studies of 6 pulse vs 12 pulse vs 18 pulse, and optimisation can be envisaged there as well. Sometimes, an appropriate permutation and combination for selection of 6/12/18/IGBT based UPS/Charger/VFDs can yield much more economical solution, provided the comparative price data of each of them is made available.

I.Case Study by considering 6 pulse-based UPS system

6pulse VFDs Connected to415V EPMCC

VFD Connected to EPCC		**Absorbed**	**Connected**
BUS-A	OVERHEADAIRCOOLER-1	7.90kW	11.00k
BUS-A	OVERHEADAIRCOOLER-2	7.90kW	11.00k
BUS-A	OVERHEADNAPHTHAAIRCOOLER-	34.08kW	45.00k
BUS-A	OVERHEADNAPHTHAAIRCOOLER-	34.08kW	45.00k
BUS-A	TEMPEREDWATERAIRCOOLER-1	25.35kW	37.00k
BUS-A	TEMPEREDWATERAIRCOOLER-2	25.35kW	37.00k
BUS-A	TEMPEREDWATERAIRCOOLER-3	25.35kW	37.00k
	Total	**160.01 kW**	**223.00**
BUS-B	OVERHEADAIRCOOLER-1	7.90kW	11.00k
BUS-B	OVERHEADAIRCOOLER-2	7.90kW	11.00k
BUS-B	OVERHEADNAPHTHAAIRCOOLER-	34.08kW	45.00k

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BUS-B	OVERHEADNAPHTHAAIRCOOLER-	34.08kW	45.00k
BUS-B	TEMPEREDWATERAIRCOOLER-1	25.35kW	37.00k
BUS-B	TEMPEREDWATERAIRCOOLER-2	25.35kW	37.00k
BUS-B	TEMPEREDWATERAIRCOOLER-3	25.35kW	37.00k
	Total	**160.01 kW**	**223.00**

6 Pulse UPS connected to 415VEPMCC

Equipme	UPSKV A	Harmon ic
110V ACUPS	135.00	56.35
230V ACUPS	12.50	5.22
220V DCCharger	25.00	10.43

30% of fundamental current asper Table 3

Total VFD and UPS Load BUS A + BUS B	492.52	Ampere	
Total Current	895.71	Ampere	
Total Current for Only VFD drives	468.66	Ampere	
THD (Current) for 6 Pulse VFD drives	**64.68**	13.80%	*as per THD data received from manufacturer for 6 pulse VFD*
Total Input harmonic Current on EPCC BUS (UPS + Drives)	136.67		

TDD Calculation at Point of Common Coupling

EPMCC Transformer rating	2.5	MVA	
Maximum load demand Current as per actuals	2019	Ampere	*Total actual load considering diversity factor of EPMCC*
Max Short Circuit Current	47	kA	*as per short circuit study in ETAP*
Short Circuit Ratio	23.28		
Total TDD at EPCC	6.8	%	*as per IEEE 519 table 2, TDD shall be less than 8% hence controlled*

II.Case Study by considering 12 pulse-based UPS system

6pulse VFDs Connected to 415V EPMCC

VFD Connected to EPCC		Absorb ed	Connect ed
BUS-A	OVERHEADAIRCOOLER-1	7.90kW	11.00k
BUS-A	OVERHEADAIRCOOLER-2	7.90kW	11.00k
BUS-A	OVERHEADNAPHTHAAIRCOOLER-	34.08kW	45.00k
BUS-A	OVERHEADNAPHTHAAIRCOOLER-	34.08kW	45.00k
BUS-A	TEMPEREDWATERAIRCOOLER-1	25.35kW	37.00k
BUS-A	TEMPEREDWATERAIRCOOLER-2	25.35kW	37.00k
BUS-A	TEMPEREDWATERAIRCOOLER-3	25.35kW	37.00k
	Total	**160.01 kW**	**223.00**
BUS-B	OVERHEADAIRCOOLER-1	7.90kW	11.00k
BUS-B	OVERHEADAIRCOOLER-2	7.90kW	11.00k
BUS-B	OVERHEADNAPHTHAAIRCOOLER-	34.08kW	45.00k

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BUS-B	OVERHEADNAPHTHAAIRCOOLER-	34.08kW	45.00k
BUS-B	TEMPEREDWATERAIRCOOLER-1	25.35kW	37.00k
BUS-B	TEMPEREDWATERAIRCOOLER-2	25.35kW	37.00k
BUS-B	TEMPEREDWATERAIRCOOLER-3	25.35kW	37.00k
	Total	**160.01 kW**	**223.00**

12 Pulse UPS connected to415VEPMCC

Equipme	UPSKV A	Harmon ic
110V ACUPS	135.00	22.54
230V ACUPS	12.50	2.09
220V DCCharger	25.00	4.17

12% of fundamental current asper Table 3

Total VFD and UPS Load BUS A + BUS B	492.52	Ampere	
Total Current	895.71	Ampere	
Total Current for Only VFD drives	468.66	Ampere	
THD (Current) for 6 Pulse VFD drives	64.68	13.80%	*as per THD data received from manufacturer for 6 pulse VFD*
Total Input harmonic current on EPCC BUS (UPS + Drives)	93.47		

TDD Calculation at Point of Common Coupling

EPMCC Transformer rating	2.5	MVA	
Maximum load demand Current as per actuals	2019	Ampere	*Total actual load considering diversity factor of EPMCC*
Max Short Circuit Current	47	kA	*as per short circuit study in ETAP*
Short Circuit Ratio	23.28		
Total TDD at EPCC	4.6	%	*as per IEEE 519 table 2, TDD shall be less than 8% hence complied*

V.CONCLUSION

The load power factor of the UPS plays a key role in sizing the UPS optimally and economically in any industrial or commercial application. As the UPS size increases, it can be observed that there is a marked difference in the cost impact owing to the power factor. Also, mitigation of UPS overloading issues can be achieved by utilizing the actual load power factor during the UPS sizing. Further, the selection of type of UPS or VFD or Charger with respect to its conversion technology depends a lot on the nature of the industry, and prudent application of this paper can help to select "fit to purpose" design of the same in oil and gas industry. These would certainly bring home some considerable optimisation in capital and operational expenditure on electrical systems in such facilities.

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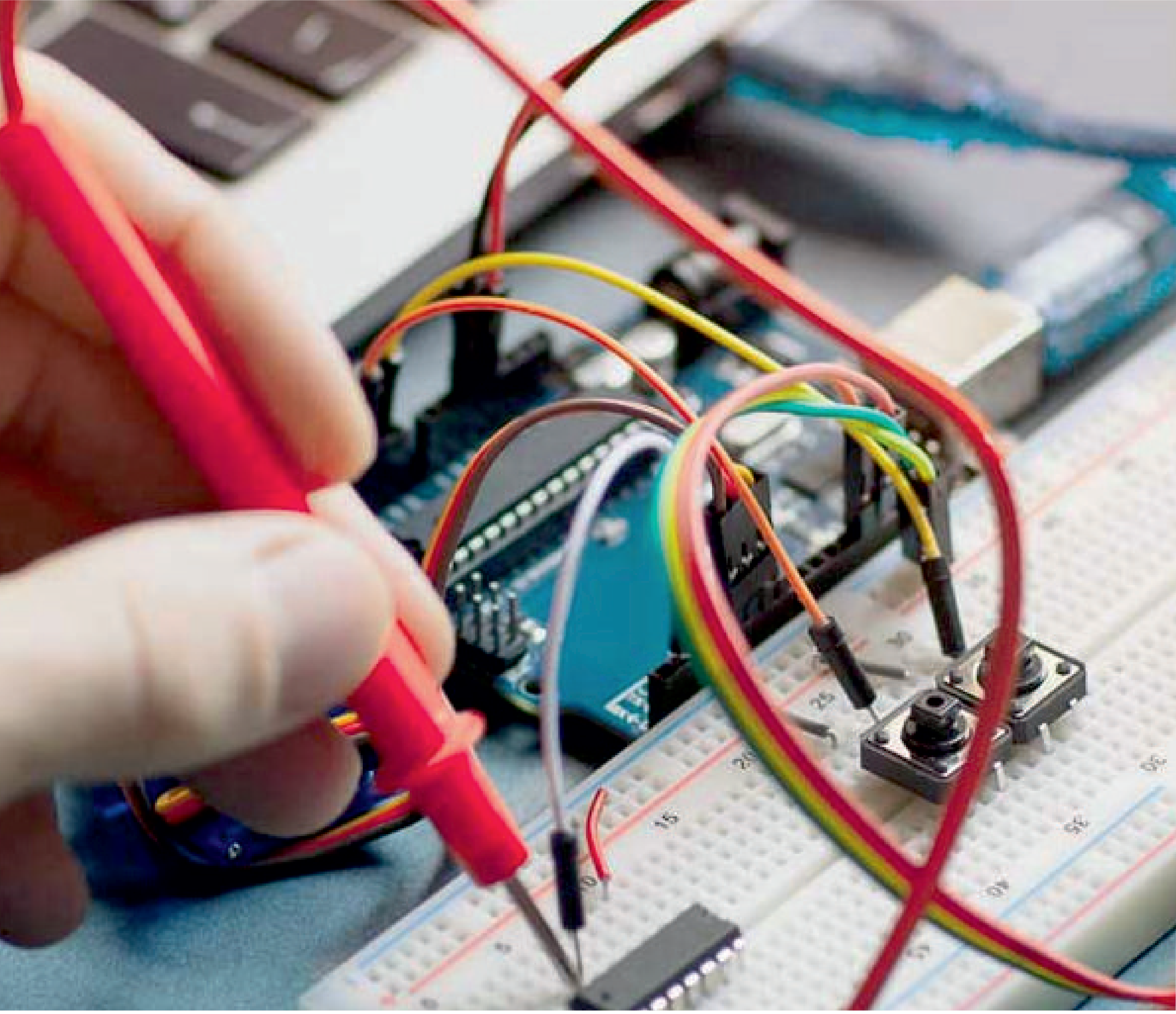

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