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Grid Connected Dual Winding Permanent Magnet Synchronous Generator Based Wind Turbine under Low Voltage Ride through Using STATCOM

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ABSTRACT; This paper elaborates the dynamic performance of a VSC-based DWP-STATCOM for power quality enhancement in agrid integrated system and low voltage ride through (LVRT) capability. LVRT requirements suggest that the injection of realand reactive power supports grid voltage during abnormal grid conditions. The proposed strategy was demonstrated with MATLAB simulations.

KEYWORDS; Grid, PMSG's, Wind Turbine, LVRT, VSC-Based Double Winding Power STATCOM, Pulse Width Modulation.

I. INTRODUCTION

The centralize transmission power supply system globally has some major defect such as low reliability, environmental pollution and poor flexibility. And as well the increased demand of non-linear loads and drifting to renewable energy penetration is also contributing to power quality problems, such as current harmonics, reactive power demands and voltage variations (voltage sag and swell), in distribution and transmission systems. Among the various power quality issues, harmonics and voltage dip are the frequently occurrence and many problems in the power system network [10]. The main cause of harmonics is high demand of electrical equipment, power electronics-based electrical appliance controls to advance their performance. More so in likewise voltage sag are majorly caused by the increasing of load current by starting large motors, transformer energization, switch ON and OFF operation of circuit breakers, that triggers faults within the user's end, equipment failure, abnormal weather conditions (lightning strikes on power systems [7]. As per IEEE Std. 1159, voltage dip is defined as the reduction in RPM (Revolution per Minute) voltage (AC voltage) from 90% to 10% of the insignificant voltage at power frequencies within 0.5 cycles to 1min [17]. Voltage dip are classified based on Magnitude and dip duration. Voltage dip accounts for over 80% of the power quality snags that exist in distribution and transmission systems [11].

Low voltage ride through (LVRT) designates that generation unit must persevere connected to grid uninterruptedly, to deliver the essential quantity of real and active power (Q) to support grid voltage recovery during voltage dip [21].

II. RELATED WORKS

The influence of traditional power plant scheme control is dipping due to unbundling, regionalization and auxiliary of predictable power plants by renewable energy source, especially wind power.Wind power is installed in larger unit, e.g., offshore wind farms, and therefore the impact of wind power becomes significant.Wind power is often installed at remote place and in weak grids, e.g.at coastal area far away from the consumption centers.Wind power is a fluctuating power source depending on the prevailing wind and must be balanced.Larger variation in generation and consumption causes larger current fluctuations and node voltage variations, which must be balanced.

The increasing utilization of non-linear loads and penetration of renewable energy source is contributing to Power quality difficulties, such as current harmonics, reactive power demands and voltage variations (voltage sag and swell),

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in distribution and transmission systems. Among the various power quality problems, harmonics and voltage are the most common and several problems in power systems [10].The main cause of harmonics is the increased use of power electronic-base electrical appliance controls to improve their performance. The main cause of voltage sag is the escalation of load current caused by the starting of large motor, transformer energization, switch ON and OFF operation of circuit breakers, faults within the customers facilities, equipment failure, abnormal weather conditions (lighting strikes on power systems) and the highly intermittent nature of renewable sources connected to distribution systems [7]. Power system stability is thus a matter of interest in terms of lager wind power penetration or wind power in very weak grids needs to be investigated. Power system stability addresses primarily two tasks;

Voltage control – reactive power compensation: In order to keep the system voltage constant at each bus bar in the grid, the reactive power production and consumption must be equalized at each point in the system. The task was traditionally performed by large centralized power plants placed if problem occurs, this task is today assigned to wind turbines located at remote places reactive power demand by themselves, which varies depending on the wind speed and which must be compensated, for. The ability of wind turbines to supply reactive power is also a very important issue in respect to short term voltage stability, e.g., after voltage dip due to grid faults. Thus, voltage control capability of wind turbines becomes an increasingly important aspect regarding wind power grid integration and the wind turbine’s market potential [22].

Frequency control – active power dispatch: As wind energy is naturally a fluctuating power source, frequency regulation and active power dispatch become a challenging factor when the available power production is uncertain [19]. Another aspect in this context is, that wind turbine until now were allow to disconnect in case of grid fault. In area with high wind power penetration this cause a significant loss of electrical power production due to disconnection of large wind turbine, which could negatively influence system stability and lead to major blackouts, Thus, transmission system operations require of wind turbine to be able to ride – through faults, so that large loses of active power supply can be avoided. It must furthermore be investigated to which external wind power can contribute to primary and secondary control. A proposed solution to this problem is e.g., to curtail wind power and to release the power reserves when needed.

Low Voltage Ride-Through;The low voltage ride-through demand requires of wind turbines to stay connected to grid during faults in order to avoid significant losses of active power production in the power systems with high amount of wind power. Before the fault ride-through requirement was introduced wind, turbines had to disconnect in case of fault. As most of the wind turbine were principally conservative fixed speed wind turbine with direct grid connected generator that might source a large source inrush current at voltage retrieval [18]. Thus, wind turbine, which are connection to the power structure today, are requested to ride-through grid fault. The first wind turbines based on squirrel cage asynchronous generators were very subtle to grid outages. The shields were tuned in such a way that the wind turbine disengaged with even minor turbulences [5]; [1]; [20]; [8]; [8 & 13];[9]; [15]; [16]. This caused two major problems for the TSO-DSO.

Reactive Power Supply- During grid faults the system voltage drops in vicinity to the location of the fault. In order to support the voltage level and required and re-establishment, voltage control and reactive power supply are required by transmission system operators. The ability to deliver reactive power to the grid is strongly dependent on the wind turbines technology. Grid codes requires not only compensation of the wind turbines own reactive power demand but also additional reactive power supply in dependency of the voltage dip. The requirement can however be met by means of capacitor bank and power electronic connected close to the turbines Moreover, modern permanent magnet synchronous generators wind turbine with frequency converters is used.

Frequency Stability- Electrical system stability is the procedure of the generation unit under different frequency. First, it must be guaranteed that the generating unit stays linked to the system even if the frequency fluctuates. Furthermore, the frequency response of the generating unit i.e., the capability to subsidize to primary and secondary control, is imperative Thus, the grid codes stipulate rules to acquaint the wind turbines active power creation rendering to frequency variations in the system. This, however, can cause problem, as wind is naturally fluctuating so that active power necessarily available on demand. Nevertheless, some grid codes, e.g., Danish grid code [23], precisely specify rules which extend wind turbines subsidize to regulate their power output. On demand of the transmission technician the wind power structure must be reduced below its optimal output (delta control) and the gradient of the power production is specified and limited (gradient constraints).

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Other important area concerning longer time frame are the contribution to active power supply on demand, the requirement to provide balancing power and to curtail wind power production in order to provide spinning reserve. In this respect wind power forecast and the introduction of incentive market mechanism for wind turbine operator become important issues.

Furthermore, in additional to the requirement mentioned above, transmission system operators demand modelling, simulation and verification of the wind turbine system. Communication and external control for the wind turbine especially for large wind farms are also required but represent anyway standard equipment in modern wind turbines. Other grid requirements e.g., the contribution of wind farms to perform a ‘black start’, which means to start and operate in an islanding system, but not yet concluded [12].

Grid code are generally different for wind turbines connected to medium voltage grids or high/extra high voltage grids [23], [24]and are more stringent for the high voltage network. Today, most of the wind turbine are still connected to medium voltage grid. However, the installation of large units and especially of large offshore wind farms always require connection to the voltage grid [25].As stated in [22], in contrast to distribution system the R/X value of transmission system is lower, which intensifies the need of reactive power control thus, the most rigorous grid code requirement for high voltage grids refer to low voltage ride-through capability and reactive power control especially during voltage dip [14].

The transmission system operator Enginet.dk requires of each wind manufacturer to provide a simulation model of the wind turbine system in an appropriate power system software (e.g., DIgSILENT, PSSE). Based on this simulation model a test report must be delivered to the transmission system operator, which verifies the dynamic behavior of the wind turbine under grid faults. The simulation of the grid fault must be performed under the following conditions. Before the fault incident the wind turbine must operate at a wind speed, which result in production of rated power and at normal speed. Moreover, full compensation of the system is required before the short circuit happens. It is sufficient to simulate a three-phase short circuit, The grid is characterized by an R/X ratio of 0.1 and has short circuit power {Sk} of ten times the wind turbine power wind turbine, rated. The wind turbine is connected to the grid via the machine transformer. In order to simulate the short circuit, a predefined voltage profile must be applied to the voltage source.

III. MATERIALS AND METHOD

Various control strategies for voltage regulation, low voltage ride-through, load reactive power compensation, and voltage balancing are available in literature with different configurations of STATCOM such as PV-STATCOM, Battery-STATCOM etc., for constant voltage provision across STATCOM DC-link capacitor for effective Low Voltage Ride-Through (LVRT) capability in wind turbine generator. Photovoltaic cell plus STATCOM is limited to use in areas only where there is available of enough land space and less effective in the night hours, while battery backed-up STATCOM become bulky when higher active power is required from STATCOM as static synchronous generator. To overcome these limitations, a dual winding permanent magnet synchronous generator is proposed in which the second (auxiliary) winding is rectified and regulated as a constant voltage back-up power for STATCOM DC-link capacitor for effective performance. MATLAB/SIMULINK R2018a software was used for simulation.

Method of Analysis**;** The method of analysis includes mathematical models for wind energy conversion system with direct-driven PMSG wind turbine generator, dual-winding permanent magnet synchronous generator (DWPMSG), voltage source converter model (VSC) for STATCOM, Simulation of case study in MATLAB/SIMULINK. A brief description of the entire scheme is illustrated in Figure 3.1.

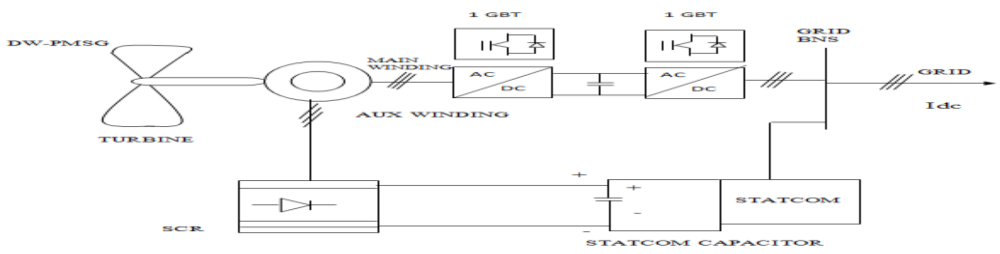

Figure 3.1: Schematic Diagram of DC Link Voltage Control and Voltage Link Mode

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Description of Wind Energy Conversion System (WECS); Wind Power, the kinetic energy which exists when an object of mass (m) in motion with a translational or rotational speed is given by:

$$E_k = {}^1/_2 m\bar{v}^2 \quad (3.1)$$

Where m is the mass of air and $\bar{v}$ is the average wind speed over a suitable time. Taking a time derivative of equation (3.1) gives the wind power as:

$$P_W = \frac{dE_k}{dt} = \frac{1}{2}\dot{m}\bar{v}^2 \quad (3.2)$$

Wind passing through a wind turbine drives the blade with a wine mass flow rate given as:

$$\dot{m} = \rho A\bar{v} \quad (3.3)$$

Where ρ (kg/m^3) is the air density and A(m^2) is air swept blade area. Substituting Eqn. (3.3) into Eqn. (3.2) gives the wind power given as:

$$P_W = {}^1/_2 \rho A\bar{v}^3 \quad (3.4)$$

The ratio of the power P_T (W) absorbed by the turbine to that of the moving air mass P_W (W) is given as:

$$C_p(\lambda,\beta) = \frac{P_T}{P_W} (3.5)$$

$$C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\,\beta - C_4\right)e^{-\frac{C_5}{\lambda_i}} + C_6\lambda (3.6)$$

$$\lambda_i = \left(\frac{1}{\lambda+0.08\beta} - \frac{0.035}{1+\beta^3}\right)^{-1} \quad (3.7)$$

$$\lambda = \frac{w_T R}{V_W} (3.8)$$

where $C_p(\lambda,\beta)$ is the performance coefficient of wind turbine, λ is tip speed ratio of the turbine rotor blade tip speed to wind speed, β is turbine blade pitch angle (deg), C_1 to C_6 are constants, R is the radius of the turbine rotor, w_T is the angular velocity of the rotor (rad/s), $V_W = \bar{v}$ is the wind speed (m/s).

From equation 3.5, the mechanical power taken by the turbine P_T from the wind power P_W is given as:

$$P_T = {}^1/_2\, C_p(\lambda,\beta)\rho A V_W{}^3 (3.9)$$

The mechanical torque T_T developed by the wind turbine delivered to the direct-driven PMSG is given as:

$$T_T = \frac{P_T}{w_T} (3.10)$$

$$T_T = {}^1/_{2w_T}\, C_p(\lambda,\beta)\rho A V_W{}^3 (3.11)$$

Equation 3.6 is a generic equation used to calculate $C_p(\lambda,\beta)$. In Simulink based modeling of turbine characteristics, the following coefficients C_1 to C_6 are: C_1 = 0.5176, C_2 = 116, C_3 = 0.4, C_4 = 5, C_5 = 21 and C_6 = 0.0068. The $C_p(\lambda)$ characteristics, for different values of the pitch angle β is given in figure 3.2, where $C_{pmax}(\lambda) = 0.48$, $\lambda = 8.1$, for $\beta = 0^o$.

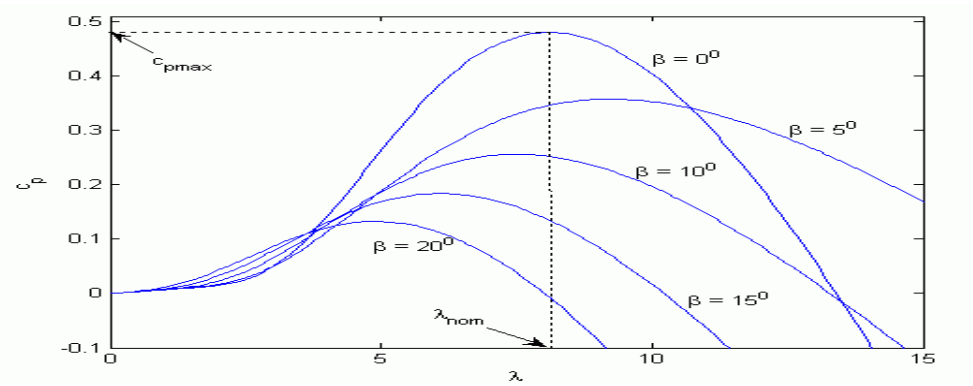

Figure 3.2: The $C_p(\lambda)$ characteristics, for different values of the pitch angle β.

Considering the values for $\lambda = 7$, $\beta = 0^o, C_p(\lambda) = 0.45, V_W = 12\, m/s$ the following parameters are calculated from equations 3.6-3.11 for a 100KW wind turbine simulation.

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Table 3.1: Wind Turbine Parameters

SN	Parameters	Notation	Value
1	Tip speed ratio of rotor blade tip speed to wind speed	Λ	7
2	Turbine blade pitch angle	β	0^o
3	Performance coefficient of wind turbine	$C_p(\lambda)$	0.45
4	Wind speed	V_W	12 m/s
5	Constant	λ_i	9.27
6	Turbine blade radius	R	8.18 m
7	Air density	ρ	1.225 kg/m^2
8	Angular velocity of turbine blade	w_T	10.28 rad/s
9	Turbine rotor speed	N_T	98 rpm
10	Mechanical Power absorbed by turbine	P_T	100 KW
11	Mechanical Torque developed by Turbine rotor	T_T	9.74 Nm

Wind Turbine Control-The project deals with a variable speed, variable pitch FSPC WT. The main circuit and control block diagrams for the chosen WT topology is presented in Figure 3.3. For variable speed operation, the WT uses a full-scale back-to-back converter. The generator side converter is controlling the speed of the generator for maximum power extraction. The grid side converter controls the voltage on the DC-link and also the reactive power flow between the WT and grid. Another control for the WT is the pitch control. It is applied to the rotor blades and modifies the angle of attack of the blades so that the output power can be controlled during high wind speeds.

Generator side converter control -The generator side converter is controlled with the Field Oriented Control (FOC) strategy. FOC is the most popular vector control method in electrical machines. In case of a PMSG, the electrical equations are transformed into a coordinate system which will rotate in synchronism with the permanent magnet flux vector ΨPM. The position information of the PM flux is required, which can be easily obtained by monitoring the rotor angle or speed, using an optical encoder.

Dual Winding PMSG Mathematical Model-A double star synchronous machine like every other rotating electrical machine is composed of two three phase stator windings each connected in star, shifted up by an angle $\gamma = 30^0$, and a rotor made up of permanent magnet. The $(\alpha - \beta)$ reference frame and (d-q) reference frame are two most widely adopted reference frames for a single three-phase star connected stator windings for a permanent magnet synchronous generator (PMSG) model considered in the analysis. From these two reference frames for a single star connected three-phase PMSG, where a double star PMSG combines two separate star connected three phase winding neglecting the effects of their mutual inductances.The study of double-star synchronous machine is based on the following assumptions;Concentrated winding of each dual star is considered, the dual stars are shifted by an angle $\gamma = 30^0$, Each three-phase star winding is shifted by an angle of 120^0, The air-gap mmf force has sinusoidal repatriation, Effects of damper windings are neglected, the machine iron-core saturation is neglected, Mutual leakage inductances are negligible due to concentrated winding.

Dual-PMSG Voltage Equation Representation in Synchronous $(d-q)$ Reference Frame-Dual permanent magnetic synchronous generator can be achieved by applying Clarke transformation to the individual star winding of the stator and subsequent multiplication of the transformation matrix by a rotating matrix or by direct application of Park transformation matrix to the generator equations. The dual-winding PMSG equations representation in synchronous reference frame are:

$$Vd_1 = R_s id_1 + Ld\frac{did_1}{dt} - w_r L_q iq_1 \quad (3.12)$$

$$Vq_1 = R_s iq_1 + Lq\frac{diq_1}{dt} + w_r L_d id_1 + w_r \emptyset_{pm} \quad (3.13)$$

$$Vd_2 = R_s id_2 + Ld\frac{did_2}{dt} - w_r L_q iq_2 \quad (3.14)$$

$$Vq_2 = R_s iq_2 + Lq\frac{diq_2}{dt} + w_r L_d id_2 + w_r \emptyset_{pm} \quad (3.15)$$

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The flux equations are given as

$\emptyset d_1 = L_d i_{d1} + \emptyset_{pm}$ (3.16)

$\emptyset q_1 = L_q i_{q1}$ (3.17)

$\emptyset d_2 = L_d i_{d2} + \emptyset_{pm}$ (3.18)

$\emptyset q_1 = L_q i_{q2}$ (3.19)

These equations are used in Simulink model for the analysis of the dual winding PMSG

where;

Vd, Vq (Volt) are stator d-q reference frame voltages,id, iq (Amps) are generator d-q reference frame currents, Ls = Ld = Lq (H) stator d-q reference frame inductances,$R_s = R_d = R_q$= R (Ω) stator resistance, w_r (rad/s) electrical angular speed, $\emptyset_{pm}$ (Vs) flux linkage of rotor PM.The electrical power $P_e$developed by the dual winding PMSG is given as:(3.21)

The air-gap power when resistive loss and rate of change of stored magnetic energy is zero at steady state

$P_e = 1.5 p_p \omega_T (\emptyset d_1 i_{q1} - \emptyset q_1 i_{d1} + \emptyset d_2 i_{q2} - \emptyset q_2 i_{d2})$(3.20)

$P_e = 1.5 \omega_r (\emptyset d_1 i_{q1} - \emptyset q_1 i_{d1} + \emptyset d_2 i_{q2} - \emptyset q_2 i_{d2})$ (3.21)

can further be stated as:

$P_e = 1.5 \omega_r \emptyset_{pm} (i_{q1} + i_{q2})$(3.22)

The electromagnetic torque $T_e$developed by the dual winding PMSG is given as:

$T_e = 1.5 p_p (\emptyset d_1 i_{q1} - \emptyset q_1 i_{d1} + \emptyset d_2 i_{q2} - \emptyset q_2 i_{d2})$(3.23)

or

$T_e = 1.5 p_p \emptyset_{pm} (i_{q1} + i_{q2})$(3.24)

$\emptyset_{pm} = \frac{V_L \sqrt{2}}{\omega_r \sqrt{3}}$(3.25)

The electrical rotational speed $\omega_r$is related to the turbine mechanical speed and electrical power as:

$\omega_r = p_p \omega_T$(3.26)

$P_e = T_e \omega_r$(3.27)

Table 3.2: Dual-PMSG Parameters

SN	Parameters	Notation	Value
1	Electrical Power Output	P_e	100 KW
2	Pole Pairs	p_p	8
3	Electrical Angular speed	ω_r	82.24 rad/s
4	Rotor Speed	N_T	98 rpm
5	Frequency	f	13 Hz
6	Stator Phase resistance	Ω	2.88 ohms
7	Electromagnetic Torque	T_e	1.22 Nm
8	Permanent Magnet (PM) Flux Linkage	$\emptyset_{pm}$	4.12 Wb
9	Stator d-axis Inductances	$L_{d1} = L_{d2}$	8.51Mh
10	Stator q-axis Inductances	$L_{q1} = L_{q2}$	8.51Mh

Table 3.3: Auxiliary Power Rectifier and Boost Converter Parameters

SN	Parameters	Notation	Value
1	Input AC Voltage to Bridge Rectifier	V_L	415V
2	Rectifier Output DC Voltage	V_{DC}	560V
3	Input Filter Capacitor	C_{in}	1500 uF
4	Boost Converter Inductor	L_B	1470 uH
5	Boost Converter Output Capacitor	C_o	1800 uF
6	Boost Converter Switching Frequency	f	40 KHz
7	Boost Converter Output Voltage ($V_{DC-BOOST}$)	V_o	800 V
8	Output Converter DC Current ($I_{DC-BOOST}$)	I_o	125 Amps
9	Duty Cycle	D	0.44
10	Output Resistance (STATCOM input resistance)	Ω	10 ohms
11	Efficiency of converter	η	80 %

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13	Inrush Current Limiting resistance	Ω	0.5 ohms
14	Output Capacitor ripple Voltage	ΔV_o	4 V
15	Estimated inductor Ripple Current	ΔI_o	35.7 Amps

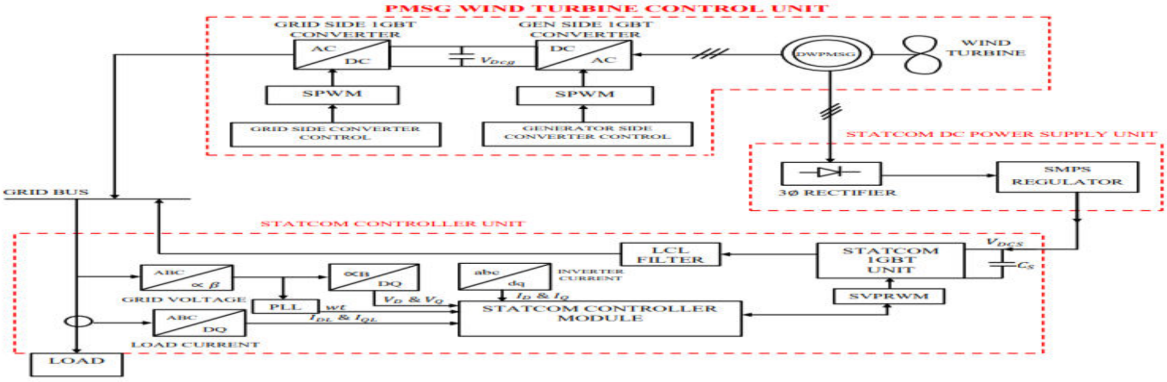

Figure 3.3: Block Diagram for DWPMSG and STATCOM for LVRT

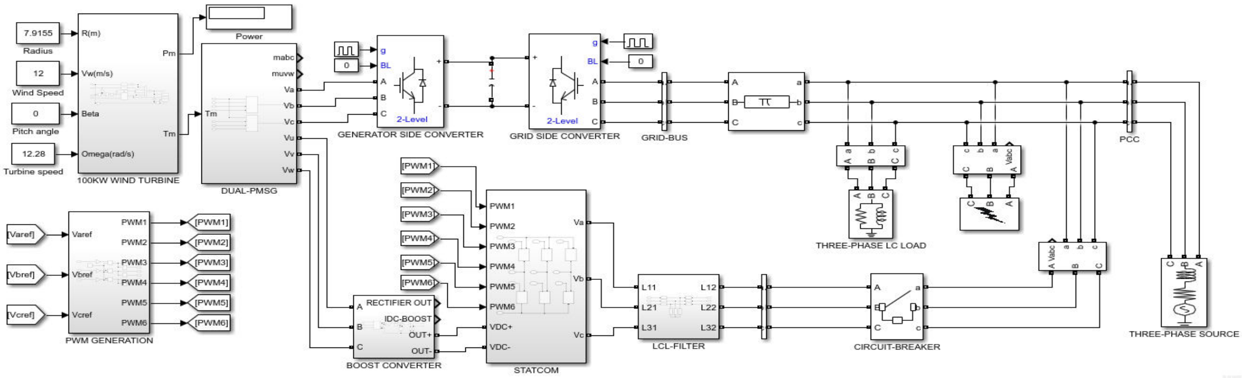

Fig 3.4: MATLAB Implementation of the Complete Block Diagram.

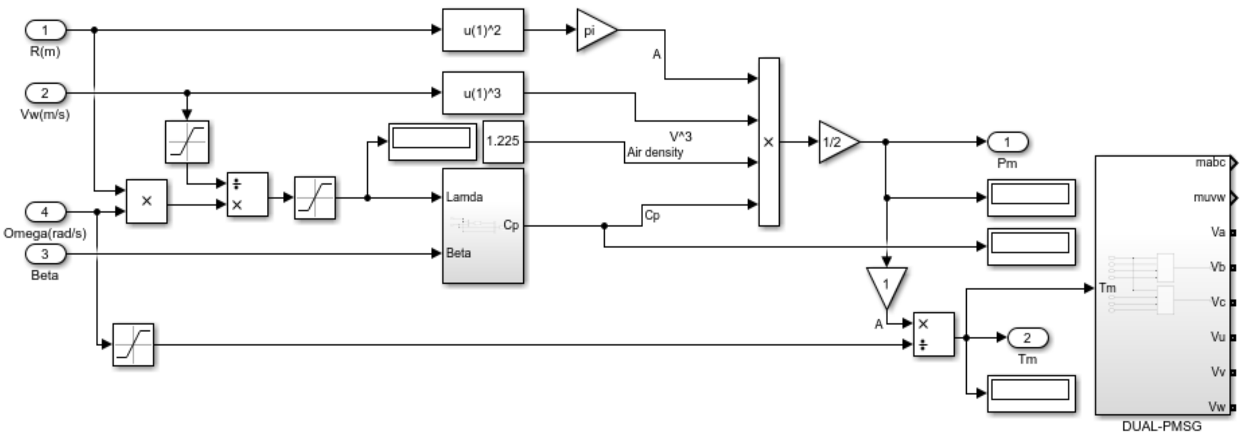

Figure 3.4: MATLAB/SIMULINK Model of 100KW Wind Turbine Generator

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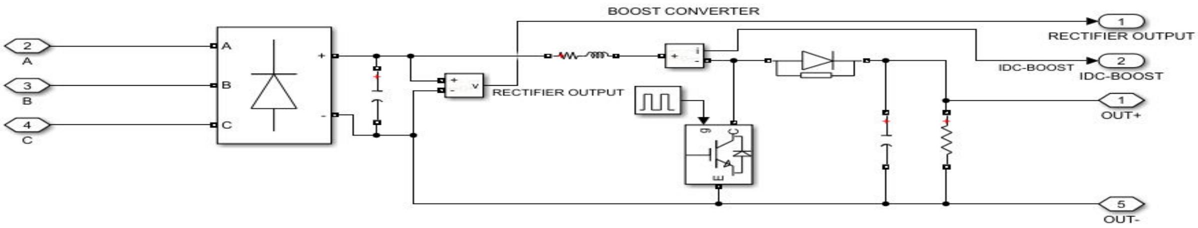

Figure 3.14: MATLAB/SIMULINK Model of Boost Converter

IV. RESULTS AND DISCUSSION

The MATLAB/Simulink-based proposed test model results depicted the active performance of a shunt connected PMSG-STATCOM for the mitigation of current harmonics and voltage sag. The test model also consisted of the non-linear load (3-phase uncontrolled rectifier) with boost converter supplying DC power to STATCOM from the auxiliary winding of DWPMSG. The controller gain values kp (proportional gain) and ki (integral gain) were considered as 5 and 200 for DC-bus voltage (outer-loop) control and kp as 25 ki as 500 for inner -loop control in d-axis and q-axis respectively, for the extraction of gate signals (SPWM generation) for the activation of electronic valves of VSC-based Auxiliary Winding Powered (AWP)-STATCOM. In the proposed test model, the voltage sag of 0.3 p.u. was created from 0.2 s to 0.4 s. AWP-STATCOM was allowed to operate from 0.1 s to 0.8 s as a STATCOM, and from 0.1 s to 0.8s, the auxiliary rectified/regulated dc source was connected and reached steady state voltage of 800 VDC at 0.12s. Reactive power was supplied based on the LVRT concept from 0.18 s to 0.8 s to support the grid.

The proposed micro-grid was supplied by both the main grid and the wind generator. Figure 4.1 clearly shows that the source voltage was reduced from its normal value, from 0.2 s to 0.4 s (sag period), because of faults in the test model and voltage sag was mitigated by the AWP-STATCOM from 0.4s to 0.8s.

The current harmonics caused by the presence of non-linear loads was completely mitigated from 0.4 s to 0.8 s. From Figure 4.1 and 4.2, it is clear that during normal operation (from 0.04 s to 0.2 s), the grid and the wind generator injected the real and reactive power of 10KW and 2KVAr, required by the load and i.e., (Iq0= iqL A), and during the abnormal condition, the AWP-STATCOM injected the increased reactive power up to 100KVAr to take care of the load, wind generator and grid i.e., (Iq = iqL + iqLVRT A), as per the LVRT requirement $\left(I_q = I_N; 0 \le v_g < (1-\frac{1}{k})\right) p.u, \left(I_q = k(1-v_g)I_N\right); \left(1-\frac{1}{k}\right) p.u \le v_g < 0.9 p.u.$

In figure 4.6 shows that the wind generator supplied voltage and current without any fluctuations. All the aforementioned compensation actions (mitigation of harmonics and voltage sag) occurred while keeping DC bus capacitor voltage constant (Vdc = 800 V), as shown in Figure 4.4. Figure 4.5 demonstrates the active power injection and reactive power compensation by AWP-STATCOM for the mitigation of power quality issues in the microgrid system.

Also, the Figure 4.3 shows that, because of the faults, the main grid source was supplying less than the rated real power from 0.2 s to 0.4 s (sag period), i.e., the source active power was reduced from 100 kW to 2.5 kW. The test model consisted of reactive components, the permanent magnet synchronous generator, STATCOM and non-linear load (RL); thus, it had a reactive power demand.

Furthermore, figure 4.5a clearly shows that the reactive power was compensated by AWP-STATCOM from 0.2s to 0.4s. To ensure the generating units remained grid-connected during the sag period and to keep the load power constant for stable operation, the AWP-STATCOM injected both real and reactive powers from 0.18 s to 0.45 s and reduced to steady state value between 0.45s to 1.0s (AWP-STATCOM in the ON condition) as shown in figure 4.5b.

Figure 4.6 shows the voltage and current from PMSG in the proposed system. MATLAB simulation results reveal the performance of the VSC-based AWP-STATCOM for the mitigation of harmonics and voltage sag in the proposed test model by supplying up to 90% of the reactive power with stable voltage. Active and reactive power supply from PMSG wind turbine for grid support are shown in figure 4.7.

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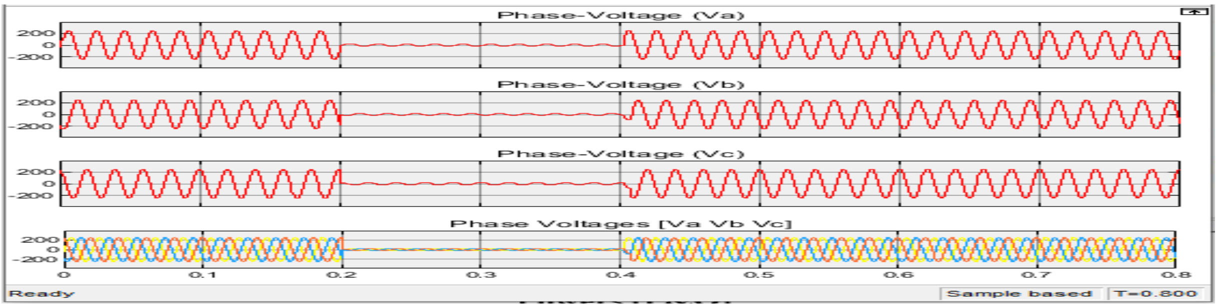

Figure 4.1: Grid Voltages Response Before and After Fault with STATCOM Support

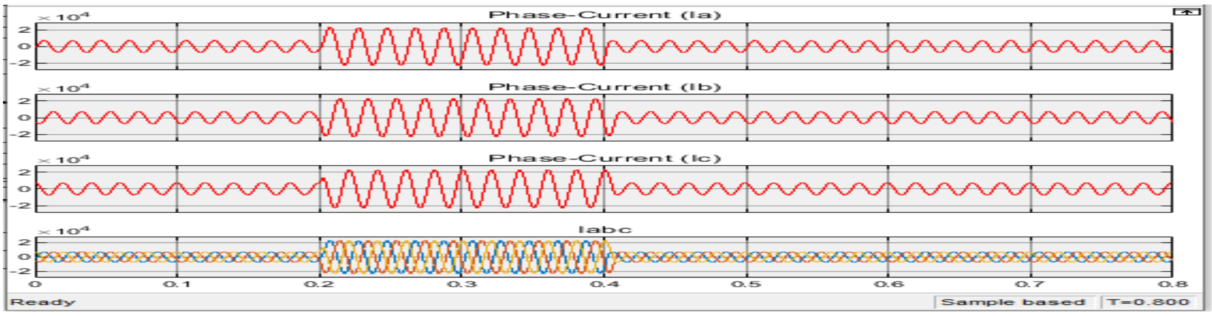

Figure 4.2: Grid Current Response Before and After Fault with STATCOM Support

Figure 4.3: Grid Active and Reactive Power Response Before and After Fault with STATCOM Support

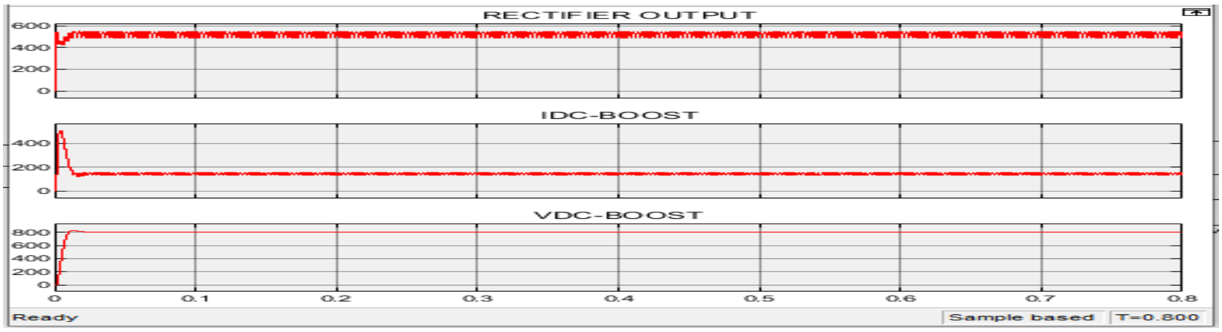

Figure 4.4: Boost Converter DC Supply from PMSG Auxiliary winding for STATCOM Back-up

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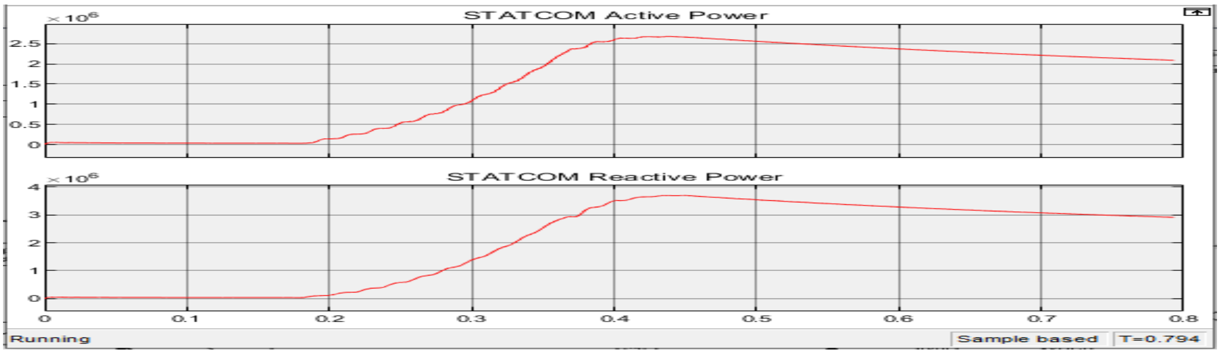

Figure 4.5a: STATCOM Active and Reactive Power Support to Grid during Fault

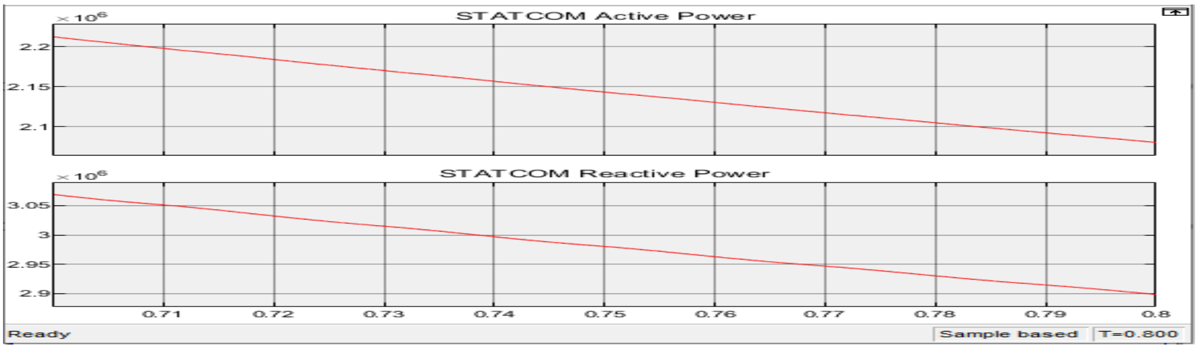

Figure 4.5b: STATCOM Active and Reactive Power Support to Grid during Fault

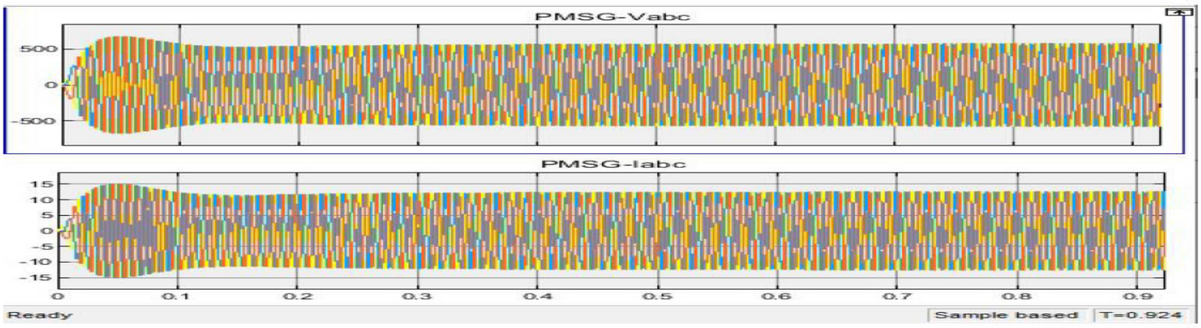

Figure 4.6: DW-PMSG Voltage and Current Waveform before and after Fault

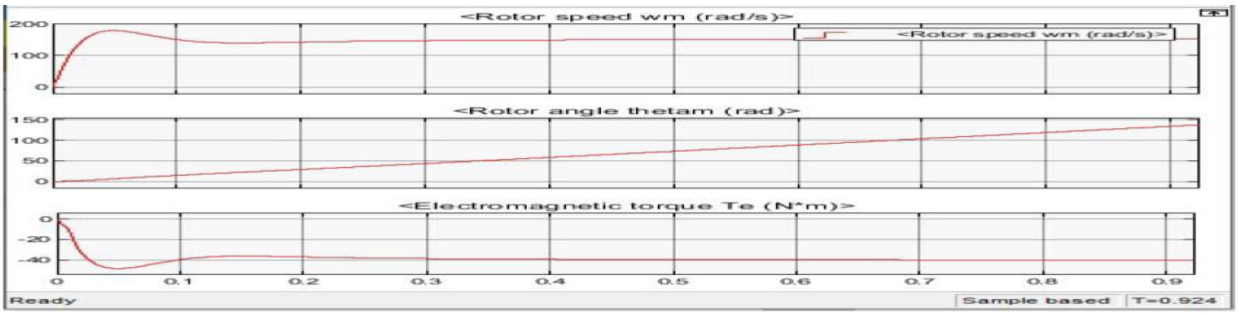

Figure 4.7: PMSG Active and Reactive Power Response during Fault

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VII. CONCLUSION

A new AWP-STATCOM Low Voltage Ride Through (LVRT) strategy, employed for the mitigation of current harmonics during normal operating conditions and for the mitigation of both current harmonics and voltage sag during grid faults in a grid integrated system, was presented in this article.

The simulation results illustrated the power quality magnification in distribution systems. Power electronic-based (non-linear) loads are responsible for the creation of power quality issues, such as current harmonics, reactive power demand and voltage variations in distribution systems. With the active and efficient participation of a shunt-connected AWP-STATCOM, the current harmonics and voltage sags were found to be completely mitigated in the test model.

From the MATLAB simulation results, it is clear that the proposed P-Q control theory (instantaneous reactive power theory) was effectively utilized by AWP-STATCOM for the injection of active and reactive power in a grid integrated system to keep load power constant and for the mitigation of current harmonics and voltage sag in the distribution system.

The voltage at the Point of Common Coupling (PCC) was regulated by keeping DC capacitor voltage constant from the auxiliary winding rectified/regulated power supply and grid-side converter DC-bus voltage. The power factor was improved from lagging PF to near Unity PF and the Total Harmonic Distortion (THD) value was reduced from 28.6% to 5.0%, which is within IEEE standards.

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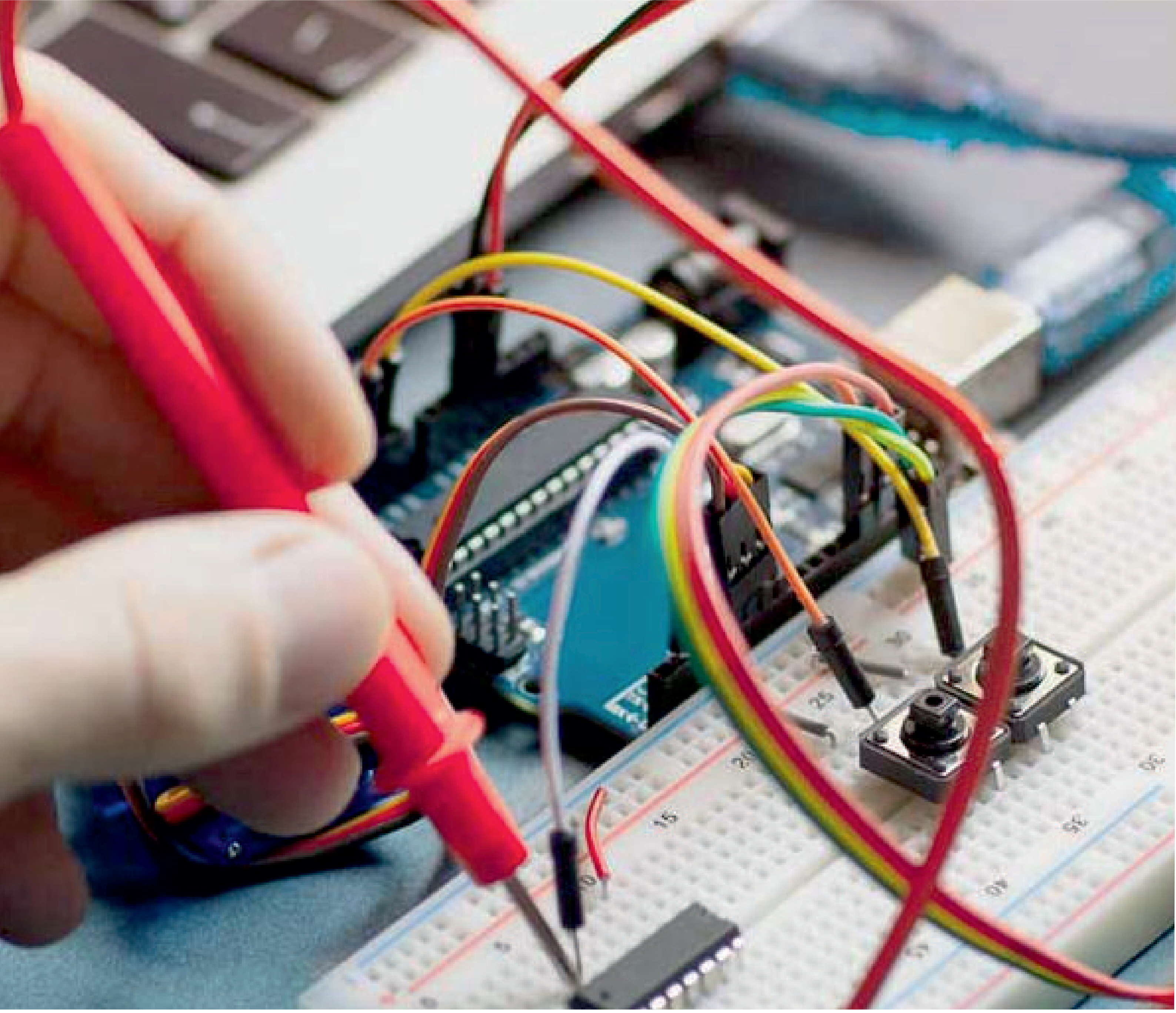

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