Harmonics Affect Power Quality

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Harmonic estimation is essential for mitigating or suppressing harmonic distortions in power systems.

harmonic frequency capacitor

1. Introduction

Distributed energy resources have increased the penetration rate of renewable energy sources but have also led to intermittency and poor power quality [1]. To address this, a microgrid combining partially distributed energy resources with a utility grid [2] has been proposed. Harmonic distortion has been proposed to increase the additional losses of electrical equipment, overheating it and reducing equipment efficiency and utilization. The harmonic problem of the microgrid has become a major issue with two main sources: electronic power devices and nonlinear loads [3]. Electronic power devices, such as inverters, rectifiers, and static compensators, which generate high-frequency harmonics that can be suppressed by LC or LCL filters [4], are widely used. Nonlinear loads are the main reason for generating output voltage drop, which leads to the distortion of the inverter output voltage waveform. To reduce harmonics and improve system efficiency, anthropological compensation strategies have been studied [3].

Harmonics affect power quality and increase system losses by up to 27%. Power quality issues are manifested in voltage, current, or frequency deviations, resulting in the failure or malfunction of equipment [5]. Common power issues are temporary or steady-state voltage or frequency variations such as impulsive or oscillatory transients and voltage sags. Voltage sags and dips are caused by short circuit faults and motor starting [6]. Harmonics derate transformers and affect high-frequency controllers, while transients and voltage sag influence protection and control equipment. Alternating current drives ride through interruptions, but induction motor starters and DC drive contactors require backup RC circuits [7].

2. Effects of Harmonics

Harmonics are a form of interference that directly affect power quality and have a very bad effect on the equipment and machinery used in a factory. Harmonics cause cables to overheat, damaging insulation [8]. Harmonics reduce motor life, cause motor overheating, and induce a loud operating noise [9]. Harmonics give rise to CB overload, overheating, and transformer explosion (while the amount of electricity used is still less than rated). Harmonics cause circuit breakers, aptomats, and fuses to be affected for unknown reasons [10]. Harmonics cause serious harm to the capacitor by damaging the dielectric, bulging the capacitor, reducing the life of the capacitor, and even causing an abnormal capacitor explosion [11]. Harmonic interference affects telecommunications equipment and automation systems. Harmonics cause measuring equipment to operate incorrectly, and they cause energy waste too (**Figure 1**). Harmonics occur when the diode rectifier has no passing current and the current goes directly to the inverters while the AC voltage at the input is less than the DC voltage at the capacitor. The sinusoidal shape of the source current is completely distorted when a case of harmonics arises for only a few seconds. The harmonics generated in the power supply cause heating of the conductors, the insulation is broken, the performance of the electrical equipment is reduced, and the life of the electrical equipment is reduced over time. The motor of electrical equipment operates with noise and it is easy to generate heat harmonics that are not well controlled and can damage the dielectrics in the capacitors, shorten the life of the capacitors, and potentially blow up the capacitors. Harmonic currents in rotating machines cause heating effects such as eddy current losses proportional to the square of the frequency [3][12]. Harmonic cycles can cause additional losses by inducing higher frequency currents and negative torques in machine rotors. Harmonic currents can lead to the overloading of power factor correction capacitors and the derating of cables. Harmonic components add phantom power to the total power consumption of a transformer, causing it to overload, heat up, and burn. They heat up and burn conductors, causing serious losses in the electrical system. In a three-phase system, the neutral conductor is heated or burned to create a stable system. The N-G (neutral-earth) voltage is too large. The breaker jumps for unknown reasons. This causes the failure of the PF reactive power compensation capacitor. Noise in communication systems can lead to the overload of capacitors and transformers due to the weakening of harmonic currents, resulting in the formation of an LC circuit. As for systems using backup generators or used on ships and drilling rigs, when running, due to the generator's inductance characteristics that are higher than conventional transformers, harmonics will be amplified more seriously, from 3 to 4 times, and the seriousness for the system equipment is greater and can even cause a generator fire, which is very dangerous and costly. Harmonics also cause losses on the coil and steel core of the motor to increase, distort the torque form, reduce machine efficiency, and cause noise to affect the error of measuring devices, leading to erroneous measurement results. More dangerously, the higher-order harmonic waves can also generate motor shaft torque or cause mechanical resonance oscillations that damage mechanical components in the engine, causing the flickering of electrical equipment and lighting, affecting people, and causing electromagnetic waves to propagate in space, affecting transceivers.

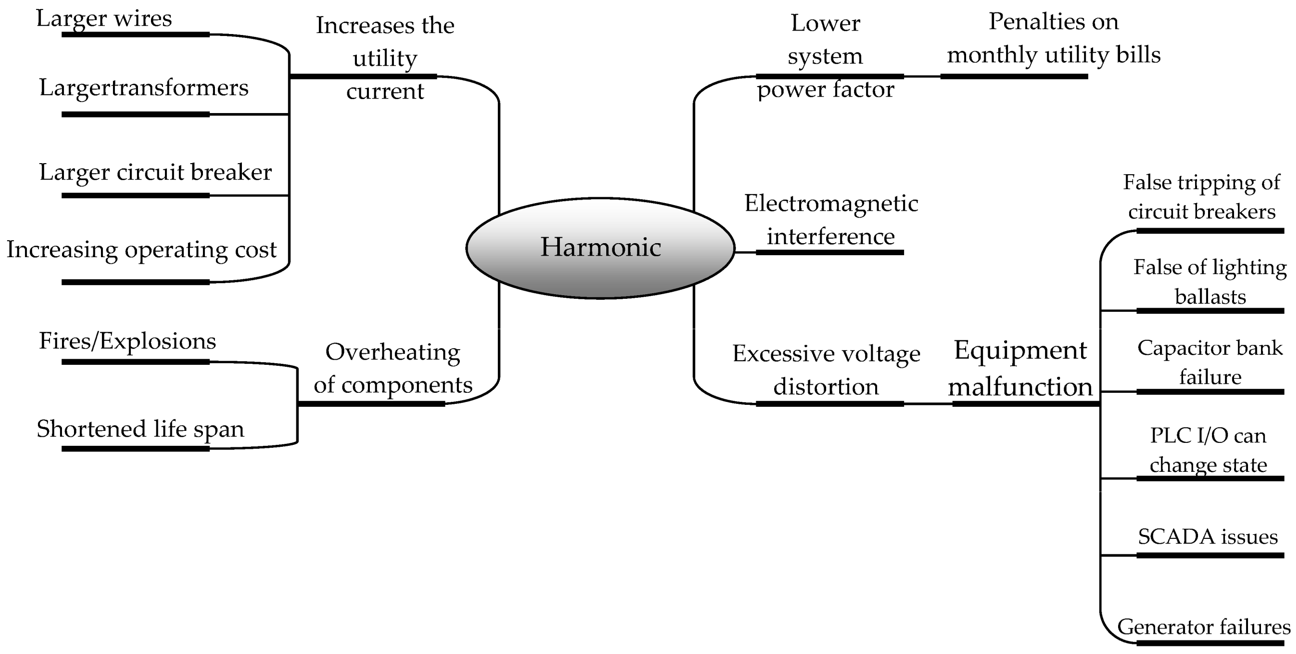

Figure 1. Effects of harmonics.

The load in the distribution power supply generates many types of harmonics, affecting the quality of use and the performance of power-using equipment, reducing its efficiency. Much electrical equipment damage, such as fire or explosion, is also caused by harmonic sources [8]. The higher frequency harmonic current causes electrons to flow to the outside of the conductor, which reduces the current-carrying capacity, resulting in a decrease in power rating causing heat gain and damage to the insulation. Harmonic distortion has a direct effect on the power factor [9][10]. Many harmonics have a low power factor value. The heat losses generated by the harmonics shifting to use and pay for the reactive power and harmonic currents can cause the capacitor to fail [10][13].

Transformer aging or heating on the surface of the transformer body is mainly caused by harmonics in the power supply [9]. The transformer structure is formed by winding several coils placed close to each other and separated by insulation; when the power flows through the windings with harmonics generated in them, overvoltage results [14]. Load occurs in the transformer, generating heat in the transformer body, reducing the operating efficiency of the transformer, and reducing the insulation strength of the windings in the transformer. Eddy currents due to stray flux losses cause overheating. A temperature increase of 7–10 degrees can reduce the life of an insulating material by half.

The protection of electrical equipment is provided in the electrolytic power supply devices that perform overload protection, short circuit protection, or protection from overheating generated in electrical circuits, eliminating all the effects potentially affecting the performance of electrical equipment. Today, industrial plants use a lot of switching devices such as inverters and switches of devices that control dynamic mechanisms in industrial machines [15][16]. The factory floor uses a lot of high-intensity discharge (HID) bulbs to light up the factory. The power source generates harmonics from the above-mentioned devices and the harmonics themselves reduce the performance of those devices. Eliminating harmonics, or minimizing harmonics generated in the power supply, requires new research to improve electrical equipment the response level of which does not create harmonics in the power supply; this is a difficult requirement for researchers. Creating methods to eliminate harmonics in power supplies by computer programs combined with high-tech equipment is also a promising research direction.

In the era of the 4.0 industrial revolution, many nonlinear loads are produced and operated in the distribution power system. Nonlinear loads such as LEDs, computer monitors, power supply switches, and transformers perform the communication between the power source and the loads. These devices generate harmonics in the power supply, harmonics causing significant damage to the performance and operability of the loads [8][9]. Harmonic currents arise in the power supply and seriously affect the communication system [17]. At magnetic couplings in telephones or information transmission sources, harmonics will cause interference and the information transmitted will not meet the requirements or the transmission speed will be delayed [10]. The method that communication equipment suppliers use to minimize harmonics affecting communication lines consists in using equipment to shield the amount of inductance in parallel conductors and building a device to measure and confirm the information interference system. The maximum value of the harmonic current can be much higher than the sine wave shape at the fundamental frequency, causing false tripping [11].

Automation devices use a lot of motors, and the performance of the motors is severely affected by the harmonics generated by the current. Many types of motors operate according to the mechanism of using the PWM method to adjust the operating mechanism; harmonics cause the mechanism to operate not as desired, e.g., torque ripples created by wave interaction harmonics cause this mechanical oscillation [16]. The harmonics generated by the PWM inverters affect the efficiency of the electric motors much more than the power supply [14]. Nonlinear loads in the distribution power supply create levels that negatively affect the performance of transformers. The transformer feeds the rectifier six pulses with a DC load and power dissipation factors such as total harmonic distortion (THD) compromise efficiency in the transformer. Squirrel-bed synchronous motors operate on the flux density at the clearances to increase the torque properties of the motor [10][16]. However, the harmonics generated at those gaps affect the magnetic field of the stator and the rotor negatively, thus impacting the torque of the motor. Researchers calculate the flux density at the gaps using the Finite Element Analysis (FEA) formula. Usually, parallel capacitors are used to perform the function of filtering high-order harmonics or a single-tuned harmonic filter. High-frequency voltage components cause eddy current losses in the core of the AC motor. These losses increase the operating temperature of the fault as well as the coil around the core and can cause undesired torque spikes. Excessive harmonic distortion will cause a lot of zero interference of the current waveform, affecting the timing of the voltage regulator. This may cause the generator to stop working.

References

1. Nikam, V.; Kalkhambkar, V. A review on control strategies for microgrids with distributed energy resources, energy storage systems, and electric vehicles. Int. Trans. Electr. Energy Syst. 2020, 31, e12607.

2. Juan, C.; Cristian, C.; Alejandro, P.; German, O. Distributed energy resources on distribution networks: A systematic review of modeling, simulation, metrics, and impacts. Electr. Power Energy Syst. 2022, 138, 107900.
3. Arranz-Gimon, A.; Zorita-Lamadrid, A.; Morinigo-Sotelo, D.; Duque-Perez, O. A Review of Total Harmonic Distortion Factors for the Measurement of Harmonic and Interharmonic Pollution in Modern Power Systems. Energies 2021, 14, 6467.
4. Colak, I.; Bayindir, R.; Sagiroglu, S. The Effects of the Smart Grid System on the National Grids. In Proceedings of the 2020 8th International Conference on Smart Grid (icSmartGrid), Paris, France, 17–19 June 2020; pp. 1–5.
5. Lumbreras, D.; Gálvez, E.; Collado, A.; Zaragoza, J. Trends in Power Quality, Harmonic Mitigation and Standards for Light and Heavy Industries: A Review. Energies 2020, 13, 5792.
6. Saleh SA, M.; Wo, J.; St-Onge, X.F.; Castillo, E. A New Approach for Estimating Frequency Variations Due to Smart Grid Functions. IEEE Trans. Ind. Appl. 2020, 56, 2292–2303.
7. Rastogi, S.; Shah Singh, B.; Bhattacharya, S. Mode Analysis, Transformer Saturation, and Fault Diagnosis Technique for an Open-Circuit Fault in a Three-phase DAB Converter. IEEE Trans. Power Electron. 2023, 1–17.
8. Yan, L.; Liao, Y.; Lin, H.; Sun, J. Torque ripple suppression of permanent magnet synchronous machines by minimal harmonic current injection. IET Power Electron. 2019, 12, 1071–1086.
9. Miao, Y.; Wang, J.; Zhang, B.; Li, H. Practical framework of Gini index in the application of machinery fault feature extraction. Mech. Syst. Signal Process. 2022, 165, 108333.
10. Wang, L.; Zhu, Z.Q.; Bin, H.; Gong, L.M. Current Harmonics Suppression Strategy for PMSM With Nonsinusoidal Back-EMF Based on Adaptive Linear Neuron Method. IEEE Trans. Ind. Electron. 2020, 67, 9164–9173.
11. Wang, Z.; Zhao, J.; Wang, L.; Li, M.; Hu, Y. Combined Vector Resonant and Active Disturbance Rejection Control for PMSLM Current Harmonic Suppression. IEEE Trans. Ind. Inform. 2019, 16, 5691–5702.
12. Hou, S.; Fei, J. Finite-Time Adaptive Fuzzy-Neural-Network Control of Active Power Filter. IEEE Trans. Power Electron. 2019, 34, 10298–10313.
13. Martinek, R.; Rzidky, J.; Jaros, R.; Bilik, P.; Ladrova, M. Least Mean Squares and Recursive Least Squares Algorithms for Total Harmonic Distortion Reduction Using Shunt Active Power Filter Control. Energies 2019, 12, 1545.
14. Büyük, M.; İnci, M.; Tan, A.; Tümay, M. Improved instantaneous power theory based current harmonic extraction for unbalanced electrical grid conditions. Electr. Power Syst. Res. 2019, 177, 106014.

15. Martinek, R.; Bilik, P.; Baros, J.; Brablik, J.; Kahankova, R.; Jaros, R.; Danys, L.; Rzidky, J.; Wen, H. Design of a Measuring System for Electricity Quality Monitoring within the SMART Street Lighting Test Polygon: Pilot Study on Adaptive Current Control Strategy for Three-Phase Shunt Active Power Filters. Sensors 2020, 20, 1718.

16. Han, S.; Ortmann, L.; Kim, H.; Kim, Y.W.; Oka, T.; Chacon, A.; Landsman, A.S. Extraction of higher-order nonlinear electronic response in solids using high harmonic generation. Nat. Commun. 2019, 10, 3272.

17. Bouhouras, A.S.; Gkaidatzis, P.A.; Panagiotou, E.; Poulakis, N.; Christoforidis, G.C. A NILM Algorithm with Enhanced Disaggregation Scheme under Harmonic Current Vectors. Energy Build. 2018, 183, 392–407.