Concept and effects of harmonic Waves in Electrical Circuits with Case Studies from Hydro Sites

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ABSTRACT
It has been the general observation that there is little awareness about the harmonics in the electrical circuits, in the minds of electrical/commissioning engineers working in the field. But it is very essential to be aware about their generation, propagation and good/bad effects on the equipment they handle in the power house. This paper is an attempt to create this awareness, to some extent, by touching upon concept and citing some case studies from hydro sites.

Abbreviations

NPS = Negative Phase Sequence
ZS = Zero sequence
EFR = Earth fault relay
I_2 NPS Current
WCR = Winding capacitance & IR
PSC = Positive Sequence Current
ZSC = Zero sequence current

I INTRODUCTION

It is well known that a 3 phase salient pole hydro generator is normally built at site by assembling and winding the remaining portion of partially wound stator sectors sent from the manufacturing plant. Likewise rotor is also built at site.

The stator winding consisting of 3 circuits with common node made at one end (3 phases with neutral), when exposed to rotating magnetic field created by rotor, produce sinusoidal voltage waves of equal magnitude and equal separation (time delay) from each other by 120° angle in time. Conventionally, these are represented by rotating voltage vectors of equal length and equally spaced by 120° angle. This is the normal desired case of balanced voltage vector system. However, due to various reasons like unequal distribution of phase windings in the stator slots or improper geometry or mounting of rotor poles, air gap variation etc. these waves get distorted in terms of non- sinusoidal shape, unequal magnitude or unequal angle, which then is referred as unbalanced system which is representable as sum of several harmonic components for each phase, predominant of which are known as positive sequence (fundamental), negative sequence (second harmonic) and zero sequence (third harmonic) which themselves are balanced as shown vectorially in Figure 1 below.

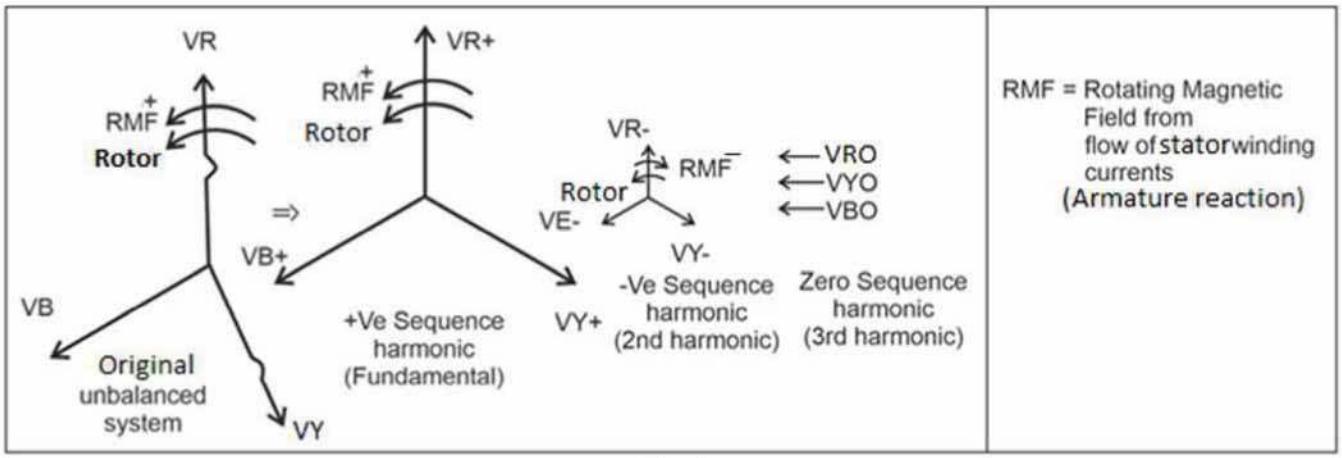

Fig. 1

II EXTERNAL CAUSES OF HARMONIC CURRENTS

In the pure sinusoidal voltage waves, harmonic currents are produced under following conditions

(a) Unequal loading on the 3 phases of voltage causing distortion in both current and voltage waves.

(b) Nonlinear loads of the types which draw heavy current in abrupt pulses some of which in a project site are as below.
  (i) Welding transformers/generators; cranes.
  (ii) Frequent ON/OFF types like OPU pump motors, compressors etc.
  (iii) Battery chargers/UPS/Digital Circuits.

(c) Faults like E/F, phase to phase faults etc. cause unbalance in the power circuit thereby generating harmonics in the generator currents which however are useful for fault detection for the protection of generator.
(d) Harmonics in current or voltage at any point of the circuit can be determined by connecting a harmonic analyzer through CT/PTs.

III EFFECTS OF HARMOINC CURRENT FROM UNBALANCED/NON-LINEAR LOADS

As only the fundamental frequency current is useful for producing power, flow of other harmonic currents adds only to loading of windings and lines. Other disadvantages are as bellow.

(a) Overheating of generators, transformers, motors etc. by increasing the RMS value of the current.
(b) Deterioration of supply voltage quality thereby disrupting normal operation of sensitive equipment's, communication networks etc.
(c) Increase in vibrations of rotor due to oscillatory torque produced.
(d) Decrease in power factor as for the same kW, kVA will be more (Power factor = kW/kVA)
(e) Increase in current drawn by capacitor circuits due to decrease in capacitive reactance at higher frequency of harmonics.

IV PRACTICAL CASES OF USEFULNESS OF HARMONICS FOR PROTECTION OF GENERATING UNITS FROM FAULTS

When generating units are connected to grid system to deliver power, various external and internal faults may happen which need to be identified and the unit isolated or stopped for its safety. Harmonic generated on faults provide necessary tools for this purpose.

Consider Figure 2 below of usual generator power circuit feeding power in the grid system.

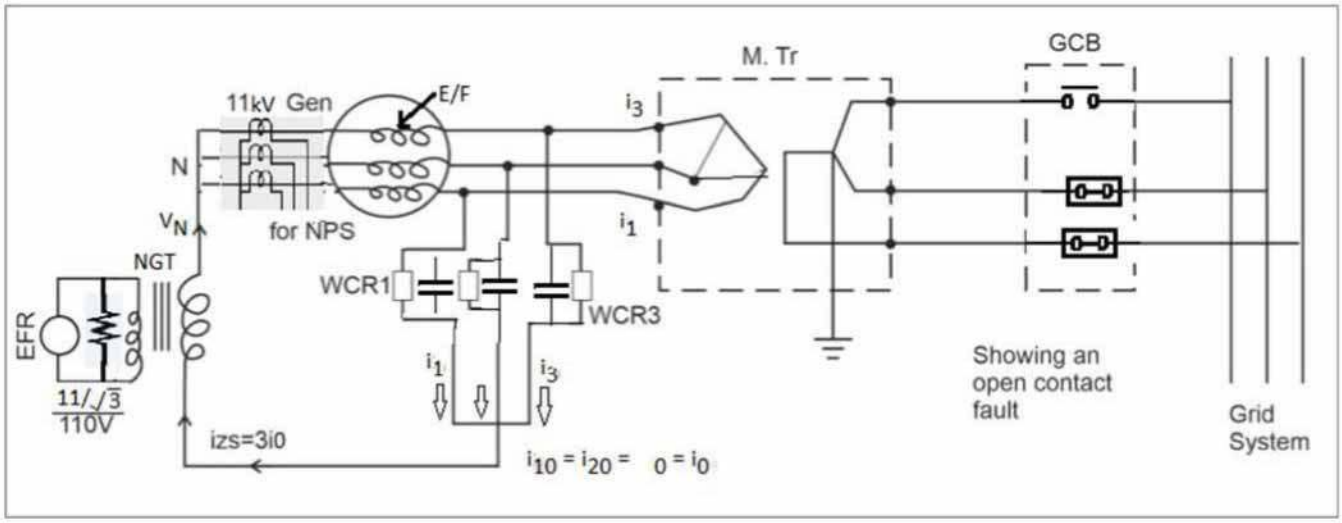

Fig. 2

In one unit of a project, GCB was tripping immediately on synchronization. On detailed investigation, it was found that one pole of GCB did not make contact. This generated negative phase sequence (NPS) currents in the generator phases which operated negative phase sequence relay on the neutral side CT's to protect it from damages by opening the GCB.

The NPS current produce reversely rotating magnetic field which cuts the rotor body at twice the rotor speed, resulting in its rapid heating. This heating effect is approximately expressed by the following equation:

$$I^2t = K \quad \ldots(1)$$

where,

I_2 is NPS current in per unit (PU) terms of rated current

t is allowable time in seconds

K is a constant representing heat bearing capacity of rotor as given by the manufacturer (generally K = 20)

(a) Stator Earth fault Detection (95% type) - In the Figure 2 above, WCRI, WCR2, WCR3 are shown representing capacitance and IR of each phase of generator winding. In the normal condition leakage currents i_1, i_2, i_3 will have mainly positive sequence component (PSC) along with some zero sequence component (ZSC). These will generate voltage V_N at neutral point N as shown. This will be too small even at 11 kV to cause stator E/F relay EFR operation. But, when E/F occurs on any phase, increase of leakage current raises voltage V_N which has both PSC & ZSC components. Relay EFR is polarized to respond to PSC component only and is usually set at 5% of phase voltage (5.5 V). A voltmeter connected across it would however read for both the components. As such the relay will not operate when voltage reads 5.5 V which however will happen anything above 5.5 V reading depending upon quantum of unbalance.

V A PRACTICAL CASE OF 3rd HARMONIC CURRENT EFFECT DURING TESTING AT SITE

In a power project, 3 phase variac is a common equipment for providing variable voltage for testing. It is also true that voltages of 3 phases are not equal due to unbalanced/non-linear loading. Therefore 3rd harmonic current will be present in the primary lines of the variac. Consider the following Figure 3 showing the set up for testing of metering circuit of a unit by using a variac.

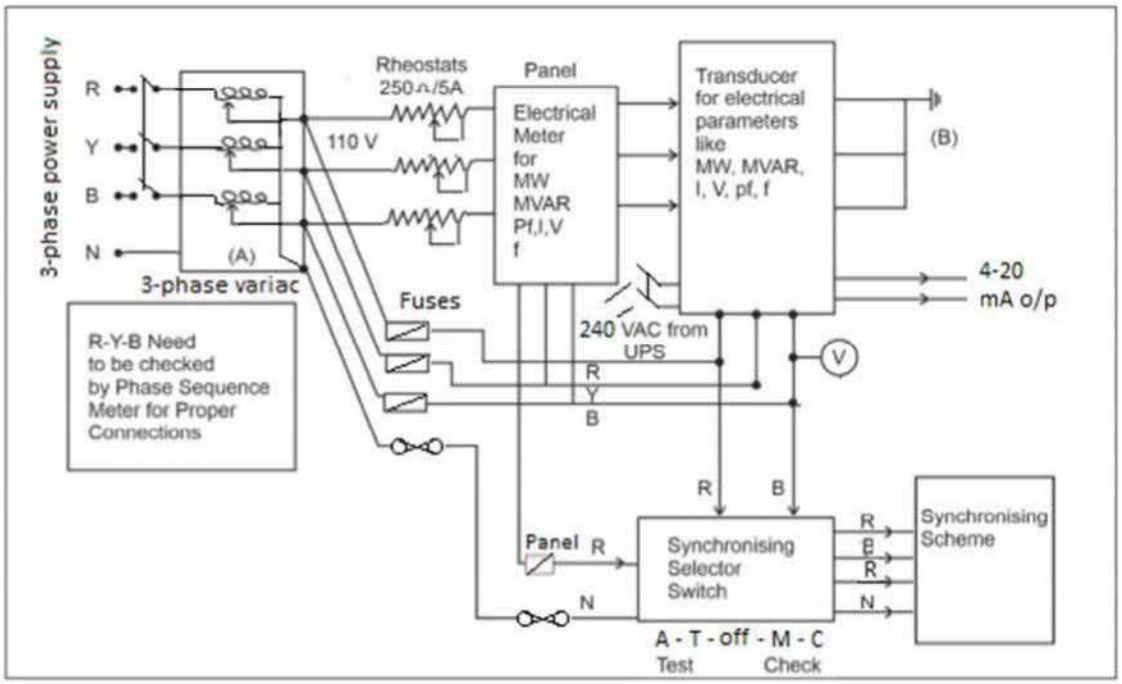

Fig. 3

As shown, when neutral of primary was inadvertently not connected to supply neutral at (A) nor was it earthed during testing of metering circuit, whereas the end of the circuit was earthed in the panel at (B) by the manufacturer. Therefore 3rd harmonic currents in the supply found path via the metering circuit to flow into the earth instead of flowing at the variac itself. This caused high output voltage from the variac even at its minimum position, which got impressed on the circuit as a surprise. Thus, it is very essential to always connect variac neutral to earth for testing. It may be mentioned here that 3rd harmonic waves in all the phases have no phase difference from each other and therefore flow unidirectionally towards the star point and according to Kirchoff's law must flow back to neutral.

VI CONCLUSION

Harmonics are a double edged weapon. When produced from faults, they are beneficial as they provide means for their identification. But, on unbalanced/nonlinear loads, they are a cause of growing concern in the management of electrical systems. Such loads are proliferating in all industrial, commercial and residential installations and their percentage of total load is growing steadily. To mitigate the ill effects of harmonics various solutions have been developed. Use of filters, reactors, proper location of non- linear loads are some of them.

REFERENCES

[1] Mulchandani T: Protection of grid connected Hydro Power Generating Units, Practical Insight with reference to some case studies, Anusandhan, Vol. 10, Issue 20 (2021)

[2] Awasthi SR: Pandey SV Renewable Energy from small & Micro Hydro Projects, Practical Aspects & Case studies – A book. The Energy & Resources Institute (TERI) (2021)