Study of Harmonics

In Industries A Power Quality Aspect

As saving of electrical energy is the main target of industrial consumer and also utility, the use of energy efficient equipment increases rapidly. The modern industrial system utilize variable speed drives through thyristor converters as the control becomes simple, more efficient accurate and widely available. However, it gives rise to a varied harmonic spectrum on the ac power systems and pollutes the system. In initial period the converter drives were used sparingly for very specialized applications due to non availability of the higher rated components and higher cost components. However due to modern developments the components are easily available, their reliability has improved and cost becomes manageable. Hence the use of these drives grew rapidly and the utilization increased. Due to large usage of these equipments, the electrical power slowly and slowly started getting corrupted by introducing harmonics in power systems. Though technocrats are generally aware of the harmful effects of the harmonics, the elimination/reduction of these harmonic currents and distortion due to this remain reflected topic as there is no strict mandatory rule and regulations and the industry does not want an additional cost burden which they feel does not give direct cost benefit. This paper deals with operation of ac variable speed drives for purpose of understanding harmonic generation and its effect on power quality at consumer end i.e. in industry a case study.

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The quality of power can be simply defined with parameters as below:

1. The supply voltage should be within guaranteed tolerances of declared value. A lower voltage called sag and a high voltage are undesirable, long duration of cut off are to be abhorred up to 10%.
2. The supply frequency must lie within guaranteed parameter 2% in India
3. The wave should be a pure sine wave with allowable limits for distortion.
4. Sudden voltage disturbances must be contained.
5. Supply of three phases of three phase system should be balanced.
6. The earthing system should serve its purpose satisfactory.

This utility's main duty is that to provide the electricity which satisfy all above factors. But the harmonic injection by various industries is the main reason of bad quality of power.

Harmonic Distortion

As we know for the better quality of power the voltage and current waveforms should be sinusoidal, but in actual practice it somewhat non sinusoidal and this phenomena is called Harmonic Distortion.

Voltage Harmonic Distortion which is generally present in supply of power from utility. The distortion in current waveform is called as current harmonic distortion which is generally injected by the non linear loads to the supply of utility and corrupts it.

Non Linear Load

From an electrical point of view, the sinusoidal waveform has a very special property that when a sinusoidal voltage is applied to a linear circuit is also sinusoidal.

When the current drawn through the circuit is non sinusoidal even there is a pure sinusoidal supply, then the load is called as non linear load.

Some examples of non linear loads are:-

1. Transformer saturation
2. Thyristor controlled equipments
3. Ac/dc, ac/ac, dc/ac converters
4. Battery chargers
5. Electronic and medical test equipment
6. PCs and office machines
7. Induction Heaters
8. Synchronous machines (non-sinusoidal air gap flux)

Evaluation of Harmonic Distortion

Any real waveform can be produced by adding sine waves together. It can also be shown that this combination is unique. It may be interesting to note that fundamental and third harmonic waveforms for two cases (in phase and out of phase) result in two distinct waveforms with no change in corresponding amplitude. In the first instant, when the odd harmonics are in phase with fundamental, distorted resultant waveform becomes more like a square wave. In the other case, when the harmonics are shifted by 90 degrees phase, the distorted resultant becomes more like a positive and negative spike.

Name	F	2nd	3rd	4th	5th	6th	7th	8th	9th
FREQ	50	100	150	200	250	300	350	400	450
SEQ	+	-	0	+	-	0	+	-	0

This analysis of waveform is useful for primary determination of harmonics weather it is in or out of phase by the analyzing the shape of waveform. Refer Fig, 1.

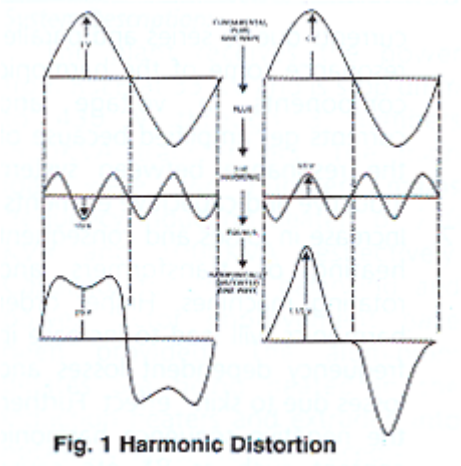

Fig. 1 Harmonic Distortion

Classification of Harmonics

Each harmonic has some frequency, it also has sequence. The sequence refer to phasors rotation with respect to the fundamental i.e. in an induction motor, a positive sequence component would generate a magnetic field which rotates in the same direction as the fundamental. A negative sequence harmonic would generate a rotating field in the reverse direction whereas the zero sequence harmonic would not rotate the magnetic field in any direction. As in India, the fundamental frequency is 50Hz the first nine harmonics are listed below:

Even harmonics disappear when the wave are symmetrical (typical for electrical systems.)

Zero sequence harmonics are called triplets which are the odd multiples of 3rd.

Effects of Harmonics

The effects of harmonics on power system are as follows –

1. Over voltage and excessive currents due to series and parallel resonance some of the harmonic components in voltage and currents get amplified because of the resonance between system inductive and capacitive elements.

Sequence	Rotation	Effects
Positive	Forward	Heating of conductors, Circuit breakers
Negative	Reverse	Heating and motor problems
Zero	None	Heating + Add in Neutral of 3 phase 4 system

2. Increase in losses and consequent heating of transformers and rotating machines. Higher order harmonics will lead to increase in frequency dependent losses and losses due to skin ` effect.

Further, the negative sequence harmonic content such as 8* etc cause additional heating in rotating machines.

3. Overloading of power factor correction shunt capacitors leading to excessive leading of current to excessive fuse blowing. This is because the capacitance offers lower reactance to higher frequency harmonics (Xc is proportional to 1/10- Sometimes occurrence of series or parallel resonance at one or more of the harmonic frequencies will result in failure of shunt capacitors and other connected equipments.
4. Aging of insulation of the electrical equipments. Hence reduction in efficiency of power generation, transmission, and its utilization.
5. Increased error in energy meters. Studies have indicated that there will be a decrease in energy recorded due to the presence of harmonics.
6. Mal functioning of protective gears such as relays, circuit breakers due to changes in voltage and current caused by the harmonics.
7. Inductive interference with neighboring communication network. The harmonic existing in the power line caused interference in the adjacent communication lines thereby corrupting the messages being transmitted on the communication networks.
8. Tripping of machines at smaller loads.
9. Fire hazards.

Sources of Harmonics

Harmonic pollution in power system is generally caused by non linear loads. The sources of harmonics in power system can be broadly classified as follows:

A) Harmonic originated at high voltages by supply authorities.

1. HVDC systems
2. Back to back systems
3. Static Var compensation system.
4. Wind and solar power converters with interconnection.

B) Harmonics originated at medium voltages by large industrial loads like Traction equipment, variable speed drives, Thyristor controlled drives. Induction Heaters, Arc furnaces, Arc welding. Capacitor bank, electronic energy controllers.

C) Harmonic originated at low voltages by consumer end like single phase loadings, uninterrupted power supplier, semiconducting devices, CFL, Solid state devices, domestic appliances and accessories using electric devices, electronic fluorescent chokes, electronic fan regulator / light dimmers.

Variable speed drives are very commonly used for many industrial applications in the industrial sectors, commercial building and municipal water system for achieving energy saving but this wide scope applications. These drives have various possible applications in the industrial sectors, water system for achieving energy saving but this wide scope of application is responsible for harmonic distortion.

The variable speed drives are the devices used for varying the speed of driven equipment to match the process requirements. Their main applications are

1. Steel plants: - Fan blowers. Cooling Towers, Process equipments
2. Cement Industry, Raw Mill, Preheaters, Coolers, Coal Mill, Cement Mill
3. Paper Industry, Recovery Boiler, Washing, screening and bleaching, Stock preparation, paper Machine, Recycle water pumps
4. Textile Industry, Ring Frames, Humidification System
5. Commercial Building, Refrigerator and air conditioning

AC Variable Speed Drives: - A Source of Harmonic Generation

As the speed is proportional to the ratio of voltage to frequency, for maintaining the speed constant the voltage across the stator terminal or frequency should be varied. So to maintain the speed of induction motor to a constant value, the line commutated converters are used in ac variable speed drives. In these drives, the three phase ac is converted to dc voltage with the use of bridge rectifier and then inverted to the desired frequency using different techniques like square wave, PWM etc. ***(Refer fig.2)*** These rectifiers draw the currents only during a certain portion of the incoming voltage

waveform. This causes harmonic distortion in the load currents even though improves the efficiency. Also in thyristor controlled drives at load speed it injects current harmonics in load.

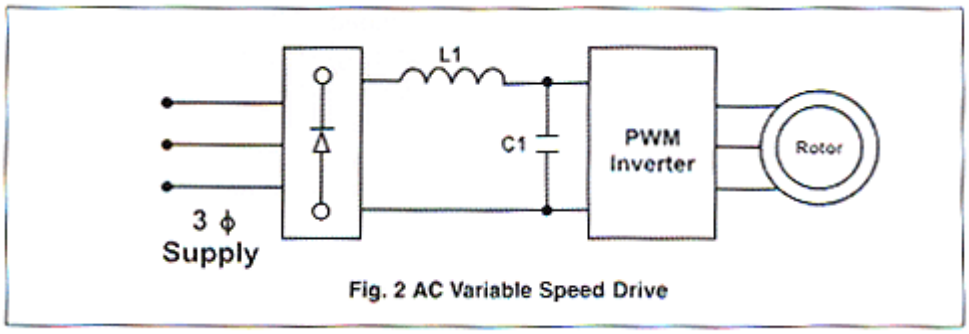

Fig. 2 AC Variable Speed Drive

Solution for Minimizing Harmonic Currents Effects

1. **Over-sizing or derating of die installation** – This solution does not eliminate harmonic currents flowing in the low voltage (less than 1000V AC) distribution system but masks the problem and avoid the consequences. The most widely implemented solution is over-sizing of the neutral conductor. In existing installation, the solution is to derate the electrical distribution equipment subjected to the harmonic currents.
2. **Specially connected Transformers –** this solution eliminates third order harmonic currents. It is a centralized solution for a set of single phase loads.
3. **Series Reactors –** this solution consists of connecting a reactor in series with non linear loads.
4. **Tuned passive filters –** a filter may be installed for one load or a set of loads. The filter rating must be coordinated with the reactive power requirements of the load
5. **Active Harmonic Filters –** The active harmonic fillers are used to introduce current component to cancel die harmonic components of the non linear loads. There are different types of active harmonic filters.

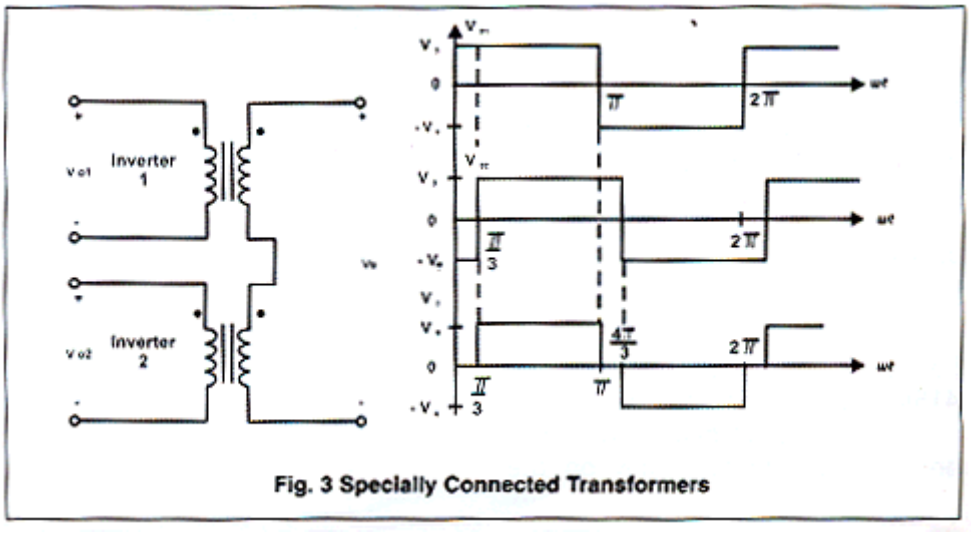

Fig. 3 Specially Connected Transformers

1. Series Filters: - This filter is connected in series with ac distribution network and compensates both the harmonic currents gemeatod by the load and voltage distortion in the ac system.
2. Parallel Filters: - they are connected in parallel with the ac line and need to be sized for the harmonic currents drawn by the non linear loads.
3. Hybrid Filters: - It is a combination of active and passive filter and may be either series or parallel type. The passive filler carries out basic filtering (for example fifth order) and the active filter covers the other harmonics.

Case Study site an Aluminium Extrusion plant in Rajasthan.

System Description: -

The plant receives the power from RSEB at 33 KV and is stop dmm to 430 V through 3 numbers 15000KVA transformers. The main loads were two numbers mains frequency induction beaters of 770 KVA and 1000KVA respectively. Capacitors for phase balancing and land power factor improvement have been provided. The aluminium billates are being heated in the induction heaters and extruded into necessary sizes. Problem Faced: -

The following problems were faced while running the plant from RSEB supply.

1. Drawing of excess current and overheating of capacitors resulting in their premature failures.
2. Overheating of cables and insulation failure.
3. The induction heaters when run on RSEB supply were drawing high current event on the lowest tap setting and tripping due to overload. Due to this the plant could not run on electricity board supply and hence was run on generators only. Observations: -

Harmonic analysis was conducted and it was observed that electricity board supply was highly polluted by fifth harmonics which were the cause behind the problems mentioned above. The total harmonic voltage distortion on 415V bus with electricity board supply was found to be 29%.

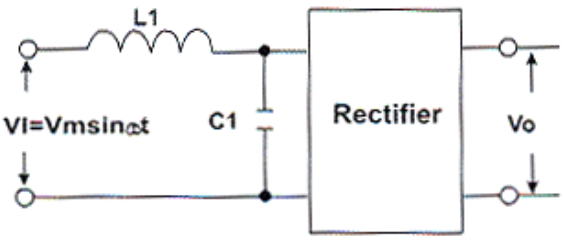

Fig. 4 - AC Filters

Conclusion

The harmonics is the important factor which affects the performance of machines, measuring instruments etc. Hence to avoid the maloperation of these equipments, we should try to get the power of better quality. We must provide necessary systems where these harmonics are generated like in ac variable speed drives. The rules and regulations on the harmonic injection in the power supply should be followed strictly. The distortion level should be within the limits. The awareness about the harmonics is very important task.

Recommendations

Based on the above harmonic analysis it was suggested that 5^{th} harmonic filter to be installed on the 415V bus. After installation of the filter the induction heaters were run on electricity board supply on the highest tap setting without being over loaded.

Damped filters are used for minimizing harmonic effects. It provides a low impendence path to a band of frequencies around a desired frequency and its filtering performances are better.

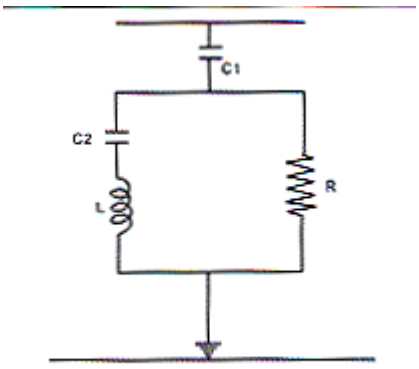

Fig. 5 - Damped Filter

The active filter is installed in parallel to the harmonic generator. It analyses the harmonic current produced by the nonlinear loads and supplies an 180^0 out of phase compensating current, either over the entire spectrum from 2^{nd} to 25^{th} harmonic or a specially selected harmonic. This action neutralizes the corresponding harmonic currents completely at the point of connection provided that the system has been appropriately dimensioned. All the problems faced before the installation of filter were thus eliminated.

The recent trends are to use IGBT with PWM techniques to supply 180" out of phase compensating current.

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Reference Book:

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