

600 MW Thermal Power Station Stability by Boiler Auxiliary Equipment Harmonic Quantification, Analysis and Its Mitigation

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Abstract:

In the Thermal power Stations, the running head of fuel cost, and to reduce the Heat rate Kwh/Kcal, inspire application of Variable Frequency Drives (VFDs). The usage of the VFD in the larger auxiliaries paves the way for reduction in the auxiliary power consumption and for saving of the fuel cost. Nevertheless, using nonlinear loads at thermal power auxiliary power buses and its network prompts harmonics, which is the principal cause of harmonics ill effects, which highlights the reason to be quantified, analyzed and to be eliminate it. This paper aims at the systematic technique of the harmonic measurement, analysis and its mitigation in the VFD of an auxiliary equipment in 600 MW Thermal power station. The paper also recommends the size and quality assurance of the filter used and improvement of the system. The harmonic filter classification is also analyzed for the thermal power station classification. IEEE Standard 519 which got the new revision by the year 2014 [1] recommends Harmonic measurements and Recommends harmonic limits for voltage and current harmonics are compiled for, and further proposed system of harmonic mitigating circuit is designed accordingly.

Keywords: Induced draft Fans, Heat rate, auxiliary buses, THSeAF,

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I. Introduction:

Energy output from Thermal power stations of modern era, becomes the imperative as a base load of the power system. Notwithstanding problems of penetration with the renewable energy sources, and uncertainty associated with it, is met out with the Thermal power stations only. The Thermal power stations plays the vital needs in meeting the peak hour demands and also to operate the power system in the 'safe region operation' in the grid management. Hence the reliability of Thermal power stations is most significant of the grid stability, in the scenario of renewable energy sources penetration. In order to have the continued and reliable operation of the thermal power stations, the major equipment like Steam Generator, Turbine and Generator and its auxiliaries should run in a

smooth cohesive way. Any hitch in its auxiliaries will affect the power generation of the base load plants, and has the influence on the grid reliability and its safe mode region of operation, and places a tough onus on the grid control center in operation of grid.

The paper aimed on the analysis of one of the major equipment, the Induced draft fan (ID Fan) main auxiliary equipment of North Chennai power plant, 600MW, Boiler in Chennai, Tamilnadu, India. The ID fan main function is to evacuate the burnt fossil fuel flue gas of 2000 T/Hr at a temperatures around 140°C from the Boiler to atmosphere. Since the IDF in this power plant is designed to draw 8000 KW, 11 KV fed brushless synchronous motor, (2X4000 KW). This ID fan is designed with varying speeds as thermal unit demand varies, henceforth

the IDF motor is applied with Variable Frequency Drive (VFD).

Thermal power station Boiler is also equipped with the Primary Fans which has the assigned function of carrying the coal, powered to the range of 15 microns in the bowl mills in to the Boiler. The Forced Draft Fan (FD fan) does the function of supplying the excess air in the boiler for the complete combustion.

II. Problem Formulation

The ID fan in Thermal Power stations has the operating conditions to function smoothly at various loads, from startup to the full load condition .The ID fan has the 11KV, 2X4000 KW brushless synchronous motor driven fans. This major load of auxiliary power has the impact on the auxiliary power consumption and increases the ‘Heat Rate’ the Kwh/Kcal which is undesirable, hence to reduce the auxiliary power both the ID fans are equipped with the Variable frequency Drives . The VFD in this plant of 600 MW has the frequent outage problems. The VFD is measured and analyzed for the harmonics it is producing. Also the influence of the harmonics [6] on the various control circuit of VFD, and the MV Buses feeding the supply and its Transformers.

The harmonics developed by the VFD industrial drives [2] applied mainly for the pumps or fans, these have the ill effects[7] of supplementary heating in motors. Bearing and bearing housing will be subjected to stress and heating and failure. The voltage harmonics also have the effect on the insulation of the motor for the class of insulation and its level which it is intended only for particular design temperature. The Harmonics produced in the input line currents also have its own effects on the other equipment of the system.Motors are considerably influenced badly due to harmonics voltage variation from its natural sine wave,which is transformed to harmonic fluxes inside the motor through motor terminal connections. These fluxes created by harmonics does not add significantly to

motor out put power, nonetheless spin at a frequency dissimilar with rotor system frequency, along with high-frequency currents in rotor. The consequence with motors is with fundamental frequency, the negative-sequence currents also fed and affects the motor fluxes.The negative sequence fluxes along with losses diminished efficacy ,heat,bearing vibrations, and hence the noise .The motors are characterized as blocked rotor reactance in shunted in line, consequence of harmonics frequency

Real time harmonics readings are taken and analyzed with the Fluke power quality analyzer model no: Fluke 435 II, and its mitigation techniques of the system are recommended and tested and the recommended. The mitigation technique is analyzed and simulated with the MATLAB simulation and the results are compared.

Hence to generate the sustained power in thermal station by preventing the auxiliary equipment outages, and to eliminate the harmonics effects on the equipment ,the harmonics should be quantified ,analysed and mitigated.This paper paves the way for measurement ,analysis and mitigation in real time industrial environment.

III.VFD for the ID FAN in Thermal Power Station:

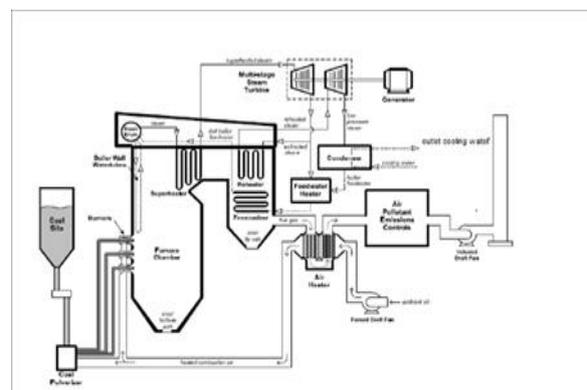


Fig1: Schematic diagram of thermal power plant.

The coal after being burnt in the boiler as per the Rankin cycle (Fig: 1) is being evacuated to the

atmosphere by the Induced Draft Fan (IDF). The IDF motor is being having the capacity of 2X4000 KW. In order to save the auxiliary power supply it is being fed by the VFD.

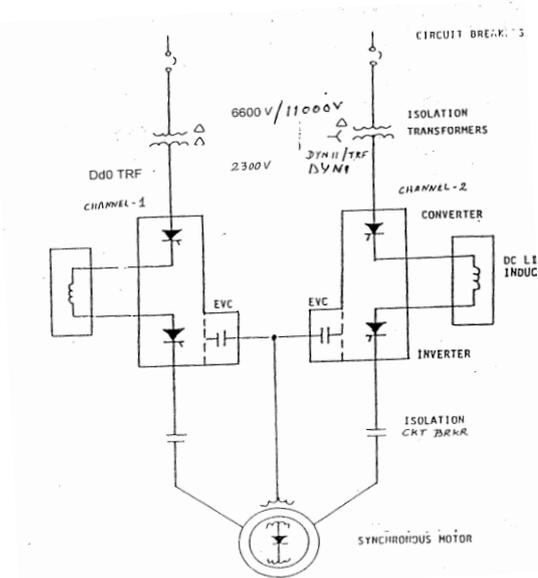


Fig 2: VFD system for ID fan

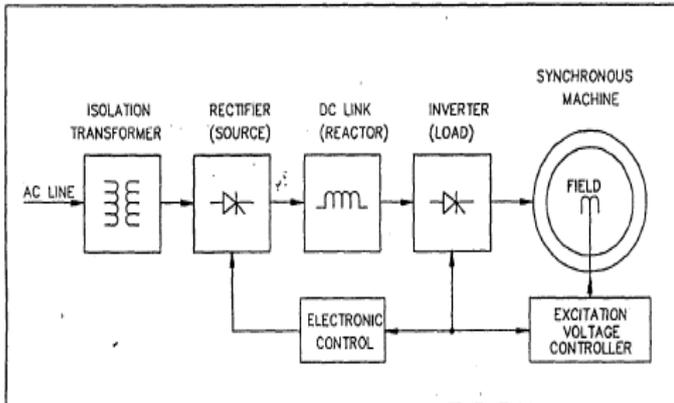


Fig3: Single line diagram of LCI

VFD in the thermal power station

VFD has Load Commutated Inverter (LCI) consist of power electronics device, with changeable frequency drive structure which control and modulates speed of a synchronous machine, depending on power plant unit demand close to its name plate speed. The elementary scheme comprises, phase controlled with line commutation converter thyristor blocks, which feed load

commutated convertor with a dc link reactor, (Fig 2 and 3) given as simplified one-line diagram of a single channel LCI. To give the correct voltage at terminal of the rectifier a transformer is provided and it isolates the AC bus system also its internal impedance confines the scale of downstream auxiliary bus in thermal from system faults.

For Thyristor Bridge rectifier, gating pulse applied in a manner that it produces a varying DC output voltage which is applied to the stator of the IDF synchronous motor. The Rectifier Bridge output is fed with dc link reactor, functions for smoothen the current and puts the within the limits of operating levels continuously .

Output of DC link reactor is given to Bridge of inverter ,This gives varying frequency voltage in stator terminal of motor which drives IDF, and also maintaining v/f ratio. The inverter and converter bridges with same hardware , run by microprocessors. It is promising for swapping inverter-converter functions, so the power flow to and forth. Hence the IDF synchronous machine of 4000 KW is braked and thereby pumps energy back to the AC auxiliary bus of Thermal power station

IV. Measurement of the Harmonics:

The harmonic measurements taken in Point of common coupling (PCC) [15] with the Fluke 435 II series analyzer in the source breaker of the VFD. As per the IEEE 519 updated 2014, The PCC is the site of power supply system, electrically adjacent to a specific load, where other loads are associated. The PCC is a point located upstream of specific installation.

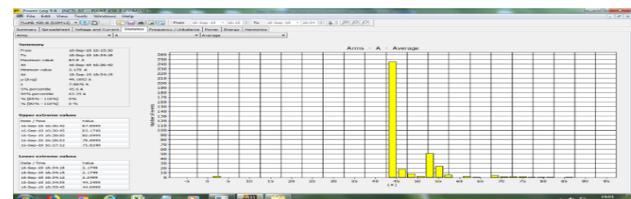


Chart: 1

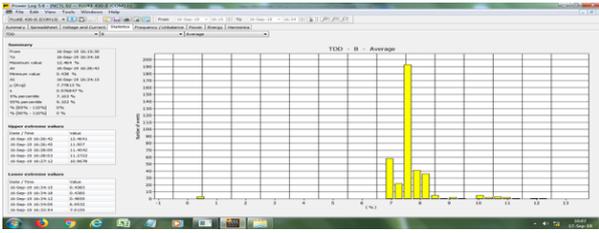


Chart: 2

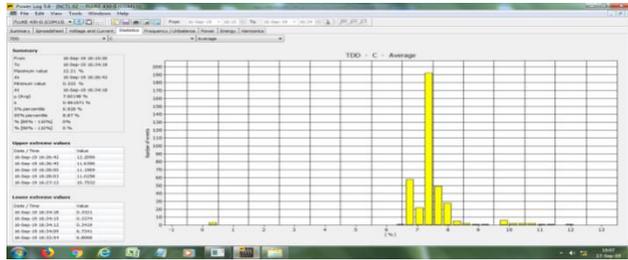


Chart: 3

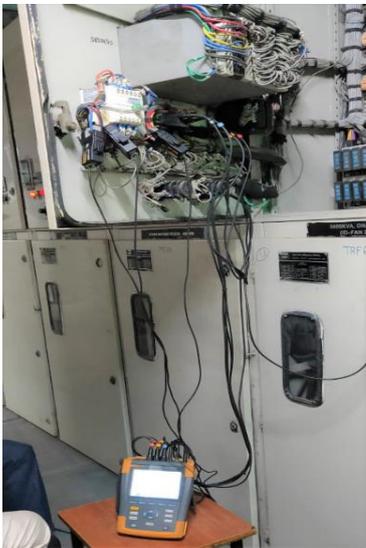


Photo 1

$$TDD(I) = \sqrt{\sum_{n=2}^{40} I_n^2} / I_{MaxDemand}$$

Imax Demand is current maximum Demand

$$THD(I) = \sqrt{\sum_{n=2}^{40} I_n^2} / I_1$$

TDD (I) s the ratio between RMS of the harmonic values up to 50th order neglecting inter harmonics, and given as the percentage of maximum value of the current required of the load, here the ID fan. The TDD is the signal deviation of pure sine wave

V. Analysis of the Harmonics

Framed initially during 1981 updated in 2014, IEEE 519[1] is a prescribed standard to mitigate ill effects of non-linear loads on electronic devices and control loops and systems in one grid as the source of harmonic distortion. Many huge loads in the industries use and depend on variable frequency drives (VFDs) for energy management, but are often the source of harmonic distortion. In Segment 5.2, of IEEE 519-2014, (table:1)[5] in the portrayal for TDD, the utmost demand current is used and is explained as “This current value is established at the point of common coupling and should be taken as the sum of the currents corresponding to the maximum demand during each of the twelve previous months divided by 12”

| MAXIMUM HARMONIC CURRENT DISTORTION IN % OF FUNDAMENTAL | | | | | | |
|--|--------------------------------|---------|---------|---------|------|------|
| I_{sc}/I_L | HARMONIC ORDER (ODD HARMONICS) | | | | | THD |
| | <11 | 11<h<17 | 17<h<23 | 23<h<35 | 35<h | |
| <20* | 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 |

Even harmonics are limited to 25% of the odd harmonic limits above.

*All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L .

Where I_{sc} = Maximum short circuit current at PCC.
And I_L = Maximum load current (fundamental frequency) at PCC

For PCC's from 69 to 138 kV, the limits are 50 percent of the limits above. A case-by-case evaluation is required for PCC's of 138 kV and above.

Table 1: IEEE standards

The VFD in the thermal station for the ID fan produces distortions as it is nonlinear load. As it draws distorted current from the source, goes from end to end of all the impedances in-between power source breaker of the auxiliary bus of Thermal power plant and the Synchronous motor (4000kw) of the ID fan. The related harmonic currents cause voltage of the auxiliary 11kv bus, with harmonic frequency, transverse the system impedances. The summation of vectors reveals THD in auxiliary bus.

These values relates with auxiliary bus impedance and also with the harmonic causing load connected as load in that instance. The drop in voltage at load side is obtained by the equation of current at n th harmonics multiplied with impedances of cable from the source breaker to the (Fig2) VFD channel breaker, transformer and the, source the auxiliary bus in the thermal plant (eq: 1)

$$V_{n,load} = I_n * (Z_{c,n} + X_{t,n} + X_{d,n}) \dots (eq1)$$

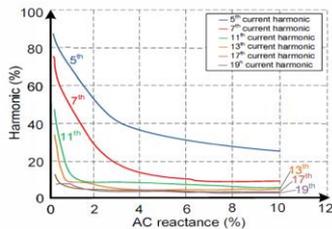


Fig4: Xac Vs. % harmonics

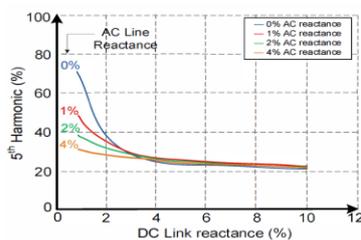


Fig5: Xdc Vs. 5th harmonics

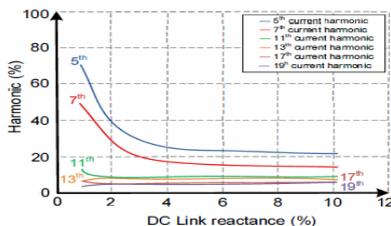


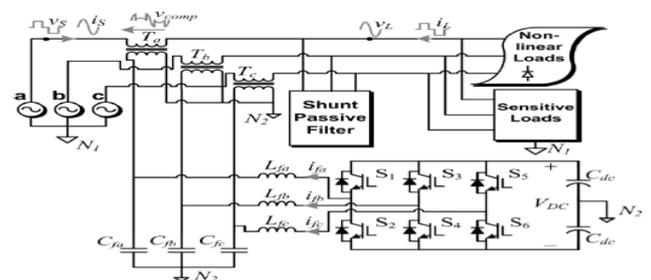
Fig6: Xlv Vs. % harmonics

The IEEE allows 7% of IL, the discrete distortion for ratio of current. Harmonic analyzer processes distortion of Harmonics depends on IL, the % harmonics lower value is around 1.2% are not as severe as they appear. Nevertheless, this grid (chart 1, 2, 3) illustrates which harmonics generate the majority of the distortion is revealed. The 5th harmonic creates distortion value of 19% of IL in monitor. The 7th harmonic creates distortion value of 4% of IL in monitor.

Pulse number of rectifier is the decisive in influencing harmonics generation [8], harmonics generated by a 6-pulse rectifier for ID fan VFD is in order of Fifth, seventh, eleventh, thirteenth, and further harmonics and its scales will be crudely converse of harmonic order times the extent of system frequency. 5th and 7th harmonics of the VFD of the fan in this case is characteristically the consequence of VFD with 6-pulse which is installed for IDF.

VI. MITIGATION OF SOURCE CURRENT HARMONICS [6]

Harmonics generated distortion in auxiliary bus present at PCC, is taken from the auxiliary [15] 11 KV bus of Thermal station which is influenced by source reactance. As the VFD controls the speed of 4 MW brushless synchronous motor by frequency control, THDi will accomplish to the value limit of 84%. The mitigation techniques focuses on the application and essential value of attenuation. With 11 KV AC input, the DC-link reactors including AC-portion filters, are linked in with nonlinear loads as parallel, these will be "tuned" to deliver minimum impedance for harmonics. This low impedance is imperative for mitigation of harmonic ill effects.



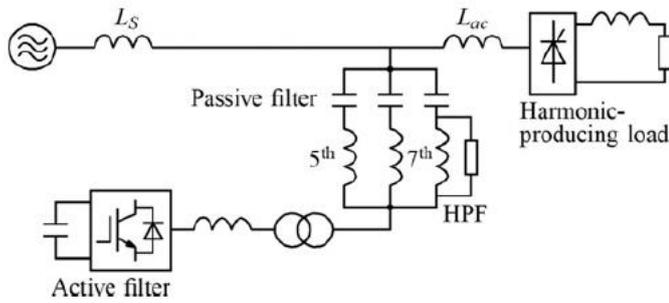


Fig-7 Mitigation of source current harmonics THSeAF

The series Hybrid active filters take a common arrangement (Fig.7) with converters and isolating transformers. This projected arrangement doesn't encompass series transformers. In Section 5.2, of IEEE 519-2014 (Fig. 8) consists of a convertor of H-bridge in two levels, linked in series in the middle of auxiliary bus system in the power station and PCC the source breaker of ID fan VFD, This arrangement permits self-governing regulator on every distinct phases irrespective of the other phases. Also series of passive filters which are "tuned" and guarantees a minimal impedance pathway for I_h (Fig 8),while a DC supply acts in both the directions is associated to gives pulses of power in the times of voltage sags and rivets at the instances of overvoltage.

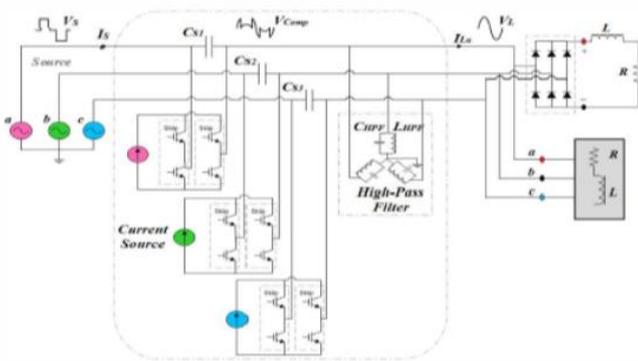


Fig 8:THSeAF

The design technologically advanced with transformerless hybrid series active filter (THSeAF), replace series transformer design for DVRs for mitigating harmonics of voltage and associated problems. THSeAF (Fig 8) which is very effective technology [11]is dependable and it saves loads from voltage variation.

A tuned passive shunt filter for 50Hz with transformerless series active filter have capacitors connected in the three lines are associated with full-bridge three single phase converters. This functions like active filter solves the current distortion problems and improving load power factor.[12]

VII.Model of THSeAF

To avert I_Lh current harmonics for implication to source the series source must possess small impedance to fundamental component and high impedance to harmonics to block it. Hence it is imperative for the application of well-tuned passive filter for compensating current problems and sustaining a voltage free from alterations in IDF synchronous motor terminals. The VFD with THSeAF is exhibited as the SeAF(fig9)

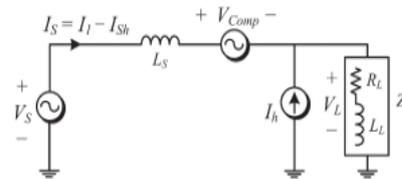


Fig9: model of THSeAF

$$V_{comp} = G_a I_h - V_Lh \quad (2)$$

Where the source voltage V_{comp} with gain G_a which depends on current harmonics I_h flowing in the bus (eq: 2) which paves way for equivalent circuit for harmonics and fundamental.

$$V_s = V_{s1} + V_{sh}$$

$$V_L = V_{L1} + V_{Lh} \quad (3)$$

Harmonic current of the 11 KV bus of thermal power system can be found as

$$V_{sh} = -Z_{su} V_{sh} = -Z_{su} I_{sh} + V_{comp} + V_{Lh} \quad (4)$$

$$V_{sh} = -Z_{su} (I_h - I_{sh}) \quad (5)$$

Hence

$$I_{sh} = V_{sh} / (G - Z_s) \quad (6)$$

By combining (4) and (5)

If G value is high which tends to infinite then, source current will convert into pure eliminating harmonics I_{sh} becomes 0, which helps to eliminate the voltage distortion at 11 KV auxiliary bus side of Thermal station side. THSeAF performs as open circuit with infinite impedance for harmonics of current, whereas shunt high-pass filter tuned to 11 KV bus frequency of 50Hz generates a minimal-impedance for harmonics, which acts as open circuit for fundamental.

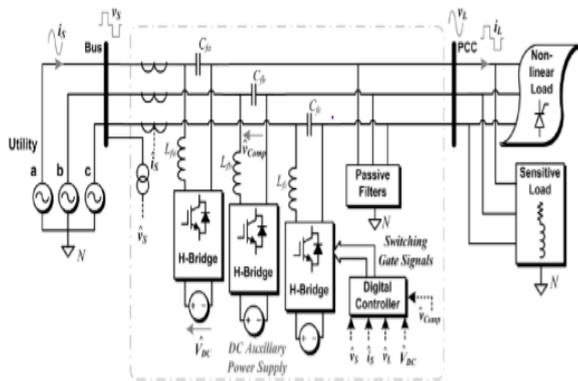


Fig.10 Mitigation of current harmonics using Hybrid active power filter using transformer less configuration

The current harmonic mitigation simulation (fig: 11) circuit, then on linear load in our case the variable frequency drive (VFD) of ID fan. The VFD is applied its voltage on the stator of brushless synchronous motor, with a three phase sinusoidal voltages. As a nature of non-linearity, connected load draws distorted (harmonic) current. Active series filter provides very high range impedance for harmonic currents. Now all harmonic currents passes through passive power filter. Active power filter inserts voltage as, series with line. These voltages are injected with help of power capacitors, hence the name “Transformerless Series Hybrid Active Filter”. THSeAF [13]

VIII. Control Algorithm:

The control technique to alleviate current and voltage problems being solved with Park’s transformation (Fig.17) The direct-quadrature-zero, dq0, transformation, also called zero-direct-

transformation, in which a tensor spins with reference frame vectors, with three elements abc vectors /matrix, assists for easy analysis. This dq0 transform arrived of Clark and the Park transformation which makes the synchronously rotating frame from a stationary locus. The synchronous orientation frame can get into line to rotation with voltage or current. The thermal power plant auxiliary system which is delta connected system, then the zero component becomes nil. It can be systematized the block to bring into line of a -axis of 3-phase 11KV auxiliary bus system to both d - or q -axis of spinning orientation frame during the time $t = 0$. In vector frame (Fig 11) dq0 obtained from abc vectors/matrix, the block accomplishes a Park transformation in a rotating reference frame and the vice versa dq0 to abc block achieves an inverse Park transformation.

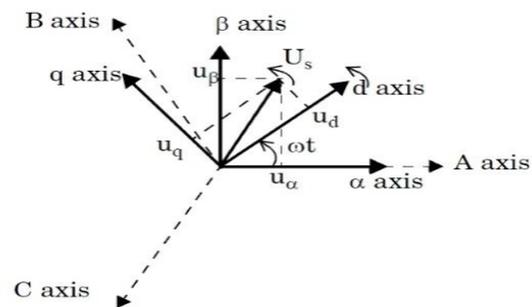


Fig: 11 Rotating frame

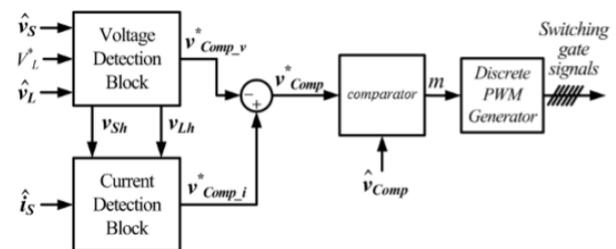


Fig: 12 Controller architecture scheme

The voltage sensor applying the synchronous reference frame - phase locked loop. It is having technique of, (SRF -PLL),(Fig:13) the dq rotating reference frame is obtained with 3-phase voltage tensor deciphered with abc natural orientation frame which is done by Park transformation [Tdq]. The orientation of dq reference frame is organized with

impulse from feedback loop which converts ‘q’ module to zero. Consequently, d component portray voltage tensor value at the steady state, the phase will be resolved with output of the feedback loop.

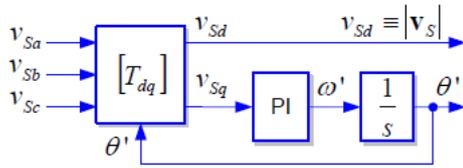


Fig 13: SRF –PLL block

IX. Control block of Harmonic current mitigation

In Control block for the mitigating harmonics of current, three-phase stationary rotating frame is changed to a synchronous rotating frame by Park’s transformation, which can be represented Vectors /matrix of the components of load voltage of the VFD motor current of ID fan

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix} \quad [7]$$

$$i_q = \bar{I}_q + \tilde{I}_q \quad [8]$$

$$i_q = \bar{I}_q + \tilde{I}_q \quad [9]$$

The MW and VAR power are disintegrated to the dq constituents (8) (9).

The auxiliary bus source for VFD of IDF produces the fundamental element of d -axis of synchronous motor of 4MW, THSeAFDC module is allied with technique of harmonic compensation. In PLL, spinning locus frame (ωt) is established as a system module. Relating Park’s transformation of inverse [11, 12, and13] the dq spinning frame is changed again to a 3-phase non-spinning frame

$$i_{sa}^* = i_d \sin(\omega t) + \cos(\omega t) \quad [11]$$

$$i_{sb}^* = i_d \sin\left(\omega t - \frac{2\pi}{3}\right) + \cos\left(\omega t - \frac{2\pi}{3}\right) \quad [12]$$

$$i_{sc}^* = i_d \sin\left(\omega t + \frac{2\pi}{3}\right) + \cos\left(\omega t + \frac{2\pi}{3}\right) \quad [13]$$

All these 3 signals are directed and summed without mitigating constituents then guided by a Pulse width modulator to produce gate pulse of converters.

Simulation:

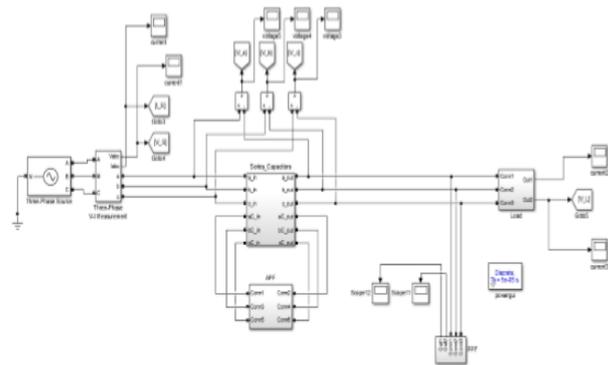


Fig 14: SIMULINK diagram for mitigation of current harmonics

The measurement values simulated with SIMULINK (fig14) before and after the compensation are obtained which shows the attenuation in the harmonics produced.

The simulated results of currents before and after the compensation are (fig15) given. Similarly the results of source voltage (fig 16) and the compensation voltage (Fig 17) is depicted.

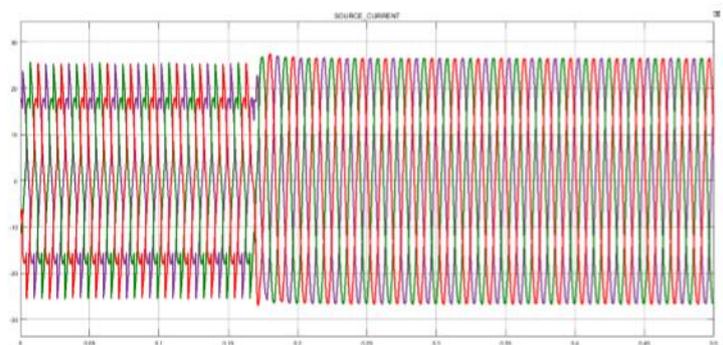


Fig: 15 simulated results showing 3 phase 11 KV bus currents before and after compensation

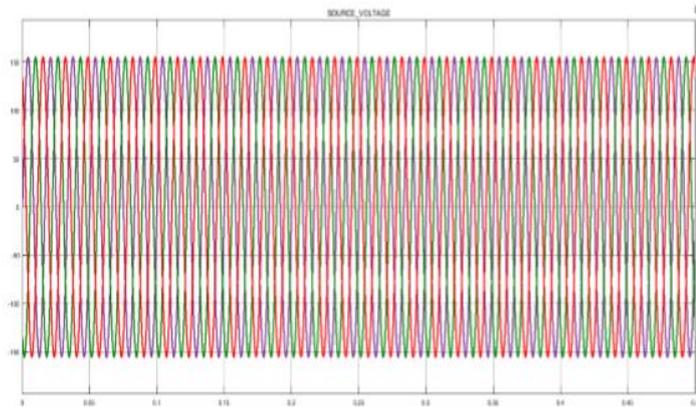


Fig: 16 simulated output of the 3 phase 11 KV Bus voltages

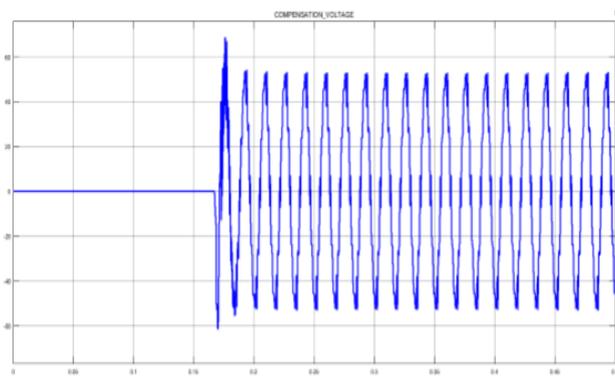


Fig: 17 simulated results showing the compensation voltage before and after compensation

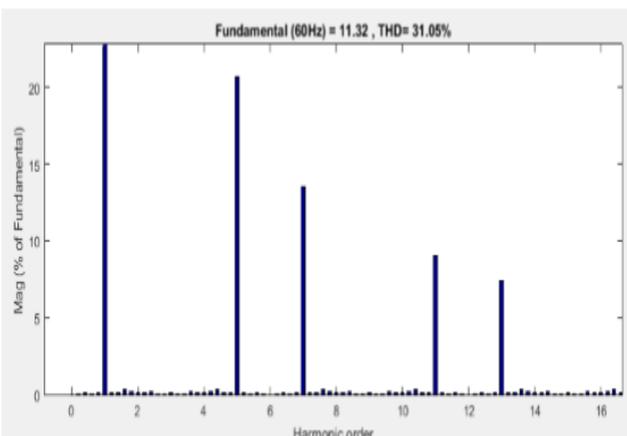


Fig: 18 THD of 11 KV current before compensation

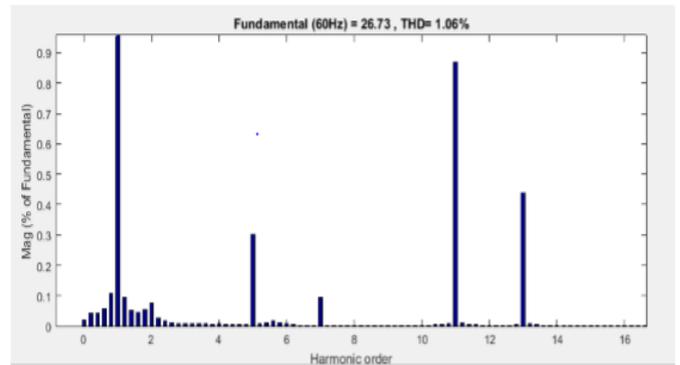


Fig: 19 THD of 11KV current after compensation

The THD before and after the compensation by the usage of hybrid active power filter with transformer less configuration obtained as before (Fig 18) and after the mitigation (fig 19) shows the improvement of the THD.

The above simulation results shows that by applying hybrid active power filter, eliminating source current harmonics performed effectively thereby decreasing the harmonic contents in the 11 KV auxiliary bus current, hence current drawn from the utility is purely sinusoidal. The compensation voltage pattern in concurrence with the source voltage and currents reveals that when the hybrid power filter starts injecting the voltage and shunt currents the source currents are free from harmonics and draws purely sinusoidal currents from the supply utility.

Conclusion: This paper has analyzed the vital auxiliary equipment, ID fan, in the thermal power station and the problem of harmonics produced by its VFD of 6 pulse LCI. The real time values of harmonics of VFD at the PCC the source breaker of the VFD are taken with analyzer. The harmonics are investigated with reference to Section 5.2, of IEEE 519-2014. The harmonics alleviation technique by “THSeAF”. The controlling technique of series Hybrid Active filter also has been recommended. The real data are simulated in the SIMULINK which reveals the improvement in the harmonics of

the VFD the results are presented. The measurement, analysis, and mitigation of the VFD of IDF finds path for the avoiding the freakish tripping of the auxiliary equipment in Thermal power station and stability and reliability of base load power plants and stability of the Grid.

Future studies: This paper presents and paves a way for the quantifying, analysis and mitigation of the harmonics produced in the VFD used in the industrial environment. Hence the large fans and pumps where the VFD are applied the harmonics

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