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MODELLING AND SIMULATION OF INDUCTION FURNACE AND MITIGATION OF TRANSIENTS IN VARIABLE FREQUENCY DRIVE

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ABSTRACT

This paper proposes the various methods to mitigate transients caused due to switching of Induction Furnaces working at 6.6KV, supplied by a double circuit 132KV feeder which also feed loads at different locations. The frequent tripping of Adjustable Speed Drives at one location led to the study of the reasons for tripping of drives and suggest methods to prevent the same. In order to study the reasons for the voltage transients due to switching of major loads,waveforms of voltages at various loads centres are observed using power quality analyzer.The study is conducted by analyzing the behaviour of transients by switching individual loads independently.During the study, it is observed that the distortion of the waveform was due to the switching of capacitor banks of horizontal and vertical induction furnaces. After analyzing the problem, remedial measures are being suggested for mitigating the transients on drives.

Keywords: Induction Furnace, power quality analyzer, mitigation, transients.

INTRODUCTION

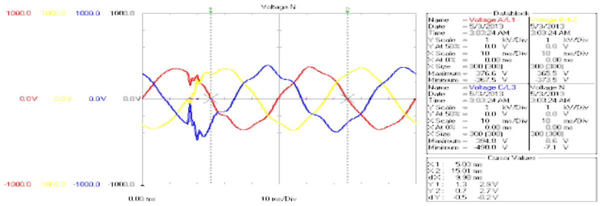
Induction furnace works on transformer working principle. It employs a coil placed in the vicinity of a job to be heated and excited by high ac voltage. This sets up an alternating flux in the coil, which according to faraday’s law of electromagnetic induction, induces an alternating voltage in the job. This voltage generates current in the job thus producing copper losses and thus heating it.
As this induction furnace operates at typical power factors around 0.2, there are various capacitor banks connected across the furnace to supply appropriate KVAr and thus improve power factor to 0.98.There is a fixed capacitor bank of 400kVAr,and switching capacitor banks of ratings 150, 300, 450, 600 KVAr.
A vacuum contactor is used to switch the furnace. It is placed just before the capacitor banks. Each of the switching capacitor banks has a switch in series to them to take the bank online whenever the power factor is observed to be poor. This addition of power factor correcting capacitors is however always done offline. When a capacitor bank switching device is closed to energize the capacitor bank, the voltage of the switched capacitor bank bus suddenly collapses to the level of the voltage on the capacitor bank which, with the capacitors discharged, is generally zero. The bus voltage then attempts to return to its normal power-frequency value, but overshoots this value and oscillates about the normal power-frequency wave until the oscillations are damped out. This oscillation typically lasts on the order of one cycle of the power frequency

POWER QUALITY ANALYZER

A power quality analyzer (PAQ) is used to measure transient voltages at the load centers. The data analyzed using PAQ is as follows:

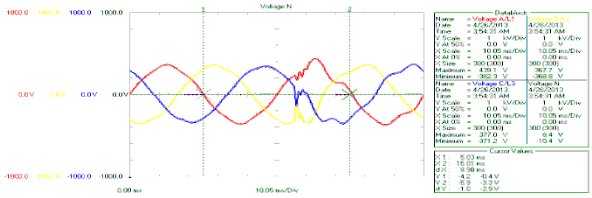
1. The voltage trends recorded at various load terminals using a power quality analyzer (PQA) are presented below:

a) Voltage trend monitored when horizontal furnace is operating and vertical furnace is shut off, is as follows:



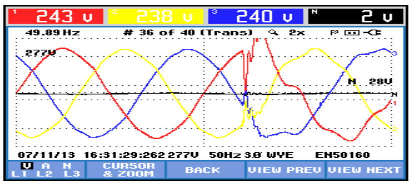
- The overshoot is observed to be 1.38 times the rated peak voltage

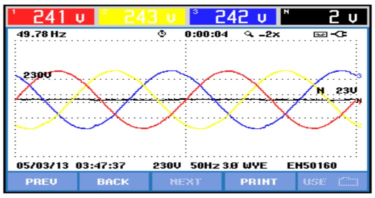
b) Voltage trend monitored when horizontal furnace is shut off and vertical furnace is operating, is as follows:



- The overshoot is observed to be 1.24 times the rated peak voltage.

c) Voltage trend monitored when both horizontal & vertical furnace are operating



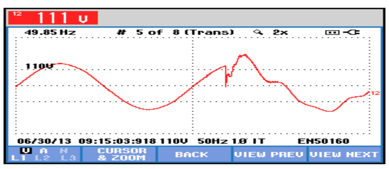


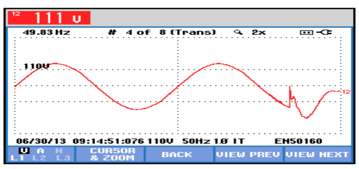
OBSERVATIONS

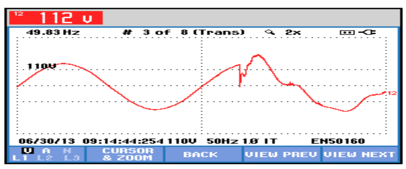
From the pattern of the voltage waveforms recorded using PQA, following observations are made:

- Distortions are not a continuous phenomenon through out the period of observation. They are distorted momentarily, shooting up to overvoltage values thus indicating that it is due to switching of major loads.
- Considering various load conditions during the transient overvoltage instants, it could be inferred that the momentary overshoots are observed in the voltage waveforms as and when horizontal and vertical induction furnaces are switching.

2. Voltage trend monitored at the secondary terminals of potential transformer connected across the phases supplying the vertical induction furnace, when it is in operation are presented below:







The overvoltage is observed to be around 1.5 to 1.6 times the rated peak voltage

OBSERVATIONS

- When all the other loads are shut off, voltage monitored while the furnace is in operation, at the secondary terminals of potential transformer which is connected across the two phases which supply the induction furnace, is showing transient over voltages.
- The voltage waveforms are observed to be purely sinusoidal when the furnace is ON, but getting distorted only when the furnace is switching.
- These transient over voltages are observed in the voltage waveforms only at the instant when the furnace is switching ON.

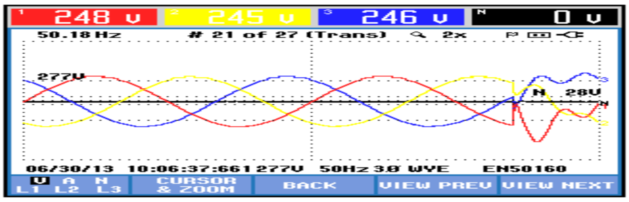
Summary of the above observations

Voltage trends observed with PQA when horizontal/vertical furnace is switching.

S.No	Location at which voltage is monitored	Overshoot observed (expressed as no of times the rated peak voltage value)
1	Motor load	1.64
2	load center-2	1.57
3	load center-3	1.38
4	load center-4	1.47
5	At the secondary winding terminals of the potential transformer connected across the vertical induction furnace.	1.60

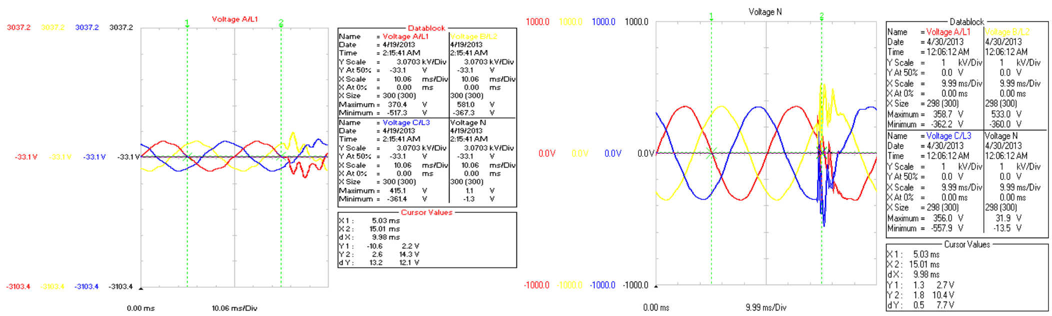
3. Voltage monitored at load center-2, when horizontal induction furnace is shut off and vertical induction furnace is operating

a) When the capacitor bank load center-2 and MSDS-2(Main Distribution System) are isolated



- Magnitude of overvoltage is around 1.5 to 1.6 times the rated peak value.

b) When capacitor bank at load center-2 and MSDS (Main Distribution System)-2 are online



The magnitude of overvoltage is around 1.64 times the rated peak value

S.No	Voltage monitored at load center-2,with/without capacitor bank	Overshoot observed (expressed as no.of times that of rated peak voltage)
1	When capacitor bank at the load center is isolated	1.5 to 1.6
2	When the capacitor bank at the load center is online	1.6

From the above table, it is evident that, there is no magnification of the overvoltage transients at the remote capacitor located in load center-2
The overvoltage recorded, as can be observed from the above graph, is

= 557.9*sqrt(3)
= 966. 311 V

As, this voltage is greater than the overvoltage trip setting of 750 V, the drives feeding the machine at load center-2, are frequently tripping.

MODELLING OF INDUCTION FURNACE

Horizontal Induction furnace is modelled as follows for the purpose of simulation.
In 900KW induction furnace, for an incalloy billet of 150mm diameter and a temperature set point of 1270 degcelcius.
Various electrical parameters are observed as follows:
pf=0.995
cos-1(0.995)=5.7319deg
V=6600KV
=6600 |_0 deg
Icon=current t vaccum contrctor
=67.6A |_5.7319 deg
Capacitor banks that are online: 300,450 and 600 KVAr
Total reactive power ssupplied by the capacitor banks=300+450+600
=1350 KVAr
So,
V^2*ωC=1000*1350000
6600^2*2*3.142*50*C=10^6*1350
C=98.6497 μF
Icap=V/Xc=VωC
=6600*2*3.142*50*98.64*10^-6
Icap=204.5454 |_90 deg
Icon=Icap+I1
I1=Icon-Icap
=(67.5|_-5.73 deg)- (204.54|_90 deg)
I1=221.70|_-72.35
for the 6600Kv/433V,2.6MVA
%Z=7
So leakage Reactance of trnsformer referred to 6600V side
X=(0.065*6600^2)/(2.6*10^6)
Xl=1.089 ohms
L=1.089/2*3.14*50
=3.4663mH
R=0.005*6600^2/2.6*10^6
=0.083769 ohms
Z=R+jXl=1.0922 |_85.6013 deg
Voltage available at the Induction Furnace terminals (Vind)

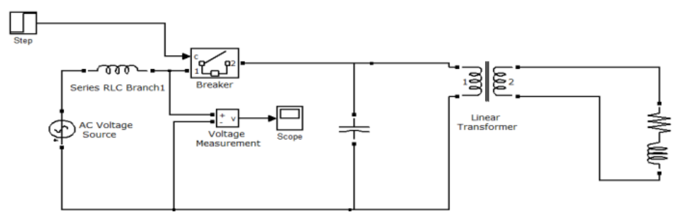
=V-I1*Z
=(6600|_0 deg) –((221.7045|_-72.63 deg)*1.0922|_85.6013)
=6364.2863-j55.4398
=6372.7576|_-0.499 deg

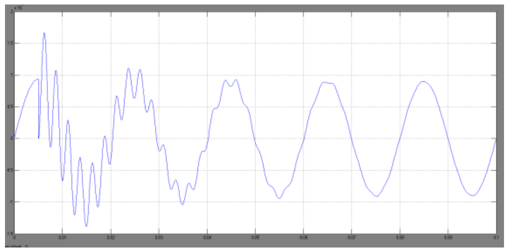
So now the impedance of Induction Furnce referred to 6.6KV side of transformer is
Zind1=Vind/I1
Zind1=8.9459+j27.3167
Actual impedance of the Induction Furnace
Zind=Zind1*433^2/6600^2
Zind=0.0385+j0.11757
Rind=0.0385
Lind=0.11757/(2*3.14*50)
=3.7425*10^-4 H

SIMULATION RESULTS

The results are checked using MATLAB Simulink software as below
(i)When 450 KVAr capacitor bank is switched alone at t=0.005
(a) Without series reactor

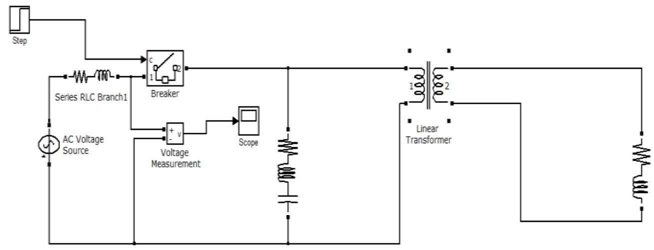
Circuit output waveform

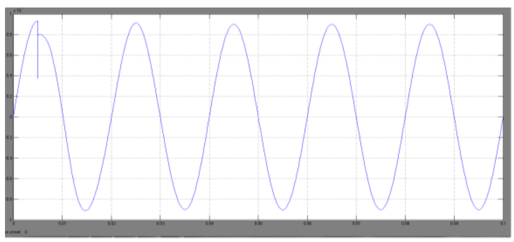




(b)With series reactor of 0.04554H and resistor of r=10 ohms

circuit
output waveform

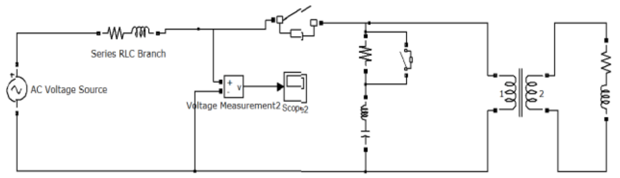


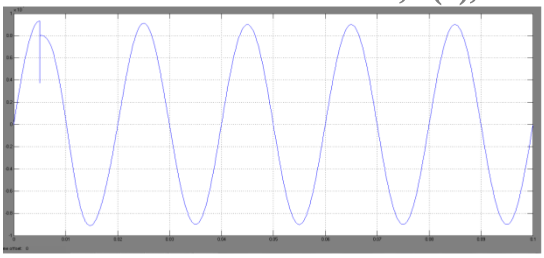


Voltage collapse observed at 6.6KV bus, when this capacitor bank is switched on at t=5ms:
As observed from this simulation waveform
%collapse= (9333-8100)*100/9333
=13%
As per theoretical calculations
%collapse =Lsource*100/(Lsource+Lcap)
=0.0050609*100/(0.0050609+0.04554)
=10%

(c) With series reactor of 0.04554H and resistor of r=10 ohms which is bypassed at t=0.015sec

Circuit output waveform

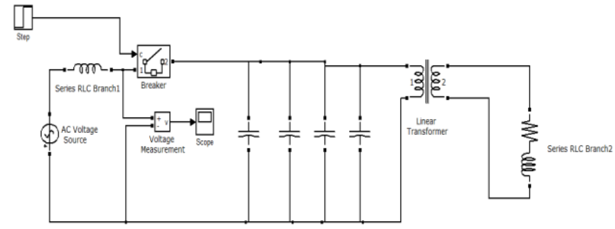


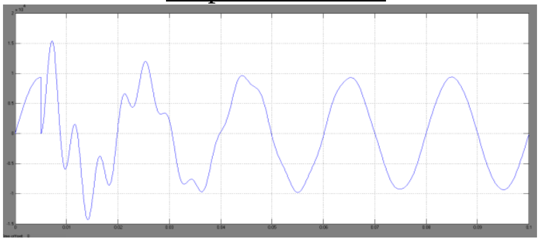


(ii)When 450,150,300,600 KVAr banks switched together at t=0.005

(a)without series reactor

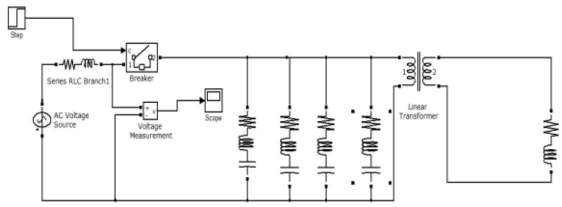
Circuit output waveform

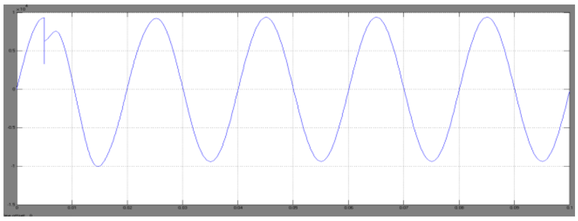




(b)With series reactor value 0.04554H, and resistor of r=10 ohms

Circuit output waveform





Voltage collapse observed at 6.6KV bus, when this capacitor bank is switched on at t=5ms:

As observed from this simulation waveform

%collapse=(9333-6000)*100/9333

=35%

As per theoretical calculations

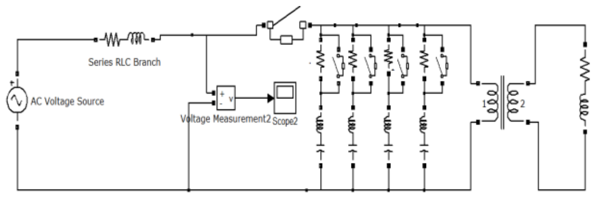
%collapse =Lsource*100/(Lsource+Lcap)

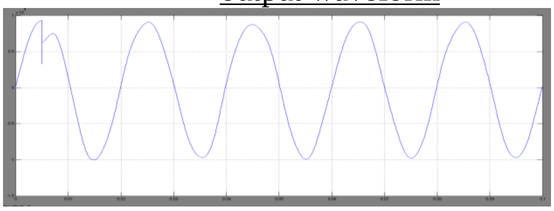
=0.0050609*100/ (0.0050609+Leff) (Where Leff =0.04554/5=0.009108 as the inductances of both the banks appear s a parallel combination)

=35%

(c) With series reactor value 0.04554H and resistor of r=10 ohms which is opened at t=0.015

Circuit output waveform





CONCLUSION

The voltage trends at the terminals of first and second induction furnaces, is getting distorted as and when they are switching ON, thus affecting the voltage at the 6.6KV bus at MSDS.

Thus, all the load centers fed on MSDS are getting affected by these transient over voltages. The drives at load center-II are frequently tripping due to over voltages.

A comparison of various solutions is presented here.

S.No	Methods used to mitigate transients	Remarks
1	Inductor in series to the capacitor bank	Overvoltage is eliminated, dip is reduced
2	Zero crossing switching	Capacitor should be switched within 1msec after voltage zero, otherwise high voltage overshoots would occur
3	Surge suppresser	Over voltages are prevented, but dips would still pre avail
4	Pre insertion resistor	By dissipating transient energy across it, it damps the oscillations quickly, but if not bypassed in 20 to 30 msec, it causes unnecessary system losses
5	Reactor in series with the drive	It protects only the drive, from all sources of transients. It is a cost effective solution for ASDs with diode bridge rectifier at the front end
6	Ultra isolation transformer for the drives	It protects only the drive

Simulations are performed by calculating equivalent circuit parameters, for both reactor in series with capacitor banks and for zero crossing switching. For simulation with reactors of 0.04554 H in series with each of the capacitor banks, the bus voltage collapse at the instant of switching as observed from simulation is matching with that calculated theoretically (the values of collapse thus encountered are observed to be less than the upper limit of 37%); and the over shoot is prevented in all cases of different combinations of capacitor bank switching.
Based on the advantages it may be proposed that:
1. Providing series reactor of 0.04554H in series with each capacitor bank connected across the first and second furnaces for improving overall power quality of the power distribution system.
2. Providing 5% reactor in series with the adjustable speed drives in the load centre 1 can be a good solution to protect the respective drives.

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