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An Investigation on Factories Power Quality (Harmonic) Problems So That to Protect Equipment's Damaging at the Distribution Network (Case Study: Maa-Garment, Mekelle, Ethiopia)

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Abstract
In modern electric power distribution systems especially at industrial distribution, there is a sharp rise in the use of non-linear loads due to high growth in industrial loads. These non-linear loads generally have solid state control of electric power and draw a non-sinusoidal unbalanced current from AC mains which resulting in harmonics injection, reactive power burden, excessive neutral currents and unbalanced loading of AC mains. In this project the industries in Mekelle city named as MAA-Garment power quality (harmonic) problem was investigated and remedies has been givenby designing filters based onitspower quality problems. So far, a number of attempts have been made on the analysis, design and development of equipment generally named as active power filter (APF) to provide a dynamic and adjustable solution to eliminate harmonics and reactive power burden on the AC mains. The work entitled here concentrated on the new control scheme of series inductive filters. The dominating sources of distortion, at MAA-Garment industry are motors, converters, power factor correction capacitor& other electronic devices plus machines. The presence of that non-linear equipment in factory yields an increasing of harmonic current on Management distribution system which leads to degradation of system performance of machines. Therefore, the mitigation technique to overcome this problem was accomplished by designing series inductive filter at branches of non-linear loads and the total harmonic order was reduced from 7^{th} to less than 5^{th} order at the respective nodes. .
Keywords: Power system harmonic, Mekelle City

Introduction

1. 1Background

Generally it's a common practice that power quality problem had been existed in power system for many years. Since, most electrical equipment in past is using balanced linear load in which the current and voltage are purely sinusoidal and hence small power quality problem was exhibited.

But in recent time due to the rapid growth in power electronic device such as diode, thyristors and hence results industrial loads to become non-linear. These components are called solid state electronic or non-linear load. The non-linear load connected to the power system distribution will generates voltage drop, harmonics current andHarmonics in power distribution system are current or voltage that are integer multiples of fundamental frequency. For example if the fundamental frequency 50 Hz, then the 2-nd harmonics is 100Hz, the 3-rd is 150Hz, A pure voltage or current sine wave has no distortion and no harmonics but non-sinusoidal wave has distortion and harmonics.

To compute the distortion, the term total harmonics distortion (THD) is used. The THD value is the effective value of all the harmonics current added together, compared with the value of the ultimate current Wave form alteration can be analysed for oscillation at different frequencies.

The flow of harmonic current into power system can damage equipment's due to sustained overheating or cause sudden failures due to resonant conditions. To overcome harmonics, *IEEE Standard 519*, "Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems," was adopted which introduces the limitations on voltage and current harmonics so that its distortion levels throughout the entire electrical distribution system, from utility to consumer, will remain low enough for the system to function properly

The harmonic currents on three-phase three wires power distribution system are dominated by the 5-th and 7-th harmonics that are generated from the three phase bridge diode rectifiers [Hansen, S., and et.al. 2003]. The main problem of harmonics current on three phase distribution power system is harmonic resonance. The harmonic resonance takes place between power factor improvement capacitor and source inductance during the 5-th and 7-th order harmonics frequency. The common types of resonance are two. They are series resonance and parallel resonance. For the series resonance, the total impedance at the resonance frequency reduces to the resistance component only. During this time, high current magnitudes at the exciting frequency will flow, which lead to large oscillating currents and hence high harmonic voltage. For the parallel resonance frequency the impedance is very high and when excited from a source at this frequency, a high circulating current will flow in the capacitance-inductance loop [James, K.P., 1994]. Harmonic Resonance occurs when the capacitor reactance and the system reactance are equal. These currents will result in greater voltage distortion. This provides a higher voltage across the capacitor and potentially harmful currents through all capacitor equipment. Harmonic resonance may occur at any frequency but the 5-th, 7-th are the frequencies with most concerned]. Some indicators of resonance are overheating, frequent circuit breaker tripping, unexplained fuse operation, capacitor failure, electronic equipment malfunction, flicking lights and telephone interference.

Nowadays, a number of methods have been proposed to address this phenomenon. One conventional method is the application of **LC** passive filter. However, LC passive filter has disadvantages: The designing form is large and weight to filter low frequency harmonic current order. The LC filters which to filter harmonic current needs specific value of LC for each order harmonic. Beside this, The LC filter has a problem formulation due to the system impedance variation and resonance condition. The other method in reducing harmonic is Active Power Filter (AFP).

1.2. Statement of the Problem

Power quality problem causes equipment malfunction, data distortion, transformer and motor insulation failure, voltage drops in nodes, overheating of neutral buses, tripping of circuit breakers, and solid-state component breakdown. Those are also cases at MAA-Garment as interview made with engineers in the industries indicates that there are problems related to number of power quality problems such as; Expensive Machines and inverters have been damaged, especially harmonic distortion due to parallel resonance frequency produced by capacitor bank of MAA-Garment. Therefore, due to high reinstallation or replacement costs of the above mentioned equipment's the remedies for mentioned power quality problem solutions was proposed in this research project.

1.3 Background of MAA-Garment Spinning Factory

MAA-garment has a total of six transformers. Out of six, four each rated with 800 KVA found in spinning department, one 800KVA transformer was found in garment department and one additional 1200KVA was exist in dying department. The Company receives 15KV from Mekelle branch EEPCO (Ethiopian Electric Power Corporation) and step down it to 0.4KV by mentioned transformers. All transformers are *Delta-Star connected transformers. There are different machines in the company rated with different voltage levels.*

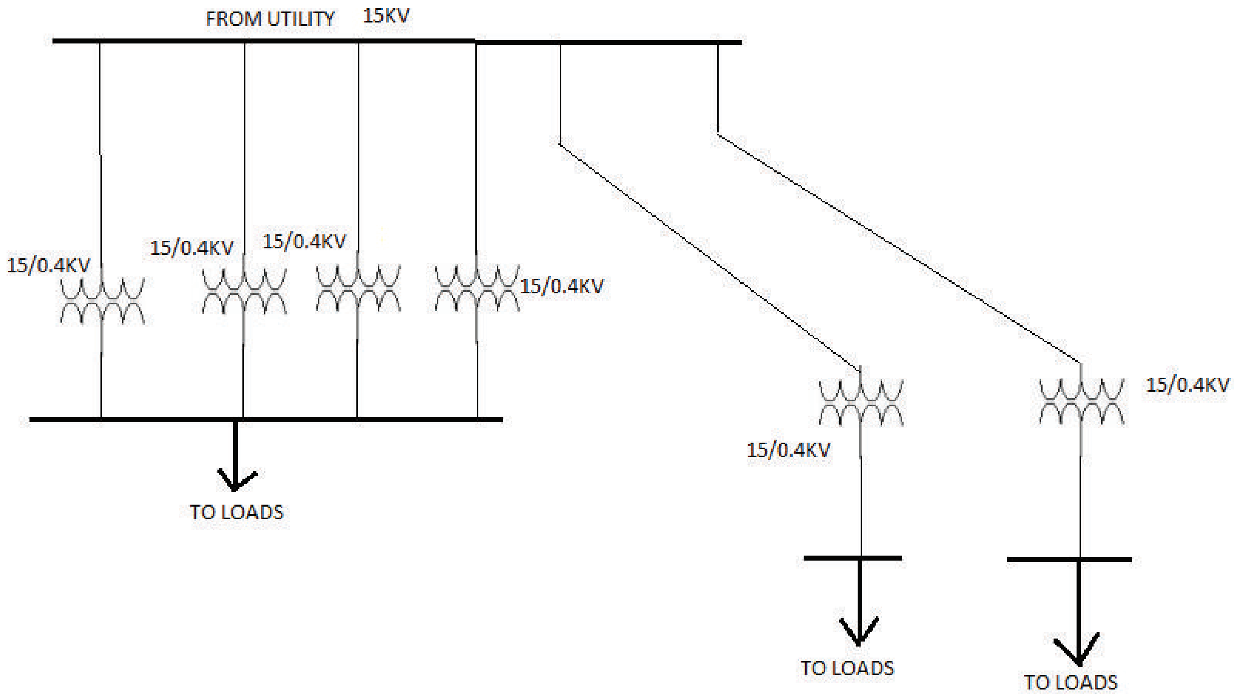

Figure1.power distribution of MAA-Garment

2. DISCRIPTION OF METHOD AND METHODOLOGY

2.1. Methodology for computing power quality problems could be

To come up on the real output of this research project; the existing system data of MAA-Garment such as; power rating of the substation, power rating of each department, the line length from the utilities substation up to each department sub distribution board (SDB), its length from SDB to load, the types of conductor, standard circuit protective rating in ohm, load type other necessary data was collected and hence factories power distribution system was modelled by converting all parameters into per unit values so that to perform power quality specifically harmonic problem analysis's.To find out the total harmonic distortion and harmonic order the short circuit MVA method was implemented so that to reduce errors occurs in power system components due to large numbers of transformers and so many mathematical hand calculations. The two common short circuits KVA's are;

1. **KVAs in series**. The total KVAs in series is the inverse sum of all series KVAs.
2. **KVAs in parallel**. The total KVAs in parallel is the arithmetic sum of all parallel KVAs in parallel. Therefore, since MAA-Garment network is connected series parallel both methods was applied so that come up on the total short circuit KVA of the factory.

***Short Circuit KVA calculation of MAA-Garment using* MVA reduction method**

By considering the impedance between each section as 'C' with subscript 1,2……9 and considering KVAs series and parallel calculation procedures for the calculated impedance of each sections as given in the table. See last page. For incoming line C1 having; 100 MVA as S_{Base} ;

$$R= 2.9684\Omega$$

$$X=9.010119\Omega$$

$$Z= \sqrt{(R^2+X^2)} =9.486\Omega$$

$$\text{Then MVAshC1}=\frac{KV^2}{z}=15^2/9.486=23.719\text{KVA}$$

2. for the transformers at spinning T1:%Z=4.3%

MVAshT1=800/%Z=800/0.043=18604.651KVA

MVAshT2=800/%Z=18604.651KVA

MVAshT3=800/%Z=18604.651KVA

MVAshT4=800/%Z= 18604.651KVA

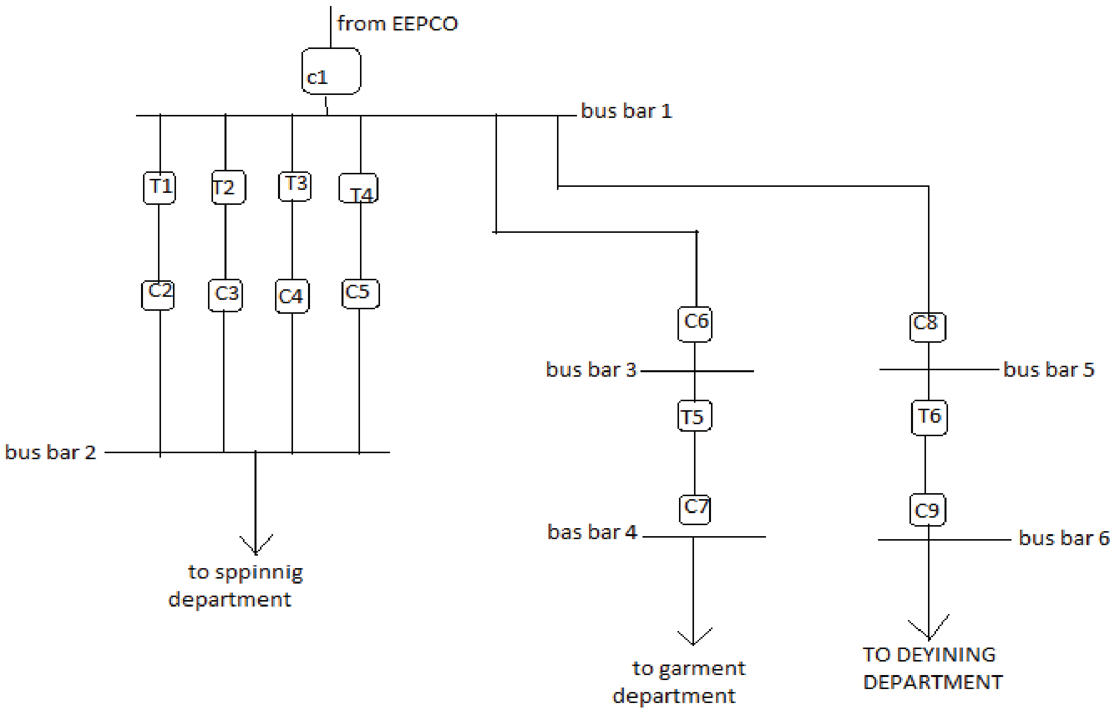

Fig 2.1 Impedance diagram of MAA-Garment

Performing same method for all departments the total short circuit KVA of the company was:

KVA_{SCT} = 1814.96 KVA and

The maximum demand KVA is (5*0.8 + 1.2)KVA= 5.2KVA_D

Where;

5*0.8- means the per unit value of five transformer having 800KVA each

1.2 – per unit value of 1200KVA transformer

Then the ratio of short circuit current to maximum demand current is or the ratio at the entrance PCC of MAA garment.

$$\frac{I_{SH}}{I_L} = \frac{KVA\ sc}{KVAD} = \frac{1814.96}{5.2} = 349.03$$

Now the ratio of the short circuit to maximum demand at each distributionboard is done as follow:
First divide the total short circuitratio in each SDB according to the rating of the transformers
I.e. dividing the short circuit ratio in to six transformers;

$$.\frac{349.03}{6} = 53.7$$

Short circuit ratio of SDB-1: Havingfour transformers with rating of each 800 KVA. Thus, total rating of 3200 KVA at spinning department. Which means the ratio at spinning department could be;
=53.7*4=214.76
Short circuit KVA of SDB-2(Garment department): For a transformer with rating of 800 KVA
$I_{sh/}\ I_L$ =1*53.7=53.7

Short circuit KVA of SDB-3: has 1 transformer with rating of 1200 KVA
$I_{sh/}\ I_L$ =1.5*53.7=80.55

Table 2.1: Ratio of short circuit to demand current

SDB	$I_{sh/}\ I_L$
SDB-1(spinning)	214.76
SDB-2(garment)	53.7
SDB-3(dying)	80.55

Having these values the researcher has compered the harmonic order at each department with IEEE standards and achieved the following assumptions.

- At Spinning department the current distortion is 12 ....taking harmonic order <11
- At Garmenting department the current distortion is 10.............taking harmonic order <11
- At dying department the current distortion is 10 .... taking harmonic order <11

But, it is clear that in this approach since the effect of power factor capacitor is not considered. Therefore the overall mitigation of harmonic distortion with the consideration of capacitor effect has been discussed as follows:

2.2 MITIGATION OF POWER SYSTEM HARMONICS

To overcome the enormous amount of harmonic current flowing from the load towards the source a series reactor is needed to block it so that control the overall system from damaging and malfunctioning. This series reactor should be selected with power frequency voltage drop and harmonic voltage distortion.
The objectives of the filter design are as follows:
1. Provide the required VARs for the system.
2. Assure that the filter is a very low impedance shunt at critical characteristic harmonic frequencies of the path for the predominant harmonic currents or,
3. Tune the filter branch to be inductive so that the harmonic currents injected in to the system are de amplified by the presence of the filter capacitor bank.

When designing or applying a harmonic filter, the question that comes to the mind of many is; what harmonic or frequency should be the harmonic filter bank is tuned too? To answer this question, it should know that why the filters are being installed in the first place. Harmonic filters are generally installed to achieve one of the following objectives:

- Capacitors are required to improve power factor, and possible system interaction may occur with the installation of a plain capacitor bank.
- Permissible distortion limits of the local utility or IEEE-519 are exceeded, and filters are required to reduce them.
- A combination of 1 and 2 above, whereby capacitors are required to improve power factor and with the addition of the capacitors, permissible distortion limits are exceeded. The main concern in this research is to compensate the harmonic current which exceeds the maximum predetermined value due to the presence of capacitor banks at the named industry. Relocating capacitors changes the source-to-

capacitor inductive reactance thus avoiding parallel resonance with the supply. Varying the reactive power output of a capacitor bank will alter the resonant frequency and hence the system harmonic distortion orders.

Capacitors can be designed to trap a certain harmonic by employing a tuning reactor whose inductive reactance is equal to the capacitive reactance of the capacitor at the tuned frequency. Parallel resonance involving a capacitor and a source inductance is achieved when

$$X_{IN} = X_{Cn}$$

The filter impedance is calculated as:

$$Z_f = Z_L + Z_C$$

$$Where; Z_L = Z_C$$ .... At resonance frequency

If this number, resonance frequency, is close to the harmonic order present in one of the harmonic loads, even small harmonic current can give very high and undesirable harmonic voltage.

At resonance the series resonant circuit appears purely resistive. Below resonance it looks capacitive and above resonance it appears inductive. In addition current is maximum at resonance due minimum impedances.

Thus the resonant frequency will be calculated as;

$$X_L = X_C \Rightarrow 2\pi fL = \frac{1}{2\pi fC}$$

$$\Leftrightarrow f_o = \frac{1}{2\pi\sqrt{L_f C}}$$

Therefore, the series reactor $L_f$will be designed to compensate the harmonic currents that exist due to capacitor bank at each departmentwill be determined by considering different parameters as follows;

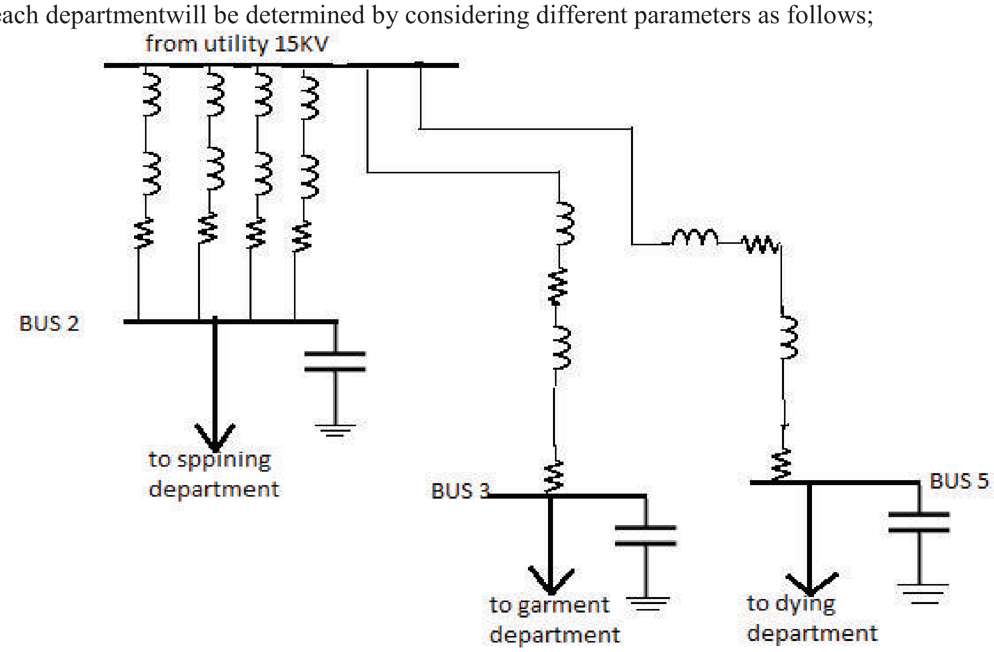

Figure 2.2 .Impedance representation of MAA-Garment including shunt capacitor

As shown in the fig there are six transformers with different ratings that supply to the loads of rated to step down 15kv to 0.4KV.Out of six four transformers supplies spinning department and the remaining two feeds Garmenting & Dying department independently. At entrance of each department there is 150 KVAR capacitor bank. Having these proponents are going to calculate the necessary parameters used to design the filter so that harmonic will be mitigated at each section. Let's start with Calculating parameters per phase for 150KVAR capacitor. At Spinning, Garment &Dying there are three150kVAR capacitor banks in three independent groups:

Working on a per phase basis, there is $\frac{150\text{kVAr}}{3} = 50KVAr / phase$.

The three-phase line to line value of voltage at the spinning is 400V, with

; $V_{R.m.s} = \frac{400\text{ V}}{\sqrt{3}} = 230.92\text{ V rms.}$

And; $X_c = \frac{V^2}{Q} = \frac{230.922}{50} = 1.0667\,\Omega\text{ per phase}$;

Therefore, for a power system frequency of 50Hz,

. $C = \frac{1}{2\pi f X_C} = 795.76\mu F$

For the remaining twocapacitor banks at Garment &Dyeing, the way is similar and the calculated values were displayed in table below.

Table 2.2: Summarized values of capacitor banks

Central Boards	Capacitor Banks	Per Phase Values
(spinning)CMDB-1	150kVAR	X_c =1.0667Ω
(garment)CMDB-2	150kVAR	X_c =1.0667 Ω
(dyeing)CMDB-3	150kVAR	X_c =1.0667 Ω

Designating the parallel resonant frequency by ω_o(rad/sec) or f_o (Hz) and equating the inductive and capacitive reactance**,** harmonic current components that are close to the parallel resonant frequency are amplified.

Higher order harmonic currents at the PCC are reduced because the capacitors are low impedance at these frequencies. Therefore, to come up with system resonant designing reactor so that to reduce harmonic current was necessitude;

The first step in analysing a power system harmonic is to get the data for the power available at the site. Now the system can be examined as follows:

Garment department

The garment department Transformer is rated:

800 kVA, 15kV/ 0.4 kV Y, 50Hz, Z=5.05%, 0.901 p.f

MVA_{SC}= 800kVA/0.0505=14MVA

For asymmetrical current, the ratio of system impedance=5.7 [IEEE]

At figure 2.3 which shows the power flow system of Garment department the power-factor-correction capacitor bank, that is connected on the 400 Volts bus can create a parallel resonance between the capacitors and the system source inductance.

For 2.4; the single-phase equivalent circuit of Garment departmentthe series resistance and reactance will be calculated as;

$$R_{sys} = \frac{kV_{LL}^2}{MVA_{sc}} \cdot \cos\left[\tan^{-1}\left(\frac{X}{R}\right)\right] =$$

15^2/14cos (tan-^{1}5.7) =2.76Ω

$$X_{sys} = \frac{kV_{LL}^2}{MVA_{sc}} \cdot \sin\left[\tan^{-1}\left(\frac{X}{R}\right)\right] ,=$$

15^2/14sin (tan-^{1}(5.7)) =15.8Ω

α=15/0.4=38 , impedance ratio when referring parameters

R'_{sys}=2.76/38^2=0.0019Ω; andX'_{sys}=15.8/38^2=0.01096Ω;

R_{tr}=0.029Ω,X_{tr}=0.129 Ω (calculated before

R_{tot}=R'_{sys}+R_{tr}=0.0.0019+0.029 ≈ 0.0309Ω;

X_{tot}=X'_{sys}+X_{tr}=0.01096+0.0129 ≈ 0.02218Ω

L_{tot}= X_{tot}/2πf= 70μH

<u>At bus 2**:**</u> when 150kVAR capacitor bank at CMDB-2 board is considered

$$X_c = \frac{1000.kV^2_{cap}}{kVAR_{cap}} = \frac{1000*(0.4)^2}{150}$$

=1.0667Ω; $C = \frac{1}{2.\pi.f.Xc} = \frac{1}{2\pi*50*1.0667} = 2984.16$ μF

$$f_0 = \frac{1}{2\pi\sqrt{Ltot.C}} = 1/2\pi * \sqrt{0.0000706*0.00298416}$$

=346.74Hz and h=346.74/50
=6.93HZ
The filter should tune to approximately 3% - 10%below the harmonic frequency by experience and trial [IEEE]. The tuning frequency is selected such that the tuned frequency of a ST filter should always be below the harmonic frequency at the maximum detuning, in order to prevent the filter from possible resonance.
The filter, comprising elements of RLC,is tuned to a harmonic frequency and forms alow impedance path for the harmonic current, hence protecting the supply system against the injection of harmonics. For h^{th}ST filter, asthe inductive and capacitive Impedances are equal at the tuned frequency;

$$\omega nL - \frac{1}{\omega nC} = 0$$

In series inductive capacitive circuits, when a state of resonance is reached (capacitive and inductive reactants equal), the two impedances cancel each other out and the total impedance drops to zero!

$$f_{resonant} = \frac{1}{2\pi\sqrt{LC}}$$

Where: Inductance (L) in Henrys and Capacitance (C) in Farads.
The filter impedance has a minimum value andis given by a small resistance. Theoretically, the tuned frequency should identically equal to that of the harmonic the filter intended to mitigate, so as to obtain the highest efficiency.
As it was discussed before, selecting **f_o=346.4Hz or 6.9^{th}**, that is 9% of the resonance frequency order harmonic, with
KV_{cap}= 0.4, KVAR $_{cap}$= 150 of garment as an example,

$$L_f = \frac{1}{C\cdot(2\pi f_{os})^2} = \frac{2\pi f\cdot X_c}{(2\pi f_{os})^2} = \frac{f\cdot 1000\left(kV_{cap}\right)^2}{2\pi\cdot(f_{os})^2\cdot kVAR_{cap}} =$$

$50*1000*(0.4)^2/2\pi\ (320)^2*150$
=0.00008289H
The new parallel combination is having resonant frequency**:**

$$f_o = \frac{1}{2\pi\sqrt{\left[(L_{tot}+L_f).C\right]}}$$

With L_{tot}=70.6μH, we have L_f=0.00013538H, C=2984.16μF
f_o=1/2π $\sqrt{(0.0000706+0.00395)*0.0029846}$
=235.16HZ
Therefore, harmonic h due to additional

$$\mathrm{Lf} = \frac{f_0}{f} = \frac{235.16}{50} = 4.7$$ (Without $L_f$were 6.93)

It is clear from the above system that in the 150 KVAR case at garment; there exists a parallel resonant frequency $f_o$close to the 7^{th} harmonic.
For spinning department and Dying department, calculations are made in similar way and the results are shown in table.
Table 2.3.Variation of Parallel resonant frequency with and without resonant inductor

Capacitor Bank (KVAR)	C (μF)	L_f Added (μH)	Parallel resonant, fo (Hz)		Harmonic order (h)	
			Without L_f	With L_f	Without L_f	With L_f
150	2984.16	176.387	365	230	7.300	4.6
150	2984.16	135.38	346.5	235	6.930	4.7
150	2984.16	85	350.05	245	7.001	4.9

As it can be seen from the above table significant reduction for all the harmonic components in the system components is achieved with the addition of filters. Individual and Total Harmonic Distortion of current (THD) were not measured. But, the calculation carried out at this board indicates the existence of harmonic around 7.3^{th} order

Therefore, if the designed filter with an inductor of near 176.387μH value is implemented for it, its harmonic order can be lowered to 4.6 (i.e. below 5^{th}) from 7.3 orders. From this one can easily see that by using *designed filters*, resonance frequency below 5^{th} harmonic order can be obtained.

Generally, reactor designed to tune the capacitor to a frequency where no harmonic energy is expected. For obvious reasons, the most popular detuning frequency is near the fourth harmonic. 3-phase nonlinear loads will not generate current triple harmonic (3^{rd}, 9th.15th...etc).those types of loads generates typically 5^{th} and 7^{th} current harmonic and lesser 11^{th}, 13th and higher order.

Since a three phase system will normally not produce the 4^{th} harmonic, and the lowest harmonic associated with three phase equipment is the 5^{th} harmonic, the (LC) network will normally not be excited at this frequency.

3. Conclusion

Different types of calculations were performed on the real factories power networks based on the data's obtained by measurements and from name plates to detect power quality levels in MAA-Garment. As the calculated and simulated data indicates that, power quality problem of harmonics beyond fifth order appeared in all the three boards of MAA-Garment due to the presence of adjustable speed drives and large amount of capacitors. Due to this fact, the addition of inductive filter as a mitigating device is required for MAA-Garment since filter is one of the effective devices in reducing harmonic distortion level in a power system. The results obtained in the reduction of harmonic level after the addition of a designed filter in the three boards of MAA-Garment. Thus, significant reduction of harmonics is achieved with the addition of filters as the resonance frequency below 5^{th} order is obtained in all the three cases. Calculations carried at spinning did indicate the existence of harmonic content near to 7.3^{th} order. Therefore, if the designed filter around 176.38 μH is implemented for it; its harmonic content can be reduced to 4.07 from 7.3.

When viewed from the perspective of either the line or load side circuits, the combination of series reactor plus shunt elements, naturally tune the filter to a frequency near the fourth harmonic. Since there is normally no harmonic energy at this frequency, or even below the 5th harmonic, the filter can achieve its objective of removing harmonics, without concern for resonance conditions.

Moreover if the designed filters with their respective values were implemented for Garment and Dying boards to, where harmonic distortion was observed during the calculation, their harmonic distortion could be reduced to the corresponding values indicated in the table.

REFERENCE

[1]. MAA-Garment power system network, Mekelle city, Ethiopia

[2]. D.E. Steeper and R.P. Stradford, "Reactive compensation and harmonic suppression forindustrial power systems using thyristor converters," IEEE Trans. on IA, Vol. 12, No. 3,May/June 1976, pp. 232-254.

[3]. L.S. Czarnecki, "Effect of minor harmonics on the performance of resonant harmonicfilters in distribution systems," Proc. IEE, Electr. Pow. Appl., Vol. 144, No. 5,July/August 1995, pp. 349-356.

[4]. L. S. Czarnecki, "Common and Fixed-Poles Resonant Harmonic Filters," Europ. Trans. OnElectrical Power, ETEP Vol. 8, No. 5, Sept./Oct. 1998, pp. 345-351.

[5]. IEEE defined standard (IEEE Std. 1159, 1995),R. C. Dugan, M. F. McGranaghan, H. W. Beaty. Electric Power Systems QualityMcGraw-Hill, New York, 1996.

[6].Chih-Ju Chou, Chih-Wen Liu, June-Yown Lee, Kune-Da Lee, "Optimal Planning ofLarge Passive-Harmonic-Filters Set at High Voltage Level," IEEE Trans. On PowerSystems, Vol. 15, No. 1, February 2000, pp. 433-441.

[7]. J. Wu, J. C. Chiang, S. S. Jen, C. J. Liao, J. S. Jang, T. Y. Guo, "Investigation andmitigation of harmonic amplification problems caused by single-tuned filters," IEEETrans. On Power Delivery, Vol. 13, No. 3, July 1998, pp. 800-806.

[8]. W. Jewell, W. L. Miller, T. Casey, "Filtering Dispersed Harmonic Souces on Distribution," IEEE Trans. On Power Delivery, Vol. 15, No. 3, July 2000, pp. 1045-1051.

[9]. J. K. Phipps. "A Transfer Function Approach to Harmonic Filter Design" IEEEIndustry applications Magazine, March/April, 1997.

[10]. Kun-Ping Lin, Ming-Hoon Lin, Tung-Ping Lin, "An Advanced Computer Code forSingle-Tuned Harmonic Filter Design," IEEE Trans. On Industry Applications, Vol. 34,No. 4, July 1998, pp. 640-648.

[11]. M. F. McGranaghan, D. R. Mueller, "Designing Harmonic Filters for Adjustable-SpeedDrives to Comply with IEEE-519 Harmonic Limits," IEEE Trans. On Industry Applications, Vol. 35, No. 2, March/April 1999, pp. 312-318.

[12] S. M. Peeran, C. W. Cascadden, "Application, Design, and Specification of HarmonicFilters for Variable Frequency Drives," IEEE Trans. On Industry Applications, Vol. 31,No. 4, July/August 1995, pp. 841-847.

[13]: T. H. Ortmeyer, T. Hiyama, "Distribution System Harmonic Filter Planning," IEEE Trans.On Power Delivery, Vol. 11, No. 4, October 1996, pp. 2005-2012

Table 1: R, X and Z parameters for spinning

	Calculated parameters	R(Ω)	X(Ω)
Incoming line	L=10000m l=2.86810^{-2}h	2.968	9.01
Circuit breaker			0.15/phase
Bus bar 1	L=6m X=0.15Ω/m		0.9
Transformer 1		0.029	0.129
Transformer 2		0.029	0.129
Transformer 3		0.029	0.129
Transformer 4		0.029	0.129
Cable 1	A=800mm^2 L=15 I=0.000020117H	0.000318	0.00632
Cable 2	A=800mm^2	0.000318	0.00632
Cable 3	A=800mm^2	0.000318	0.00632
Cable 4	A=8000mm^2	0.000318	0.00632
Circuit breaker			0.15/ phase
Bus bar 2	L=3m X=0.15 Ω/m	negligible	0. 45

Table 2: R, X and Z parameters for garment

	Calculated parameters	R(Ω)	X(Ω)
Cable 6	L=60m l=0.02868803557 **ρ=1.7*10^{-8}** **A=10mm^2**	0.102	9.008
Circuit breaker			0.15
Bus bar 3	L=3m X=0.15mΩ/m		0.45
Transformer 5		0.029	0.129
Cable 7	L=25m **P=1.7*10^{-8}** l=0.00003612604 A=800mm^2	0.00053	0.01134
Circuit breaker			0.15
Bus bar 4	L=4 X=0.15m Ω/m		0.6

Table 3 R, X and Z parameters for dying department

	Calculated parameters	R(Ω)	X(Ω)
Cable 8	L=75m l=0.000158596085 A=10mm^2	0.1275	0.050
Circuit breaker			0.15/phase
Bus bar 1	L=1m X=0.15Ω/m		X=0.15Ω
Transformer 6		0.0021	0.009632
Cable 9	L=35m A=900mm^2 l=0.0000557H	0.00066	0.0175
Circuit breaker			0.15/ phase
Bus bar 2	L=3m X=0.15 Ω/m	negligible	0. 45

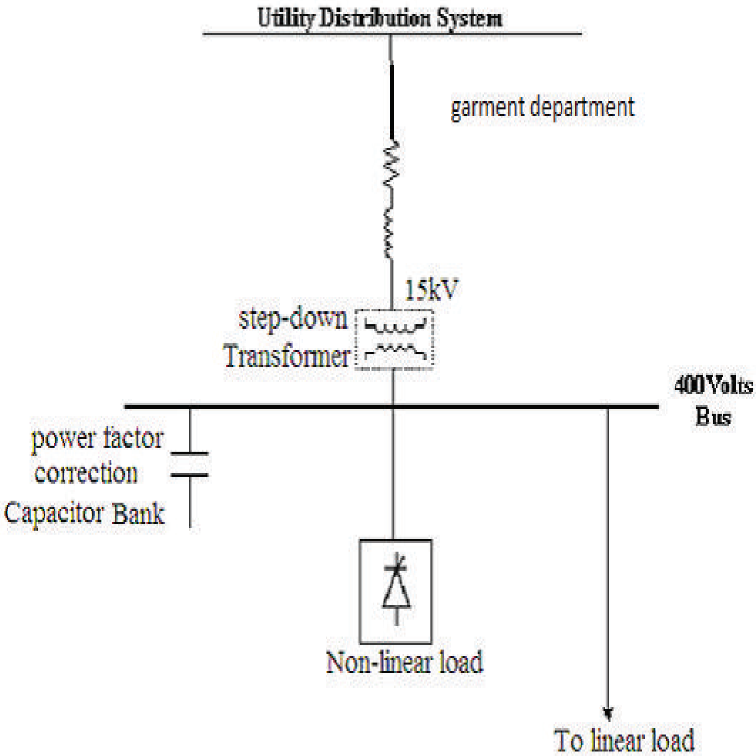

Fig.2.3: Garment department power flow system [1]

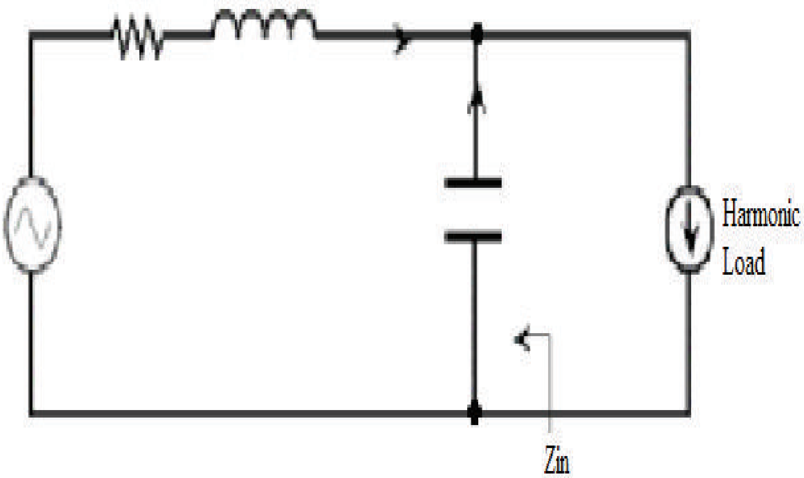

Fig.2.4:. Single-phase equivalent circuit of the garment [1]