POWER QUALITY ANALYSIS & POWER SYSTEM STUDY IN 11 KV HT SYSTEMS

S.Mathankumar[1], V.Agalya ,Member IEEE
Assistant Professor[1, 2] , Department of Electrical & Electronic Engineering[1, 2]
Vinayaka Mission's Kirupananda Variyar Engineering College[1 , 2] ,
Vinayaka Missions University, Salem[1, 2].
mathansub84@gmail.com[1], agalya.vetri@gmail.com[2]

***Abstract*- This paper mainly focuses on the causes for the series reactor failures and 11KV protection monitoring power system components. Failure causes the harmonics, transients and other power quality related problems. Power quality is the major concern of our modern industries and other consumers. Poor quality of power supply will affect the performance of customer equipments such as computers, microprocessors, adjustable speed drives, power electronic devices, etc.Due the production problem, the major industries get financial losses to the customers, loss of life in hospitals etc. The two major power quality disturbances are voltage sag and harmonic distortion. In the event of voltage sag due to insufficient energy supply, equipments may malfunction or trip. Another disturbance of Harmonics introduced by nonlinear loads can pollute the input supply to the sensitive equipments and be a cause for the connected equipments to malfunction. In this paper, a Power Quality Provider is proposed and modeled by simulation with the help of an external agencies meter.**

***Keywords* – Harmonics, Reactors, Capacitor bank, PSCAD/EMTDC Package, Phase and Earth relay**

I.INTRODUCTION

A Water Supply Company in Tirupur is operating a booster pumping station located near Perundurai, Erode. The pumping system has three huge size KBL pumps, which are driven by CGL HT motors of 11kV and 1800KW. For the incoming power supply of 11kV, the pumping station is provided with the separate designated TNEB 110kV sub-station. The TNEB sub-station has been enabled with dual incoming feeders, the first one is 110kV- feeder from Erode S/S and another is 110kV – feeder from Ingur S/S. The TNEB sub-station [4,5] has two power transformers (one transformer[1] is normally in service and the other one is stand-by) of 10 MVA and 110kV / 11kV from which they feed supply to the BPS. From TNEB the supply is fed to HT incoming panel through a 2-pole structure. From the HT panel, this supply is distributed through vacuum circuit breakers to three HT motors rated at 11kV 1800kW, HT power factor correction capacitors of 500KVAR each, and each of the motor pump and 2 of the auxiliary transformers (one standby) of 200KVA rating. Auxiliary transformers have been servicing various LT loads. In the usual 24x7 operations, MWUL normally operate only one motor continuously and operate the second motor if required. At present, the second motor is being run twice a week. The motor power circuit[5] consists of a HT motor, driving the pump, coupled through a speed control device named as Fluid coupling, HT capacitor bank with current limiting reactors for power factor correction and FCMA neutral soft starter to regulate the starting current to HT motor. HT panel incomer is provided with Earth fault, over current and under voltage protections and the HT motors are provided with motor protection relays which serve for many protections related to the motor. As per the company, the failure of the current limiting series reactors had taken place repeatedly 3 to 4times with in the short time of 3 / 4 days. After heating the same in oven, the Customers had been changing the spare reactors or rewound reactors. The failure takes place only when the second motor is getting connected to the system parallel with the first motor which is already running. An apparent failure takes place randomly at any of the phases. Already working motor's (power factor) pf capacitor reactor failures are noticed in the incoming motor set capacitor, current limiting reactors

Physical inspection of the reactors available at the site indicated only inter-turn flashovers. There might be flashover to earth as suggested by the photographs of the badly charred reactors (since such a fault will result in large magnitude of current). When the failure had taken place in the last instant, there was a transformer tripping with Buchholz relay operation. Subsequently, the transformer has been isolated and removed, and has been taken to the manufacturer for investigation and repair. The photographs of the opened up transformer at the manufacturer's site indicates that some of the LT coils have come out of the position along with their clamps and the bolts indicating high current flow through the windings.

This paper is very useful in the EHV / HV systems where huge capacity loads are switched ON / OFF intermittently. This project covers the load flow system study and suggests the proposed methods for Power

Transformer[4] and protection of other power system elements.

The broad study covers the following areas:

- Load flow analysis
- Short circuit study
- Relay settings review and co-ordination
- Evaluation of earthing and grounding system
- Electromagnetic transient studies and conclusions
- Observations during physical inspection of the reactors

.

II.CONVENTIONAL METHODS

TWSSP company is operating a booster pumping station (BPS) located near Perundurai, Erode with high power HT motors along with their power factor correction capacitor circuits. These circuits are with current limiting reactors. The pumping operation normally consists of single pump operation, but occasionally operates with two pumps. It is noticed that, there were series of failures in the current limiting reactors [16] during the starting of the second pump; as a result it had affected the two pumps operation. This paper is mainly taken up to find out the root cause for the failure as well as protection methods for reactors during the two pumps operation. In Conventional Method, 0.2 % Reactor and Normal Inverse type relay for load side protection are used.

a). Drawbacks: (i). Notwithstanding the high starting current of the circuit.(ii). Failure of the reactor may lead to major system failure.

Fig.2. Existing Current Limiting Reactor

III. PROPOSED METHOD

The block diagram showing the SLD of 11 KV up to Motor.

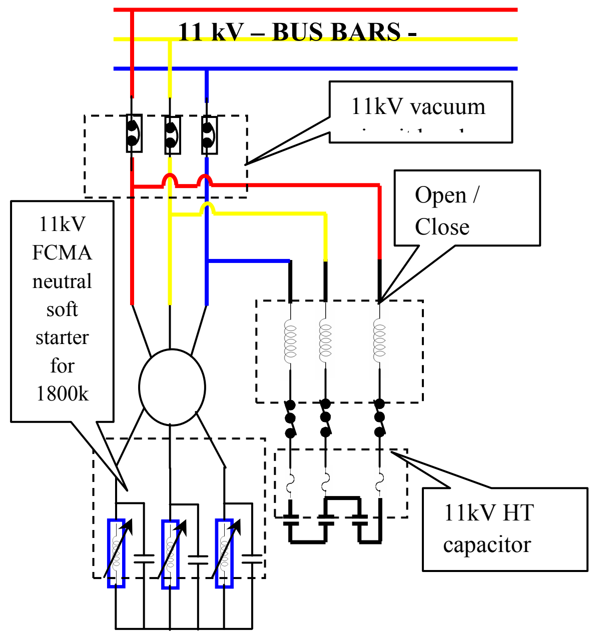


Fig.3. Block Diagram of the 11 KV Systems

A. Block Diagram Explanation

To study the single line diagram (SLD) for the system of MWUL, as per the data available from the customer, Perform load flow analysis [2] to determine the equipment adequacy of the existing system and the short circuit studies (determine the fault level for three phase and single line to ground fault and determine the adequacy of the fault rating of the existing system)

a. Operation:

To review the present relay settings of MWUL and to give the observations and recommendations on the same have to evaluate the earthing and grounding system in 110 / 11 kV switch yard. To perform the EMTP related switching transient studies and to determine the over voltages / over the recordings indicated increase in the Voltage, and Current THD values a significant level at random intervals. It was also noted that the most predominant of the harmonics is the 13th harmonic[6,10]. Based on the above findings and further analysis of the electrical system, along with the existing current limiting reactor of value L and power factor correction capacitor of value C (for both single motor operation and two motor operation) was undertaken to find out the possible resonance situation taking place due to the harmonic frequencies. The analysis indicated series resonance (resulting into minimum impedance) condition taking place at harmonic number of 12.92. This is a close enough frequency to the predominant (13th) harmonic [6] noticed during the long time parameter measurements. Considering the above, it is recommended to shift the occurrence of resonance situation to a higher frequency to avoid the problem of current amplification under high harmonic level condition.

B. Scope of work

The above can be achieved by either increasing the reactor value or by decreasing the Capacitor value. The simple means of achieving the reduction of the value capacitors is by reconnecting the existing power factor correction capacitors (connected in delta) to star connection. It is also found that the above reconnection results in the reduction of overall operating power factor from the existing recorded value of 0.98 to 0.92, which is still above the minimum value of power factor[13] to be maintained of 0.9 hence, it can be considered for implementation. To present the conclusions comprehensively, and the probable cause(s) regarding the failure of the reactors suggest the following remedial measures.

a. Load flow analysis:

One of the most common computational procedures used in power system analysis is the load flow calculation. The planning, design and operation of power systems require such calculations to analyze [13] the steady state performance of the power system under various operating conditions, and to study the effects of changes in equipment configuration. The outcome of Load flow analysis provides information about;

- Component or circuit loading.
- Steady state bus voltages.
- Real and Reactive power flows.
- Transformers tap settings.
- System losses.
- Performance under emergency conditions.

The load flow[1] model is also the basis for several other types of studies, such as short circuit, stability, motor starting, and harmonic studies. The load flow model supplies the network data, and an initial steady state condition for these studies. Load flow analysis has been carried out based on the data available from the customer. The developed load flow model is solved by Newton Raphson method. The study is conducted to determine the adequacy of the existing condition of the system. During the analysis it is observed that neither of the bus voltages have crossed their limits, nor the system need any voltage compensation. All the components/Accessories connected in the system network, have proved its adequacy. No component / accessory to be removed from the system network.

b. Short circuit study:

Short circuit analysis is another important power system study[11] to be carried out. The short-circuit studies are being conducted to determine the fault currents and fault MVA levels in the system, and for various other faults at different locations throughout the system. The proper selection of the circuit breakers depends on the immediate flow of current after the fault of the interruption current. In addition, the results of the short circuit studies are used to determine the settings of relays, which control the circuit breakers. The model developed for the load flow analysis can also be used to carry out the short circuit analysis.

IV. RELAY SETTINGS REVIEW AND CO-ORDINATION

The data of present relay settings have been collected and subsequently reviewed. Phase to Ground fault & Single line to Ground fault are created at a motor terminal of motor – 1 i.e., at Bus – 12 (running motor) with minimum fault condition. The present settings for Phase current and Earth current of MWUL along with the suggested settings;

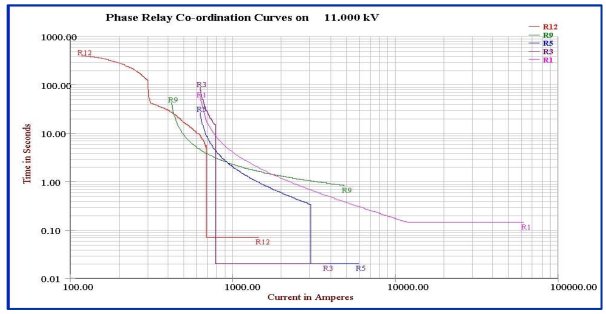


Fig. 4.a. Phase relay curves for present settings

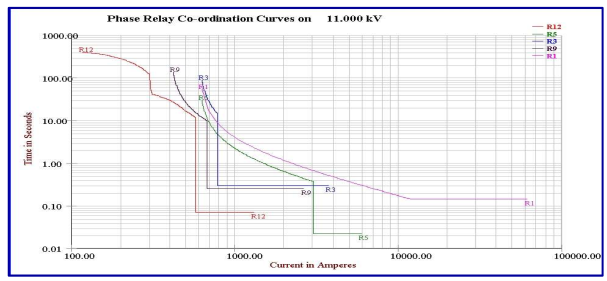


Fig. 4.b. Phase relay curves for suggested settings

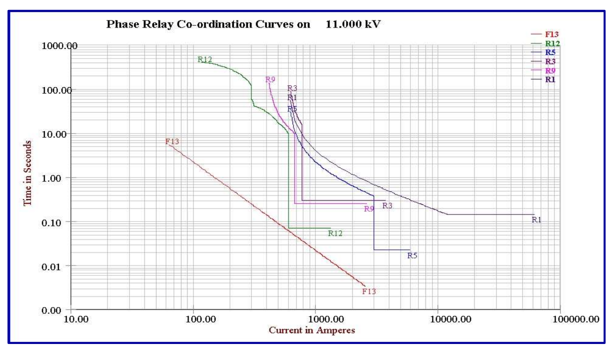


Fig. 4.c. Phase relay curves for suggested settings with 11 kV fuse

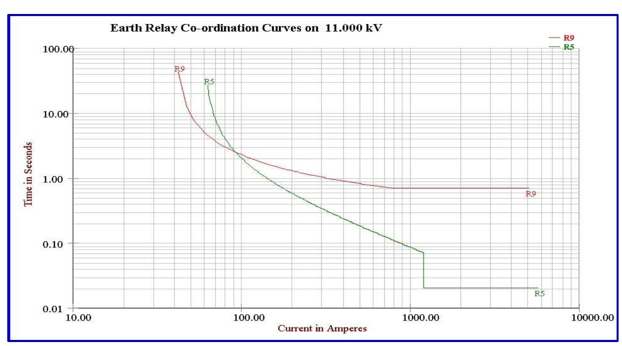


Fig. 4.d. Earth relay curves for present settings

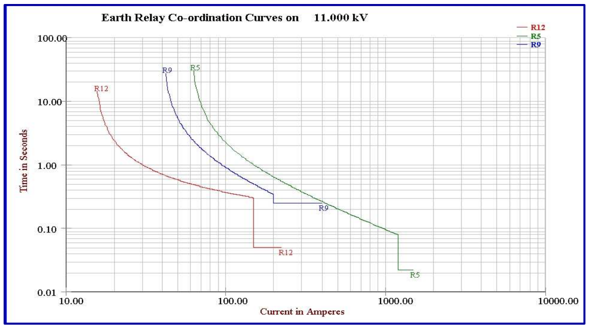


Fig. 4.e. Earth relay curves for suggested settings

A. Observations

(a). Phase relay settings:

For motor protection relay R12, the short circuit instantaneous time has been reduced to four times taking care of a motor starting current. For main incomer Relay R9 is recommended with new relay with a Very Inverse Characteristic and settings of the same is provided in table 5.1. It is better to provide instantaneous time delay element at R3 relay. Since, it is observed from the exhibit 5.1 that the relay is tripping instantaneously at 780 Amps which interrupts the supply to MWUL.

(b). Earth relay settings:

A CBCT is recommended for motor with CT ratio 150/5 to protect from SLG faults since present setting of the motor relay is provided with residual earth fault protection. For main incomer, Relay R9 is recommended with a new relay setting with very inverse characteristic settings of the same are provided in table 5.2.

V. SIMULATION STUDY

Under the present scope of work, to find out reasons for the failure of the current limiting series reactors, a transient switching study has been performed by using PSCAD/EMTDC package and considered for the simulation study provided.

A. Description

When a capacitor bank is energized, the bank and the network are subjected to transient voltages and currents. The severity of the effect is determined by the size of the capacitor and the network impendence.

The worst case occurs when a capacitor bank is energized close to a bank that is already connected. The inrush current into the newly connected bank is determined by the size of the capacitor bank and the inductance between the two banks. The frequency of the inrush current is determined by the combination of inductance of the energizing circuit and the capacitance of the banks. In installations without the current limiting reactors, the inductance between the banks will be only few micro-Henries and a peak current of more than 150 times of nominal current, at a frequency of more than 8 kHz can be expected. Capacitor standards such as IEC 60871 state that, capacitors should be able to withstand inrush currents up to 100 times nominal. The standards also suggest a lower value for inrush current if the capacitor banks are switched frequently.

B. Electromagnetic Transient Studies

Based on the sequence of events provided by the client, two case studies have been considered for the simulation viz,

- This case (Case 1) considers starting of the one motor. It is assumed that other motor is out of service. The switching instant is so selected such as the one motor is started when the energizing voltage is near its peak value (switch closed at 0.505 sec).
- In the second case (Case 2) it is assumed that one motor is already in service and the other motor is started at time equals to 0.505 sec. The resultant waveforms are shown in figures 5.1 to5. 9 considering existing value (0.2%) of series reactor.

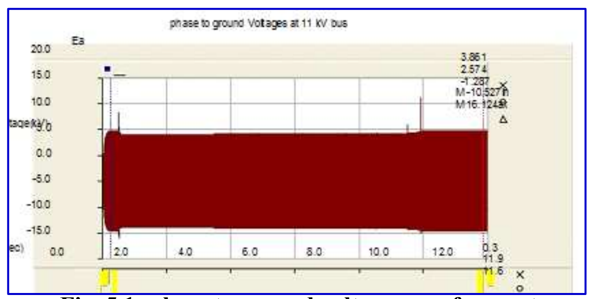


Fig .5.1: phase to ground voltage waveforms at 11 kV bus for case 1 from Table 5.1 with considering 0.2% series reactor.

The maximum and minimum phase to ground voltage observed for existing 0.2 % series reactor is **16.124 KV and -10.527 KV.**

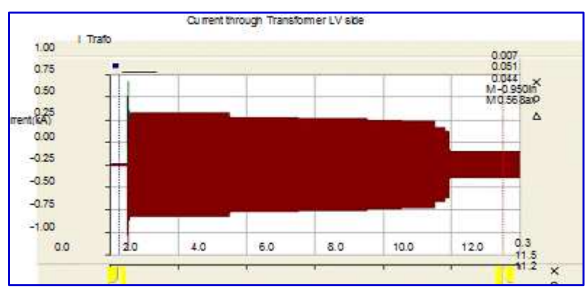


Fig. 5.2: Current through Transformer LV side for case 1 from Table 5.1 with considering 0.2% series reactor

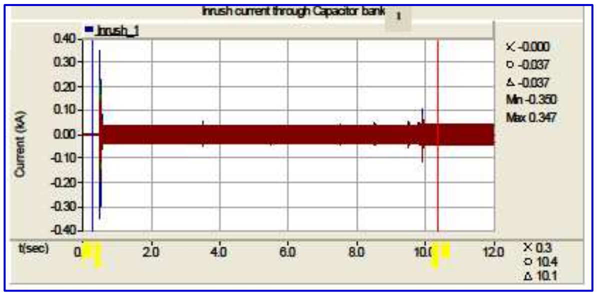


Fig. 5.3: The Inrush current is flowing through the series reactor for case 1 from Table 5.1 with considering 0.2% series reactor.

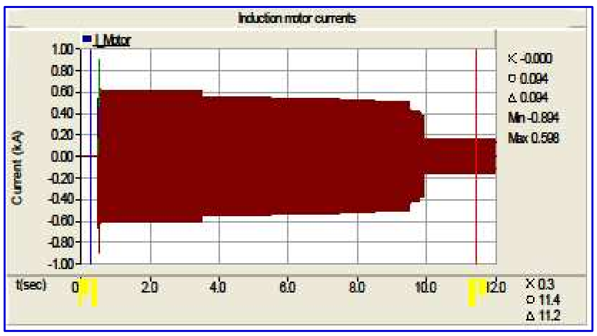


Fig. 5.4 : The currents drawn by induction motor for case 1 from Table 5.1 with considering 0.2% series reactor.

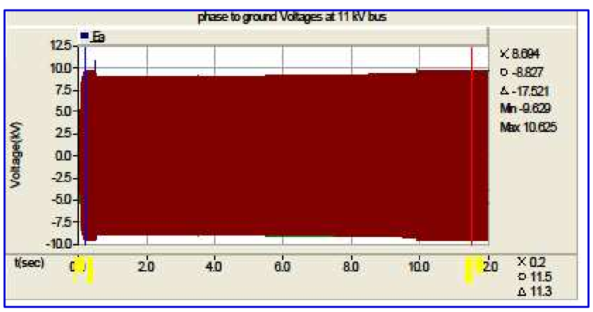


Fig. 5.5: phase to ground voltage waveforms at 11 kV bus for case 2 from Table 5.1 with considering 0.2% series reactor.

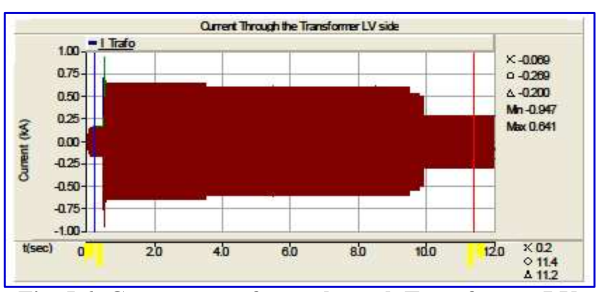


Fig. 5.6: Current waveforms through Transformer LV side for case 2 from Table 5.1with considering 0.2% series reactor.

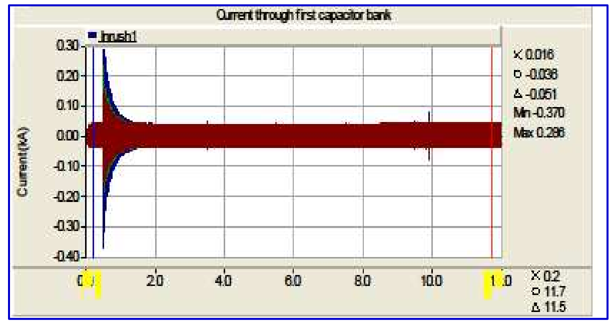


Fig. 5 .7: The Inrush current is flowing through the first series reactor for case 2 from Table 5.1 with considering 0.2% series reactor

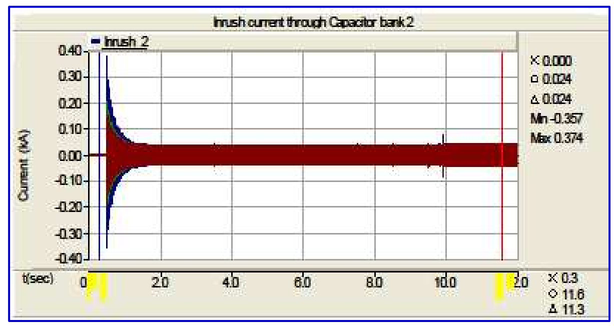


Fig. 5.8: The Inrush current is flowing through the second series reactor for case from Table 5.1 with considering 0.2% series reactor.

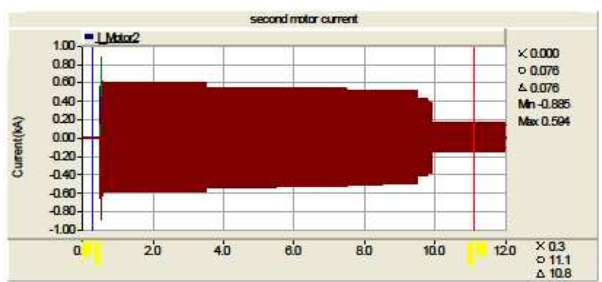


Fig. 5.9: The currents drawn by second induction motor for case 2 from Table 5.1 with considering 0.2% series reactor.

From the above results the transient inrush current drawn by capacitor banks are very high as compared to their rated currents and they damp out slowly for back to back switching of capacitor banks (Case 2) as compared to the figure 5.3 (case 1). Hence, it is considered that the existing selected value (0.2%) for series reactor appears to be low. So as to arrive at amore optimum value of the reactor to limit the transient currents, the EMT studies were conducted for 5% reactor value. The selection procedure for the L and C are as described as follows for both 0.02% and 0.5 %. The capacitor units of 500 kVAr, 11 kV deltas connected are used in electrical system of plant under study.

The voltage across the capacitor is system voltage plus other voltages as follows;

- Induced voltage occurred by reactor when electric current is flowing it.
- Voltage occurred by harmonic current flowing to capacitor unit.

Calculation to choose capacitor units suitable for detuned filter is described in following two steps.

Step 1: Induced voltage calculation

We assign *Un*, *Uc* and *p* to be system voltage, the voltage across the capacitor after series reactor installation and ratio between impedance of reactor and impedance of capacitor respectively. When the current is passing through reactor, *Uc* = *Un* / (1 - %*p*). When the voltage (Uc) is higher, reactive power of capacitor (*Qc*) = *Nc* / (1 - %*p*) which Nc is reactive power of capacitor at system voltage or nominal voltage.

Step 2: Calculation Harmonic current flowing to capacitor

Due to the presence of the harmonics, the RMS value of the currents through the reactor and the capacitor increases from the rated 100 % value to a marginally higher value. The actual calculations require some more details. Presently a 10 % rise may be assumed.

The capacitance value C is calculated from step 1 by use of Uc and Qc. C is computed as 4.38µF for the case of 0.2% reactor and 4.17 µF for the case of 5% (this matches within -5%tolerance of the selected capacitor bank and Inductance of series reactor is also computed as 4.62 mH for the case of 0.2 % reactor and 0.122 H(considering 5% of Xc instead of the 0.2% used in the existing system).With these calculated new values of L and C considering 5% reactor, , the simulation of two case studies described earlier have been carried out and corresponding resultant waveforms are shown in figures 5.10 to 5.18.

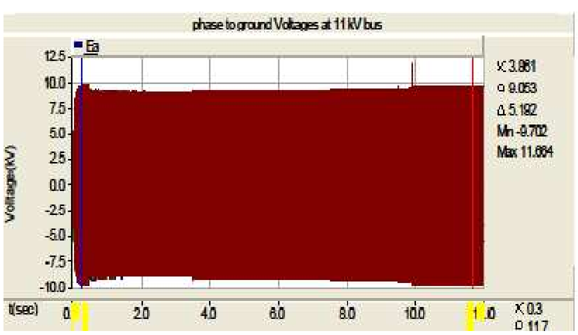


Fig. 5.10: phase to ground voltage waveforms at 11 kV bus for case 1 from Table 5.1 with considering 5% series reactor.

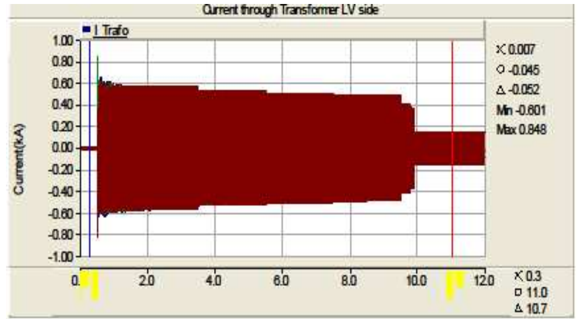


Fig 5. 11: Current through Transformer LV side for case 1 from Table 5.1 with considering 5% series reactor.

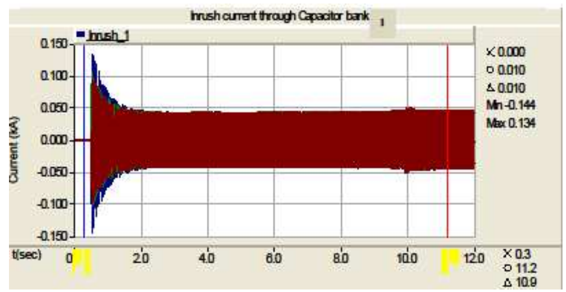


Fig. 5.12: The Inrush current is flowing through the series reactor for case 1 from Table 5.1 with considering 5% series reactor.

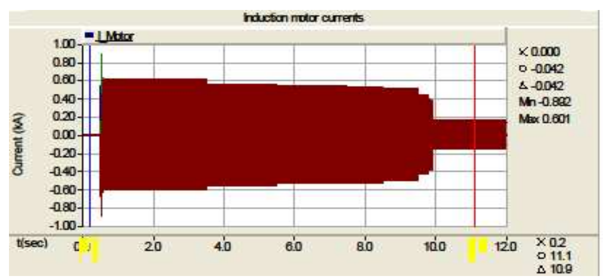


Fig. 5.13: The currents drawn by induction motor for case 1 from Table 5.1 with considering 5% series reactor.

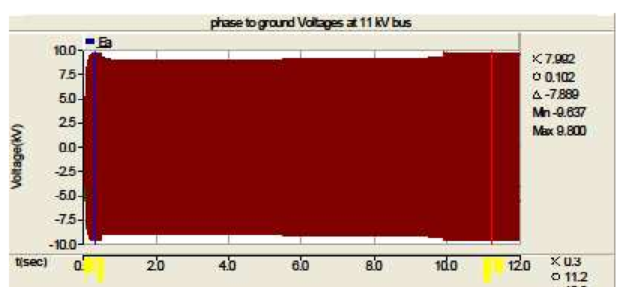


Figure 5.14: phase to ground voltage waveforms at 11 kV bus for case 2 from Table 5.1 with considering 5% series reactor.

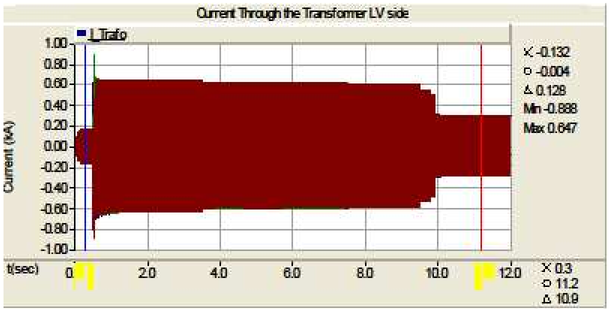


Figure 5.15: Current waveforms through Transformer LV side for case 2 from Table7.1 with considering 5% series reactor.

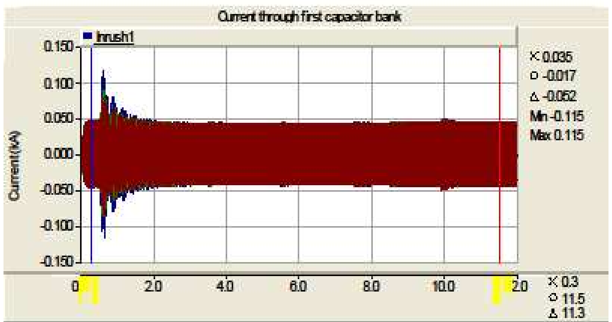
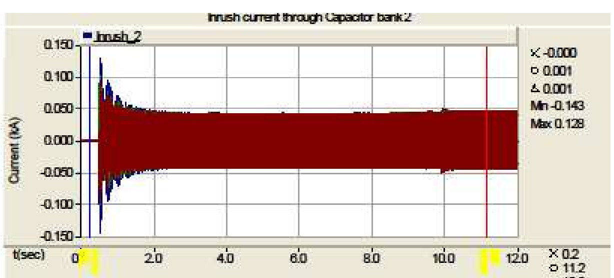


Fig 5.16: The Inrush current is flowing through the first series reactor for case 2 from Table 5.1 with considering 5% series reactor



The comparison of results for both configurations, observations are made and presented in Table 5.1 for ready reference.

Case	Description	With 0.2% series reactor		With 5% series reactor	
		Current (A)	Refer Fig	Current (A)	Refer Fig
1	Only one motor switching on at time of 0.5 sec, along with its terminal capacitor bank	347	Fig 5.3	134	Fig 5.12
2	Second motor switching on at time of 0.5 sec, along with its terminal capacitor bank when the first motor in operation	374	Fig 5.7 & 5.8	128	Fig 5.16 & 5.17

Table 5.1 Results of EMTP Studies for MWUL system study

The above studies show significantly large currents as compared to the rated currents of 26 A, especially for the case of 0.2 % series reactor. Also it is seen that except for the case of 0.2 % reactor and single motor operation, in the other three cases, the transient reactor current damps down slowly, which requires careful design and consideration for the reactor. The appropriate transient current variation curves along with the worst case repetition of the starting cycles need to be forwarded to the prospective vendor of the new reactors.

C. Study of System Harmonics and Calculation of Maximum & Minimum Impedances at Harmonic Frequencies

Subsequent to the preliminary report submission and discussion with customer on 28th July and19 August 2010, it was decided to have continuous recording of the power system over a long-time (24 hrs or more). The recording given below under figure 5.4 a to 5.4 c indicates the random occurrence of high level of harmonics with predominant number being 13. Considering the occurrence of large harmonics in the supply system and further studies were conducted of the electrical system to check the possibility of the resonance condition setting in.

The result of the study indicated that at the harmonic number of 12.92, (646 Hz) the existing electrical power system with connected power factor capacitor and reactor experiences the series resonance condition providing a minimum impedance path of less than 0.2 Ohm (for one motor operation) and less than 0.1Ohm (for two motor operations). The above analysis was repeated for several of X / R ratio of the reactor considering additional cable resistance. From the above, it is clear that the existing system has the tendency to get into resonance condition when the predominant harmonics (13th) exceeds a certain level. The direct solution to this problem is to provide appropriate de-tuning filter circuit of appropriate harmonic number or rating. However, considering the randomness of the occurrence of the harmonic voltage, it is recommended to go for shifting the resonance condition– occurrence of minimum impedance by modifying the values of the reactor (L) and capacitor(C).

A simple and the most inexpensive method is to connect the power factor correction capacitors in star connection, instead of the existing delta connection, by which, the capacitor value ineffectively is reduced by a factor of 3. With this condition the resonant frequency is shifted to a value more than 22 in Exhibits 5.11 which is a safe value. Customer may consider going in for this option and overcoming the problem of current amplification experienced due to resonance. The other option is to use higher values of the reactor; calculations have been done for 0.5 %, 1%, 5% reactors; it is seen that with 5% reactor, there is hardly any resonance condition and with 1% and 0.5 % reactors, the series resonance conditions shift 5.6th and 8.2th harmonic number respectively. Hence it is seen that by having larger value of reactor, the resonance condition effectively shifts to lower frequencies and since the actual harmonic voltages noted at 5th, 7th and 9th harmonics are comparatively lower, so it can be operated without changing the existing capacitor connection from delta to star.

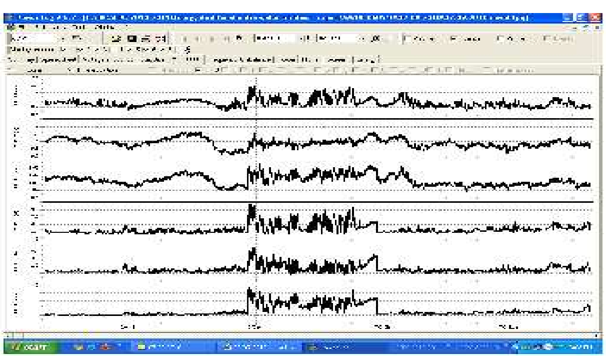


Fig 5.18: Voltage and Current Harmonics recorded showing Increased harmonic voltages and currents (THD)

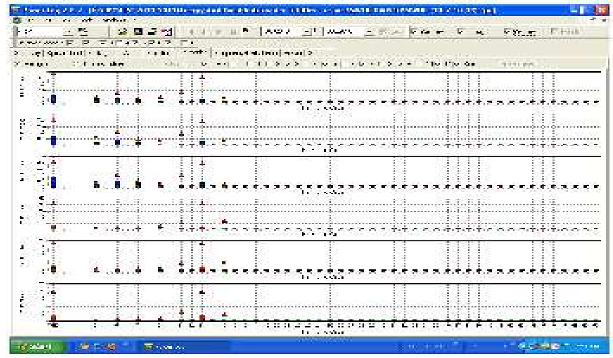


Fig 5.19: Voltage and current harmonic spectrum of the recordings done showing high level of 13th Harmonic voltages and Currents.

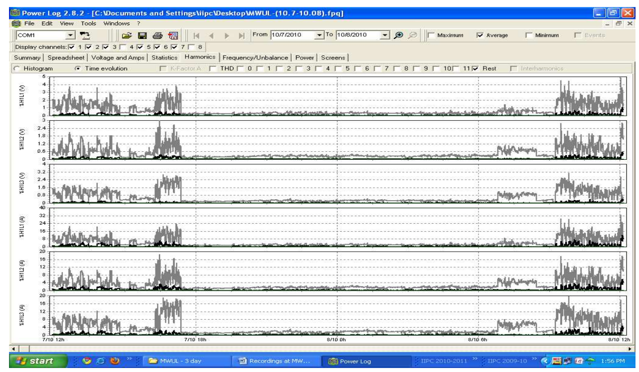


Fig. 5.20: Voltage and Current Harmonics recorded on 7/8 October 2010 showing increased harmonic voltages and currents (13th Harmonic) between 12 Noon to 5:45 PM and 9 AM to 12 Noon.

VI. CALCULATION OF THE POWER FACTOR OF OPERATION WITH THE SUGGESTED RECONNECTION OF POWER FACTOR CAPACITORS

This section provides the calculations for the power factor of operation when the pf compensation capacitors are reconnected in star as recommended in the earlier section to overcome the problem of 13th harmonic resonance when operating with 2% reactor. The following recording shows the maximum active power, reactive power and the corresponding power factor recorded at the maximum load condition (80 amperes load).

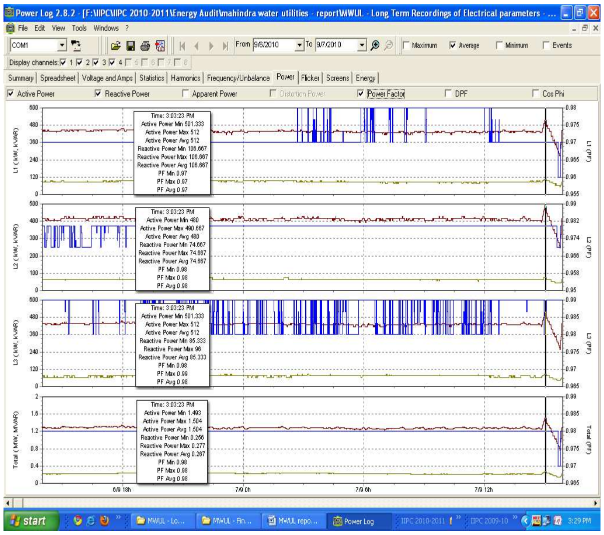


Fig. 6. Active & Reactive Power [With Respect To power factor]

VII. CONCLUSION

A conclusion has been arrived at after extensive deliberation of all the direct possibilities which might result in over voltage flash-over failure listed as follows;

1. Large capacitor banks which might have got included into the upstream supply system in the recent past which could induce larger switching over voltages; from the information received from MWUL no such supply system changes had taken place.

2. Extensive earthing integrity measurements were carried out as detailed in section 6 and the results of the measurements indicated a healthy earthing system.

3. Possibility of discrepancy of the closing contacts of a particular breaker which can result into over voltage possibilities during switching. This possibility is also unlikely and excluded as the switching breakers involved were different for the different switching instants when the failure had been reported.

4. In the EMTP studies conducted and as elaborated under section # 7, no major over voltage situations have been identified under the conditions of both single motor and two motor switching conditions.

Since the above direct over voltage possibilities are ruled out, the other possible indirect reasons are enumerated as follows;

1. Based on EMTP studies conducted for MWUL system described under section 7, it is seen that with the existing series reactor (0.2%), the magnitude of inrush current is significantly high especially for the case of second motor switching on when first motor is in operation. This operation, which is repeated couple of times a week, can result in the deterioration of the insulation levels of the reactors, and over a period of time results into their failures unless the same is designed to take up the very high transient currents. The wet atmospheric condition of December 2009 could have been the immediate specific reason for the inter-turn flashover. Hence, the solution for this situation is to provide the reactor which is designed to take the large transient conditions with the proper design of the conductors, core and insulation. The desired specification of the reactor is 5 % based on the visual observation of the existing failed reactors.

2. Based on the recording of the long time electrical parameter measurements, the presence of significant values of 13th harmonic voltages / currents have been identified at random intervals - maximum value of 4.2 % 13th harmonic voltage has been recorded at one instant . The resonance condition study has indicated that with 0.2 % reactor, the electrical system provides minimum impedance at 12.92th harmonic. Hence, the other strong reason for the failure of the reactor is the possible occurrence of the current getting amplified during the second motor starting when the minimum impedance presented is 50 % of the case with one motor operation.

3. With the alternate value of reactor (5%), the EMTP studies indicate maximum inrush current value of around 128 A (about 5 times to nominal current of capacitor). This is much less than the maximum inrush current of 374 A (about 15 times). The figure of 5% is a recommended value in the literature of similar systems to limit the inrush currents experienced by the capacitor and the reactor itself and hence the EMTP studies have been conducted for this value of reactor as detailed under section # 7.

4. It is seen that with 5% reactor, the chances of resonance is also not there and it is also elaborated. This is technically the correct solution.

5. However considering the large size of the 5% reactor, as compared to the panel mounted 0.2 % reactor, an intermediate value can be selected; e.g. 0.5 % and 1.0 %. In terms of the transient currents which are likely to flow, the transient currents will be lesser with larger inductor value. In addition, it has been calculated, that with 0.5 % reactor, the tuning frequency for minimum impedance is 8.2th harmonic and for the value for 1% reactor, it is 5.6. These are much safer than the existing situation of having harmonic number of 12.92 as the tuning frequency. The practicality of providing either 0.5 % or 1% or any other appropriate value of reactor can **be considered as a compromise solution.**

6. In case, providing higher values of the reactor is totally not practical due to space problems, the existing value of 0.2 % reactor should be replaced by a reactor manufactured by taking into consideration of the various transient conditions likely to experience. The specification given

under has to be followed thoroughly for the manufacture of the reactor.

7. Under this condition – i.e. retaining the existing value of reactor appropriately manufactured as per the specification - it is however necessary to shift the tuning frequency for minimum impedance, to higher value by reducing the capacitor value (instead of increasing the inductor value as suggested above) to overcome the possible current amplification . This can be achieved by connecting them in star instead of the existing delta connection. This is quite practical and safe at MWUL site, except that the total reactive power compensation supplied will be only one third of the existing kVAR provided. The Company may consider going for this option as a practical solution with the technical understanding that this is the least preferred option.

This proposed method is very useful in the High Voltage systems to maintain the Power factor and protect the sophisticated equipments from the power quality issues. Normally this method can be used at large capacity pumping stations, steel industries etc.., where huge capacity induction loads are present and to improve the power factor as per Electricity Board guidelines.

REFERENCES

1. Mays, J.L.; Vilcheck, W.S.; Harris, L.J.; Domitrovich, T.A. “Using fixed gear mounted power quality monitors to perform a power factor and harmonic analysis”, Industrial and Commercial Power Systems Technical Conference, 1998 IEEE, 1998 , pp.77 – 81.

2. Prasai, A.; Sastry, J.; Divan, D. “Dynamic Var / Harmonic Compensation with Inverter-Less Active Filters”, Industry Applications Society Annual Meeting, 2008. IAS '08. IEEE,2008, pp.1 – 6.

3. Kingston, R.; Baghzouz, Y. “Power factor and harmonic compensation in industrial power systems with nonlinear loads”, Industrial and Commercial Power Systems Technical Conference, 1994. Conference Record, Papers Presented at the 1994 Annual Meeting, 1994 IEEE, 1994, pp.235 – 239.

4. Schlabbach, J., “Improvement of power quality for 6-kV industrial power system with motor load”, Industrial Electronics, ISIE 2005. Proceedings of the IEEE International Symposium, Vol. 2, 2005, pp.815 – 820.

5. Xiaodong Liang; Ilochonwu, O., “Passive Harmonic Filter Design Scheme”, Industry Applications Magazine, IEEE , Vol. 17 , Issue - 5 , 2011 , pp. 36 - 44 .

6. Kurita, Y.; Ukai, H.; Nakamura, K.; Aoki, M.; Uehara, M. “Application of a commutation type reactor restricting 5th harmonic resonance in distribution power system”., Power System Technology, 2002. Proceedings. Vol. 3, 2002, pp.1923 – 1927.

7. Gutierrez, J.; Montano, J.C.; Castilla, M.; Lopez, A. “Power-quality improvement in reactive power control using FC-TCR circuits”, IECON 02, Industrial Electronics Society, IEEE 2002 28th Annual Conference, Vol. 2, 2002 , pp.880 – 885.

8. Chen Junling; Li Yaohua; Wang Ping; Gao Congzhe; Jiang Xinjian; Yin Zhizhu; Dong Zuyi , “A novel control method for a combined system using active power filter and static var compensator”, Electrical Machines and Systems (ICEMS), 2010 International Conference, pp.334 – 337.

9. Kocatepe, C. “The effects of reactors and capacitors connected to power systems on the harmonic load flow”, Electrotechnical Conference, 1996. MELECON '96., 8th Mediterranean,Vol.2,1996,pp.869 – 872.

10. Mertens, E.A.; Dias, L.F.S.; Fernandes, E.F.A.; Bonatto, B.D.; Abreu, J.P.G.; Arango, H. “Evaluation and trends of power quality indices in distribution system”, Electrical Power Quality and Utilisation, 2007. EPQU 2007. 9th International Conference,pp.1 – 6.

11. Morsi, W.G.; El-Hawary, M.E. “A new fuzzy-wavelet based representative quality power factor for stationary and nonstationary power quality disturbances”, Power & Energy Society General Meeting, 2009. PES '09. IEEE, pp. 1 - 7.

12. Yop Chung; Dong-Jun Won; Joong-Moon Kim; Seon-Ju Ahn; Seung-Il Moon; Jang-Cheol Seo; Jong-Woong Choe, “Development of power quality diagnosis system for power quality improvement”, Power Engineering Society General Meeting, 2003, IEEE ,Vol.2. pp 137 – 143.

13. Mohod, S.W.; Aware, M.V. “A STATCOM-Control Scheme for Grid Connected Wind Energy System for Power Quality Improvement”, Systems Journal, IEEE, Vol.4 , Issue – 3, 2010, pp. 346 – 352.

14. Yuvaraj, V.; Pratheep Raj, E.; Mowlidharan, A.; Thirugnanamoorthy, L. “Power quality improvement for grid connected wind energy system using FACTS device”, Nonlinear Dynamics and Synchronization (INDS) & 16th Int'l Symposium on Theoretical Electrical Engineering (ISTET), 2011 Joint 3rd Int'l Workshop, pp. 1 - 7.

15. Li Penghui; Zhao Lijie; Bai Haijun; Zhang Yanhua, “Power Quality Monitoring of Power System Based on Spectrum Analysis”, E-Product E-Service and E-

Entertainment (ICEEE), 2010 International Conference, pp.1 – 4.

16. Chanxia Zhu; Minqiang Hu; Zaijun Wu; Xiaobo Dou; Shanglin Zhao, "Design and realization of regional power quality monitoring system", Electric Utility Deregulation and Restructuring and Power Technologies, 2008. Third International Conference, pp.2023 – 2027.

17. Tesarova, M., "Analysis of voltage dips in power system - case of study", Power Tech, 2005 IEEE Russia, pp.1 – 5.

18. Willems, J., "Direct method for transient stability studies in power system analysis", Automatic Control, IEEE Transactions,Vol.16, Issue - 4, 1971, pp. 332 – 341.

19. Chenxi Lin; Tamayo, M.; Jiang, J.N., "An analysis of transient characteristics of interconnected wind power generation system with DFIG", Sustainable Energy Technologies (ICSET), 2010 IEEE International Conference, pp.1 – 6.

20. Jiang, J.; Zhang, B.H.; Hao, Z.G.; Yuan, Y.Y.; Bo, Z.Q.; Klimek, A., "Study on factors affecting the harmonics of large-scale rectification device in power grid", Universities Power Engineering Conference (UPEC), 45th International, 2010 , pp.1 – 5.

21. Shrestha, A.; Cox, R.W.; Salami, Z.; Anderson, J.; Parikh, P., "Using hardware and software studies to teach power-system modeling and analysis", Power & Energy Society General Meeting, 2009. PES '09. IEEE, pp. 1 – 6.

22. Nastac, L.; Wang, P.; Lascu, R.; Dilek, M.; Prica, M.; Kuloor, S., "Fault analysis study using modeling and simulation tools for distribution power systems", Power Symposium, Proceedings of the 37th Annual North American, 2005, pp.225 – 232.

23. Haque MH, Yam CM. "A simple method of solving the controlled load flow problem of a power system in the presence of UPFC", Electric Power Systems Research 2003, pp.55–62.