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Power Quality Analysis Including Dips and Swells

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Abstract

The increased requirements on supervision, control, and performance in modern power systems make power quality monitoring a common practice for utilities. Large databases are created and automatic processing of the data is required for fast and effective use of the available information. This paper is a treatment of the concerns being addressed especially as they relate to new technologies of energy control, energy conservation, and modern power conversion. This paper illustrates the dips and swells analysis in power system. The study is expected to yield recommendatory suggestions for specific usages and their merits and difficulties.

Introduction
Reliability and quality of power has become one of the most critical issues facing business today. For critical loads, such as transformers, motors, computer hardware components, instrumentation and control systems and protective devices, anything less than high quality power and reliability means possible equipment malfunction and system downtime. All the sources of electrical energy are basically designed on the consumption of balanced three phase loads at fundamental frequency (50 Hz). Therefore the performance of the equipments and system elements to other frequencies has not been given great importance.

Voltage Sags or Dips
A voltage dip is a short-term reduction in, or complete loss of, RMS voltage. It is specified in terms of duration and retained voltage, usually expressed as the percentage of nominal RMS voltage remaining at the lowest point during the dip. A

voltage dip means that the required energy is not being delivered to the load and this can have serious consequences depending on the type of load involved. Voltage sags - longer-term reductions in voltage – are usually caused by a deliberate reduction of voltage by the supplier to reduce the load at times of maximum demand or by an unusually weak supply in relation to the load. Voltage sags -- or dips which are the same thing -- are brief reductions in voltage, typically lasting from a cycle to a second or so, or tens of milliseconds to hundreds of milliseconds. Voltage swells are brief increases in voltage over the same time range. Voltage sags are caused by abrupt increases in loads such as short circuits or faults, motors starting, or electric heaters turning on, or they are caused by abrupt increases in source impedance, typically caused by a loose connection.

Voltage Swells

Voltage swells are almost always caused by an abrupt reduction in load on a circuit with a poor or damaged voltage regulator, although they can also be caused by a damaged or loose neutral connection. Voltage Swell is defined by IEEE 1159 as the increase in the RMS voltage level to 110% - 180% of nominal, at the power frequency for durations of ½ cycle to one (1) minute. It is classified as a short duration voltage variation phenomena, which is one of the general categories of power quality problems mentioned in the second post of the power quality basics series of this site. Voltage swell is basically the opposite of voltage sag or dip. Despite of these common terms described here, there are also some extra parameters which degrade the power quality. Our main work is to identify study and find the new ways to suppress and reduce them. The power quality analysis of Indo Japanese Industrial Park is a small step towards it. Indo Japanese Industrial park is powered by 220KV GSS established in the campus. The data to shown below resembles to that GSS.

Dips and Swells Analysis

In this paper it is explained about the power quality problems, its causes and effects previously. The analysis was done using the three phase power quality analyzer in a220KVA GSS. This measurement not only lead to the analysis of dips & swells but also to frequency balancing, crest factor, fundamental varying voltages. The measurement was done for seventy five hours continuously and the observed data can be studied by considering the figures and tables shown below.

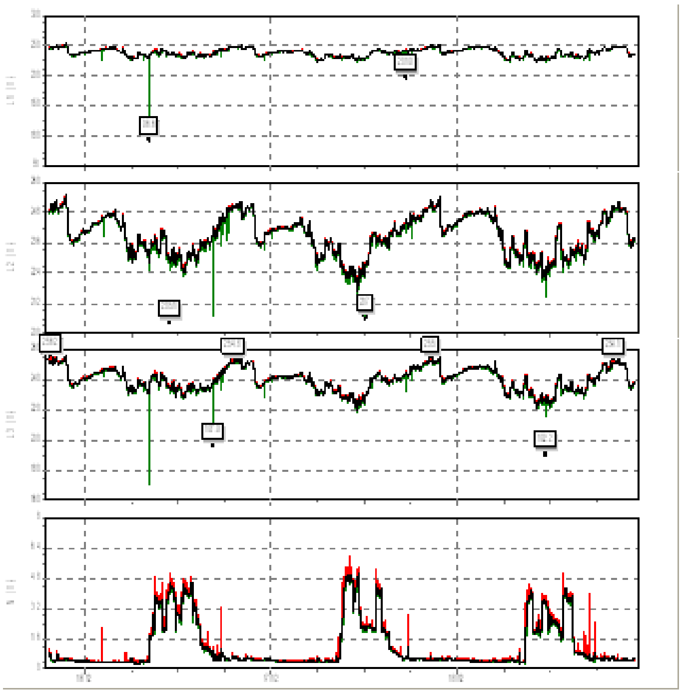

Figure 1: Waveform showing fundamental voltage.

The above waveform shows the fundamental voltage present in the park. The average frequency unbalancing is found to be 49.73Hz and the concerned graph was found to be as shown below in fig2.

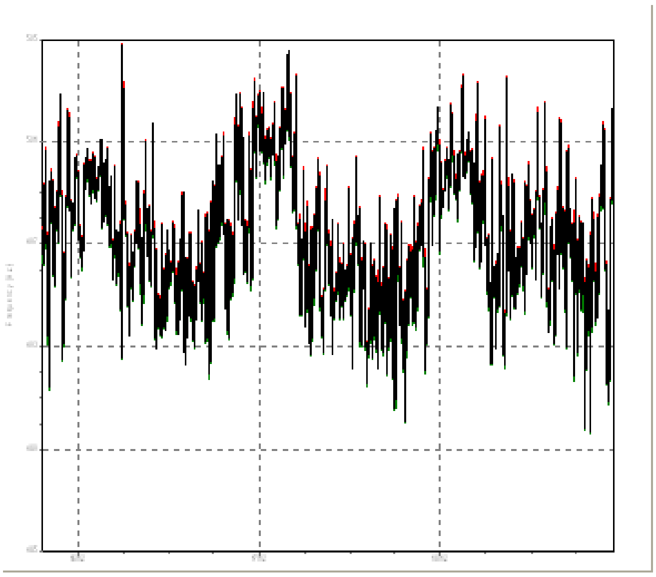

Figure 2: Average Frequency Unbalancing.

Despite of the combine line voltage shown in fig 1, the individual line voltage graph gives a sound knowledge of the voltages present and varying at the time under supervision. Line voltages are shown in fig3,4,5,6 respectively.

Table 2: Data observed for Crest Factor and avg. line voltage.

Phase	Voltage fundamental Crest Factor	Average line Voltage (V)
L1	1.402	238.95
L2	1.395	239.12
L3	1.409	240.24
N	266.95	1.145

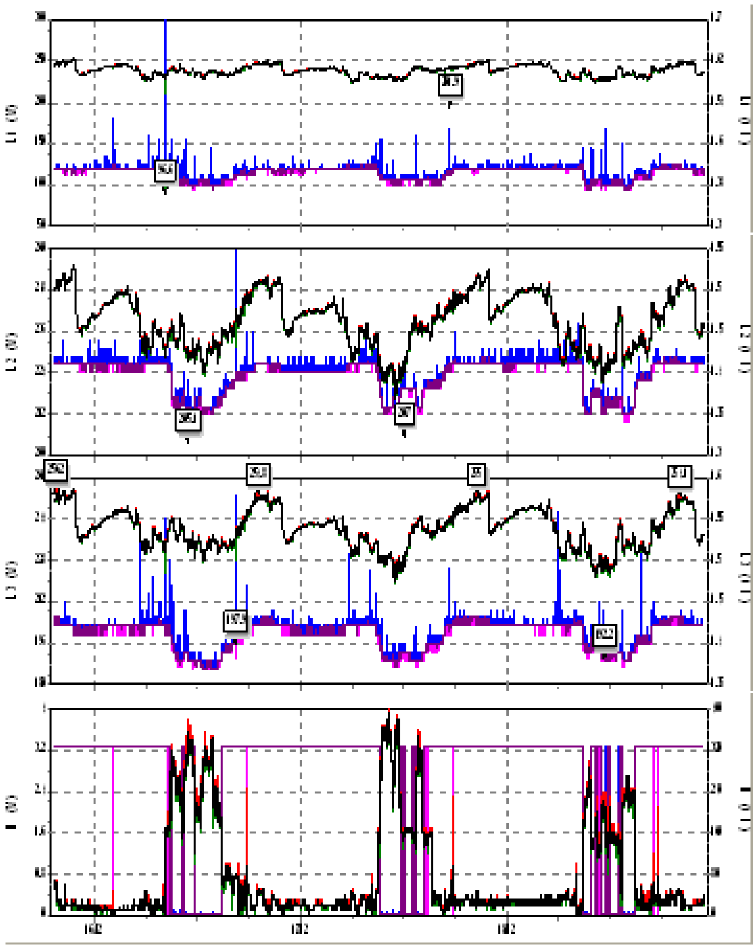

Figure 7: Crest Factor.

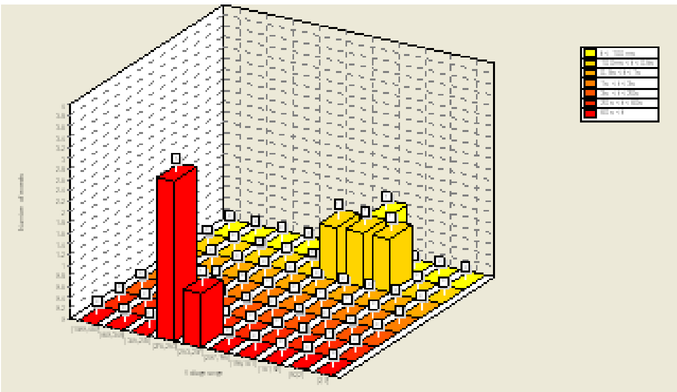

Figure 2: Dips and Swells.

These dips and swells shown above mainly occurred with the following duration and different colors are used for representing it.

t < 100ms
100ms < t <.5s
0.5s < t <1s
1s < t < 3s
3s < t <20s
20s < t <60s
60s < t

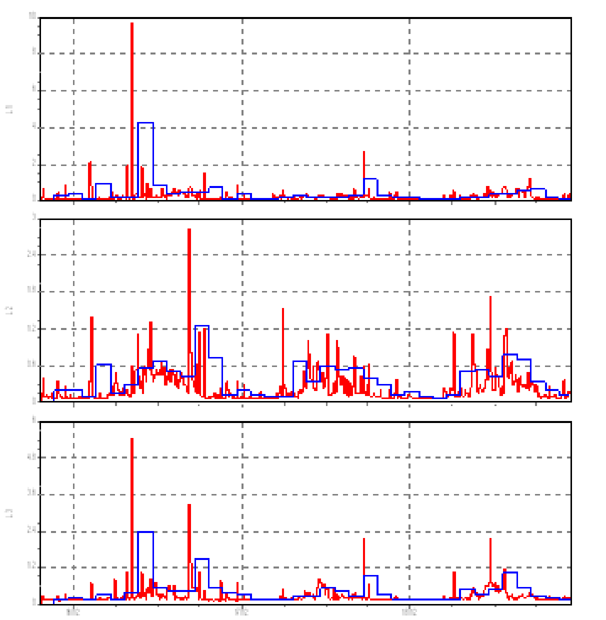

Figure 11: Flicker present in line voltages.

The above illustrated diagram gives the idea of the power quality measures. These results were not found to be theoretically correct.

Our research is underway to find a new and effective method for minimizing all the losses, increasing the power quality parameters.

A Proposed Method for Accurate Calculation for Power Quality Parameters.

Series compensation is a means of improving the performance of transmission line as well as distribution circuits. The application of series compensation makes the line or circuit appear electrically shortly because it reduces the total effective reactance. A new series compensation technique is proposed, a series capacitor is used for reactive power compensation in transmission line. Here a method is suggested for maximizing the net saving due to power factor correction at the load sides and at the receiving end of power. By using LC compensator a concern can also compensate reactive power. Basic circuit of single line diagram of power system is presented here.

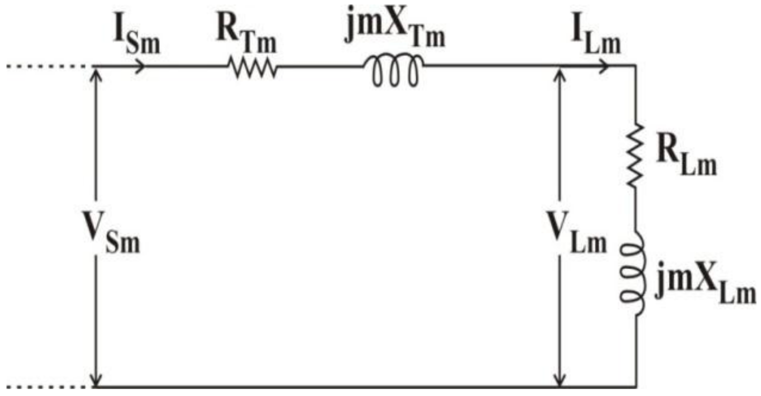

Figure 4.1: Single line diagram of power system without compensation.

From above fig 4.1

$Z_{Tm} = R_{Tm} + jmX_{Tm}$

$Z_{Lm} = R_{Lm} + jmX_{Lm}$

Z_{Tm} and Z_{Lm} are parallel to each other

Therefore

$$Z_{TLm} = \frac{Z_{Tm} Z_{Lm}}{Z_{Tm} + Z_{Lm}}$$

$$R_{TLm} = \left(R_{Tm} R_{Lm} - m^2 X_{Tm} X_{Lm}\right)$$

$$X_{TLm} = \left(mX_{Tm}R_{Lm} + R_{Tm}mX_{Lm}\right)$$

$$Z_{TLm} = \frac{R_{TLm} + jX_{TLm}}{Z_{Tm} + Z_{Lm}}$$

We know that Series capacitors are also used for control of voltage in power system. The series capacitors also provide reactive power compensation. So, now system is compensated by series capacitor and LC compensation as shown in fig 4.2. Further the final calculated value for efficiency, power factor, and power loss is shown which is depicted from fig 4.2.

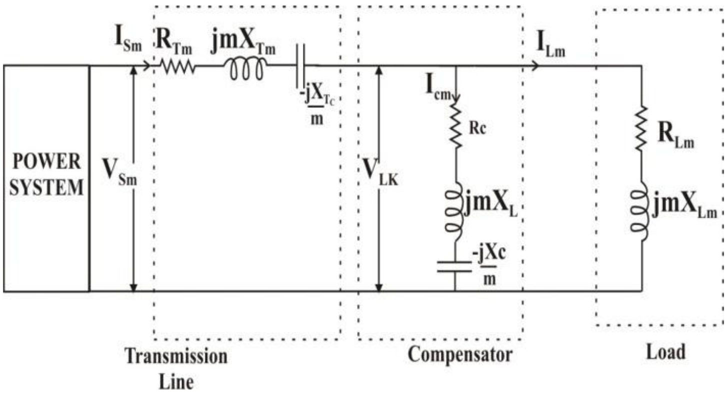

Figure 4.2: Single line circuit of power system with series capacitor and LC compensation

From fig 4.2 it is clear that Z_{Cm} is parallel to Z_{Lm}

Therefore,

$$Z_{CLm} = \frac{Z_{Cm}Z_{Lm}}{Z_{Cm} + Z_{Lm}}$$

$$Z_{Cm} = R_c + j\left(mX_L - \frac{X_C}{m}\right)$$

$$Z_{Lm} = R_{Lm} + jmX_{Lm}$$

$$Z_{CLm} = \frac{\left\{R_C + j\left(mX_L - \frac{X_C}{m}\right)\right\}\left(R_{Lm} + jmX_{Lm}\right)}{Z_{Cm} + Z_{Lm}}$$

$$Z_{CLm} = \frac{\left\{R_C R_{Lm} + jR_{Lm}\left(mX_L - \frac{X_C}{m}\right)\right\} + \left\{jmR_C X_{Lm} - mX_{Lm}\left(mX_L - \frac{X_C}{m}\right)\right\}}{Z_{Cm} + Z_{Lm}}$$

$$Z_{CLm} = \frac{\left\{ R_C R_{Lm} - mX_{Lm}\left(mX_L - \frac{X_C}{m} \right) \right\} + j\left(R_C mX_{Lm} + R_{Lm}\left(mX_L - \frac{X_C}{m} \right) \right)}{Z_{Cm} + Z_{Lm}}$$

Calculating after substituting we get

$$PF = \frac{\sum \frac{R_{Lm}}{R^2_{Lm} + m^2 X^2_{Lm}} \times \left[\frac{ \left(V_{Sm}\left[-mX_{Lm}\left(mX_L - \frac{X_C}{m} \right) + j\left\{ R_{Lm}\left(mX_L - \frac{X_C}{m} \right) \right\} \right] - I_{Lm}\left[j\left(mX_L - \frac{X_C}{m} \right) \right] \right) \bullet \left[R_{Tm}R_{Lm} - mX_{Tm}mX_{Lm} + j\left(R_{Tm}mX_{Lm} + mX_{Tm}R_{Lm} \right) \right] }{ R_{Tm}R_{Lm} - mX_{Tm}mX_{Lm} - \left(mX_L - \frac{X_C}{m} \right)\left(mX_{Lm} + mX_{Tm} \right) + j\left\{ R_{Tm}mX_{Lm} + mX_{Tm}R_{Lm} + \left(mX_L - \frac{X_C}{m} \right)\left(R_{Lm} + R_{Tm} \right) \right\} } \right]^2 }{ \sqrt{ \sum \left[\frac{ V_{Sm}\left[R_{Lm} + j\left\{ mX_{Lm} + mX_L - \frac{X_C}{m} \right\} \right] + I_{Lm}\left[\left\{ -mX_{Lm}\left(mX_L - \frac{X_C}{m} \right) \right\} + j\left\{ R_{Lm}\left(mX_L - \frac{X_C}{m} \right) \right\} \right] }{ R_{Tm}R_{Lm} - mX_{Tm}mX_{Lm} - \left(mX_L - \frac{X_C}{m} \right)\left(mX_{Lm} + mX_{Tm} \right) + j\left\{ R_{Tm}mX_{Lm} + mX_{Tm}R_{Lm} + \left(mX_L - \frac{X_C}{m} \right)\left(R_{Lm} + R_{Tm} \right) \right\} } \right]^2 \times \sum \left[\frac{ \left(V_{Sm}\left[-mX_{Lm}\left(mX_L - \frac{X_C}{m} \right) + j\left\{ R_{Lm}\left(mX_L - \frac{X_C}{m} \right) \right\} \right] - I_{Lm}\left[j\left(mX_L - \frac{X_C}{m} \right) \right] \right) \bullet \left[R_{Tm}R_{Lm} - mX_{Tm}mX_{Lm} + j\left(R_{Tm}mX_{Lm} + mX_{Tm}R_{Lm} \right) \right] }{ R_{Tm}R_{Lm} - mX_{Tm}mX_{Lm} - \left(mX_L - \frac{X_C}{m} \right)\left(mX_{Lm} + mX_{Tm} \right) + j\left\{ R_{Tm}mX_{Lm} + mX_{Tm}R_{Lm} + \left(mX_L - \frac{X_C}{m} \right)\left(R_{Lm} + R_{Tm} \right) \right\} } \right]^2 } }$$

Equation 1: Derived Power factor formula.

The above calculated value resembles the I_{SM} and PF (Power factor). We also calculated the equation for efficiency which is shown in equation2. Using the above defined equation, the values has been calculated and found to be very satisfactory. The graph has also been plotted to give an illustrative idea of the values that has been calculated using this equation. The brief summary of all the values are given here in tabular form shown in table1. It comprises of X_L , X_C ,P.F, and Efficiency. Using this previous discussed equations for power factor, power loss and efficiency , a java based computational program is developed for better and most efficient and accurate calculation of power factor, power loss, efficiency and etc. Figure1 shows some of the snapshots of that java based application software. Figure1.1 shows the main dialog box where provision for providing the inputs like X_L XC, and Rl etc is given. After entering the input values, calculate button is to be clicked for getting the output like power factor, efficiency etc. fig1.2 and fig1.3 shows the output dialog box.

$$\eta = \frac{\sum \frac{R_L}{R^2_L + m^2 X^2_{Lm}} \left[\frac{V_{Sm}\left\{ -mX_{Lm}\left(mX_L - \frac{X_C}{m}\right) + jR_L\left(mX_L - \frac{X_C}{m}\right)\right\} - I_{Lm}\left[j\left(mX_L - \frac{X_C}{m}\right)\right]\cdot\left[R_T R_L - (X_{LT} - X_{CT})mX_{Lm} + jR_{Tm}X_{Lm} + jR_L(X_{LT} - X_{CT})\right]}{\left[R_T R_L - (X_{LT} - X_{CT})mX_{Lm} - \left(mX_L - \frac{X_C}{m}\right)\left(mX_{Lm} + (X_{LT} - X_{CT})\right)\right] + j\left[R_T mX_{Lm} + (X_{LT} - X_{CT})R_L + \left(mX_L - \frac{X_C}{m}\right)(R_L + R_T)\right]} \right]^2}{\sum_m \left[\frac{V_{Sm}\left((Rc + R_{Lm}) + j\left(mX_{Lm} + mX_L - \frac{X_c}{m}\right)\right) + I_{Lm}\left(\left(RcR_{Lm} - mX_{Lm}\left(mX_L - \frac{X_c}{m}\right)\right) + j\left(RcmX_{Lm} + R_{Lm}\left(mX_L - \frac{X_c}{m}\right)\right)\right)}{\left(\left(R_{Tm}R_{Lm} - (X_{LT} - X_{CT})mX_{Lm}\right) + Rc(R_{Lm} + R_{Tm}) - \left(mX_{Lm} + (X_{LT} - X_{CT})\right)\left(mX_L - \frac{X_c}{m}\right)\right) + j\left(\left(R_{TK}mX_{Lm} + (X_{LT} - X_{CT})R_{Lm}\right) + Rc\left(mX_{Lm} + (X_{LT} - X_{CT})\right) + (R_{Lm} + R_{Tm})\left(mX_L - \frac{X_c}{m}\right)\right)} \right]^2 R_{TK} + \sum \frac{R_L}{R^2_L + m^2 X^2_{Lm}} \left[\frac{V_{Sm}\left\{ -mX_{Lm}\left(mX_L - \frac{X_C}{m}\right) + jR_L\left(mX_L - \frac{X_C}{m}\right)\right\} - I_{Lm}\left[j\left(mX_L - \frac{X_C}{m}\right)\right]\cdot\left[R_T R_L - (X_{LT} - X_{CT})mX_{Lm} + jR_T mX_{Lm} + jR_L(X_{LT} - X_{CT})\right]}{\left[R_T R_L - (X_{LT} - X_{CT})mX_{Lm} - \left(mX_L - \frac{X_C}{m}\right)\left(mX_{Lm} + (X_{LT} - X_{CT})\right)\right] + j\left[R_T mX_{Lm} + (X_{LT} - X_{CT})R_L + \left(mX_L - \frac{X_C}{m}\right)(R_L + R_T)\right]} \right]^2}$$

Equation 2. Derived formula for frequency.

Figure1 shows some of the snapshots of that java based application software. Figure1.1 shows the main dialog box where provision for providing the inputs like X_L X_C, RL, RT and etc is given, finally after entering the input values, calculate button is to be clicked for getting the output like power factor, power loss, efficiency etc. fig1.2 and fig1.3 shows the output dialog box. This application software consists of earlier discussed equation in form a java program. The values are summarizes and shown in table1.

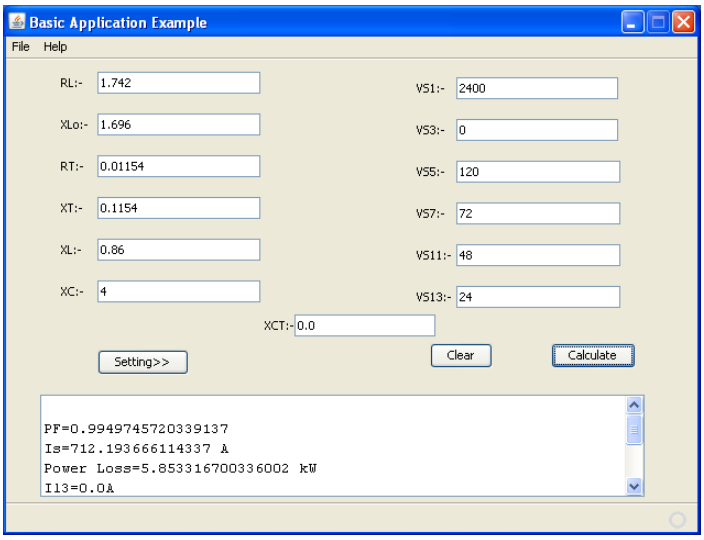

Figure 1.1: Main dialog box showing the input and output.

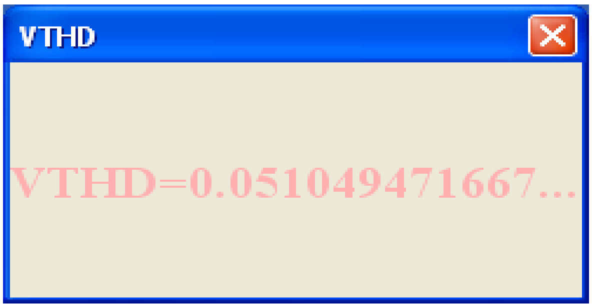

Figure 1.2: Output dialog box showing VTHD parameter.

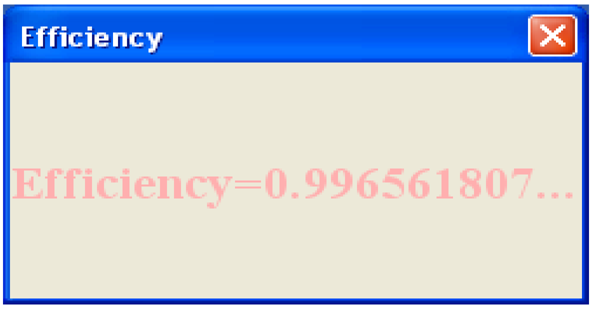

Figure 1.3: Output dialog box showing Efficiency.

Table 1: Values calculated sung the previous equations.

X_L	X_C	P.F.	Efficiency (%)
0.30	1.0	0.2497	95.163
0.34	1.2	0.3185	97.012
0.38	1.4	0.3906	98.012
0.42	1.6	0.4648	98.605
0.46	1.8	0.5390	98.964
0.50	2.0	0.6124	99.195
0.54	2.3	0.7229	99.414
0.58	2.5	0.7829	99.495
0.62	2.7	0.8354	99.537
0.66	2.9	0.8796	99.595
0.70	3.1	0.9156	99.610
0.74	3.4	0.9579	99.642
0.78	3.6	0.9753	99.653
0.82	3.8	0.9873	99.654
0.86	4.0	0.9949	99.655

Considering the parameters given in tabular form shown in table1, the following graphs are plotted.

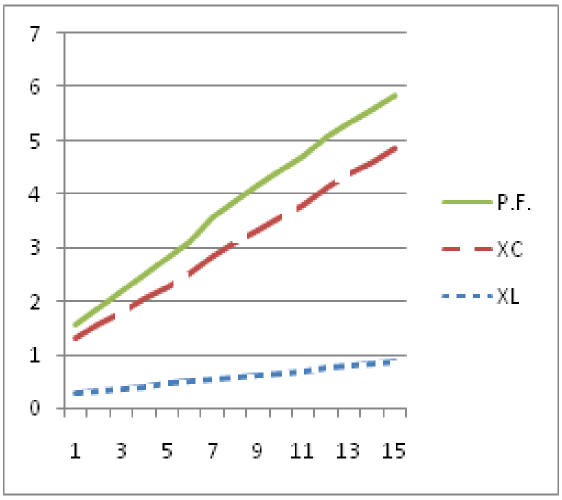

Figure 2.1: Graph plot of X_L X_C and PF.

From the above figure we conclude that the power factor increase tends up to unity as the value of X_L & X_C is being altered. Here the final value of Power factor rises till the 0.9995. Same thing happens in case of efficiency, the efficiency starts increasing when the values of X_L & X_C are altered and is found to be 99.65% for the value of X_L & X_C to be 086 & 0.4 respectively. It can easily be observed from the fig2.3. Similarly the next graph plot shows the variation of the VTHD and Efficiency in respect to the value of X_L X_C.

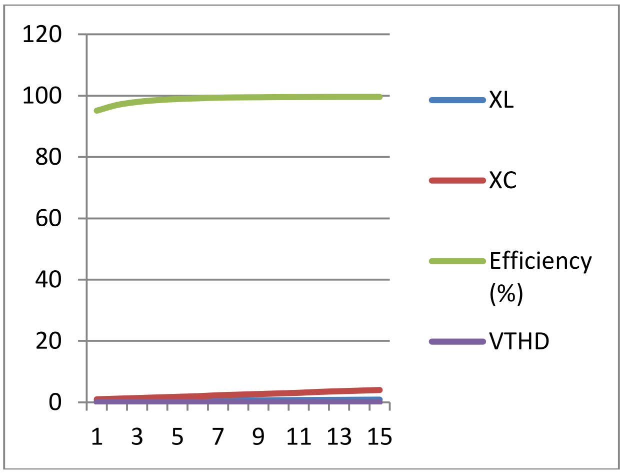

Figure 2.3: Graph plot of X_L X_C and VTHD and Efficiency.

Conclusions

This work is designed to give the reader a comprehensive understanding of the Optimal analysis of Dips and Swells. This method attempts to optimize power quality, system power factor and to minimize system losses. This work also gives the idea about the development of a software for most efficient and accurate calculation of power factor through a computational program based on JAVA Enterprises. The results found this way is found to be very satisfactory. Efforts are presently underway to develop the new and better ideas for more accurately calculation and analysis of Dips and Swells.

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