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Research Paper

Development of Power Correction Equipment for Detecting Relationship Between Crest Factor And power Factor In Electrical Loads

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ABSTRACT
This research presents the relationship between crest factor (C.F) and power factor (P.F) in ac electrical equipment.Non-linear loads such as computers and some other electrical loads complex effects on uninterruptible power supply (UPS) systems. A locally made single-phase power factor correction (PFC) UPSequipment with 8kVA output power is developed so as to investigate; (1) causes of high crest factor and low power factor of electrical loads in power transmission system, (2) the effect of crest factor and power factor on each other for various electrical loads applied to an AC source, (3) method to achieve stable crest factor in the distribution system and to achieve an improved power factor.
Results show that high crest factor current and voltage lower the power factor of electrical loads.In the six electrical loads, the higher crest factor of the current or voltage drawn by the loads causes discrepancies in the apparent power and real power calculated from measured data.
Keywords: *Crest Factor, Power Factor, Correction,Switched Capacitor, Real and Apparent power.*

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I. INTRODUCTION

Two important quantities to consider when dealing with AC power sources are the power factor (PF) and the crest factor (CF). While both are different in their meaning, each provides information about the capability of the equipment.Both quantities are important when determining the workings of an electrical system. Power factor refers to the general efficiency of a system. Crest factor describes the ability of an AC power source to generate current or voltage at a particular level. This paper attempts to define each and explain how they relate to electrical systems.Crest factor and power factor are both ratios that relate one quantity to another. They also both can be used to relate the general “effectiveness” of a signal.
Crest Factor:crest factor of voltage or current is the ratioof peak to rms values.

CREST FACTOR DERIVATIVES

C.F. = $\frac{\boldsymbol{Peak\ Value}}{\boldsymbol{RMS\ Value}}$, ……………………………..1

CF = $\frac{\boldsymbol{Pk}}{\boldsymbol{RMS}}$, where CF is Crest Factor, (Pk) Peak is in volts or amps and (RMS) root mean square is in volts or amps.

C.FPure Sine Wave = 1.414while C.FCurrent drawn by a Desktop Computer = 3

RMS is the effective DC value of an AC signal. Since a DC voltage is essentially constant over time, the work performed at the load for a DC voltage is also constant. However, an AC signal is constantly changing in amplitude over time. Therefore the work done at the load is also constantly changing. So the required effect is to have the DC signal perform the same amount of work as the AC signal.

Peakvalue of voltage or current is the maximum, or minimum, crest value of the waveform. Equipment damage is possible if the peak value becomes too great, even if the rms value is within allowable limits.Also the peak value of a signal is the magnitude of the largest positive value or negative value.
Apparent current is a unique value, related to crest factor that is reported by the Circuit Monitor. Apparent current is defined as;

$I_{app} = \frac{I\text{peak}}{\sqrt{2}}$ ………………2

This quantity reflects the value that would be reported by a peak-sensing rms-calibrated ammeter or solid-state trip unit. Trip units thatmeasure peak current may operate prematurely when serving non-linear loads. Comparing rms current with apparent current indicates the level of error involved with this type of protective device.The higher crest factor of the current drawn by the loads causes a larger difference between the values of apparent power and real power of load. Thus, as crest factor increases, power factor diminishes.

The graphical relationship between AC peak, AC RMS and DC is shown in figure 1.

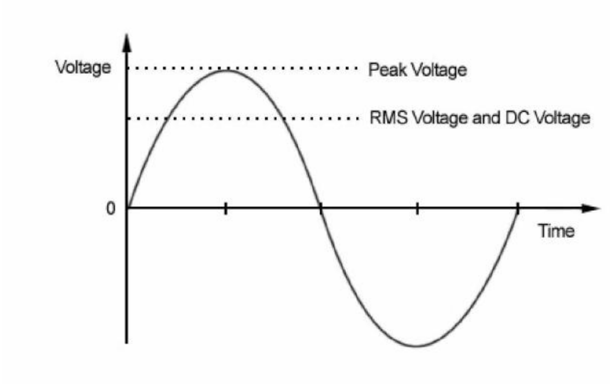


Figure 1.0

Power Factor

The power factor defined as the ratio of true power or actual power (kW) that is,power needed by the consumer premises equipment to operate to apparent power (kVA) which is theamount of the power delivered by the utility. It is also ameasure of electrical efficiency. The apparent power is thevectorial summation of kVAR and kW, where kVAR is the reactive power.For a purely resistive circuit the power factor is 1 and for a purely capacitive or inductive circuit the power factor is zero. It is desirable to have loads and power supplies with a power factor as close to 1 as possible. The reason being is reactance does not dissipate power so there is no ability to do work. That is not to say that reactance cannot be useful in the design of circuits and electronic products. For example, it would be highly desirable to have transmission lines that have a power factor of zero in order to minimize energy loss in distribution system.
The power factor can also be determined by the Cosine of the phase angle between resistance and reactance in a circuit or true power and reactive power.

POWER FACTOR DERIVATIVES

Power factor is the ratio of actual power to apparent power.

$$P.F. = \frac{KW}{KW+KVAR} \text{……………………………………….3}$$

The higher the percentage of kVARs, the lower the ratio of kW to kVAR. Thus, the lower the power factor, the lower the percentage of kVAR, the higher the ratio of kW to kVAR. As kVAR approaches zero, the power factor approaches 1.0. A power factor of 1.0 is ideal.

The power triangle (figure 1.0 below) illustrates the relationship between kW, kVA, kVAR and power factor (P.F.)

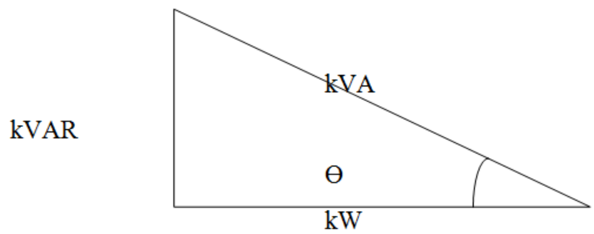


Fig. 2.0 Relationship between kW, kVAR and Power Factor (P.F)

$P.F. = \frac{KW}{\sqrt{KW^2+KVAR^2}}$ = cosΘ……………………..……………………………4

$\frac{KW}{KVAR}$ = sinΘ …………………………………………………………5

kVA = $\sqrt{kW^2 + kVAR^2}$……………………………………………………………6

In order to have an efficient system, power factor must be closer to one (1.0) as possible and the crest factor of a sinusoidal signal in electrical transmission must be closer to 1.414 for an effective distribution (Fernandez et al. 2005).

Sometimes, electrical distribution has a power factor much less than 1.0 and a high crest factor value. This came to the idea of investigating the causes high crest factor and low power factor and the effect of crest factor on power factor in power transmission.

II. CAUSES OF HIGH CREST FACTOR AND LOW POWER FACTOR IN POWER TRANSMISSION

A poor power factor and high crest factor can be the result of either a significant phase difference between the voltage and current at the load terminals or it can be due to a high harmonic content or distorted/discontinuous current waveform or irregular waveform signal in power transmission. Poor load current phase angle is generally the result of poor load current phase angle, and is generally the result of an inductive load such as an induction motor, powertransformer, lighting ballasts, welder or induction furnace, Induction generators, Wind mill generators and high intensity discharge lightings.

Since power factor is defined as the ratio of kW to kVA, low power factor result when kW is small in relation to kVA. This occurs when kVAR is large.

The major causes of large kVAR in a system are “inductive loads which are source of reactive power.These inductive loads constitute a major portion of the power consumed in industrial complexes.

Reactive power (kVAR) required by inductive loads increase the amount of apparent power (kVA) in electrical distribution power result in large angle Θ (Measured between kW and kVA). Thus, as Θ increases, cosine Θ (or power factor) decreases.

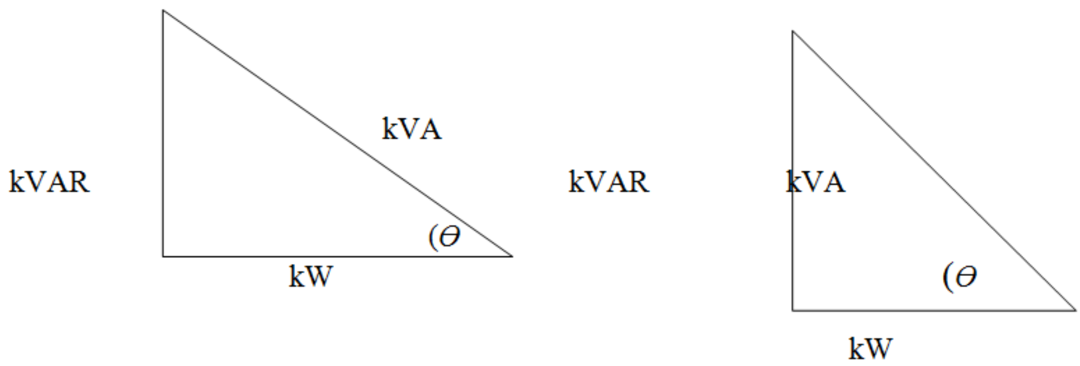


Figure 3.0 the behavior of angles (Θ) formed between kW and kVA by the action of Reactive power (kVAR).

Hence, inductive loads (with large KVAR) result in low power factor and high crest factor.

EFFECT OF HIGH CREST FACTOR WITH LOW POWER FACTOR (P.F) ON ELECTRICAL LOADS

1. Increases heat losses in transformers and distribution equipment,
2. It reduces electrical appliance life,
3. Unstabilized voltage levels,
4. Decreases energy efficiency,
5. Increase power losses,
6. Increases electricity cost by paying power factor surcharges.

REASONS FOR REDUCING HIGH CREST FACTOR AND CORRECTING LOW POWER FACTOR

Appliances and machineries located in consumer premises emit reactive power which lowers the power factor and simultaneously gives unstable crest factor during power transmission. Therefore, improvement of inductive loads at consumers end is usually done for several reasons.

1)Lower utility fees by:

a. Reducing peak kW billing demand;

Note that inductive loads, which require reactive power, caused unstable crest factor and a low power factor. This increase in reactive power (kVAR) causes an increase in apparent power (kVA), which is what the utility is supplying. So, a facility's low power factor and high crest factor causes the utility to increase its generation and transmission capacity in order to handle this extra power demand.
By increasing load power factor and reducing high crest factor, less kVAR demand is experienced. This results in less kW, which equates to a financial savings from the utility billing demand.

b. Eliminating the power factor penalty;

Power generation companies usually charge customers an additional fee when their power factor is less than 0.95. (In fact, some companies are not permitted to deliver electricity to their customers at any time the customer's power factor falls below 0.85.) Thus, an additional fee could be avoided by increasing loads power factor in order to reduce high crest factor values.

2)Increased system capacity and **reduced system losses** in an electrical system.

By adding capacitors (kVAR generators) to the system, the power factor together with crest factor is improved and the kW capacity of the system is increased.
Uncorrected power factor and crest factor causes power system losses in power distribution system. By improving load power factor and crest factor, these losses can be reduced. And with lower system losses, consumers are also able to add additional load to electrical distribution system.

3) Regulated voltage level in an electrical system and **cooler, more efficient System performance;**

As power losses increase, voltage drops is experienced. Excessive voltage drops can cause overheating and premature failure of motors and other inductive equipment. So, by increasing load power factor as well as reducing crest factor to a safe limit, we can minimize these voltage drops along feeder cables and avoid related problems. The electrical motors will run cooler and be more efficient, with a slight increase in capacity.
For the reasons stated above, a power factor correction (PFC) circuit block diagram shown in figure 1, is developed so as to investigate; ((1) causes of high crest factor of electrical loads in power distribution system, (2) the effect of crest factor on power factor of electrical loads applied to an AC source (3) method to achieve a low and stable crest factor in the distribution system and to achieve an improved power factor (Jenkins, 2005).

III. MATERIAL AND METHOD

Manyloads on electrical power distribution system fall into one of these three (3) categories;

1. Capacitive
2. Inductive or
3. Resistive

In most electrical loads, the common is the inductive and examples of this include transformers, fluorescent lighting and AC inductive motors. Most inductive loads use a conductive coil winding to produce an electromagnetic field allowing the motor function.

USING CAPACITORS FOR POWER FACTOR AND CREST FACTOR CORRECTION

Installing Capacitors decrease the magnitude of reactive power (kVAR), thus increasing power factor and at the same time reduce high crest factor to a low and stable value.

A Capacitive power factor is applied to electric circuit (Jimrong, 1997) as a means of minimizing the inductive components of the current and thereby reducing the losses in the supply.
It is not usually necessary to reach unity, i.e. power factor 1.0 since most companied are happy with a P.F of 0.95 to 0.98. By installing suitably switched capacitor into the circuit, power factor is improved and the value becomes nearer to 1.0, thus, reducing a high crest factor to value close to 1.414 which is an ideal crest factor in electrical power transmission and also improve the efficiency of electrical appliances.

SWITCHED CAPACITOR

A switched Capacitor method is adopted in this research work.
Type: A.C. switched Capacitors (Non-polarity).
This Capacitor is suitable for centralized power factor correction in applications where electrical loading is constantly changing, resulting in the need for varying amounts of reactive power.
An advanced micro-controller base reactive controller measures electricalload power factor via a single current transformer, and switched capacitors modules in and out of service to maintain a user selected target power factor; typically applied at service entrance or near fluctuating loads (Hua, 1993).

HOW CAPACITOR CANCELS OUT THE EFFECT OF AN INDUCTIVE LOADS

Reactive power (kVARs), cause by inductive loads, always act at 90-degree angle to working power (kW).

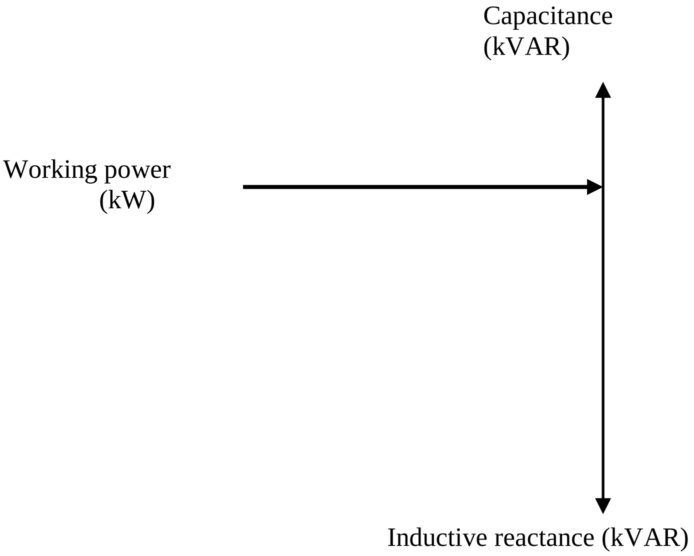


Fig.5.0 Relationship between capacitive reactance and inductive reactance as applied to working power.

Inductance and capacitance react 180degree to each other. Capacitor store kVARs and release energy opposing the reactive energy caused by the inductor.

The presence of both a capacitor and inductor in the same circuit results in a continuous alternating transfer of energy between the two.

Therefore, when the circuit is balanced, all the energy released by the inductor is absorbed by the capacitor.

For an accurate measurements and calculations, the corrected P.F must be able to approach a value of 1.0 that is unity, also the corrected crest factor be closer to 1.414 as possible. While the measured values obtained are illustrated using tables and graphs.

DESIGN OF CREST FACTOR / POWER FACTOR MEASUREMENT EQUIPMENT

DESIGN AND CONSTRUCTION METHOD

In this design of power factor correction equipment, a switch capacitor method is adopted, so as to centralize applications where power plant loading is constantly changing, resulting in the need for varying the amount of reactive power. It is also resistance to heat and can withstand high voltage values in power transmission, very economical compare to other power factor compensative measures *(Ibik, 2002).*

CREST FACTOR WITH POWER FACTOR MEASUREMENT BLOCK DIAGRAM

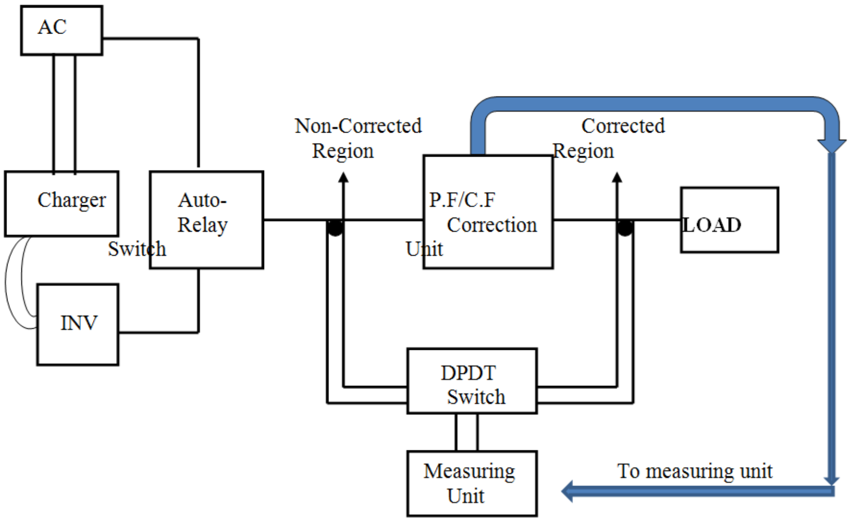


Figure 6.0 Power factor measurement block diagram

The diagram above explains the design layout/plan of a proposed power factor/crest factor correction device. It gives a sketch layout of the connections to be made within the stages of the P.F.C/C.F.Cequipment constructed in order to ensure error free circuit arrangement.

COMPLETE CIRCUIT DIAGRAM OF POWER FACTOR AND CREST FACTOR CORRECTION EQUIPMENT.

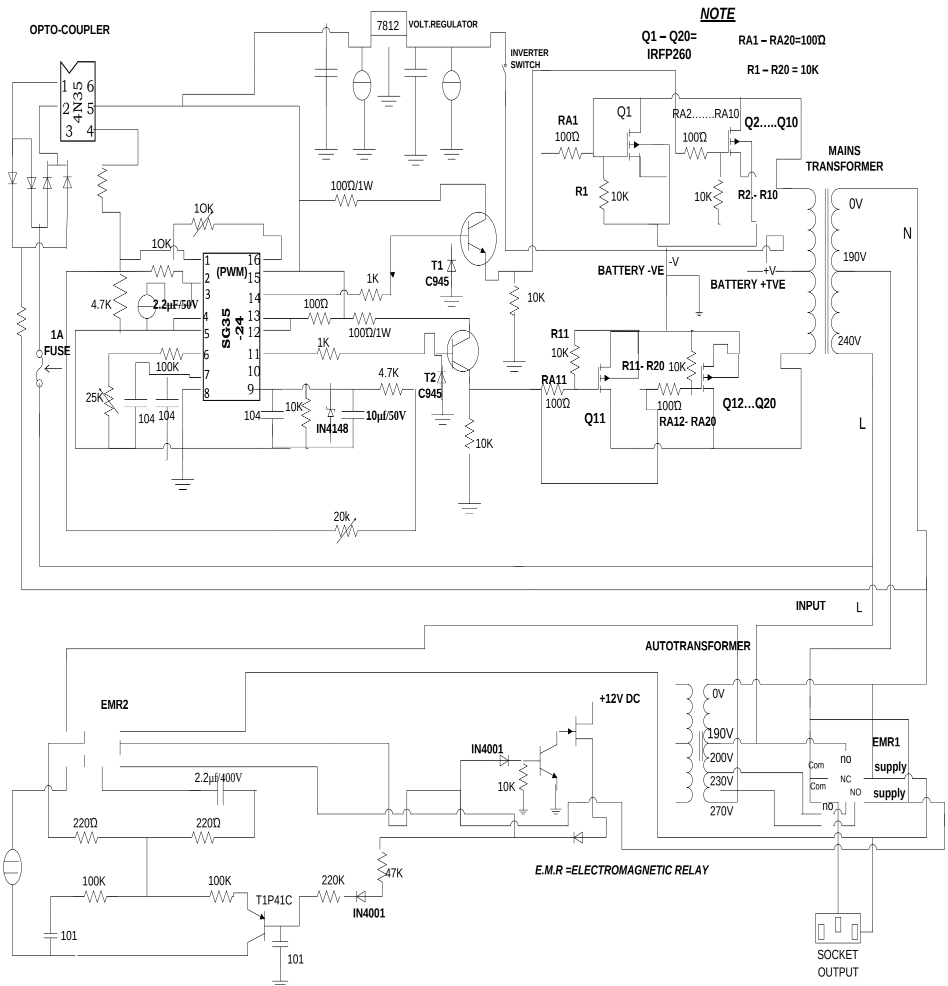


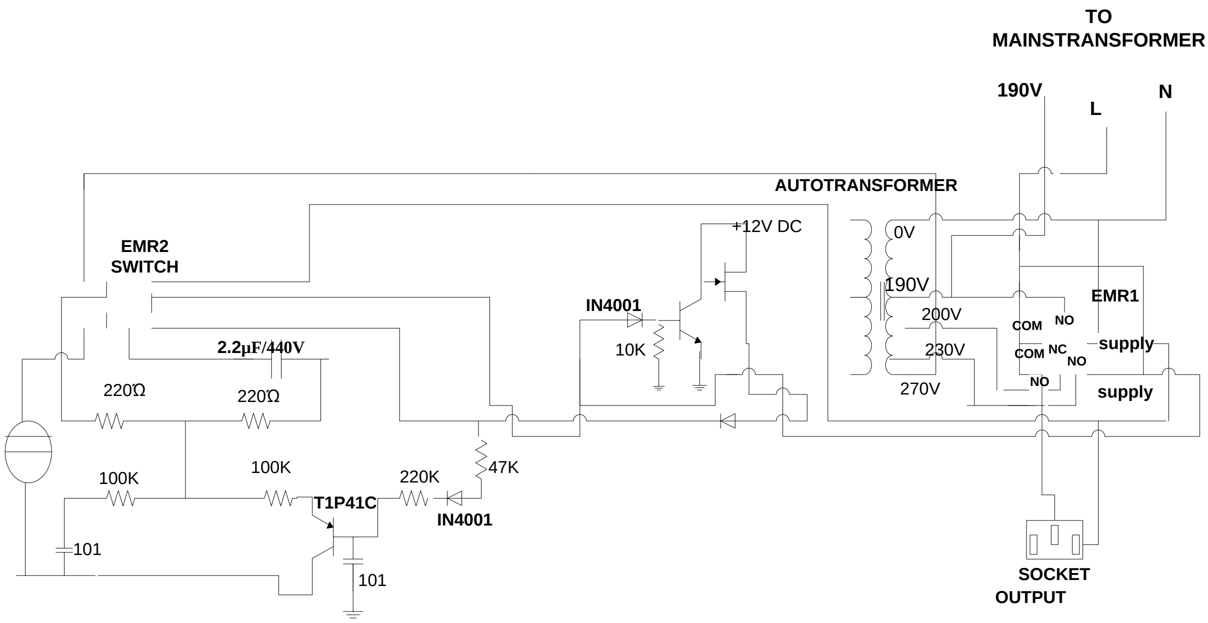
Figure 7.0

THE POWER FACTOR/CREST FACTOR CORRECTION MEASURING SECTION

This section is the most important aspect of this paper. In this section connections are made in order to measure uncorrected and corrected values for both Crest factor and Power factor for various electrical loads applied in order to minimize wasted power in power transmission.

The output of the Centre-tap-transformer is connected to the input of the P.F.C/C.F.C measuring circuit via Electromagnetic Relay 1, (E.M.R.1) to the circuit. A Double-Throw-Double-Pole (DPDT) switch is connected across the circuit so as to switch between the uncorrected (input C.F and P.F) as well as for corrected (output C.F and P.F) values obtained for each load applied forcrest factor and power factor measurements, while the output of this section is connected through E.M.R.2 to the socket (outlet), where loads are applied for measurement as shown in figure below.

The input load voltage, input load current and uncorrected output load factor values and as well as corrected output load factor values are displayed on the LCD via measuring meters of the correction measuring section of the equipment. The corrected and the uncorrected power factor/crest factor as well as the wasted powerare calculated using crest factor and power factor formula.



.DIAGRAM OF POWER FACTOR/CREST FACTOR CORRECTION MEASURING CIRCUIT

Figure 8.0

MEASUREMENT OF CREST FACTOR/ POWER FACTOR FOR VARIOUS LOADS APPLIED

The following electrical appliances/loads were selected as case study for this research work; these appliances were supplied with AC through 6kVA power factor correction power supply (UPS) equipment at their different maximum power demand.

1.	Deep-freezer Refrigerator	4.	Sandwich Toasting Machine
2.	Desktop Computer Set	5.	Electric Incubator
3.	L.G Air Conditioner	6.	Drilling Machine

The above listed electrical loads will be tested and measured one after the other for uncorrected C.F/P.F and for corrected C.F/P.F in AC power transmission.

The measurement of crest factor (C.F), power factor (P.F), Active power (P), Reactive power (Q), Apparent power (S) and current (I) shall be taken for each load applied. The initial and the required i.e. Uncorrected and corrected crest factor / power factor for individual load are calculated, and later illustrated in the tables and graphs.

COMPARISM OFRESULTS FOR VARIOUS LOAD APPLIED USING CREST FACTOR AND POWER FACTOR FORMULA

The following results were obtained for each load applied for crest factor and power factor correction measurements.

Load (1)

DEEP-FREEZER REFRIGERATOR

Crest Factor before P.F.C.(Input Ac)

Peak Voltage (V_{Peak}) = 561V
R.M.S Voltage (Vrms) = 255V
Peak Current (I_{Peak}) = 22.44A
R.M.S Current (Irms) = 10.20A

Therefore, crest factor (C.F) before Power Factor Correction (P.F.C)

Crest Factor (C.F) = $\frac{Vpeak}{Vrms}$ or $\frac{Ipeak}{Irms}$ 7

C.F = $\frac{561V}{255V}$ = 2.20 or $\frac{22.40A}{10.20A}$ = 2.20 8

C.F before power factor correction is 2.20
Hence, power factor before correction is,
Load Real Power (P) = 2000W = 2kW
Load Voltage (V_{rms}) = 225V
Load Current (I_{rms}) = 10.20A

Power factor (p.f) = $\frac{Real\ Power}{Apparent\ Power} = \frac{P}{S}$ 9

Apparent Power (S) = Vrms x Irms 10

S = 225V x 10.20A
S = 2601VA

p.f. = $\frac{2000}{2601}$ 11

p.f = 0.77

Where:

kVA = $\sqrt{KW^2 + KVAR^2}$ or, 12

S = $\sqrt{P^2 + Q^2}$ 13

Where kVAR = reactive power (Q)

Therefore,

kVAR = $\sqrt{KVA^2 - KW^2}$ 14

Q_1 = $\sqrt{(2601)^2 - (2000)^2}$ 15

$kVAR_1$ = 1662.89 or
Q_1 = 1.663kVAR

Power Factor after correction (P.F.C)

Load Real Power = 2000W
Vrms = 230V
Irms = 9.20A

Apparent Power (S) = 230V x 9.2A 16

S = 2116VA

Power factor (P.F) = $\frac{Real\ Power}{Apparent\ Power} = \frac{P}{S}$ 17

Power Factor (P.F) = $\frac{2000}{2116}$ = 0.95 18

Therefore, Crest factor (C.F) after Power Factor Correction (P.F.C) is;

C.F = Crest Factor (C.F) = $\frac{Vpeak}{Vrms}$ or $\frac{Ipeak}{Irms}$ 19

C.F = $\frac{326.6V}{230V}$ = 1.420 or $\frac{13.064A}{9.20A}$ = 1.420 20

kVAR = $\sqrt{KVA^2 - KW^2}$ 21

$kVAR_2$ = $Q_2\sqrt{(2116)^2 - (2000)^2}$ 22

= 690.98

Q_2 = 690.98 VAR

These calculations were done for electrical loads 2 to 6 and measurement results are tabulated below;

IV. RESULTS AND DISCUSSION

RESULTS

The calculated values for uncorrected and corrected crest factor as well as power factor for each load applied for this research are further illustrated in the following tables.

Table 1:
Peak Voltage, R.M.S Voltage, Peak Current, R.M.S Current, Crest Factor (C.F.) and Power Factor (P.F.) before correction for each load applied on AC supply.

LOAD S/N	PEAK VOLTAGE BERORE C.F.C/P.F.C (V_{Peak})(V)	R.M.S VOLTAGE BEFORE C.F.C/P.F.C (V_{rms})(V)	PEAK CURRENT BEFORE C.F.C/P.F.C (I_{Peak})(A)	R.M.S CURRENT BEFORE C.F.C/P.F.C (I_{rms})(A)	P.F BEFORE CORRECTION	C.F BEFORE P.F.C
1	561	255	22.44	10.20	0.77	2.200
2	1068.60	260	43.57	10.60	0.65	2.980
3	318.15	260	60.00	12.00	0.48	5.000
4	541.42	253	13.38	6.25	0.63	2.140
5	713.40	246	17.40	6.00	0.75	2.900
6	1075.20	266	34.86	8.30	0.72	4.200

Table 2:
Peak Voltage, R.M.S Voltage, Peak Current, R.M.S Current, Crest Factor (C.F.) and Power Factor (P.F.) after correction for each load applied on AC supply.

LOAD S/N	PEAK VOLTAGE AFTER C.F.C/P.F.C (V_{Peak})	R.M.S VOLTAGE AFTER C.F.C/P.F.C (V_{rms})	PEAK CURRENT AFTER C.F.C/P.F.C (I_{Peak})	R.M.S CURRENT AFTER C.F.C/P.F.C (I_{rms})	P.F. AFTER CORRECTION	C.F. AFTER P.F.C
1	326.60	230	13.06	9.20	0.95	1.420
2	685.20	230	25.84	8.67	0.90	2.980
3	318.15	225	9.90	7.00	0.96	1.414
4	321.94	228	6.61	4.68	0.94	1.412
5	331.44	240	6.35	4.59	0.99	1.381
6	331.82	235	9.90	7.00	0.97	1.412

Table 3:
Apparent Power and Reactive Power before Crest Factor Correction (C.F.C) / Power Factor Correction (P.F.C) and after correction for each load applied on AC supply.

LOAD S/N	APPARENT POWER (kVA) BEFORE C.F.C/P.F.C	APPARENT POWER(kVA) AFTER C.F.C/P.F.C	REACTIVE POWER (kVAR) BEFORE C.F.C/P.F.C	REACTIVE POWER (kVAR) AFTER C.F.C/P.F.C
1	2.60	2.12	1.66	0.69
2	2.76	1.99	2.09	0.86
3	3.12	1.58	2.74	0.48
4	1.58	1.07	1.23	0.37
5	1.48	1.10	0.98	0.06
6	2.21	1.65	1.52	0.38

Table 4:
Crest Factor (C.F) before and after Power Factor Correction (P.F.C), Corrected and uncorrected Power Factor (P.F) for each load applied on AC supply.

LOAD S/N	CREST FACTOR(C.F) BEFORE P.F.C	P.F BEFORE CORRECTION	P.F AFTER CORRECTION	CREST FACTOR (C.F) AFTER P.F.C
1	2.200	0.77	0.95	1.420
2	4.110	0.65	0.90	2.980
3	5.000	0.48	0.96	1.414
4	2.140	0.63	0.94	1.412
5	2.900	0.75	0.99	1.381
6	4.200	0.72	0.97	1.412

The following graphs were plotted below in order to compare the values of data collected for various crest factor and power factor measurements.

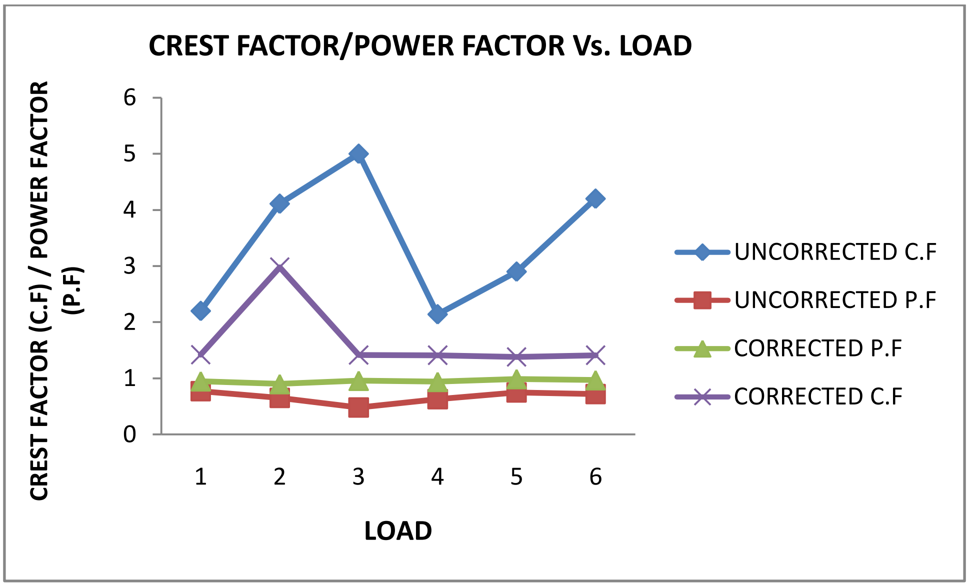


Figure 1: Corrected and uncorrected Crest Factor (C.F) and Power Factor (P.F) vs. various loads applied for measurement.

V. DISCUSSION OF RESULT

The locally designed and constructed electrical power factor correcting (UPS) equipment for reducing high crest factor of electrical appliances consist of inverter, changeover and protection relay circuits, power factor correction and measurement section via the auto transformer. Different measurements on 6 loads show that more electrical power were utilized when there is high crest factor with low power factor as seen from the calculated value in the table 3. As seen from table 4 and graph 1, the higher the crest factor the lower the power factor of electrical loads, the lower the crest factor in electrical transmission, the higher the power factor of electrical loads, the more the stability of electrical loads efficiency.

The power factor correction reduced high crest factor, increased power factor and reduced reactive powers thereby saving more electrical powers, and thus reducing overheating of transformer and improve electrical efficiency of electrical appliances.

VI. CONCLUSION

The major objective of this research is to know the relationship between crest factor and power factor of various loads applied to an AC source and to investigate the effect of the these two quantities over one another in power transmission . The method of correction made is to correct input power factor in order to reduce high crest factor. The power factor measurements results made it clear that power factor of loads applied were relatively low with high crest factor values but sufficiently improved when switched capacitor method was applied for correction. As a result of this, a relationship between crest factor and power factor was established, as crest factor (C.F) increases, the power factor (P.F) diminishes.

By adding suitably P.F.C into the input Power Supply circuit, the crest factor is lowered and power factor is improved and thus minimizing Power loss and improving the efficiency and life span of electrical loads.

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