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Phase and Waveform Comparative Analysis for Electric Heater, Induction Motor and Static Capacitor

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Abstract
Measurement, evaluation and comparative analysis of phase relationships between load currents and load end voltages are very essential in power system studies. Low lagging power factor loads are undesirable in power systems whereas unity or near unity power factors loads are preferable. Low lagging power factors loads have high I^2R losses and thereby increases tariff for consumers. This study provides phase and waveform comparative analysis for three different loads, both linear and unlinear loads to evaluate the phase angle, power factor and I^2R losses for each load at different operating states. For each load, the oscilloscope displays the waveforms of three quantities, the generator e.m.f the terminal voltage and the load current in voltage vs time graph. The different phase angles were calculated with angle-time relationship, angle being a function of time subentry the I^2R losses were got and future research on this will present and algorithm and prediction of tariffs for different loads.

Keyword: *Problem based study, Machine related skill, Industrial Manpower Development*

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Background to the Study

Voltage and current have a phase relationship in A.C circuits. Thus current may lag, lead or be in phase with voltage if load at the receiving end is inductive, capacitive or resistive respectively (Nwosu N.O 2016). In Engineering, this phase relationship is represented either in phasor form or waveform. Whereas the former shows the phase difference between voltage and current in form of angle relationship, the latter shows the phase difference in from of time, angle being a function of time (Rajput Er. R.K 2008)

It is also very important to define phase angle relationship in terms of peak values. Thus when current and voltage are in phase, it means the two quantities attain their maximum, zero and minimum value before or after the voltage (Kraus/Fleish, 1999) Linear loads like electric heaters draw current from the supply which is proportional to the applied voltage. Non-linear loads like power semi-conductor devices have their impedances changing with the applied voltage. Due to this change in impedance, the current drawn by non-linear loads is also non-linear i.e non-sinusoidal in other examples of non-linear loads are computer, variable frequency drives, discharge lightning e.t.c (Nikunj Shah, 2013). Non-linear loads draw distorted waveforms containing harmonics. These harmonics cause problem ranging from telephone transmission interference to degradation of conductors and insulating material in motors and transformers. However, these are beyond the scope of this paper.

Introduction of different loads at the generator busbar also help in transient stability studies of the generators. Here different loads and fault conditions will cause the rotor angle deviation in generators. When different loads are connected to generator's busbar, a swing is developed. This loss of synchronism is immediately countered and stability restored by some factors like the Generator's rotor inertia. (Gupta J.B 2002) Waveform and phasor analysis here are limited to electric heater, induction machine and static capacitors connected to a permanent magnet synchronous generator (PMSG). Also a cathode Ray oscilloscope is connected in such a way to provide a phase comparison between the different current and terminal voltage when an electric heater, induction motor and a static capacitors are connected in turns. Phase comparison helps in determination of power factors and power factor enhancement. This is because it is desired that the power factor of any load is unity. Here the KVA value in the system balances the KW value. Any small distinction between the two systems suggests that the power factor is less than unity. This is undesirable in power engineering. Low lagging power factors leads to high I^2R losses (V.K Mehta et al, 2004). This study is aimed at providing algorithm for loads. Also an archive based on collected data is developed and referenced by stakeholders. And more importantly, this gives data on various power factors of different loads, knowledge of this may be helpful in calculating and predicting the tariff for each load.

Literature Review

Many researchers have testified the waveform relationship between currents and voltages ranging from linear loads to non-linear loads, (Johan Rens et al, 2008) measured the voltage and current waveforms at the service entrance of a data centre with distributed three phase and single phase non-linear loads. The waveform values were plotted and after application of fortesque transform was applied to the non-sinusoidal waveforms, results of Fourier analysis was obtained. (W K Lee et al, 2005) used the concept of load signatures for load monitoring. The waveform signatures are the waveforms of the current and voltages of each load at their different states of operation i.e steady state, transient and operational pattern. This study involved the identification of an electrical appliance and the determination of its operating state. He presented the methodology and observation of the load signature in their operation modes. Firstly, by measuring the current and voltage of typical appliances, the characteristics of the waveform signatures were analyzed. Secondly, through the data study it is planned to develop an algorithm that can provide a basis for classifying electrical loads. It will also provide a complete record of data for stakeholders reference.

In the modeling work of (Lu-Lulu et al, 2012) power electronics modelling used in domestic and small scale industrial distribution system was achieved. The various domestic loads that were modeled include computer fluorescent lamp and small scale industry loads such as adjustable speed drive were also modeled. He used computer simulations to providing harmonic analysis through system components modelling.

Objective of the Study

This work only measures and examines the voltage and current waveforms of electrical load like electric heaters, induction machines and static compensators. It draws a comparative analysis through the waveform and phasor analysis of each loads current, terminal voltage and the e.m.f of the source. Future review of the work will also provide an algorithm and archive for identifying electrical loads.

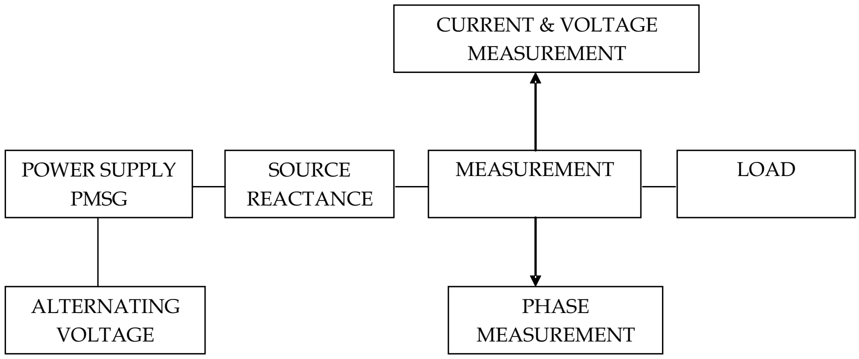
Materials and Methods

The materials and components specifications for the study are shown below:

Table 1

Generator type	Permanent magnet synchronous Generator (PMSG)
KVA rating	A.C direct drive 3000VA 3KVA
Steady state supply voltage	220 – 240v
Alternating voltage Regulators (AVR) power rating	5,000watts
Load current Ammeter current rating	15 – 20 Amps
Terminal voltage voltmeter	
Waveform displaying oscilloscope	General Purpose Cathode Ray Oscilloscope (GPCRO)
Output Frequency	50Hz±0.5Hz
Angular speed	$w = 2\pi f = 314$ rad/s

Fig. 1: Block Diagram for the Phase Comparison



Methodology

The proposed methodology was introduced to achieve various objectives. Two major steps of voltage/current measurement and phase measurement were involved. A constant voltage of 220v was got from the source through the alternating voltage regulator. The source impedance is made up of the synchronous reactance Xs the resistance of the source Rs. The synchronous reactance in turn is made up of the leakage reactance X_L and the Armature reaction reactance X_A. A15Amp rated ammeter is connected in series for measuring the load current whereas a voltmeter connected between the Generator terminals measure the voltage at the load end.

At the second stage measurement, a General purpose Cathode ray oscilloscope is connected for the measurement and display of the waveforms of the load current and the receiving end voltage i.e the terminal/applied voltage. Also the source e.m.f waveform is displayed. From the displayed waveforms, the phase difference between the source e.m.f, the voltage and load current are got when the three loads of electric heater, induction motor and static capacitors are connected across the terminals of the generator in turn. The displayed waveforms of the load current(I) terminal voltage (V) and the source e.m.f (E) are representations of the parameters plotted against time. Calculations were made to obtain the phase angle difference between these parameters, angle being a functions of time.

The Displayed Waveforms in GPCRO

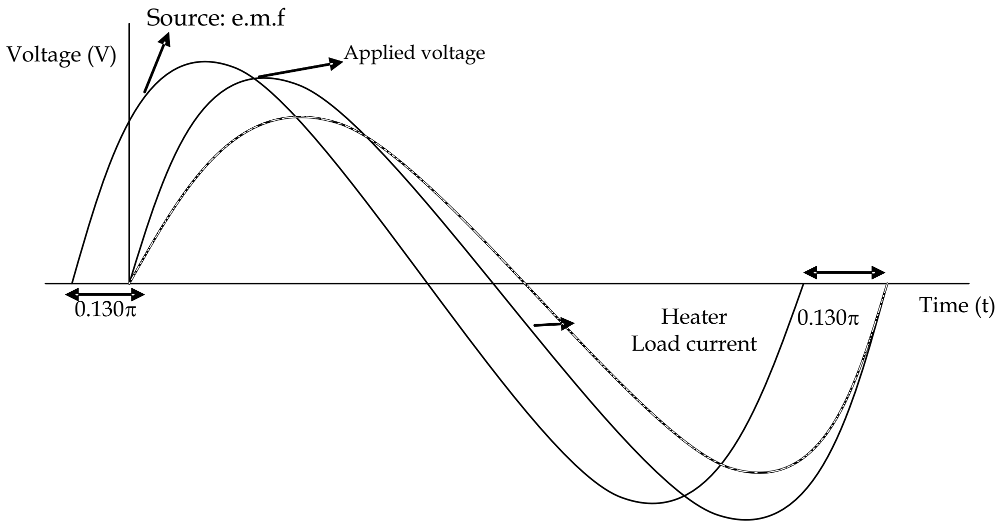


Fig. 2: The waveform of the load current applied voltage and source e.m.f of the loaded electric heater.

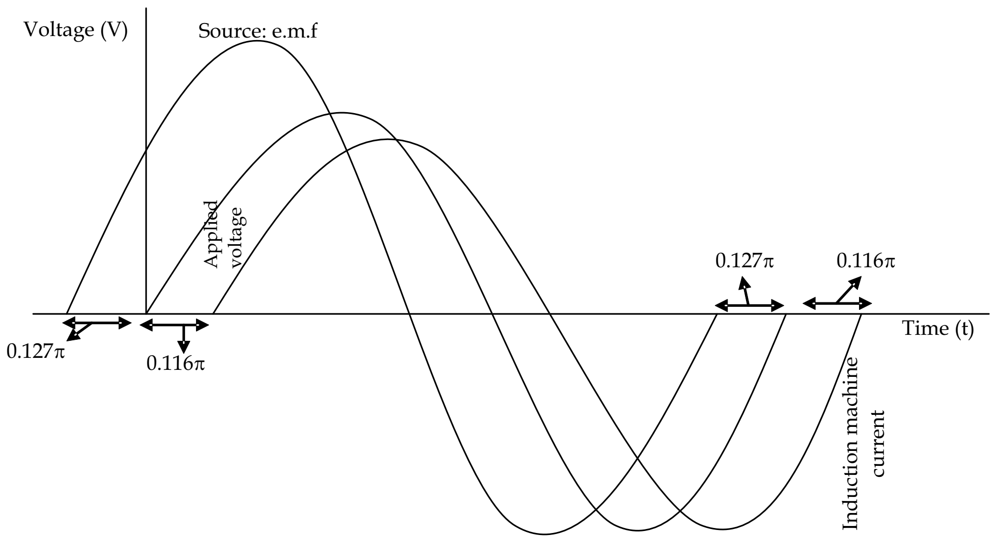


Fig. 3: The waveform of the load current, applied voltage and the source e.m.f of the induction motor.

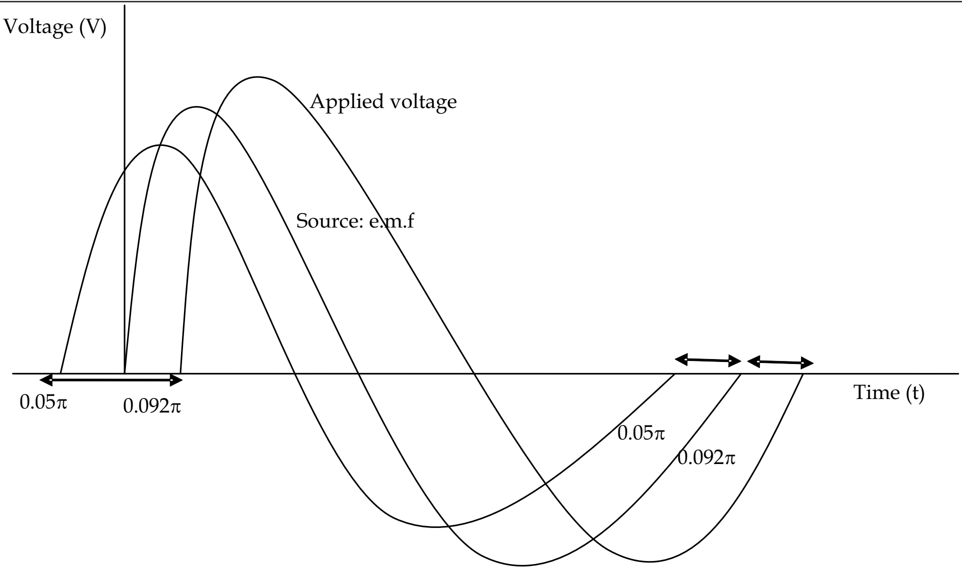


Fig. 4: The waveform of the load current, applied voltage and source e.m.f of the static capacitor.

Calculations for obtaining the different phase angles

Phase angle between the source e.m.f and applied voltage for electric heater = 0.130π

Converting to degree = 360×0.130
= 46^0

Phase angle between the applied voltage v and heater loaded current = 0

Phase angle between the source e.m.f and heater loaded current = 46^0 + = 46^0

Phase angle between the source e.m.f and applied voltage for an induction motor = 0.127π

Converting to degree = 0.127×360
= 45.72 (46^0)

Phase angle between the applied voltage and induction motor loaded current = 0.116π
= 41.76^0 (42^0)

Phase angle between the sources voltage and loaded current = $46^0 + 42^0 = 86^0$

Phase angle between the source e.m.f and applied voltage for static capacitors = 0.05π
= 360×0.05 degrees
= 18 degrees

Phase angle between applied voltage and static capacitor

Load current = 0.097π

= 360×0.097 degrees

= $34.9^0 = (35^0)$

Phasor Diagram Representation

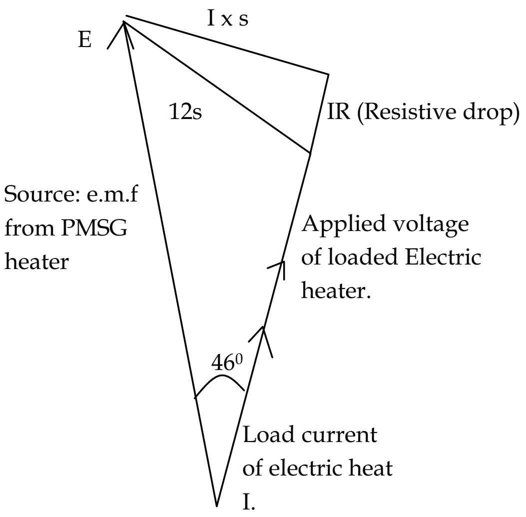


Fig 5:Phasor diagram for electric heater

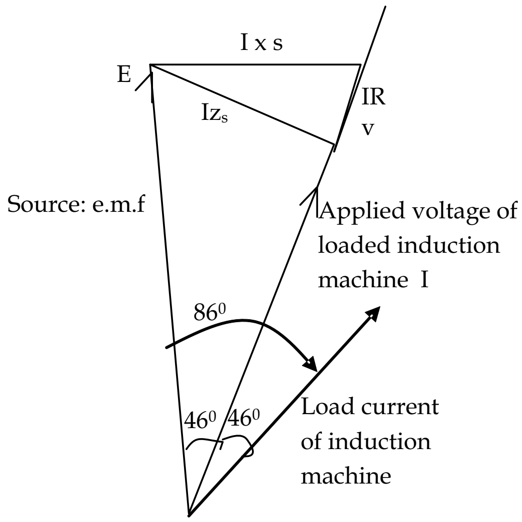


Fig 6: Phasor diagram for Induction motor

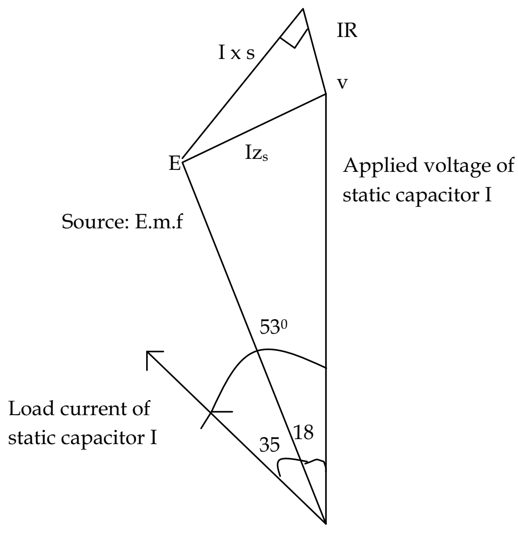


Fig 7: Phasor diagram for static capacitors

The Table Below Gives the Result for the Test

	e.m.f (E)	Applied Voltage (v)	Load current (T)	Phase (1)	p.f Cos ∅	Gen KVA rating
Electric heater	230	220	13.6A	0^0	1	3KVA
Induction	215V	200	15A	42^0	0.74314	3KVA
Static Capacitor	205V	210	14.2A	35^0 load	0.81 lead	3KVA

$$\text{Load current} = \frac{\text{Generator KVA rating x 1000}}{\text{Terminal voltage}}$$

$$= \frac{3 \times 1000}{220} = 13.6A$$

$$\text{Load current for Induction machine } I_1 = \frac{3 \times 1000}{200} = 15A$$

$$\text{Load current for statistic capacitor } I_{sc} = \frac{3 \times 1000}{210} = 14.2A$$

N.B (The lower the p.f, the higher the load current)

Discussion of Result

Here, result discussion is done in two ways (i) phasor analysis and (ii) table discussion.

Waveform Analysis

In the displayed waveform analysis for electric heater the load current for loaded heater LH attains its maximum, minimum and zero values at the same time. The applied voltage, attains is values i.e its maximum, minimum and zero values at time equivalent of 0.130 leading both the applied voltage and load current. For the loaded induction machine, the load current attains its maximum, minimum and zero values at time equivalent of 0.116 lagging the applied voltage whereas the applied voltage lags the source e.m.f at time equivalent of 0.127. The static capacitor's load current ahs a leading time equivalent of 0.097 leading. In this case, the applied voltage, having a greater magnitude now lags the source e.m.f by time equivalent of 0.05

Phasor Analysis

Phasor diagram is the phase angle difference between the voltage. Current and e.m.f. Therefore conversion of the time equivalents from radians to degree was done by simply multiplying by 3600. The angle obtained becomes the phase angle between the load current, source e.m.f and applied voltage as the case may be for the electric heater, there is no phase difference between the load current and the applied voltage. Thus having approximate zero phase difference implies that the load current and the applied voltage are in phase for a load electric heater. Both quantities lag the source e.m.f by an angle calculated to be 46^0. The resistive drop(IR) in the circuit which is a component of the total impedance drop is also in phase with both the applied voltage and the loaded current whereas the leakage reactance drop ahs a 90^0 phase difference with the two.

For the induction motor the load current lags the applied voltage by 42^0 and lags the source e.m.f by 56^0. Also the resistive drop in the circuit is in phase with load current, but not the applied voltage. The source e.m.f leads the applied voltage by 46^0. A leading case is obtained when the static capacitor is loaded in turn. Thus the load current leads the applied voltage by 58^0. The source voltage in this case is less in magnitude that the applied voltage and lags it by 18^0.

Table Analysis

Observation of the results in table I shows the KVA rating of the generator at 3KVA. This value is constant for all computations. Also the lower the power factor, the higher the load current and vise versa. For the power factor of 0.74314, the highest load current of 15A was obtained, whereas for the highest and unity power factor 1 of the electric heater, the lowest load current was obtained.

Conclusion

Knowledge of phase angle relationship between current and voltage for some linear and non-linear loads is very essential. First, it is a vital tool for power factor correction and enhancement. Low lagging power factors are undesirable in power systems, recording some disadvantages like low efficiency and voltage Regulation. Waveform and phasor comparative analysis become very necessary when it is observed that different loads have different waveforms when operating at three distinct states; transient state, steady state and operational pattern, hence the waveforms are known as load signatures. Also in phasor form when the phase relationship between the load current and the receiving end voltage of different loads are studied, the different phasor diagrams shown appreciable variables at different operating states.

Although this paper presents an insight into tariff prediction for various loads by knowledge of the waveform and phasor differences between load currents and receiving end (applied) voltages of different loads, it is desired that future research on this topic will provide a clearer mode of tariff prediction for various loads. Low lagging power factors cause grater I^2R losses and consequently greater increase in tariff. Furthermore an algorithm for loads is desired to be developed through this study. High tariff, low tariff, mid tariff, extra high tariff loads are observed through development of this study. It is a very common practice that nowadays, tariff from power distribution companies like the Enugu Electricity distribution companies are done by erroneous estimations, thus inconsistency in tariff of different loads becomes a problem,. Consumers always complain of high monthly tariff in their homes. Knowledge of the algorithm developed through this study will go a long way in solving disputes between power consumers and staff of the power distribution companies. Transparency developed through this will create a good working relationship between the consumer of power and officials of the power distribution companies.

Sometime in August 2011, in Okposi a town in south eastern part of Nigeria, some officials of the then National Electric Power (NEP Plc) were manhandled and brutalized. The reason is because a consumer had repeatedly written and petitioned the office of the general manager over what he called illegal and erroneous estimation of tariff repeatedly debited to him. The office seemed to turn deaf ears to his agitations and this made him to resort to self help by taking laws into his hands. This studies if developed will go a long way in solving these problems mentioned above.

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