 ISSN: 2321-8169
2745 - 2749

Investigation on the Performance of Metal Oxide Varistors in Energy meter

Srinath kv
Mtech student,EIE Department,
RNSIT, Bangalore, India
e-mail: srinath.reddykv@gmail.com

Dr. Andhe Pallavi
Prof. & HOD, EIE Department
RNSIT,Bangalore, India
e-mail: pallavi_ap@yahoo.com

***Abstract*—** An Energy meter includes current and voltage input, a surge protection section, a measurement device. The measurement device will generate power consumption measurements based on current input and voltage input. The surge protection section includes components like resistor, inductor, capacitor, Metal oxide varistors, and fuse. Metal oxide varistors are important devices which will mitigate the voltage spikes caused from lighting and other external sources. Every electronic equipment will undergo failure due to this overvoltage and spikes hence it is important to choose the proper overvoltage protector for the electronic equipment. This paper presents the performance analysis of the metal oxide varistors under different load conditions in an electronic Energy meter and a solution based on regression analysis for prevention of the failure of installed commercial energy meters hence resulting in reduced maintenance costs to the utility company.

Keywords: *Metal oxide varistors, Energy meter, field testing*

*****

I. INTRODUCTION

Electrical transients, over-voltage are disturbance in the power system which are caused by switching, faults, lightning, etc., if not properly controlled and reduced they can cause damage to equipment powered by standard AC input, or can adversely affect their performance. The electrical power utilities servicing electricity has to take responsibility to reduce the effect of transients on their network to level that are safe for their customers to utilize.

Uncontrolled transients can cause serious damage to the customers' equipment. On the secondary side of transformers, electrical equipment evaluated to global product safety standards, and they are equipped with minimum level of transient voltage that will be expected at different points and if the equipment cannot withstand that level of expected transient, hence the equipment should be protected by surge protection devices (SPDs) that knock transient voltages down to an accepted level.

II. DISTURBANCE IN POWER LINE

In a single-phase or three-phase utility power supply, the commercial companies are expected to supply AC power at a nominal RMS voltage with a percentage tolerance such as ±6% with limited amounts of harmonics as per applicable standards. However, the practical utility grade power supply carries many unwanted RMS voltage disturbances, harmonics, noise and transients. Figure 1 shows the ideal waveform of a 50 Hz, 230V RMS power supply and its corresponding frequency spectrum. Figure.2 and Figure.3 shows the RMS voltage disturbances and transients and noise respectively.

Voltage surges are voltage increase ie, overvoltage which is typically last from about 15 milliseconds to half of a second. A surge that lasts greater than two seconds is typically referred to as an overvoltage. Voltage sags are under-voltage conditions, which also last from 15 milliseconds to half of a second. Voltage sag that lasts for more than two seconds is typically referred to as an under-voltage.

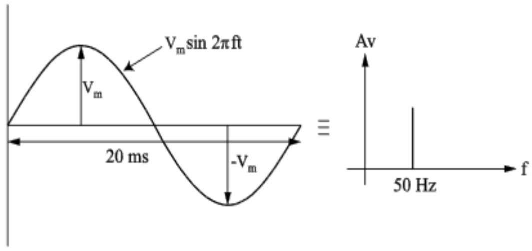

Fig. 1 Ideal sinusoidal wave and its spectrum

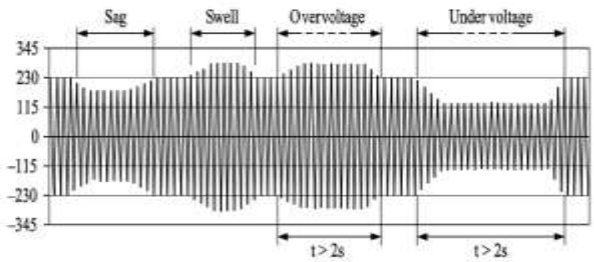

Fig. 2 RMS voltage fluctuation

Surge voltages occurring in low-voltage ac power circuits originate from two major sources, system load switching transients and direct or indirect lightning effects on the power system.

A power surge or a spike is an increase in voltage significantly above the standard voltage of 230 volts. The precise definition is:
1.When the increase lasts 3 ns or more, it's called a surge.
2.When it only lasts for 1-2 ns it's called a spike.
However, if the surge or spike is high enough, it will damage a device or machine. And in fact power-line Surges can easily reach 6,000 volts.

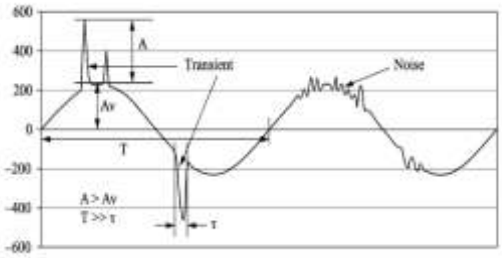

Fig. 3 Transient and Noise induced on sine wave

As shown in Figure.3 voltage transients are sharp. The sudden variation in voltage are commonly caused by the on and off of heavy loads such as, electric power tools, machinery, air conditioners and elevators. Lightning transients can cause even larger spikes in the electric equipment. Although they usually last lesser than 200 microseconds, which is positive or negative, in the range from about 180% of the AC peak value to over 6 kV can typically lead to dangerous situation to unprotected equipment. These high magnitude and sudden voltage variations can wipe out stored data, alter data in progress, and cause fatal electronic hardware damage.

Electrical noise is high-frequency interference which might vary in frequency from Seven thousand Hertz to over fifty mega hertz. Noise or burst of signal are often transmitted and picked up by the wire acting as an antenna or it are often carried through the facility line. These disturbances are often caused by the interference (RFI) from radio, Television signal, cellular and microwave transmission, radar, arcs and distant lightning. Noise also can be caused by electromagnetic interference (EMI) produced by electrical type writers, heaters, air conditioners, and different thermostat-controlled or motor-operated devices.

Although generally non-destructive, electrical noise can sometimes pass through a power supply as a signal and can wipe out stored data or cause erroneous data output. Problems result when electronic circuitry is invaded by transient, high frequency voltages collectively called “line noise”.

Harmonic distortions are sometimes caused by the employment of nonlinear loads by the users of electricity. Nonlinear loads, a massive load caused by the power electronic devices, draw current typically in non-sinusoidal manner. With the major use of such devices by consumers, the presence of distortions in current and voltage waveforms became a frequent incidence nowadays. it\'s quite common to own a flattened-top wave with these nonlinear loads like pc power provides, UPS rectifiers. The final result would be the terminal voltage at the user end which is going to be a non-sinusoidal wave with a good deal of harmonics.

III. METAL OXIDE VARISTOR

A. Review of the literature

A varistor or metal oxide varistor (MOV) is a special resistor that is used to protect circuits against high transient (short term) voltage called as surges, these surges and spikes attacks the equipment by the power line and will destroy the power supply of the equipment. A varistor is able to short these surges and spikes and keep them away from these surges.

B. Function and VI characteristics

Under normal conditions the resistance of the varistors is very high. When the connected voltage gets higher than the specification of the varistor the resistance immediately gets extreme low. This circumstance is used to protect electronic applications from over-voltage.

The varistors is simply added to the power supply input. When high voltage surges and spikes appear the varistor will short them and protect the circuit after the varistor as shown in the Figure. 4

The varistors electrical characteristics Voltage- Current characteristics curve are normally expressed as in the Figure 5.

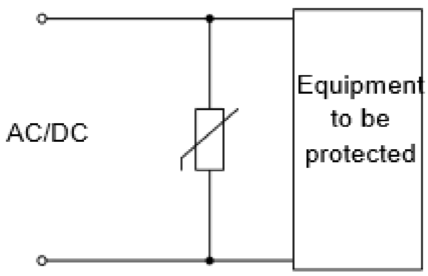

Fig. 4 Varistor at the input as protector

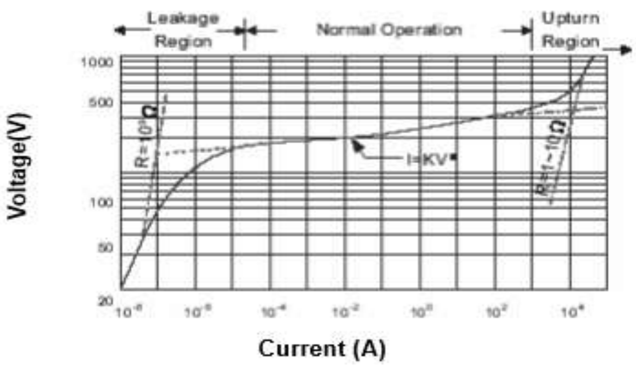

Fig .5 VI characteristics of MOV

At leakage region, the V-I curve shows a linear relationship. The varistor is in high resistance mode and shows as an open circuit. In normal operation, the V-I curve of a varistor from the figure 5 can be described by Equation (1).

$$I=KV^{\alpha} \tag{1}$$

Where K is a constant dependent on the materials of the device and α defines the degree of nonlinearity of device conductance I and V are current and voltage respectively. At high current, the varistor is in low resistance mode and shows as a short circuit.

IV. CASE STUDY

The energy meters with AC supply of 230v were getting turned off due to overvoltage in the field condition. Based on the situation and observation, concluded that the problem was

ISSN: 2321-8169
2745 - 2749

with metal oxide varistor which acts as overvoltage protector in the input section of energy meter. Solution was drawn with experimental and statistical analysis that the metal oxide varistor with higher clamping voltage has to be used in the input section.

V. EXPERIMENTAL ANALYSIS

To stimulate the field conditions the following Design of experiments identified to confirm the root cause as high voltage site condition.

a) Verification of MOV clamping voltage as the voltage rating is 230 +/- 10% tolerance.

MOV (S14K230) is connected in parallel with power supply and in series with ammeter and resistor . The voltage from 200v to 275v was given with interval of 10v.when an external tiny voltage is applied across the electrodes, a reverse leakage current appears across the MOV.

The current produced will also be very small. But, when a large voltage is applied across the electrodes, the junction breaks down as a result of the combination of electron tunneling and avalanche breakdown.

Thus the device is said to show a high level of non-linear voltage – current characteristics. From the characteristics, it has noted that the component will have low amount of resistance at high voltages and high resistance at low voltages.

MOV clamping voltage as the voltage rating is 230V +/- 10% tolerance. When they absorb excess transient voltage they tend to dissipate it as heat. When this process of supplying overvoltage than the threshold of the component, continues repetitively for some time, the device begins to wear out due to the excessive heat.

b) Connecting the Energy meter to auxiliary supply. Supplying voltage greater than threshold of meter to confirm whether the meter is working fine.

10 sample of meters with the reference number/ serial number as shown in table 1 are taken. For each meter the auxiliary supply is given as shown in the figure 6. Supply is given from the voltage (0 to325v) and ampere readings are noted which is listed in Table 1.

Meters were able to sustain 300v of supply and getting turned off if the supply is more than that of 300v. Here in the table 2 in each row of meters, the last column indicates the meter sustainable range of voltage supply with respect current.
After the respective threshold voltage or current the meters will get turn OFF, at this condition if user make the supply to nil for about 2 minutes and then applying cut off voltage to turn on the meter

TABLE 1: Auxiliary supply on meter test analysis

SL no	Meter SL no	250v	260v	270v	280v	290v	295v	300v	305v	310v	315v	320v	325v
1	34132640813	11.1	11.4	11.7	12	13.2		15.5	21.7	30	41		
2	34122723832	10.5	10.7	11	11.2	11.3		12.2	13.4	16.4	22.2	30	54
3	34120712727	11	11.3	11.6	12.5	13.9		20.4	27	33	45	52	
4	34122430349	10.5	10.7	11.1	12.2	10.2		23	30	41	50		
5	2168971/ 5746408-5111	10.8	11	11.3	11.8	13	16.2	20.9	26	33	42		
6	34134820785	11	11.5	12.9	17	27	41	54					
7	34132640875	11.1	11.3	12.1	14.4	21.5	28	39.5	55				
8	34134820786	11	12.1	16.7	28	50							
9	34134914120	11	11.3	12.1	13.4	20	24	30	42	48			
10	34122720083	10.5	10.9	11.2	12.3	14.5	19	22	29	39	47		

c)Verification of meter display at different temperatures.

Sample 10 meters with the same reference number are taken and connected them in series and auxiliary supply from the voltage range 0 to 325v is given as shown in the figure 7.
All 10 meters were placed in the heat chamber and maintained the temperature of 45, 50, 55, 60 degree centigrade respectively. Test were performed for each temperature by varying the voltage from 0 to 325v.

Fig 7: Sample meters in the Heat Chamber

TABLE 2: Voltage Analysis of sample meters at respective temperatures

SL no	Meter Sl no	45*C	50*C	55*C	60*C
1	34134820786	290	290	288	288
2	216897/5746408	315	315	314	310
3	34120712727	315	315	314	310
4	34134914120	300	310	305	305
5	34132640813	305	305	300	300
6	34132640875	300	300	298	295
7	34134820785	300	300	295	290
8	34122723832	334	325	320	319.5
9	34122430349	328	320	319.5	319.5
10	34122720083	315	310	310	305

For the temperature with 45*C, say the meter with reference number- 34134820786 is got turned OFF for the given voltage of 290v. Similarly all the meters were got turned OFF as the voltage raised at 45*C as shown in the first column of table 2. Similarly for other temperatures the meter characteristics which got turned OFF as voltage raised.

d) Verification of meter display status at different harmonics

Here meters were subjected to Harmonics say for 5th, 7th, 9th 11th and 21st using harmonic analyzer.

A harmonics analyzer is used to provide a detailed analysis of the suspect source. Using this data, the harmonic ratio function calculates a value from 0% to 100% to indicate the deviation of non-sinusoidal and sinusoidal waveform

ISSN: 2321-8169
2745 - 2749

TABLE 3: Harmonics subjected to MOV

Harmonics	5%	10%	15%	20%
5	49*	79.5	600	4000
7	51	59.5	74.5	115
9	54	77.2	280	1050
11	54.7	73.6	117.6	649
13	57.5	84.5	214	780
21	66.5	108.9	214	757

Harmonics degrade the level of power quality and its efficiency. Here from the data in table 3 shows that MOV will have significant effect from harmonics. Similarly Harmonics were subjected to Energy meter, results showed the harmonics on meter have significant effect.If the nonlinear loads exceed 20%, some non-apparent negative consequences can result.

VI. CAUSE AND EFFECT MATRIX

A Cause and Effect matrix is often used to link the Critical to Quality aspects of the project to the Causes and Effects of a problem that have already identified.

Critical to Quality aspects, also known as CTQs, are the factors that are recognized to be critical to customer satisfaction and the success of the business. Critical to quality factors are most often related to low defects and high-quality products and services.

The C&E Matrix is a very useful tool that can be used to prioritize these critical to quality factors that have the highest impact on a process, and to choose the right ones for further measurement.

For no display failure of energy meter in Schneider electric company the following cause and effect matrix has been recorded as shown the figure 8.

With the results of Cause and Effect Matrix, it is very evident that Auxiliary Voltage, Harmonic conditions and Temperature have high impact on meter display results.
Hence the further investigation on these three factors and perform logistics regression to understand statistical behavior of chosen factors.

VII. STATISTICAL ANALYSIS AND RESULTS

For statistical analysis the Minitab tool was used. This is most widely used tool to get the statistical model in Quality.
Binary logistics regression was done with the Factors: Auxiliary Voltage, Temperature, and Harmonic condition and response as meter display results.

		1	2	3	
		No Failures in displaydue to Power supply issues	No Failure in Display due to microcontroller issues	No Failure in Display due to Software corruption issue	
	Customer Priority	9	3	3	
	Process Input				Total
1	Harmonics condition	9	3	3	99
2	Auxillary connection of Meter	9	1	1	87
3	High Voltage Coupling on voltage measurement section	1	8	7	54
4	High Voltage coupling of RS485 communication	1	5	5	39
5	design Specs of MOV	8	1	1	78
6	Temperature	8	4	4	96
7	Humidity	5	1	1	51
8	Auxillary Voltage	9	6	6	117
	Total	450	87	84	

Figure 8. Cause and effect matrix recorded in Utility company

For the response two conditions were considered as shown below

1) Meter Display OK - 1
2) Meter Display NOK – 0

Factors from experimental data is taken and regression has been done. Total trail for experiment was 64 runs.

1. Auxiliary Voltage (in V) : 290, 300, 310 and 320V
2. Temperature (in Degree C) : 45,50,55,60 Degree C
3. Harmonic condition (in %): 5, 10, 15, 20 %

Binary logistics regression results for Temperature versus auxiliary voltage versus harmonics are obtained which is as shown in the figure 9.

a) Interpretation of the results obtained by regression

1. Low P-Value (< 0.05) of Auxiliary Voltage and Harmonics signify that they are significant and are having high contribution for display results, however Temperature has no significant contribution.
2. High R Sq signifies that the selected factors explains high proportion of variations in “Display Results”
3. Negative coefficients signifies that Auxiliary voltage and field Harmonics yields better display results when they are at lower values of specification
4. Low odd ratio for Auxiliary Voltage indicates that every 10V increase will have lower odds of occurring Ok Display results, similarly every 5 unit increase in Harmonics will have lower odd of occurring Ok display results
5. High P Value (> 0.05) is a indicative that the model fit the data well

ISSN: 2321-8169
2745 - 2749

Binary Logistic Regression: Displayresul versus Temperature , Auxillary Vo, Harmonics Da

Link function Logit
Rows used 64
Response Information

Variable	Value	Count	
Displayresult	1	20	(Event)
	0	44	
	Total	64	

Deviance Tabl

Source	DF	Adj Dev	Adj Mean	Chi-Square	P-Value
Regression	3	60.3663	20.1221	60.37	0.000
Temperature (Deg)	1	0.4733	0.4733	0.47	0.491
Auxillary Voltage (V)	1	48.1329	48.1329	48.13	0.000
Harmonics Data (in%)	1	29.0991	29.0991	29.10	0.000
Error	60	19.1328	0.3189		
Total	63	79.4991			

Model Summary

Deviance R-Sq	Deviance R-Sq(adj)	AIC
75.93%	72.16%	27.13

Coefficients

Term	Coef	SE Coef	VIF
Constant	167.6	57.5	
Temperature (Deg)	-0.072	0.107	1.05
Auxillary Voltage (V)	-0.520	0.178	5.81
Harmonics Data (in%)	-0.737	0.260	5.79

Odds Ratios for Continuous Predictors

	Unit of Change	Odds Ratio	95% CI
Temperature (Deg)	5	0.6969	(0.2445, 1.9862)
Auxillary Voltage (V)	10	0.0055	(0.0002, 0.1822)
Harmonics Data (in%)	5	0.0251	(0.0020, 0.3197)

Regression Equation

P(1) = exp(Y')/(1 + exp(Y'))

Y' = 167.6 - 0.072 Temperature (Deg) - 0.520 Auxillary Voltage (V) - 0.737 Harmonics Data (in%)

Goodness-of-Fit Tests

Test	DF	Chi-Square	P-Value
Deviance	60	19.13	1.000
Pearson	60	38.24	0.987
Hosmer-Lemeshow	8	3.73	0.881

Fig 9. Results obtained by logistics regression

Main effects plot for display results was obtained which shows the best fitted probabilities for auxiliary voltage and harmonics.

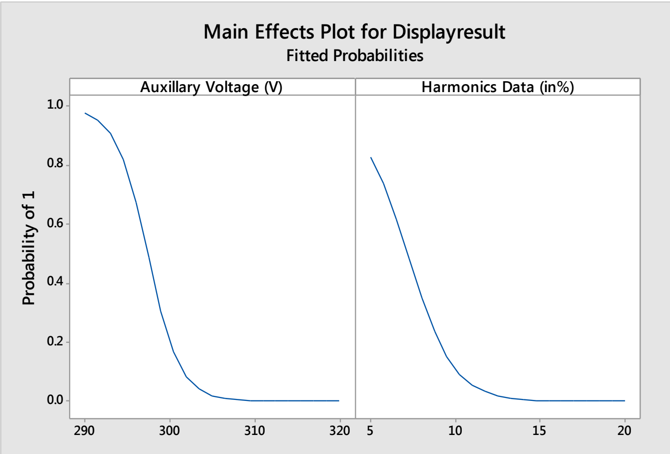

Fig 10. Plot for display results

"0" represents display failure
"1" represents display is OK

VIII. CONCLUSION

1. High Auxiliary voltage and High field Harmonic condition impacts the display results adversely.
2. Probability of best results for display (with 95% confidence) can be obtained at Auxiliary Voltage < 292 V and Harmonics < 6%.
3. By now it is understood that due to High voltage and Harmonics conditions, the meter goes in "No display mode". We carried further simulation to understand that the display is recovered once the auxiliary power is switched off and switched on after 10 minutes of idle time.
4. Awareness among the customers about the simulation as a temporary solution.
5. Increase MOV rating to accommodate high impact of Auxiliary voltage on the meter display. By analyzing the data sheet go for next higher rate of clamping voltage.
   Current spec of MOV : 230V
   Recommended spec : More than 250v.
6. Rating of other components like capacitors has to changed according to the new specification of MOV.

IX. REFERENCES

[1] Cerdson de salles, Manuel LB. Martinez, "Ageing of Metal oxide varistors due to surges", 2011 International symposium on Lightning Protection, Fortaleza, Brazil, Oct 3-7.
[2] IEEE Working Group 3.4 11, Modelling of Metal Oxide Varistors Surge Arrestors, IEEE Transaction on Power Delivery, Vol.7. No 1.
[3] Metal Oxide Varistor: a new way to suppress transients by J.D Harnden and F.D martzloff Corporate Reaserch and Development, General Electric.
[4] Epocs, Leaded Varistors- Datasheet.
[5] ABC of MOV, Application Note By Little Fuse.
[6] Selecting varistor clamping voltage: Lower is not better! By François D. Martzloff and Thomas F. Leedy National Institute of Standards and Technology.
[7] ANSI C84.1-1982, American National Standard Voltage Ratings for Electric Power Systems and Equipment.
[8] Minitab Tutorials for Design and Analysis of Experiments by Dr. Jianbiao (John) Pan.
[9] Power Factor and Harmonics, Energy University, Schneider Electtric Pvt, ltd.
[10] Transient Overvoltage Protection by ON Semiconductor, TND335/D Rev. 0, APR – 2008
[11] The Seven Types of Power Problems by Joseph Seymour, Schneider Electric.