Variable Frequency HV Testing of Capacitor Using PIC 18F452

S. D. GOKHALE and Dr. S. A. PATIL

Abstract: The damage to power capacitors caused by harmonic pollution was very serious in recent years due to the wide spread of power electronic related, nonlinear loads. The violent failure of power capacitors may result in power interruption and even accidents in industry. In this paper, pic microcontroller based testing method is designed for dielectric testing of the capacitor. A pic microcontroller generates variable frequency sine and square wave and power MOSFET is used in H bridge , signal is then stepped up using transformer at the secondary the test capacitor is connected. For sine wave push pull configuration is used and along with voltage the frequency of the signal is also varied. The variation is as per the harmonic requirement. The variable frequency high voltage testing certainly helps in finding performance of capacitor.

I: INTRODUCTION

High dielectric constant material thin films are now commonly used in microelectronic devices. [2] The characteristics, such as dielectric constant and dielectric loss tangent, directly determine the quality of the devices and systems. Before high-k materials can be used in conjunction with modem Si processes for circuit design, the materials must be accurately characterized. An advanced test structure design methodology for dielectric characterization of novel high-k materials has been proposed. In order to extract the dielectric constant (Er), a number of different coplanar-waveguide structures and circular capacitor test structures have been designed. For initial characterization, the circular capacitor test structure has been found to be the most straight- forward to interpret. The main difficulty in verifying a particular wafer probe characterization method is the lack of an available standard which can be used for reference purposes. Thin dielectric composite films with enhanced electrical and mechanical properties are used in electronics as building blocks of functional circuits and as the insulation materials for power distribution. The electrical performance of these materials can be evaluated by measuring the dissipation current, breakdown voltage, and/or dielectric loss tangent. The conventional standard testing procedures that are currently in use have been developed for thick high-impedance dielectrics and measure performance in terms of breakdown voltage. Since the impedance of thin dielectric films and those with a high dielectric constant is rather low, conventional measurement procedures are inadequate and may lead to ambiguous results.

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The conventional testing techniques use either dc or ac current. However, ac testing voltage is preferred, especially for asymmetric metal-insulator configuration that may have rectifying characteristics and for high- composite materials that exhibit dielectric saturation and/or polarization reversal. Under ac high field the dielectric response can be nonlinear. Monitoring and analysis of both the incident voltage and the resulting current waveforms is a more useful mean for proper evaluation of the dielectric responsiveness The measurement of nonlinear di-electricity in ferroelectric polymers using computerized Data Acquisition and digital Fourier transform techniques was described by Furukawa . To date, no published successful attempt has been made to measure complex impedance, the phase component of the dissipation current as a function of a high ac voltage. This system describes a measurement technique for recording and analyzing the incident voltage and the resulting dissipation current waveforms at fundamental frequency and higher order harmonics using a multichannel DAQ card. This technique is applied to determine the complex impedance and nonlinear dielectric response at high ac voltages. The effect of high voltage on the electrical performance of materials and nonlinear dielectric response is to be monitored for conventional BOPP dielectrics and for novel composites with enhanced dielectric properties.

Fig.1 shows the block diagram of the VVVF power supply. PIC 18F452 is used to generate variable frequency sine wave as well as square wave required for testing. The H-bridge topology has been used for switching. The step up transformer is used to get the high voltage level.The H-bridge is power MOSFET based and its switching is controlled by a buffered isolated driver card that in turn is controlled by a micro-controller. The micro-controller adjusts the timing sequence for switching requirements of MOSFET including the Dead Time. This is achieved by programming its 16bit timers, to generate pulsed waveforms of desired frequency (50 Hz to 750 Hz). The frequency is varied using a push button interfaced to the microcontroller. An LCD can also be interfaced with the microcontroller to display the online frequency.

II: Proposed system

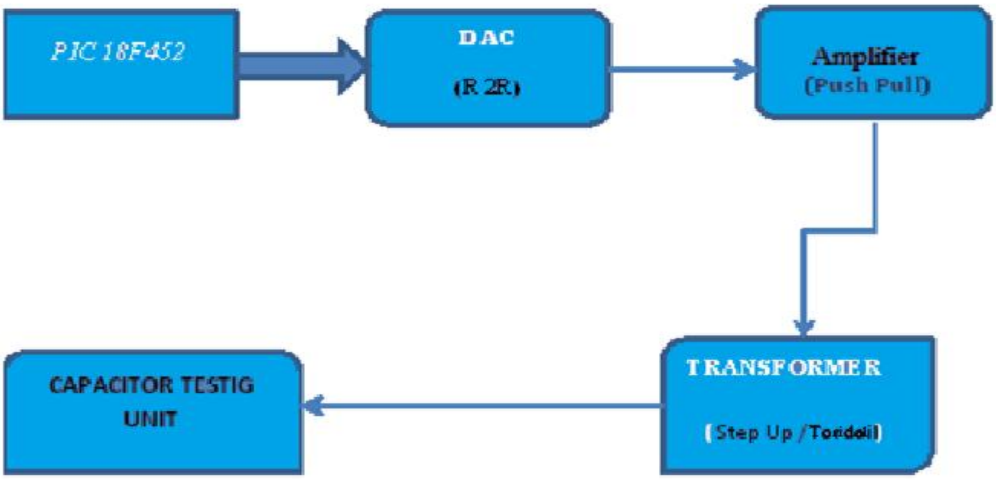


Fig.1 block diagram

III: Hardware requirement

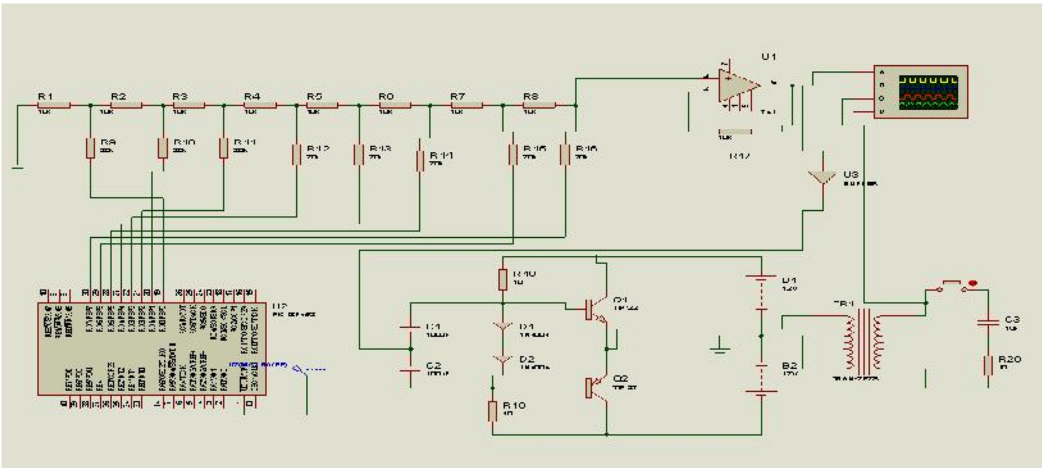


Fig 2 Variable frequency high voltage sine wave generation

IV :Current threshold detection

When a test voltage is applied to a sample, you observe - up to a certain value of the latter - a proportional increase in the leakage current; this current is due to the insulation resistance and/or the capacitance of the item tested (with AC, or by load effect in DC). As shown in Diagram 3, as from the voltage the leakage current increases very swiftly and the breakdown voltage is reached for value V1. The current is then at a maximum, its value is determined by the current capacitance of the dielectric strength test station, or - an instantaneous value - by the discharge current of the capacitive element of the sample (value that cannot be tested by the dielectric strength tester and which can in certain cases involve destruction of the insulator). Current threshold detection consists in choosing a value Is of the leakage current, corresponding to a voltage V1 and to consider as bad any sample whose leakage current exceeds the value Is chosen as detection threshold. The most widespread value of the threshold current and generally adopted for non-destructive tests is 1mA. [1][9] Although the use of this detection method and the choice of this value does not offer any difficulty for DC tests on purely resistive components it becomes inaccurate and delicate to use for AC tests on capacitive elements. When the high voltage is applied, some current flows even when there is no breakdown. This current is caused by a parallel combination of the insulation resistance and capacitance that are formed when two conductors are separated by an insulator. When using an ac test voltage, the capacitance is the major cause of the current flow. A false indication of failure can occur when the trip current on the hipot tester is too low. Many testers indicate a failure when the current exceeds a preset limit between 0.5

and 20 mA. Any current beyond the trip limit will cause the tester to indicate a failure, even though the current is not caused by a breakdown in the insulation. To make matters worse, switching type supplies use line-to-ground capacitors to reduce the EMI. When the ac hipot voltage is applied from ac input to ground, the current flow caused by these capacitors will be sufficient to cause some hipot testers to indicate a breakdown that may or may not exist. If ac voltages are used, any line-to-ground capacitors can be temporarily removed from the circuit. This is permitted for type tests, but is obviously impractical for production testing. A hi-pot tester with higher current capability must be used.

Primary-to-secondary hi-pot problems:

When testing from primary circuits to secondary circuits, extraordinary effort must be made to prevent basic insulation from being overstressed. Safety standards identify the insulation used between primary or secondary circuits and ground as basic insulation. The higher voltages specified for primary to secondary tests will overstress the basic insulation which is intended to support only 1500 V. This can result in a catastrophic failure of the unit. Most low-voltage secondary circuits are connected to ground. With the secondary circuits grounded, the hipot voltage is unavoidably applied from primary circuits to ground. Arcing across spacing's from primary circuits to ground under these conditions does not constitute a failure of the reinforced insulation. It has been suggested that removing the ground connection from the low-voltage secondary will solve this problem. This is not necessarily true. The insulation from secondary circuits to ground usually can withstand only a few hundred volts. Most switching supplies use secondary-to-ground capacitor of at least 10 nF to reduce the EMI and output ripple in the event that the output is not grounded. With the outputs ungrounded, this capacitor is effectively connected in series with the ac line-to-ground capacitors. This series combination acts as a voltage divider. The result is that a portion of the hi-pot voltage appears between primary circuits and ground and the rest between secondary circuits and ground. Depending on the ratio of the two capacitors, either the basic insulation in the primary circuit or the secondary circuit (frequently both) will be over-stressed.

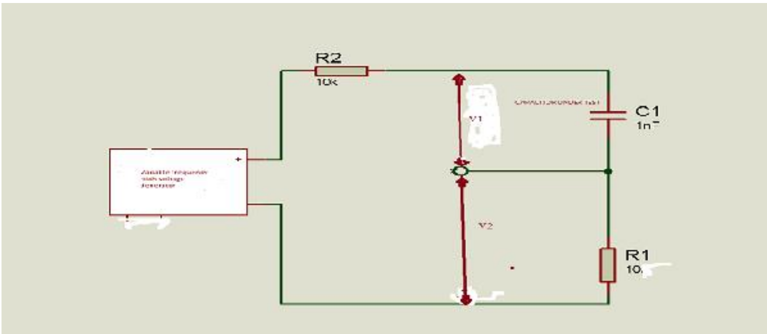


Fig 3 Simplified test loop

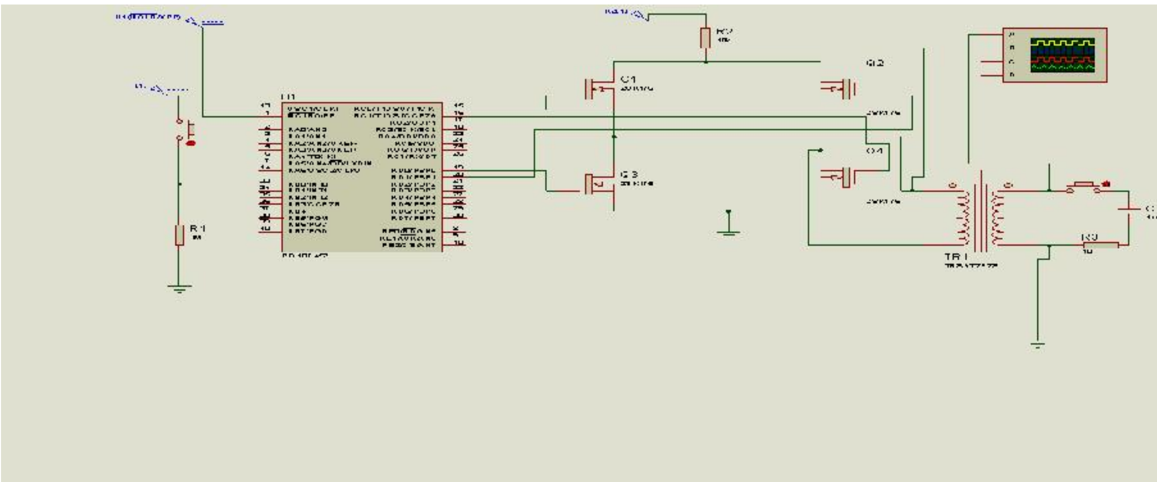


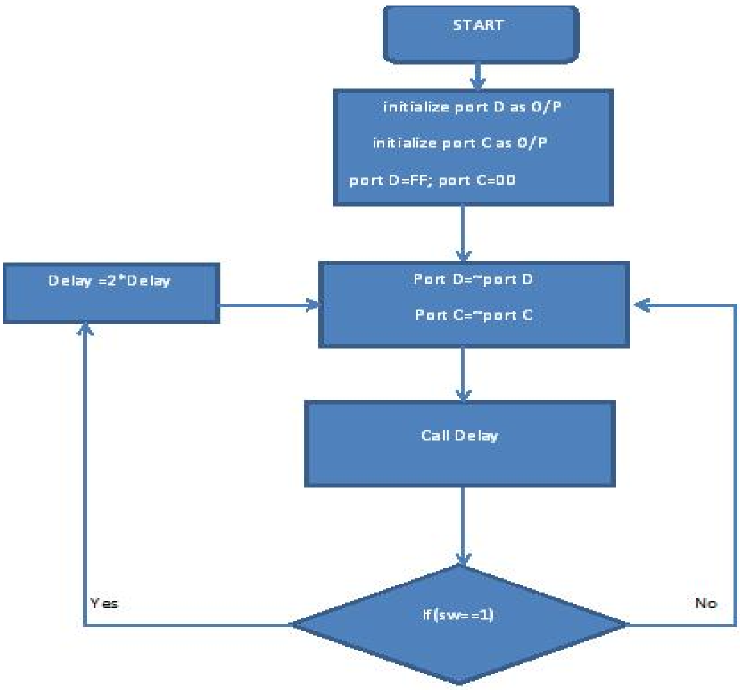
Fig 4 Variable frequency high voltage square wave generation

This mode of detection cuts out the defects of the previous method; it is justified by the actual nature of the breakdown phenomena. [4][5] Through observation of the breakdown phenomena, via oscilloscopic methods, it is possible to assert that they are featured by very sharp variation in current in the test circuit; this latter consists of the dielectric strength test station and the sample tested (Fig 3). The breakdown is always preceded by partial discharge phenomena that we shall analyze further on. The breakdown current in itself generally has the form of an extremely steep positive-going edge pulse, lasting about 1 micro-second or even less, and whose peak value is limited by the combined characteristics of the test station and the sample being tested. As shown in Diagram 3, the discharge pulse has practically no steady level and the pseudo - exponential negative - going edge whose time constant is variable (it depends on the transfers of energy in the dielectric at the time of the breakdown). The use of detectors which only take into account the rapid variations in the leakage current can eliminate the causes of error due to the permanent current flowing through the sample (impedance of the element). ΔIr = 1 mA variation is the value most currently employed to characterize a breakdown. It must be linked to the detector's response time. The response time is very important in determining the breakdown voltage. In fact an over-rapid detection (less than 1 micro-second) would make the apparatus sensitive to the partial discharge phenomena preceding the breakdown. In return, a slow detection (more than some tens of micro-seconds) can make the apparatus insensitive to certain breakdowns whose energy (produce $\Delta If^2.\Delta t$) will be sufficient to be destructive, but whose duration is too short to be taken into account by the detector. The detector's response time should however be very short to avoid micro-carbonation phenomena on certain insulators or the definitive destruction of others.

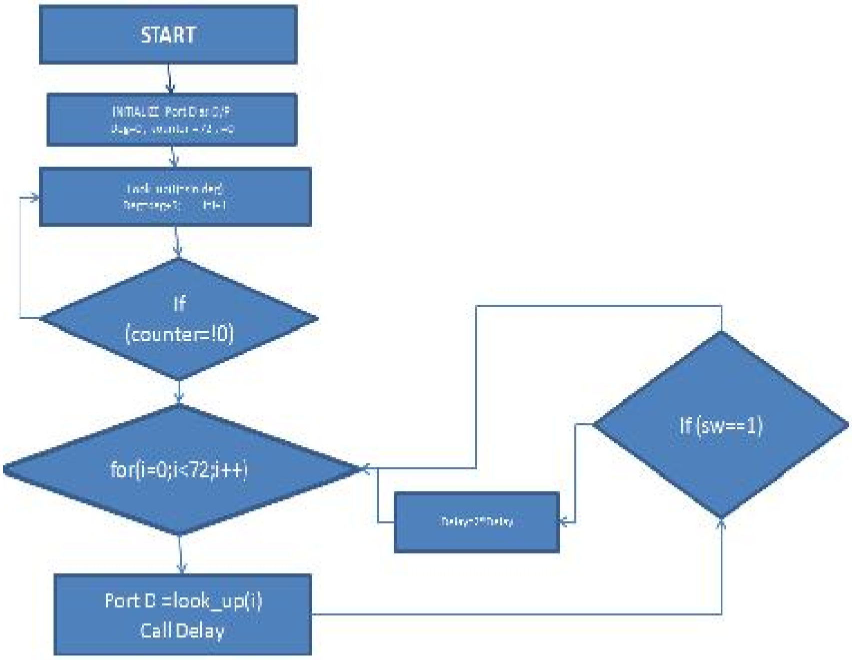
V: Software Requirement.

The program flow is given below. The default frequency of the output pulse is set to 50Hz. As soon as the system is started, the output generates 50Hz. This can be simultaneously displayed over the LCD. The frequency is generated using digital equivalent value of analog sine wave. The program then waits for the push-button to be pressed (for a change in frequency). Once the push button is pressed, the program counter increments to the new value in the look up table (LUT) and collects the data and starts generating the new frequency with the simultaneous display over LCD. A circular programming loop is used for frequency increments .For sine wave digital equivalent value is generated and applied to R-2R ladder network

FOR VARIABLE SQUARE WAVE



FOR SINE WAVE GENERATION



PROGRAM FOR SINE WAVE GENERATION

```
        unsigned int i,j,arry[72];
//short int arry[36] ;
void main()
{
TRISB=0X00;
TRISD=0X00;

 j=0;

 for(i=0;i<72;i++)
 { arry[i]=(sinE3(j)/10)+127;
 j=j+5;
 }
 do{
 for(i=0;i<72;i++)
 { PORTD=arry[i];
 Delay_us(330);
 }
  }while(1);    }
```

PROGRAM FOR VARIABLE SQUARE WAVE

Actual C Program for Square wave generation

```
unsigned  int i,j,k;

void main()
{
TRISB=0XFF;
TRISC=0X00;
TRISD=0X00;
LATC=0XFF;
LATD=0X00;
j=0X01;
do
{
if(PORTB==0X01)
{
j=j+1;
Delay_ms(1000);
}
switch(j)
{
case 1:
Delay_us(656);
break;
case 2:
Delay_us(755);
break;
case 3:
Delay_us(892);
break;
case 4:
Delay_us(1091);
break;
case 5:
Delay_us(1428);
break;
case 6:
Delay_us(1990);
break;
case 7:
Delay_us(3100);
break;
```

```
}
LATC=~LATC;
LATD=~LATD;
}while(1);
```

VI: Results

Observation Table-I

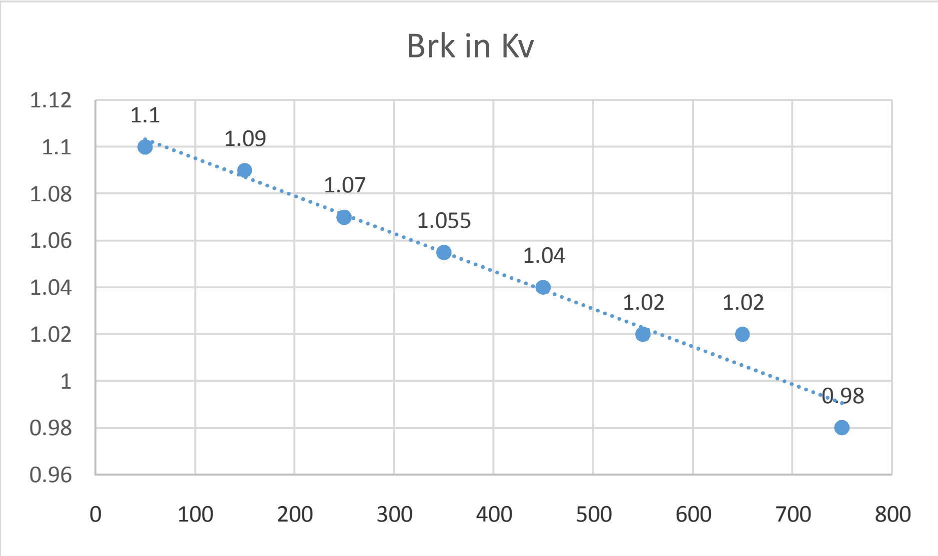
Capacitor Type	Nominal voltage (kV)	Capacitance before breakdown (pf)	Resistance after breakdown (Ohm)
Ceramic disc	1	1	4-9
Ceramic disc	1.2	10	5-11
Ceramic disc	1.2	100	6-14
Ceramic disc	1	1000	4-17
Ceramic disc	.75	100	4-19
Ceramic disc	1	1	4-9
Ceramic disc	1	1	4-9

Observation Table-II

Capacitor Type	Nominal voltage (kV)	Capacitance before breakdown (pf)	Resistance after breakdown (Ohm)
Film capacitors	.65	1	7-11
Film capacitors	.75	10	5-11
Film capacitors	.75	100	6-14
Film capacitors	.75	1000	5-11
Film capacitors	.70	100	6-16

Observation Table-III

F in Hz	Break down voltage in Kv
50	1.1
150	1.09
250	1.07
350	1.055
450	1.04
550	1.02
650	1.02
750	0.98



Relation between breakdown voltage and frequency

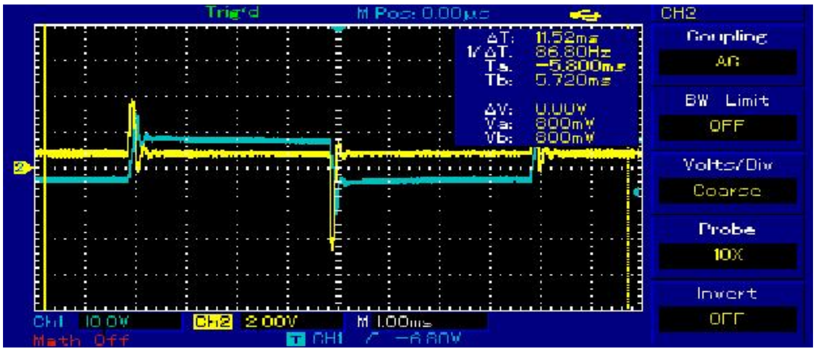


Fig 5Typical waveform of the leakage current variation during a breakdown

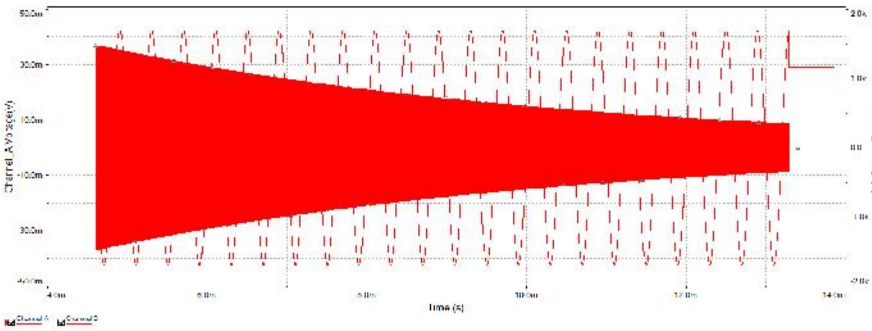


Fig 6:Typical waveform for sine wave.

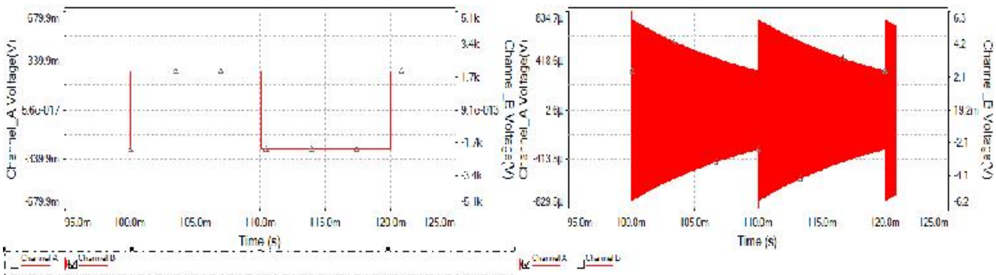


Fig 7:Transient response for 50Hz

For this reason and especially since 20 years ago (commercialization of the first ΔI current variation detectors), the response times lie between 19 and 20µs. Here again a different setting on precise and clearly defined grounds, may be considered necessary. Nevertheless the availability of this parameter to an uninformed operator, risks making the breakdown station systematically destructive and the results obtained perfectly incoherent, if the initial conditions and the reasons for their choice have not been clearly indicated. Moreover it is easy to imagine the divergencies of view which would not fail to arise between customers and suppliers and also between production and "quality control" departments. Numerous observations on a very broad variety of components and sub-assemblies have fixed an optimum response time of around 10 µs.

VII: Conclusion

The development of HV equipment should be combined with the development of the related test techniques. Most of the existing standards need only an extension up to the voltage level of the HV equipment. For some particular points research work are necessary. It should be evaluated if the extension of the front time or the acceptance of a large overshoot for lightning impulse tests could be accepted without weakening the test requirements. It should be evaluated if the time to peak should be adapted for test of HV equipment with switching impulse voltages. It should be defined a linearity test for high voltage dividers with very high rated voltage. It should be defined a wet test for HV equipment with large dimension taking into account the distance between the rain equipment and the equipment under test due to the high test voltage. It is clear that some capacitors can be operated for short times and for a number of cycles at voltages from 10 to 17 times the nominal rating. The energy stored in the capacitors for a short time under overstress conditions is from 100 to 250 times higher than their normal energy. It does matter which type of capacitor and it may matter which manufacturer. Of course, the data presented here is for a limited number of samples and it is always possible that capacitors with the same ratings produced in different runs by the same manufacturer may exhibit different breakdown voltages

VII: References

[1] Sergey I. Shkuratov Evgueni F. Talantsev Lynn L. Hatfield "*Single-Shot, Repetitive, and Lifetime High-Voltage Testing of Capacitors*" IEEE Transactions on PLASMA SCIENCE, Vol. 30, No. 5, October 2002

[2] J.-C. Wu, H.-L. Jou, K.-D. Wu, Y.-T. Kuo and Y.-J. Chang "*Power converter based method for suppressing power capacitor harmonic current*" IEEE Proc.-Gener. Transm. Distrib., Vol. 151, No. 3, May 2004

[3] X. Qi Z. Zheng S. Boggs " *Engineering with Nonlinear Dielectrics*" IEEE Electrical Insulation Magazine Vol. 20, No. 6 November/December 2004

[4] Jan Obrzut, Member, IEEE, and Kenji Kano , "*Impedance and Nonlinear Dielectric Testing at High AC Voltages Using Waveforms*" IEEE transactions on instrumentation and measurement, vol. 54, no. 4, august 2005

[5] J. Obrzut and K. Kano " *Non-linear Dielectric Testing at High AC Voltages using Waveforms and Harmonics*" Annual Report Conference on Electrical Insulation and Dielectric Phenomena Nov 2005

[6] Guo Jun, Qiu Jianxin, Chen Yin, Xie Xiao Jie and Lianjinxin " *High-Power, High-Frequency and High-Voltage Power*" Paper 11B2 ICESP X – Australia 2006

[7] Wenbin Chen, Kevin G.McCarthy and Alan Mathewson "*Practical Considerations for Measurements of Test Structures for Dielectric Characterization*"IEEE Transactions, Vol 49, No 5, Sept. 2009

[8] S. R. Jang1 H. J. Ryoo J. S. Kim Y. B. Kim "*Design and testing of the high voltage Capacitor charger for 150KJ pulsed power application*" IEEE Transactions 2009

[9] Dr. Norbert Grass Dr. Michael Steingraeber Roland Metz ," *A new Mobile IGBT Inverter HV Test System for Electrostatic Precipitators*" IEEE Transactions 2010

[10] Fuji IGBT modules application manual Feb. 2011

[11] Toyohashi Univ. of Technol., Toyohashi, Japan ; Kurimoto, M. ; Takahashi, R. ; Kawashima, "*Dielectric breakdown mechanism of polypropylene laminated paper in liquid nitrogen*" Electrical Insulation and Dielectric Phenomena (CEIDP), 2011 Annual Conference 16-19 Oct. 2011

[12] Chen, George Zhao, Junwei University of Southampton, SO17 1BJ, United Kingdom , "*Space charge and dc dielectric breakdown in polymeric insulation*" Plasma Science (ICOPS), IEEE International Conference, E-ISBN :978-1-4577-2128-1 8-13 July 2012

[13] Liang Zhao Key Lab. of Phys. Electron. & Devices of Minist. of Educ., Xi"an Jiaotong Univ., Xi"an, China Jiancang Su ; Xibo Zhang ; Yafeng Pan, "*Experimental investigation on the role of electrodes in solid dielectric breakdown under nanosecond pulses*". Dielectrics and Electrical Insulation, IEEE Transactions on (Volume:19 , Issue: 4) August 2012.

[14] Shneider, M.N. Dept. of Mech. & Aerosp. Eng., Princeton Univ., Princeton, "*Theoretical study of the initial stage of sub-nanosecond pulsed breakdown in liquid dielectrics*" Dielectrics and Electrical Insulation, IEEE Transactions on (Volume:19 , Issue: 5) October 2012.