

DESIGN OF DATA ACQUISITION SYSTEM FOR MEASUREMENT OF POWER AND ENERGY USED IN CHARGING CAPACITOR BANKS.

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Abstract: In pulsed power applications, the energy is first stored in large capacitor banks that are charged using different types of power supplies. The charging process is controlled by current limiting device. No detailed analysis of circuits is done. Although it is possible to write analytical equation but the solutions are too cumbersome we have analyzed the behavior of the circuits through software based Data Acquisition System using Lab VIEW to evaluate the performance parameters of the power supply.

Keywords: Power Supplies and their performance parameters, Lab VIEW 7.0.

1. INTRODUCTION

In pulsed power applications like solid-state pulsed lasers, the energy is first stored in large capacitor banks that are charged using different types of power supplies like using current limiting impedance in the primary, constant current and voltage doublers. The limiting impedance can either be resistive, capacitive, inductive or combination of more than one type.

The concepts of conversion of AC waveform into DC using various types of rectifier circuits and analysis of such circuits are presented in detail in textbooks on power electronics. However, such circuits are modified when the capacitor filter takes the form of an energy storage device, as in the case of solid-state lasers. Here, the capacitor banks are charged using either an AC or a DC source for a time as required for maintaining desired repetition rate of the laser, and discharged in flash lamps for achieving the lasing action.

The charging process is controlled by means of a current limiting device in the primary or secondary circuit. A mention of such circuits is also found in well-known books on solid-state lasers. A detailed analysis of DC and AC charging techniques is given, but it mainly covers cases which involves half and full cycle charging. No detailed analysis of circuits used for charging capacitor banks over several cycles is seen in published literature on either lasers or power electronics.

Various charging methods are available for charging capacitor banks. It is very much necessary to calculate its performance parameters like charging time and efficiency of such circuits. Although it is possible to write analytical equation for such circuits but the solutions are too cumbersome due to the presence of rectifying diodes, which controls the direction and flow of current depending on their bias. To know various parameters like charging time, peak current and efficiency of such schemes for the design and selection of components, it is necessary to acquire the data like instantaneous charging current

and voltage over charging duration. In this project an attempt is made to give an understanding of the behavior of basic capacitor charging circuits by developing software based Data Acquisition System to evaluate their performance.

For this purpose a PC based National Instruments Data Acquisition card containing 16 analog channels and ADC is used. Analog channels are interfaced to the power supply. A program is developed using NI-DAQ 7.0 version Lab VIEW software along with National Instruments data acquisition card to acquire the data over specified time and the acquired data is use to calculate various parameters. We have used National Instruments Acquisition card 025E with Lab VIEW (7.0 version) for acquisition of data. We are saving data into Microsoft excel worksheet and graphs are drawn to study and compare the performance parameters with the theoretical values.

Here we have taken 40 μ F capacitor bank and we are charging by a power supply whose charging process is controlled by limiting the primary current through limiting impedances. The limiting impedance can either be resistive, capacitive, inductive or combination of more than one type.

2. PERFORMANCE CRITERIA

There are standard criteria for evaluating performance of DC power supplies, such as regulation, ripple, and accuracy etc. We have calculated following parameters for measuring their performance:

1. **Charging time:** This is the time taken to charge the capacitor bank to a fixed value (90% chosen arbitrarily) of the maximum voltage. This time is necessary to ensure a required repetition rate of firing the laser.
2. **Efficiency:** This is the ratio of E_c and E_p , where E_c is the energy stored in capacitor bank and E_p is energy supplied by the source.
3. **Peak current:** This is the peak value of source current, which will decide the specification of diodes.

It must be noted that the main aim of this project is to calculate these performance parameters along with power consumed by the power supply and energy stored in the capacitor banks using acquired data through a PC based National Instruments data acquisition card.

The Lab VIEW software process very fast and represent the acquired data along with these parameters in a simple and user-friendly way. In LabVIEW a front panel is created to show the input voltage, input current, capacitor's peak voltage, charging time, peak current value and overall efficiency of the power supply. We have designed a power supply to charge a 40μF capacitor bank. The power supply is designed for testing over different limiting impedances for different time period.

3. CAPACITORS IN DISCHARGE CIRCUITS

The electrical capacitor is still the most important reservoir for electrical energy, which will subsequently be discharged at a high rate into the consumer circuit to produce a quick flow of energy. The weight and cost of the power supplies are mainly due to the capacitors.

Capacitor consists of metallic plates, or foils, with an insulating material called a dielectric between them. Paper saturated with oil is commonly used as dielectric material, while other capacitors use a thin layer of plastic. When a voltage is applied to the capacitor plates, electrical charges flow to the plates, and the dielectric is subjected to an electrostatic field. Electrical energy is required to charge the capacitor to a given voltage according to the important relationship

Energy stored in a capacitor=

$$\frac{1}{2} CV^2 \text{ joules}$$

where V is the voltage across terminals in volts, and C the capacitance in farads. The capacitance C is a number indicating the ability of a capacitor to store electrical charge per volt of applied voltage. A capacitor with a large capacitance will store more energy than one with a smaller capacitance at the same voltage. In pulsed power applications like Lasers, the light output from a flash lamp is a function of the energy from the capacitor and, therefore, can be proportional to the capacitance. By obtaining a suitable capacitor at a given voltage, the amount of light from a flash lamp can be predetermined when the efficiency is known.

4. DESIGN OF SYSTEM IN LABVIEW

Calculation of performance parameters becomes very cumbersome when calculation is done mathematically. They can be solved very easily

using numerical methods and with the use of digital computer. To see the effects as predicted by theoretical calculations we have setup a prototype power supply with diagnostic system that is PC based NI- DAQ card and LabVIEW.

To calculate performance parameters for practical circuits, we need instantaneous voltage and current. Charging time, Efficiency and Peak current can thus be calculated. To store data and for further calculations we are using LabVIEW software. A front panel is created in LabVIEW as shown and described in Fig 1.



Fig 1: Front panel in LabVIEW showing all controls and calculated parameters

Designing a data acquisition system for measurement of power and energy used for charging capacitor banks contains a software part and a hardware part, and a PC based data acquisition card containing 8\16 analog channels is to be used. NI-DAQ 7.0 is PCI slot based National Instruments data acquisition card with LabView as application software of 7.0 versions. You can acquire data by interfacing the NI-DAQ card across the terminals where you want to acquire data and LabView saves and process the acquired data. This data acquisition system is externally triggered which starts by charging and stops when charging is over. So as soon as you switch on the source or main the DAQ card will start acquiring data and as the charging gets over it stops acquiring. And within milliseconds the front panel will display all the calculated parameters with graphs.

The front panel mainly contains Input controls and calculated output parameters as listed below:-

Input Controls are:-

- (1) Acquisition time (s),
- (2) Sampling rate.

Outputs Displayed are:-

- (1) Vm – maximum value of input voltage.
- (2) Vc max – maximum output voltage across capacitor banks.
- (3) Ep –Energy supplied.
- (4) Ec – Energy stored in capacitor bank
- (5) Graph showing instantaneous input voltage,

current & power (VA).

- (6) Graph showing V_c max w.r.t Acquisition time.
- (7) Charging time: Time taken to charge the capacitor bank to 90% of its maximum voltage.
- (8) Efficiency: it is the ratio of E_c and E_p .
- (9) Peak Current: peak value of source current

The front panel created to display the acquired data and graphs is shown in Fig 2 and Fig 3 respectively.

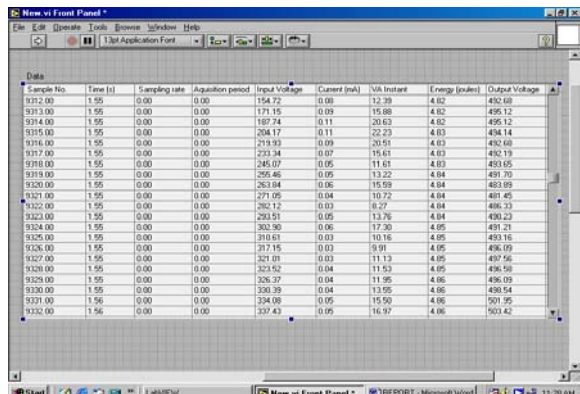


Fig 2: Front panel, which shows table to display the acquired data

This is the table in LabVIEW front panel which is prepared to display the instantaneous acquired data. In this format information of each sample is taken and displayed. Here you can get instantaneous information by scrolling the up and down bar. You can take up to 200k samples per second, as this is the maximum sampling rate provided by LabVIEW. Now we will discuss the graph shown in Fig 3. The capacitor bank voltage is displayed in the graph with respect to time. The maximum value of capacitor bank voltage is up to 1000 volts only, if the value of the stored voltage of the capacitor bank exceeds this value the power supply automatically disconnects from the main line. So Y-axis maximum value fits to 1100 volts.

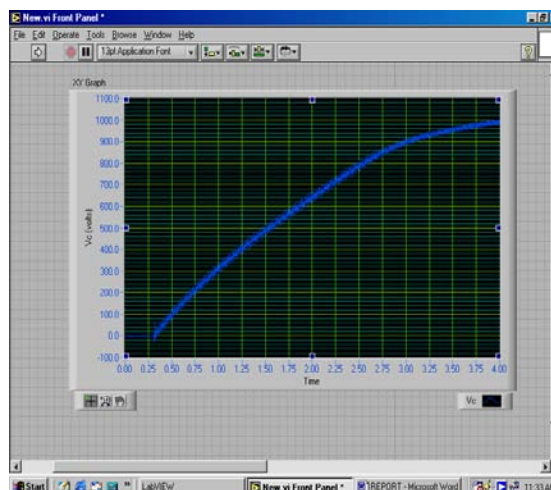


Fig 3: Graph in front panel to display capacitor output voltage reading.

Here Y-axis is showing voltage across capacitor bank and X-axis is showing time. From this graph one can easily locate the time taken to reach a particular capacitor voltage value. Charging time can be seen from this graph at 900 volts or 90% of the maximum capacitor bank voltage.

In Fig 4 the graph shown is created to display input voltage and input current waveform, with respect to number of samples, fed to the power supply. In the graphs you can easily view the instantaneous values of the input waveforms. We can also view phase shift between current and voltage. In the front panel you can set the sampling rate and acquisition period as shown in Fig 1.

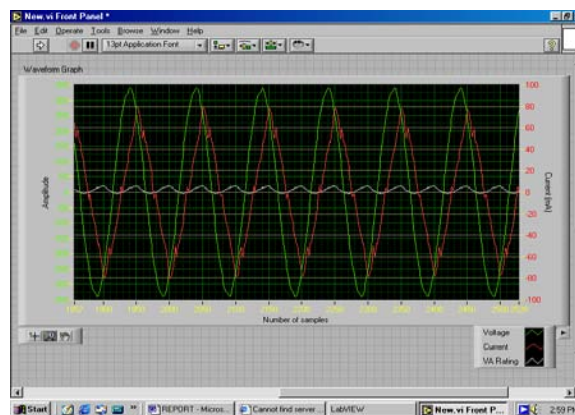


Fig 4: Graph in front panel to display instantaneous input voltage and input current

The columns included in the front panel table are listed below. This list is in the same order as is given in the LabVIEW front panel table. They include the following:

1. Sampling number,
2. Instantaneous time,
3. Sampling rate,
4. Acquisition period,
5. Instantaneous input voltage,

6. Instantaneous input current,
7. Instantaneous VA,
8. Instantaneous energy in joules,
9. Instantaneous capacitor bank voltage.

5. EXPERIMENTAL SETUP

A power supply is designed to test the LabVIEW design. Different readings are taken by changing the primary current limiting impedances for different acquisition period. The power supply designed for testing is shown in Fig 5. This supply is used to charge 40- μ F capacitor banks, and the terminals A and B are for the limiting impedances.

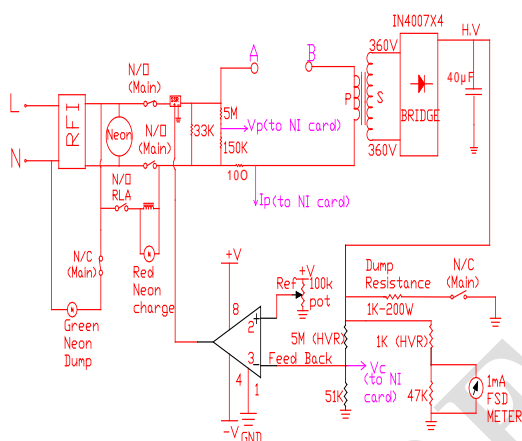


Fig 5: Power Supply design used for testing

Fig 5 shows the main power supply circuit, Fig 6 shows the circuit for control of CHARGE and DUMP switches and the Fig 7 shows the circuit which supply voltage source to the comparator and to the circuit for CHARGE and DUMP. The comparator is used for controlling the SSR (solid state relay) of the main supply. All the circuits are explained now in detail.

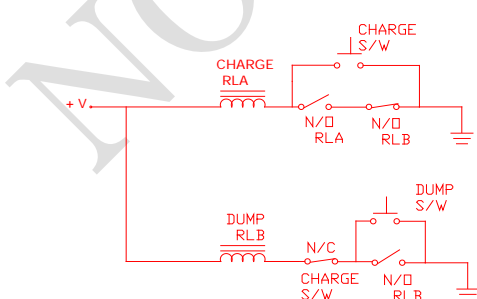


Fig 6: Control circuit for charging the power supply

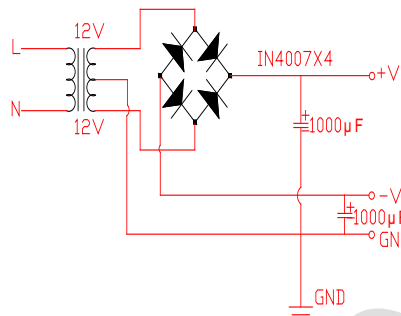


Fig 7: 12V dc generator circuit

In Fig 5 the line 'L' and neutral 'N' is first given to a filter (RFI) and then through a neon switch it is fed to the primary current limiting circuit via SSR and voltage divider circuit. The neon switch operates manually and it is used just to have manual control over the supply.

When the charge button switch is pressed the Relay A coil is energized by +V volts [+V is the output of the circuit shown in Fig 7]. As soon as the Relay A (RLA) coil gets energized it closes the N/O switch of RLA in Fig 5. Now in Fig 5, when the N/O RLA switch is closed it connects the main contactor coil with the 'L' of main supply and the main contactor coil gets energized. The red neon charge indicator glows because it is in parallel connection with main contactor coil, which shows that the charging process is going on.

The energized main contactor coil closes the N/O (main) switch. This connects the rest part of the supply with the Line and Neutral of the MAIN supply. The Line 'L' is fed to a voltage divider circuit through SSR.

The voltage divider circuit is described here:

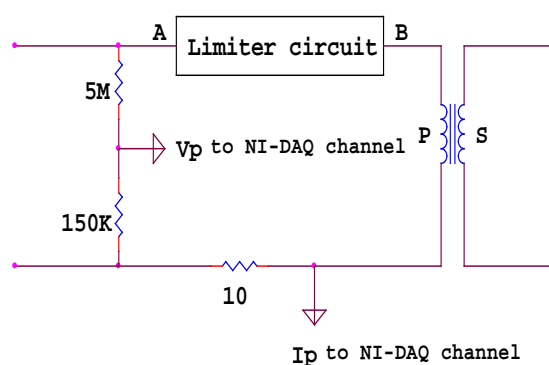


Fig 8: Voltage divider circuit

As stated earlier the NI-DAQ card channels can acquire voltage up to 10 V. therefore this divider

circuit is used. The primary voltage is measured across the 150 kΩ resistor and for primary current measurement the voltage across the 10 Ω resistor is measured and then it is divided by the value of the resistance (10Ω) to get the current. We have used the formula $I = V/R$ for measuring the input current.

The point Vp is fed to the pin 3 (ACHO) of NI-DAQ 6025Ecard, which is the channel 0 in LabVIEW design. This channel will acquire constantly the voltage across 150 kΩ resistor and for displaying this voltage it is first multiplied with the dividing ratio 33 and then it is displayed in the block diagram as shown in fig 17 and stored in excel files.

Similarly the point Ip is connected with the Pin 5 (ACH1) of the NI-DAQ 6025E acquisition card, which is the channel 1 in LabVIEW design. First the voltage is acquired, it is divided by 10 and then it is displayed in LabVIEW as shown in fig 17 and then stored in excel files for future calculations.

Again we come to the main supply circuit,[Fig 5], the terminal A and B is for the current limiting impedance. Readings are taken by changing the

Calculated parameters	2μF limiting capacitor
Efficiency	75.57 %
Time	1.95 sec
Peak input current	459.9 mA

limiters. The limiting element can be resistive, inductive, capacitive or combination of more than one type.

Now, a step-up transformer is used which step up the primary voltage to 720 V. the bridge rectifier circuit is used to convert the AC waveform to DC. The DC is fed to 40 μF Capacitor bank (the parallel combination of four 10μF capacitors). The 40 μF capacitor bank is connected in parallel with a N/C (main) switch as shown in the Fig 5. Normally this N/C (main switch remains) open or disconnected when charging process is going on because whenever the mains is on the N/C switch opens automatically. As soon as the capacitor voltage exceeds 1000V, the comparator sends the signal to SSR which disconnects the main supply. This provides safety to the power supply.

The comparator is fed with 12v dc supply which is generated by the circuit shown in Fig 7. During the charging process the red neon charge button glows continuously. To discharge the capacitor bank, the dump switch in Fig 6 is pressed and the RLB DUMP coil gets energized (green neon switch glows), which

open the N/C RLB switch in the Fig 6 and two N/O (main) switches in Fig 5.this stops the charging process and the charged capacitor bank dumps through the 1k-200W resistor, as the N/C (main) switch closes when mains is disconnected.

6. RESULTS

Testing is done over the power supply by taking various values of the limiting impedances and graphs are plotted between the output voltages of capacitor banks with respect to time. Here, we have shown different graphs and all readings taken in LabVIEW for different values of limiting impedances.

6.1 Case I: 1kΩ resistor as limiting impedance. All the calculated parameters for 1k resistance as primary current limiter are shown below. All these readings are captured from LabVIEW design.

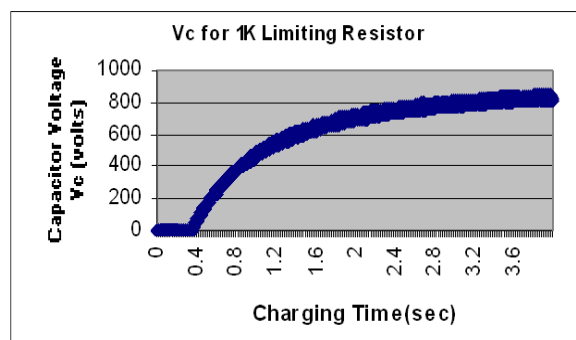
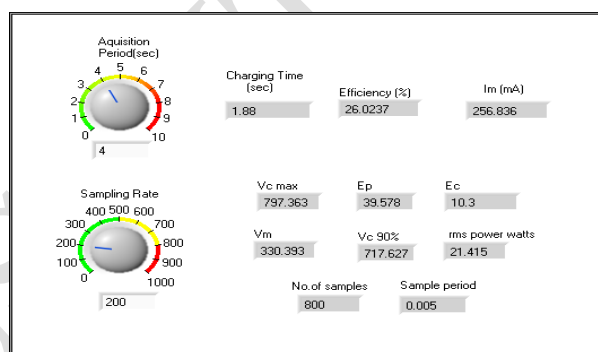


Fig 10: Excel Chart showing Vc wrt time for 1kΩ resistance as Limiting Impedance

This is the excel chart drawn between the capacitor bank voltage and time. The LabVIEW also produces graph with the same data as shown in fig 11 but the LabVIEW graph can be produced very fast in comparison with the excel chart.

Calculated parameter	1kΩ limiting resistance	2μF limiting capacitor
Efficiency	26.02%	75.77%
Time	1.88sec	1.95sec
Peak input current	256.83mA	459.9mA

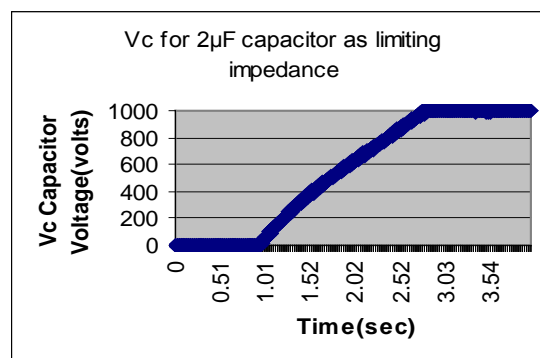


Fig 11: Graph showing Capacitor bank voltage wrt time in LabVIEW for 1kΩ resistance as Limiting Impedance

6.2 Case II: two: 2μF capacitor as limiting impedance.

In Case 2 we have taken 2μF capacitor as limiting impedance. All the calculated parameters and graphs are shown below. in fig 12.

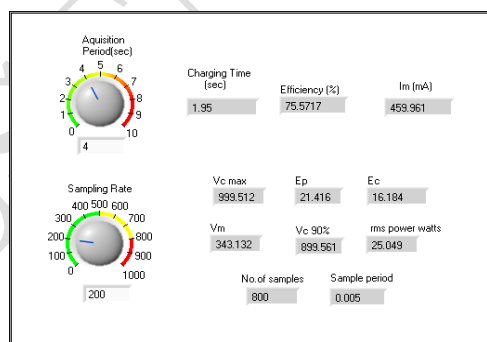


Fig 12: Calculated parameters in Lab VIEW for 2μF capacitor as Limiting Impedance

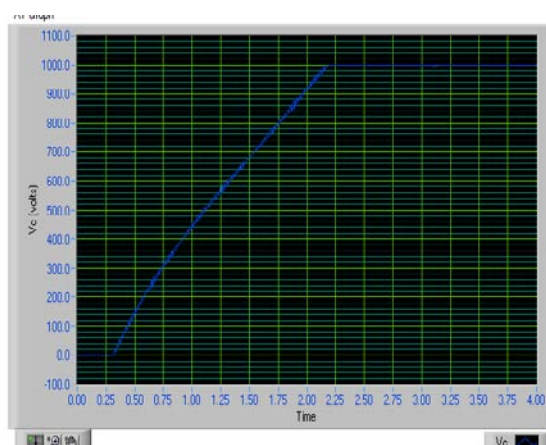


Fig 13: Excel Chart showing Vc wrt time for 2μF limiting capacitor

6. CONCLUSION

Testing is done over the power supply taking current limiting resistance of 1 Ω and capacitance of 2 μ F. Data is collected through the NI-DAQ card for each limiting impedance separately in excel format.

The collected data contains sample number, sample instants in seconds, sampling Rate, acquisition period, instantaneous input voltage, instantaneous input current, VA instantaneous rating, instantaneous energy (Joules) stored in capacitor banks and instantaneous output voltage of the capacitor banks.

We have calculated the performance parameters mainly efficiency, peak current and charging time of the power supply. It must be noted that this is the time taken to charge the capacitor bank to a fixed value (90% chosen arbitrarily) of the maximum voltage.

This time is necessary to ensure a required repetition rate of firing the laser as mentioned earlier also. Graphs are plotted between capacitor's voltage and time for different limiting impedances and we found that these readings match with the theoretical values give by simulations with same limiting impedances.

The calculated parameters over two different limiting impedances are given below:

TABLE 3

Calculate parameter	1k Ω limiting resistance	2 μ F limiting capacitor
Efficiency	26.02 %	75.57 %
Time	1.88 sec	1.95 sec
Peak input current	256.83mA	459.9 mA

This shows that the efficiency and peak current is more in using capacitor as limiting impedance as compared to resistive limiting impedance and the charging time is less in case of capacitive limiting impedance.

Here the conclusion drawn is that the capacitive limiting impedance is more efficient than the resistive limiting impedance. The parameters evaluated by simulation are of higher value that may be due to neglecting losses in parameters of a practical circuit.

This shows that the Data Acquisition System, which is developed using Lab VIEW, is a fast and easy method of analysis of different power supplies. This system can be used where energy is first stored and then discharged like in supplies for different types of lasers, energy is first stored in capacitor banks then it is discharged through flash lamps to get lasing action. This system can be used to plot behavior of any power supply and to calculate instantaneous power and energy supplied by the supply. Now you can

easily compare different power supplies and can choose the one according to your requirements. This system gives accurate behavior of any power supply and saves time and labor.

7. FURTHER IMPROVEMENT

Further improvement of the system can also be done by giving harmonic analysis of the signals acquired through the NI-DAQ card channels. You can do analysis of any circuit diagram in LabVIEW. Data acquisition is very much necessary in analysis of any system. For that data acquisition system based on LabVIEW and National Instruments acquisition card 6025E is a very good tool. For applications where large amount of data is to be handled and calculations over data are required then also LabVIEW and National Instruments acquisition card 6025E is a very good tool.

8. REFERENCES

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