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Simulation of Output Voltage Waveforms of Power Electronic Converters and Measurement of their Average and Effective Values by Using LABVIEW

Abstract: - The target of this research is to investigate the possibility of finding online true RMS or average value for a none uniform or distorted ac signal. Such signals are frequently found at the outputs of power electronic converters as a result of signal chopping when using power electronic switches. This is an important issue especially when it is required to stabilize or regulate the effective voltage value at the output of the converter. Using Lab VIEW environment, we proposed a practical methodology in order to simulate different types of signals associated with different converter configurations and to find online their RMS values. Results of simulation are compared with known analytical equations and the results are found to be the same.

Keywords: Lab VIEW, electronic Converters, RMS voltage value, array indexing, electronic power switches

I. Introduction

The trend in control system design is to make use of computer- based software using different programming tools and applications in order to realize an integrated control algorithm. The inputs to control systems come from external environment as feedback signals by means of different types of transducers. This information is manipulated inside the computer in accordance with the principle of control algorithm. Controller signal is outputted to external physical system in order to modify controlled system performance in the required direction. When using computer as a controller, one of the important engineering design tasks is to facilitate an adequate power interfacing and compatibility between low power computer-based controller and high power actuating element. This activity is versatile and depends on the characteristics of the actuator. In general, this is done by utilizing different switch-mode amplifiers and electric power conditioners which include different electronic power switches [1-5].

Unfortunately, the output of most switch-mode converters and inverters is not a uniform signal and in many applications the output signal represents a chopped unsymmetrical AC signal. The target of this research is to investigate a methodology in order to find online the average and RMS values of such distorted or non-uniform alternating waveform that is not symmetrical or sinusoidal in nature by using Lab VIEW environment. Most multi-meters' measure RMS value assuming a pure sinusoidal waveform. For finding the RMS value of non-sinusoidal waveform a True RMS measurement is required. In Lab VIEW software [6-8].

This problem is not investigated, especially when it is required to carry out online measurement directly in order to make use of it in control strategy. Finding online Vdc and Vrms has a practical importance for realizing power regulators and control systems. An example is stabilization of converter or regulator output voltages [9-12], where voltage sag problems and network voltage stabilization are addressed. Another application is given in [13-17], where regulating luminous flux of luminaries was done by regulating the voltage supply. In order to find the average voltage value V dc and the voltage effective value Vrms, two methods are in use. The graphical method and the analytical method. The graphical method is a very good way of finding Vdc and Vrms of complex waveform that is not symmetrical or sinusoidal in nature, which is of most concern in this work. However, when dealing with pure sinusoidal waveforms it may be easier to apply analytical or mathematical method. The mean or average voltage of a waveform can be found by taking equally spaced instantaneous values (mid-points) or samples. The width of each mid-ordinate is the sample interval. The higher the number of samples and the smaller the sample interval, the more accurate the graphical method will be. In Lab VIEW, this sampling task is done easily by indexing any waveform through the tunnel of a for or while loop. The sample interval discrimination will be one millisecond. The sample interval is programmed by using Wait (ms) lab VIEW function.

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II. METHODOLOGY

This research focuses on the simulation and analysis of output voltage waveforms from various power electronic converters using Lab VIEW software. The methodology involves designing virtual instruments in Lab VIEW that can simulate different types of AC signals, specifically non-uniform and distorted waveforms, typically found at the output of power electronic converters. The waveforms are indexed as arrays of instantaneous values, and both the average (Vdc) and the RMS (Vrms) values are calculated.

The average voltage is computed by summing the sampled voltage values and dividing by the total number of samples. For RMS value calculation, each voltage sample is squared, summed, and then the square root of the result is taken. Lab VIEW functions such as "Add Array Elements" and "Array Subset" are used for handling the waveform data, while the "Simulate Signal" function is employed to generate voltage waveforms corresponding to different converter topologies. The methodology also incorporates the delay angle for converters to assess the effects on the voltage characteristics.

III. EXPERIMENT

Several experiments were conducted to verify the accuracy of the simulation results against known analytical equations for different converter configurations. These experiments include the simulation of a sine wave with a programmable delay angle, single-phase full-wave converters, and three-phase half-wave and full converters. For each converter, the output voltage waveform was indexed, and the average and RMS values were computed for various delay angles.

In one experiment, a single-phase full-wave converter was simulated with a highly inductive load. The voltage waveform was sampled, and the average and RMS values were measured and compared with analytical results for different delay angles. Similarly, for a three-phase half-wave converter, the output voltage waveform was analyzed for delay angles greater than π/6. The simulation results were compared with theoretical calculations, showing a high degree of accuracy, with negligible differences due to rounding errors. Additional tests with other converter configurations demonstrated consistent results, validating the effectiveness of the Lab VIEW-based simulation approach.

If a smaller discrimination is required Lab VIEW real –time tool or FPGA tool could be used. For most practical applications millisecond range is very adequate. In order to find the average voltage, we use the following equation:

$$Vav = \frac{Sum\ of\ all\ samples}{number\ of\ samples} \qquad (1)$$

Important to note that any signal acquired by Lab VIEW is merely a waveform that could be indexed and represented as an array of instantaneous values (samples). Sum of all samples is found directly by using the function (Add Array Elements). The sum of the samples of a segment of a waveform may be found by using (Array Subset) function with Add Array Elements function. The average value is obtained by adding the samples values over one half cycles only. But in the case of non- symmetrical wave the average voltage must be taken over the whole periodic cycle.

Concerning the waveform RMS value, each sample value of voltage waveform is squared and added to the next. The sum of the squared samples is divided by the number of samples and finally the square root of the previous result is found. This is given as:

$$Vrms = \sqrt{\frac{Sum\ of\ all\ samples}{number\ of\ samples}} \qquad (2)$$

To create a virtual instrument for calculating Vrms, the external feedback signal is input into the computer using any Lab VIEW Analog Input VI. The signal waveform is then indexed to determine the number of samples and calculate the sum of squared samples, ultimately obtaining the Vrms value. In the following, we will discuss several designed programs related to power electronics technology, which are used to find the Vdc and Vrms values for various common power electronics converters. Figure 1a, illustrates the fundamental components of a virtual instrument designed to compute the Vdc and Vrms values for an arbitrary array, Meanwhile, Figure 1b, demonstrates the front panel a simulated sine wave.

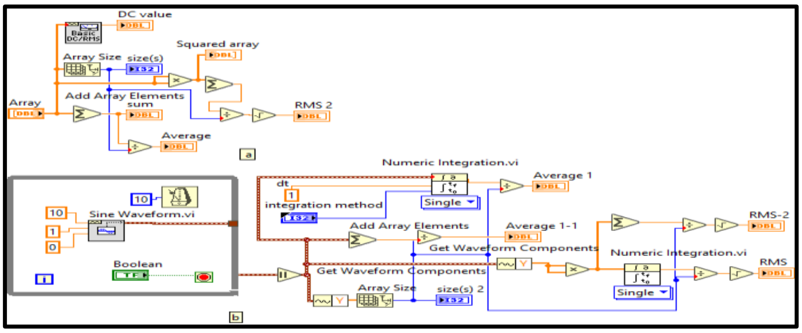

Fig.1a: Block diagram of a sine wave array

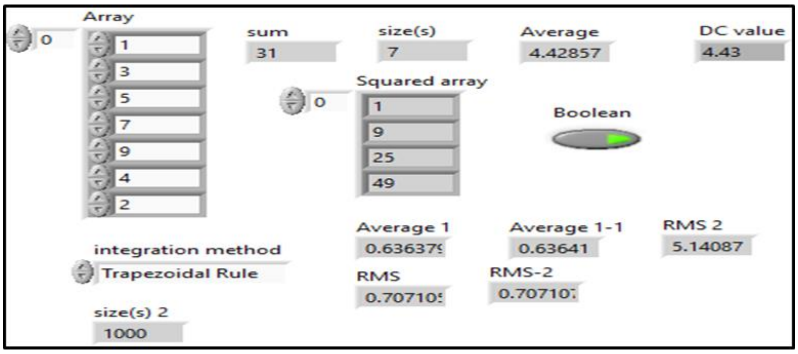

Fig.1b: Front panel a simulated sine wave

The program shows that it is possible to use (Numeric Integration VI) and (Add Array Elements) functions to find the Vdc or Vrms values. As the amplitude of the sine wave is one, the average and effective values are found to be 0.636 and 0.707 respectively. Figure2-a shows how to find the Vdc and Vrms of a sine wave with a delay angle α=900. Delay angle is programmable and could be any value in the range (0- π) radians. Figure 2-b, illustrate Block diagram average voltage and effective voltage of a sine wave with a given delay angle. Number of samples of a complete cycle is also programmable and selected to be 1000.Array subset function is used to give a variable array subset, depending on (α). Number of array subset samples is found by Array Size function. Sine wave magnitude is taken 169.7V. The results of calculation are shown in the front panel for α = 90 degrees and for α= zero degrees. Figure.3a shows a single-phase full converter with a highly inductive load [9], where:

$$Vrms = \left[\frac{2}{2\pi}\int_{\alpha}^{\pi+\alpha} V^2m \sin^2 \omega t \, d(\omega t)\right]^{\frac{1}{2}} = \frac{Vm}{\sqrt{2}} = Vs \qquad (3)$$

$$Vdc = \frac{2}{2\pi}\int_{\alpha}^{\pi+\alpha} Vm \ \sin \omega t \, d(\omega t) = \frac{2Vm}{\pi}\cos\alpha \qquad (4)$$

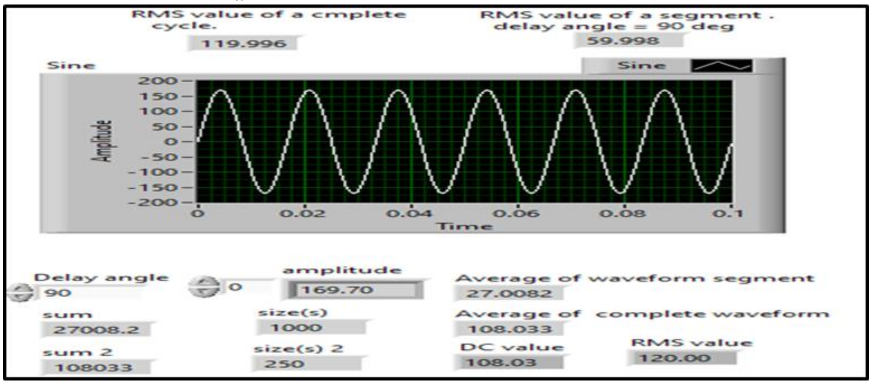

Fig.2 a.: Finding average voltage and effective voltage of a sine wave with a given delay angle.

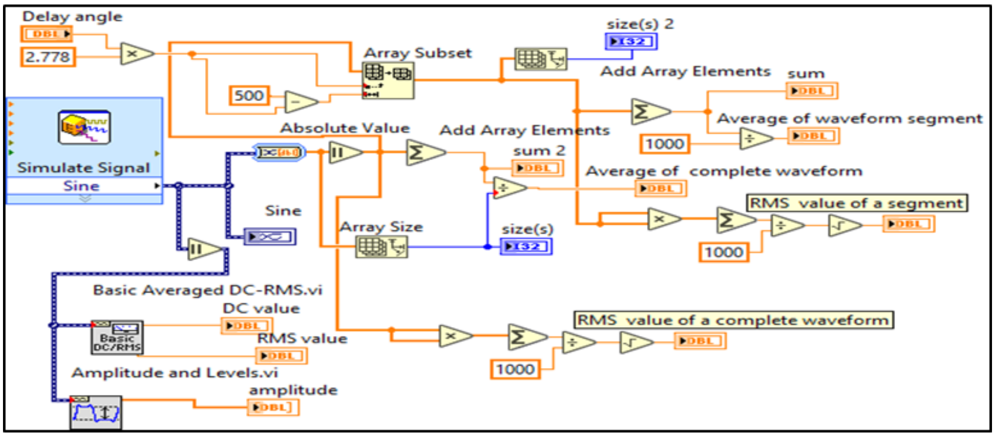

Fig.2b: Block diagram average voltage and effective voltage of a sine wave with a given delay angle.

The program shown in table 1 finds array subset for the interval (α –π) and array subset for the interval (π – π+α). Taking in consideration that the total samples for a complete cycle is 100 samples, the array subset index value and array subset length in samples are defined as shown in the block diagram, Figure 3b. of Single -phase full converter. For α= 60 degrees' total number of samples is equal to 34 + 16 = 50. For α=60 degrees' measurement results are shown in the table 1.

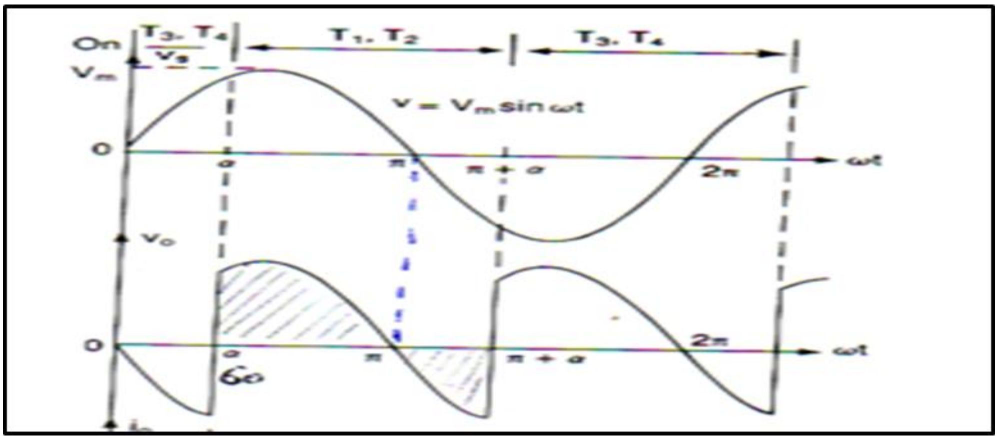

Fig.3a: Output voltage of a single-phase full converter with highly inductive load

Table 1. Front panel controls and indicators

Size(s)	Size(s)2	Vdc	VRMS
34	16	55.1202	119.798

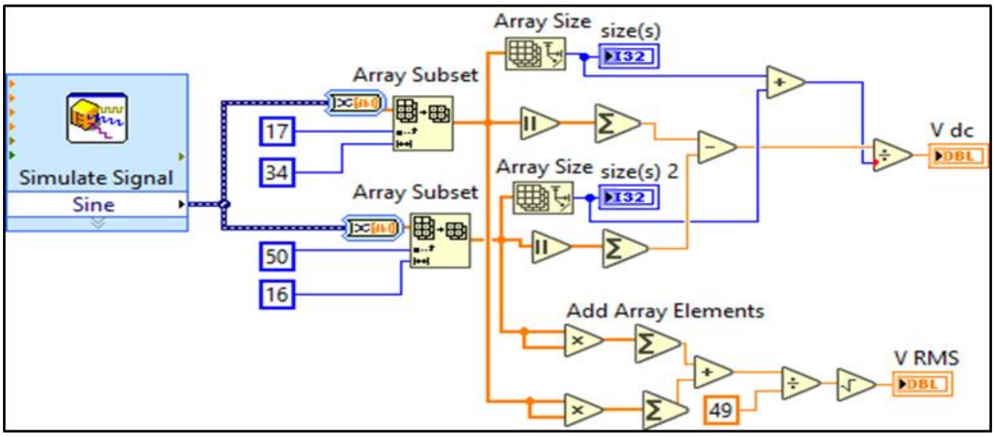

Fig.3.-b Block diagram of Single -phase full converter

To validate the program results, three sets of measurements were taken for delay angles of α = 30°, 45°, and 60°. The program results were then compared with analytical calculations, as shown in Table 2.

Table 2. Verify the program results of Single -phase full converter

Delay Angle in degrees	Program results, volts	Analytical results, volts
60	V dc = 55.12 Vrms = 119.8	V dc = 54.08 Vrms =120
45	V dc = 74.09 Vrms =121.35	V dc =76.4 Vrms =120
30	V dc = 94.4 Vrms =120.97	V dc =93.68 Vrms =120

For the above table values, maximum absolute error is 1.7 %.

Figure 4, simulates three-phase half-wave converter with a resistive load and a delay angle more than π/6.According to [9,10] we have:

$$V\ dc = 3\frac{Vm}{2\pi}\left[1 + cos\left(\frac{\pi}{6} + \alpha\right)\right] \quad (5)$$

$$aV\ rms = \sqrt{3}Vm\frac{\left[\frac{5}{24} - \frac{\alpha}{4\pi} + \frac{1}{8\pi}sin\left(\frac{\pi}{3} + 2\alpha\right)\right]1}{2} \quad (6)$$

For this case we consider α= 67.7 degrees. The output voltage for this converter is composed of phase to neutral voltages. Therefore, we shall use the phase voltage Van and find the array subset between π/6+α and π. The array subset index value will be 27samples and the array subset length will be 23 samples.

The values have been rounded and are displayed in the block diagram. The average (DC) and effective (RMS) voltage values are shown on the front panel, as illustrated in Table 3. According to Table 3, the average voltage (Vdc) is 71.4118 V, and the effective voltage (Vrms) is 95.9289 V.

Table 3 The average and effective voltage values front panel

Vdc	Vrms
71.4118	95.9289

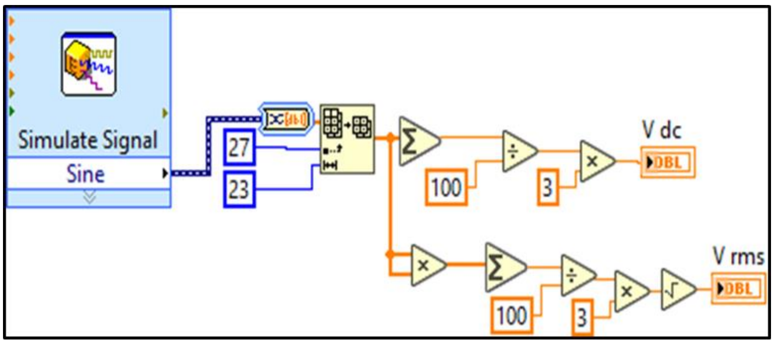

Fig.4 Front panel and block diagram of Three-phase half-wave converter

Table 4. Compared Program results with calculation results of Three-phase half-wave converter

Delay angle = 67.7 0	Vdc, Volts	Vrms, Volts
Program results	71.4	95.9
Analytical calculation results	70.25	94.5

Program results are Compared with calculation results [9, 10] for α=67.7 degrees. As shown above in table 4, a high degree of coincidence exists and the negligible difference is due to rounding of sample values.
Concerning three- phase semi-converters, we investigated two common cases. The first one when the delay angle, α, is within the interval 0 – π, and the output voltage is discontinuous. For this case we considered α= 90 0 and α=75 0. The second case is when α< or equal to π/3, and the output voltage is continuous. For this case we considered α= 30 0 and α= 450. The voltage curves for both cases, as given by (Rashid, 2013), are shown in figure 5.

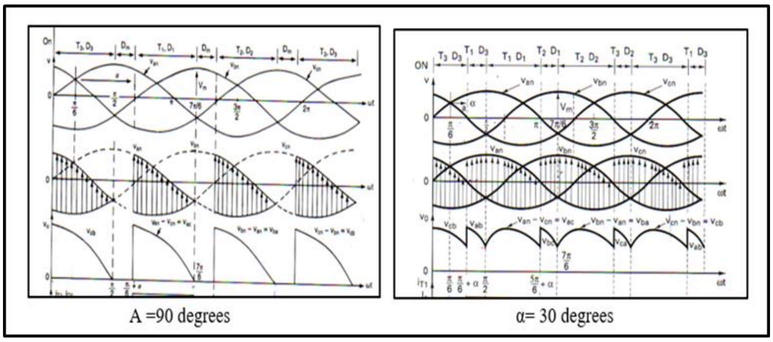

Fig.5: The voltage curves for both cases (A =90 degrees, α= 30 degrees).

When α=90 0 according to equation:

$$Vdc = \frac{3}{2\pi}\int_{\frac{\pi}{6+\alpha}}^{\frac{7\pi}{6}} Vac\, d(\omega t) = \frac{3}{2\pi}\int_{\frac{\pi}{6+\alpha}}^{\frac{7\pi}{6}} \sqrt{3}\, Vm\, \sin\left(\omega t - \frac{\pi}{6}\right) d(\omega t) \qquad (7)$$

The output voltage is composed of line to line voltages: Vba, Vac, and Vcb. As a result of that we can express V L-L through the phase voltages. Taking in consideration that V ab leads the phase voltage Van by 30 0 , V ac voltage will be expressed as:

$$V_{ac} = \sqrt{3}\, V_m\, sin\left(\omega t - \frac{\pi}{6}\right) \qquad (8)$$

The simulated voltage signal was generated using the "Simulate Signal Express VI" in the block diagram shown in Figure 6. The results of the simulation are presented in Table 5. The direct current (DC) voltage value is recorded as 138.995 V, while the root mean square (RMS) voltage is measured at 178.93 V. Additionally, the DC values and RMS values are reported as 187.29 V and 208.00 V, respectively. The size of the signal, in terms of sample count, is 1000.

Table 5 The results of the simulation

Vdc	Vrms	DCvalues	RMSvalues	Size(s)
138.995	178.93	187.29	208.00	1000

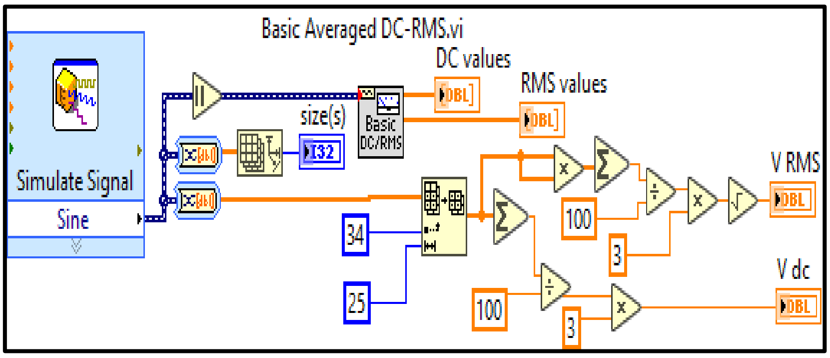

Fig.6: Block diagram for three phase semi-converter with delay angle = 90 degrees

The array subset has and index value equal to 34 samples and the array subset length is 25 samples. For Vm = 169.83V the Vdc and Vrms voltage values are equal to 139V and 179 V respectively. Table 6 compares the program results with analytical calculations for delay angles of α = 90° and α = 75°. For α = 90°, the program results show a DC voltage of 139 V and an RMS voltage of 179 V, while the analytical results yield 140.45 V for the DC voltage and 180.13 V for the RMS voltage. For α = 75°, the program results indicate a DC voltage of 174 V and an RMS voltage of 205.5 V, whereas the analytical calculations give 177 V for the DC voltage and 207 V for the RMS voltage.

Table 6 compares the program results with analytical calculations for three phase semi-converter

Delay angle(α)	Vdc	Vrms
α= 90 0		
Program results	139	179
Analytical results	140.45	180.13
α = 75 0		
Program results	174	205.5
Analytical results	177	207

The results show a high degree of coincidence between the graphical (program) results and the analytical(calculation) results. Fig.7 represents the front panel and block diagram in order to find the V dc and Vrms of a three phase semi-converter with a delay angle α less or equal to π/6. The output voltage is composed of segments of line to line voltages. The shape of output voltage V0(t) is complex and includes an array subset of Vab voltage and another array subset of Vac voltage.
In this case we express Vab and V ac through their phase expressions taking in consideration their phase angle shift. Thus we have:

$$V_{ab} = \sqrt{3}\, V_m \sin\left(\omega t + \frac{\pi}{6}\right) \quad (9)$$

$$V_{ac} = \sqrt{3}\, V_m \sin\left(\omega t - \frac{\pi}{6}\right) \quad (10)$$

Both sine waves are simulated by using Express.VI, Simulate signal as shown in the block diagram.

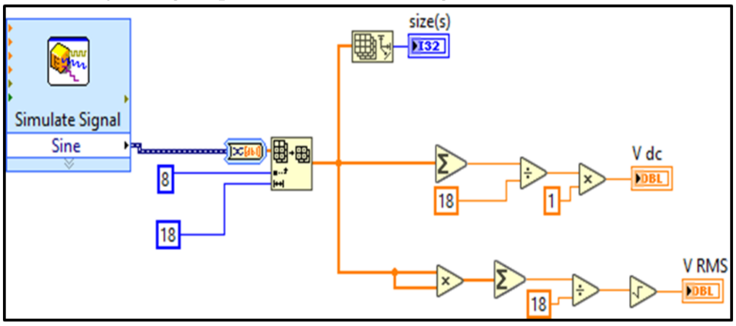

Fig.7: Block diagram of a three phase semi-converter with α= 30˚.

In order to find Vdc we find samples sum of the first array subset and the sum of samples of the second array subset and then the total of both array subsets. After that we divide the last total by the total number of samples, which is equal to 8 +25=33 samples for α = 300 . In order to find the Vrms value, we carry out analogous self-explanatory steps as shown in the block diagram. In order to verify this program, we tested it with three delay angles α=300 , α =45 0 and α =550. The program results and analytical results are given in the following Table 7, Absolute percentage error is between 0.003 and 0.033, which shows a high level of agreement

Table 7 The program results and analytical results of a three phase semi-converter with α= 30˚

Delay angle(α)	V dc	V rms
α= 30˚		
Program results	257	264
Analytical results	262	264.7

α = 45˚		
Program results	242	253
Analytical results	240	247
α = 55˚		
Program results	221.12	234
Analytical results	229	242

The last case we investigate is three phase full converter. we assume α=π/3. The output curve is composed of line to line voltages and during every phase to neutral phase voltage cycle six output segments exist and the duration of each is equal to α. All voltage segments are positive and the average voltage will be defined by using one-line voltage segment. We shall use V cb curve. For this array subset the index value will be 8 samples and the array subset length will be 18 samples as shown in Figure.8.

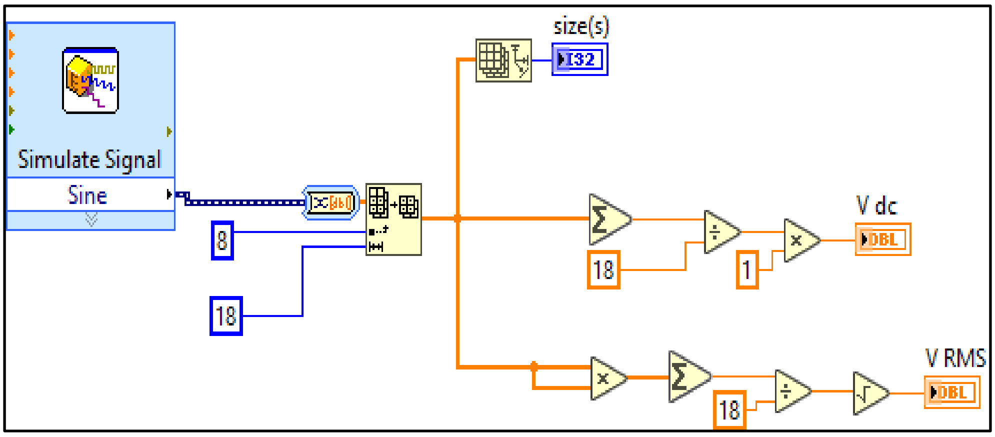

Fig.8: Block diagram of Three Phase Controlled Full converter

Important to note that the phase angle of V cb is + 90 degrees. If we use the Vab instead of Vcb the phase angle becomes + π/6 and the results will be practically the same. Table 8, shows the program and analytical results.

Table 8: program and analytical results of Three Phase Controlled Full converter

Delay angle 60˚ For Segment V cb	V dc	V rms
Program results	141.9	163.08
Analytical results	140.52	159.3
Delay angle 60˚ For segment V ab		
Program results	138	159.13
Analytical results	140.5	159.3

IV. Conclusions

This research successfully demonstrates the feasibility of using Lab VIEW to compute the online true RMS and average voltage values of non-uniform or distorted AC waveforms, particularly at the output of power electronic converters. By simulating different signal types and converter configurations, the study shows that LabVIEW can effectively index waveforms, calculate instantaneous values, and provide accurate RMS and average voltage values in real-time. The comparison of simulation results with known analytical equations confirms the reliability and accuracy of the Lab VIEW-based approach, with minimal deviations due to rounding errors. This methodology is particularly useful for real-time monitoring and control applications in power electronics, where non-sinusoidal waveforms are prevalent, and precise voltage regulation is essential. The ability to find these values online is crucial for implementing control strategies in power systems, enhancing the efficiency and stability of electronic converters.

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