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Graphical User Interface for Asynchronous Motors Clarke-Park Transforms Using LabVIEW

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Abstract

Before any electrical system is used in industrial applications, its behavior under different operating conditions must be studied. A mathematical model must be constructed beforehand in order to observe the behavior of the system under different conditions. Modeling of three-phase asynchronous motors with an electromechanical converter is very difficult due to the time varying current and voltage. While performing dynamic analysis of such motors, a common reference system must be determined. The most commonly used methods to facilitate the analysis of three-phase induction motors are Clarke-Park transforms. In this study, a visual interface has been prepared to ease the teaching of Clarke-Park transforms. The users are moved from the 3-phase (A, B, C) axis to the reference 2 phase (α, β) axis through the interface and to the (d, q) axis with the θ angle at the magnitudes defined in the (α, β) axis system. With the interface prepared, users can change the voltage, frequency and angle values and graphically observe their effect on Clarke and Park transforms. In addition, the conversion from 2-phase axis to 3-phase axis is made with inverse Clarke and Park transforms. Mathematical modeling of the transform and the interface were made using LabVIEW.

Keywords

Clarke Transform; Park Transform; Clarke-Park Transforms; LabVIEW

LabVIEW Kullanarak Asenkron Motorlar Clarke-Park Dönüşümleri için Grafik Kullanıcı Arayüzü

Öz

Herhangi bir elektriksel sistem, endüstriyel uygulamalarda kullanılmadan önce farklı çalışma koşulları altında davranışlarının incelenmesi gerekmektedir. Sistemin farklı koşullarda davranışlarının gözlemlenebilmesi için öncelikle matematiksel modeli oluşturulmalıdır. Bir elektromekanik dönüştürücü olan üç fazlı asenkron motorların zamanla değişen akım ve gerilim ifadesinden dolayı modellenmesi oldukça zordur. Bu tarz motorların dinamik analizi yapılırken ortak bir referans sistem belirlenmesi gerekmektedir. Üç fazlı asenkron motorların analizini kolaylaştırmak için en çok kullanılan yöntemler Clarke ve Park dönüşümleridir. Bu çalışmada Clarke ve Park dönüşümlerinin öğretilmesi amacıyla görsel bir arayüz hazırlanmıştır. Kullanıcılar arayüz aracılığıyla 3 fazlı (A, B, C) ekseninden referans 2 faz (α, β) eksene ve (α, β) eksen sisteminde tanımlanmış büyüklüklerde θ açısıyla (d, q) eksenine taşınmaktadır. Hazırlanan arayüz ile kullanıcılar gerilim, frekans ve açı değerlerini değiştirerek bunların Clarke ve Park dönüşümleri üzerine olan etkisini grafiksel olarak gözlemleyebilmektedir. Ayrıca ters Clarke ve Park dönüşümleriyle 2 fazlı ekseninden 3 fazlı eksene dönüşüm yapılmaktadır. Dönüşümün matematiksel modellenmesi ve arayüz LabVIEW programı kullanılarak yapılmıştır.

Anahtar Kelimeler

Clarke Dönüşümü; Park Dönüşümü; Clarke-Park Dönüşümleri; LabVIEW

1. Introduction

Parameters such as voltage, current and flux are used during dynamic analysis of three-phase systems. Modeling time-varying parameters not only takes a long time but also requires heavy theoretical calculations. Mathematical transforms are used to solve such equations. The most preferred mathematical models are Clarke and Park transforms. Clarke-Park transforms are used in many areas in the literature. For instance; Sadoughi et al. compare the performance of rotor flux estimators of induction motors used in electric motors and rail transport systems. Fixed and rotary reference axes are used for comparison. Clarke-Park transforms are also used in the study to pass from 3 phase axis to fixed and rotating reference axis (Sadoughi et al. 2009). In space pulse width modulation (SPWM) applications, the control signal must be defined in a 3-dimensional space called the active zone. This active field is obtained with vector representations of the current switching states via the Clark transform. The authors carry out a new transform method that yields the same results as the Clark transform (Chakraborty and Bhattachaya 2016). One of the most common fault types observed in power systems is single phase-ground short circuit fault. Bellan proposes a new method for analytical resolution of short circuit fault. The proposed method is based on the representation of the alpha, beta and zero components obtained by the Clarke transform in the Thevenin circuit. The accuracy of the method is verified using Matlab / Simulink (Bellan 2018). Today, environmentally friendly renewable energy sources are used to meet the increasing energy demand. Solar energy is the most preferred one among renewable energy sources. The electric energy generated by the photovoltaic (PV) panels is transferred to the grid via the PV-Grid system. Ryadi proposes a new control method inverter to transfer the energy produced in PV panels to the grid without energy loss. The proposed control algorithm is based on the Inverse Clarke transform. The references produced by inverse Clarke transform are compared with the inverter. The success of the proposed controller is demonstrated by PSIM (Riyadi 2014). One of the

most frequently used methods in power grid monitoring is Classical Discrete Fourier Transform (DFT) algorithm. The most important disadvantage of this algorithm is that it causes errors in different frequency conditions. Zhan et al. propose a new prediction algorithm based on Clarke transform to solve this problem. The main reason of using Clarke transform in this algorithm is that it creates a new 90° signal phase different from the single-phase input signal and offers a wide frequency range. The performance of the proposed algorithm is computationally verified (Zhan et al. 2018). Dobrucky et al. perform virtual instrumentation using LabView to measure multi-phase impulse waveforms. The authors use Clarke transform to convert the signals from 3 phase to 2 phase orthogonal reference system (Dobrucky et al. 2016). In the control of 3-phase inverters and machines, A, B, C phases must be transformed into α, β and d, q axes. Rourke et al. present a new geometric approach for these transforms that one performed with classical matrices (Rourke et al. 2019). The rapid developments in the field of power electronics in recent years have made the control of asynchronous motors easy. Thanks to its advantages such as being more robust and cheaper than other machines, asynchronous motors replace direct current (DC) machines in industrial applications. Asif et al. obtain the torque and speed characteristics by performing dynamic analysis of 3-phase asynchronous machines. Clark transform is used during mathematical modeling while Matlab / Simulink is used for dynamic analysis and modeling (Asif et al. 2016). Veona et al. perform dynamic analysis of an advanced 3-phase permanent magnet brushless DC motor. Clarke-Park transforms is used to obtain dynamic equations from 3 phase system to reference 2 phase system. In addition, harmonic distortions are compared using Pulse Width Modulation (PWM) and Space Vector Modulation (SVPWM) control methods (Veona and Praveen 2014). Clarke and Park transforms are the most frequently used methods in the analysis of 3 phase systems. Vatansever develops software to better teach the elusive Clarke and Park transforms. Visual C # is used for software development (Vatansever 2019).

Today, in parallel with the rapid development of technology, computers act the main role in most of the computational studies. Systems are now simulated by the help of computers before being used in industrial applications and results are obtained with real-time accuracy through computer-aided simulation programs. In this study, a graphical interface is designed in order to better teach the Clarke-Park transforms used in many areas. Thanks to the user-friendly interface, one can visually observe the effect of magnitudes such as voltage, frequency and phase on transforms.

2. Material and Method

Clarke-Park transforms are basic mathematical methods that are used to facilitate the analysis of 3-phase systems. Clarke transform reduces 3D three-phase signals to 2D $\alpha\beta$ space. Clarke transform offers spatial dimensionality reduction which gives stationary reference frame. Park transform further reduces $\alpha\beta$ space to only two constants, dq axes. dq axes are orthogonal to each other and dq reference frame is also called rotational reference frame (Mandic et al. 2019).

2.1 Clarke Transform

Clarke transform, which is also known as the $\alpha\beta$ transform, is used to convert a 3-phase system given in Equation (1) into fixed 2-phase reference frame.

$$\begin{cases} V_A = V_m \sin(\omega t) \\ V_B = V_m \sin(\omega t - \frac{2\pi}{3}) \\ V_C = V_m \sin(\omega t + \frac{2\pi}{3}) \end{cases} \quad (1)$$

V_α , V_β and V_0 values are obtained by Clarke matrix. The mathematical expressions of the transform are given in Equation (2), and the matrix representation of the Clarke transform is given in Equation (3).

$$\begin{cases} V_\alpha = \frac{2}{3}(1V_A - \frac{1}{2}V_B - \frac{1}{2}V_C) \\ V_\beta = \frac{2}{3}(0V_A + \frac{\sqrt{3}}{2}V_B - \frac{\sqrt{3}}{2}V_C) \\ V_0 = \frac{2}{3}(\frac{1}{2}V_A + \frac{1}{2}V_B + \frac{1}{2}V_C) \end{cases} \quad (2)$$

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} = \frac{2}{3} \underbrace{\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}}_{\text{Clarke matrix}} \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} \quad (3)$$

While V_α , V_β signals indicate α and β sequences, the zero-sequence value specified by the c signal is determined by letting $V_0 = 0$ in balanced 3-phase systems. For this reason, the reduced Clarke matrix given in Equation (4) is used when analyzing 3-phase balanced systems.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \frac{2}{3} \underbrace{\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}}_{\text{Reduced Clarke matrix}} \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} \quad (4)$$

2.2 Inverse Clarke Transform

Inverse Clarke transform is used to obtain 3-phase reference frame from fixed 2-phase reference frame. Mathematical equations of the inverse Clarke transform are given in Equation (5).

$$\begin{cases} V_A = 1V_\alpha + 0V_\beta \\ V_B = -\frac{1}{2}V_\alpha + \frac{\sqrt{3}}{2}V_\beta \\ V_C = -\frac{1}{2}V_\alpha - \frac{\sqrt{3}}{2}V_\beta \end{cases} \quad (5)$$

Since V_0 is equal to 0 for balanced 3-phase systems, the values of V_A , V_B and V_C depends on the values of V_α and V_β . The matrix expression of the inverse Clarke transform is given in Equation (6). 3 phase and $\alpha\beta$ reference systems are shown in Figure 1, respectively.

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \underbrace{\begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}}_{\text{Inverse Clarke Matrix}} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \quad (6)$$

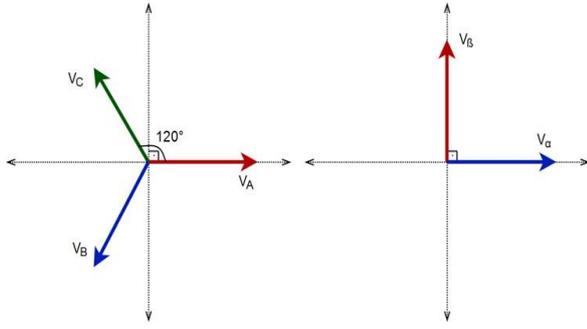


Figure 1. 3 phase and $\alpha\beta$ reference frame

It can be observed that there is a 90° phase difference between V_α and V_β meaning that there is also a 90° phase difference between the sinusoidal signals in the α and β sequences.

2.3 Park Transform

Park transforms are also known as the direct-quadrature ($d - q$) transforms. They are used to transform the fixed 2 phase reference frame to the rotary 2 phase reference frame. Fixed 2-phase reference frame obtained by Clarke transform is used when performing the Park transform. Mathematical expressions of the transform are given in Equation (7), and transform matrix representation is given in Equation (8).

$$\begin{cases} V_d = \cos \theta V_\alpha + \sin \theta V_\beta \\ V_q = -\sin \theta V_\alpha + \cos \theta V_\beta \end{cases} \quad (7)$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \underbrace{\begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix}}_{\text{Park Matrix}} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \quad (8)$$

While performing the park transform, V_α and V_β values are used to obtain the reference angle. θ can be calculated in terms of V_α and V_β as given Equation (9).

$$\theta = \tan^{-1}\left(\frac{V_\beta}{V_\alpha}\right) \quad (9)$$

2.4 Inverse Park Transform

Inverse Park transforms are used to convert time dependent 2 phase reference frame to a fixed 2 phase reference frame. Equations for inverse Park transform are given in Equation (10), and matrix expression is given in Equation (11). The frequency of the system is used to obtain the angle. The expression for finding the reference angle is given in

Equation 12. Figure 2 shows the related $\alpha\beta$ and dq reference system, respectively.

$$\begin{cases} V_\alpha = \cos \theta V_d - \sin \theta V_q \\ V_\beta = \sin \theta V_d + \cos \theta V_q \end{cases} \quad (10)$$

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \underbrace{\begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix}}_{\text{Inverse Park Matrix}} \begin{bmatrix} V_d \\ V_q \end{bmatrix} \quad (11)$$

$$\theta = \frac{\pi}{2} - 2\pi ft \quad (12)$$

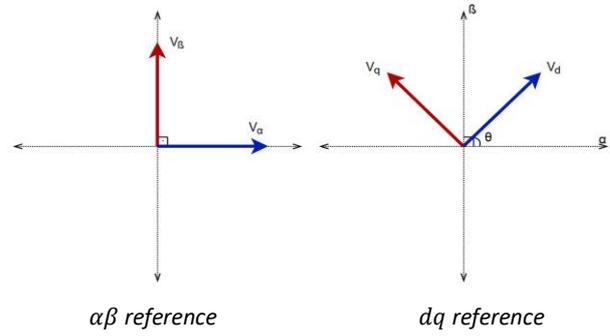


Figure 2. $\alpha\beta$ and dq reference frame

2.5 Clarke-Park Transforms

When analyzing three phase systems, the 3 phase references can be directly expressed in terms of dq reference signals. The $ABC - dq$ transform is given mathematically in Equation (13) and the matrix expression of the Clarke-Park transforms are given in Equation (14). 3 phase and dq reference systems are respectively shown in Figure 3.

$$\begin{cases} V_d = \frac{2}{3}(\cos(\theta) V_A + \cos(\theta - \frac{2\pi}{3}) V_B + \cos(\theta + \frac{2\pi}{3}) V_C) \\ V_q = \frac{2}{3}(\sin(\theta) V_A + \sin(\theta - \frac{2\pi}{3}) V_B + \sin(\theta + \frac{2\pi}{3}) V_C) \end{cases} \quad (13)$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos \theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin \theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} \quad (14)$$

Equation (15) is used to obtain the 3-phase reference frame from the rotary 2-phase reference frame and Equation (16) is used to convert 2-phase reference to 3-phase reference frame.

$$\begin{cases} V_A = \cos \theta V_d - \sin \theta V_q \\ V_B = \cos(\theta - \frac{2\pi}{3}) V_d + \sin(\theta - \frac{2\pi}{3}) V_q \\ V_C = \cos(\theta + \frac{2\pi}{3}) V_d + \sin(\theta + \frac{2\pi}{3}) V_q \end{cases} \quad (15)$$

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} \cos \theta & -\sin \theta \\ \cos\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta - \frac{2\pi}{3}\right) \\ \cos\left(\theta + \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} V_d \\ V_q \end{bmatrix} \quad (16)$$

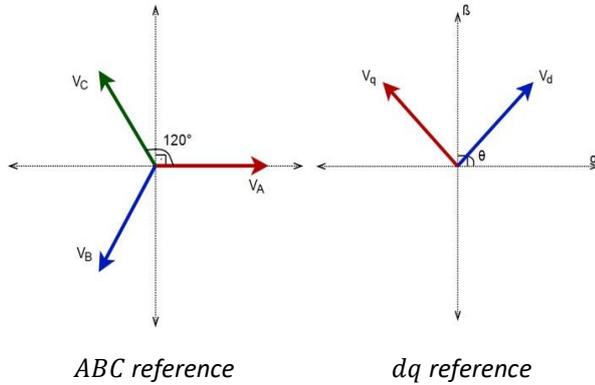


Figure 3. 3 phase and $\alpha\beta$ reference frame

2.6 LabVIEW

LabVIEW is a graphical programming interface that enables visualization of several aspects of computer applications such as configuring hardware, measuring and debugging. Visual programming makes it easy to create all kinds of measurement operations, complex logical operations, data analysis algorithms and reveals customized engineering interfaces (Bress 2013).

LabVIEW was first released by National Instruments (NI) in 1986 for the Apple Macintosh. It is generally used for data acquisition, control and industrial automation. It can be operated in Microsoft Windows, Unix, Linux and MacOS operating systems. LabVIEW offers a combination of user interface and application development platform. Applications created with LabVIEW are defined as Virtual Instruments (VI). Each VI consists of three basic parts; front panel, block diagram and connector panel. The front panel is the part that contains the controls and indicators. Controls are the elements from which data entry is done, and indicators are the elements that show the output. Block diagram is the visual part where coding takes place.

All controls and indicators on the front panel have a counterpart on the block diagram. All controls, indicators, structures and functions on the block panel are defined as nodes. Nodes are connected to each other with cables and perform the desired operation (Jeffrey and Kring 2006).

It is possible to create simple applications just by tying the nodes. However, it requires a deeper knowledge on LabVIEW to create more complex algorithms. Thanks to LabVIEW, it is possible to obtain standalone programs visually. In LabVIEW, data flow goes from left to right, but in C/C++ programming, data flows from top to bottom. Hence, errors in the graphic code can be identified with greater ease during the execution of the program. With LabVIEW, many industrial applications can be modeled and simulated. It allows us to analyze the performance of the application. For example, induction motors can be modeled and simulated with LabVIEW. It is also possible to track processing of the dynamic data. Based on mathematical and physical model of the motor, dynamic analysis can also be conducted via LabVIEW tools [Ramprasath and Manojkumar 2015]. For power systems, optimum overcurrent relay coordination in distribution networks can also be done with LabVIEW [Biswas et al. 2018].

3. Applications

The entrance screen of the interface created in the LabVIEW program is given in Figure 4.

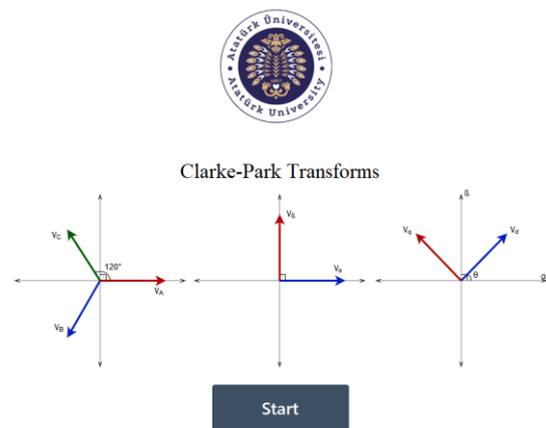


Figure 4. Interface main screen

When the user clicks the "START" button, the screen given in Figure 5 appears from which the type of transform can be selected.

- Clarke Transform (ABC to $\alpha\beta$)
- Park Transform ($\alpha\beta$ to dq)
- Clarke-Park Transforms (ABC to dq)

- Inverse Clarke Transform ($\alpha\beta$ to ABC)
- Inverse Park Transform (dq to $\alpha\beta$)
- Inverse Clarke-Park Transforms (dq to ABC)
- Mathematical Model



Figure 5. Transform selection screen

When one of the transform methods (Clark, Park etc..) on the interface is selected, the mathematical equations and graphics of the transform will be illustrated on the screen. The flowchart belong to interface is given in Figure 6.

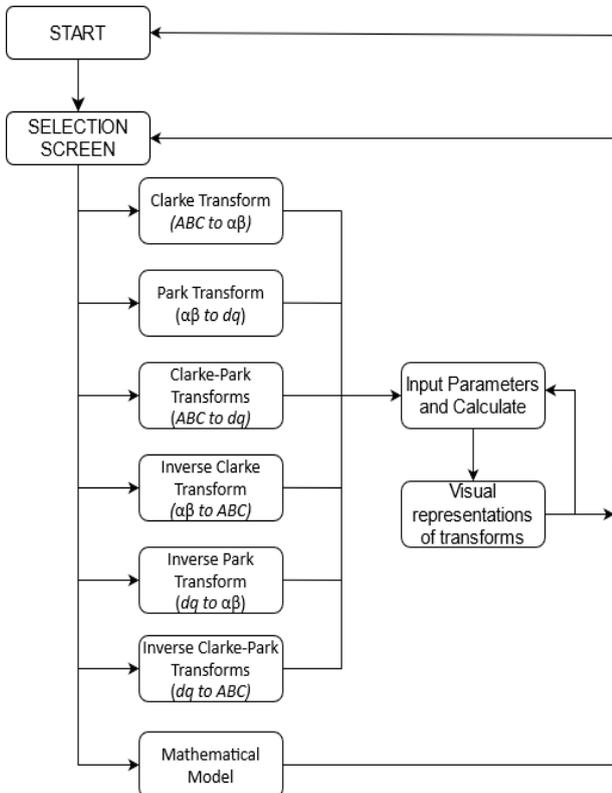


Figure 6. Interface flowchart

Figure 7 shows the results of selecting $V = 50 V, f = 50 Hz$ for Clarke transform. In Figure 7, the transform of 3-phase stator voltages of asynchronous motor with 2 axes using Clarke transform is illustrated.

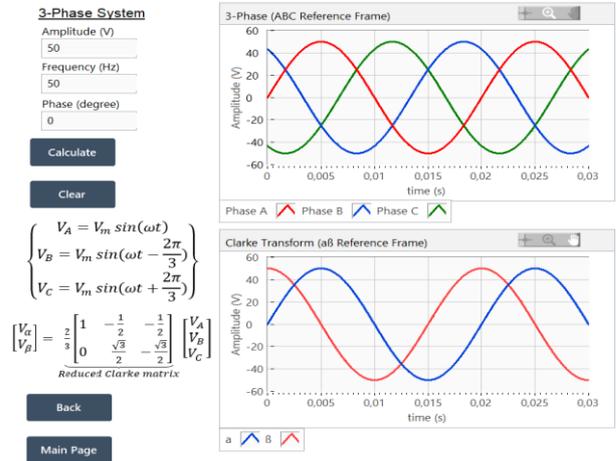


Figure 7. Clarke transform

Figure 8 shows the results of selecting $V = 50 V, f = 50 Hz$ for Inverse Clarke transform. In Figure 8, the transform of V_α and V_β voltages on the fixed reference axis to 3 phase voltages as a result of the Inverse Clarke transform is plotted.

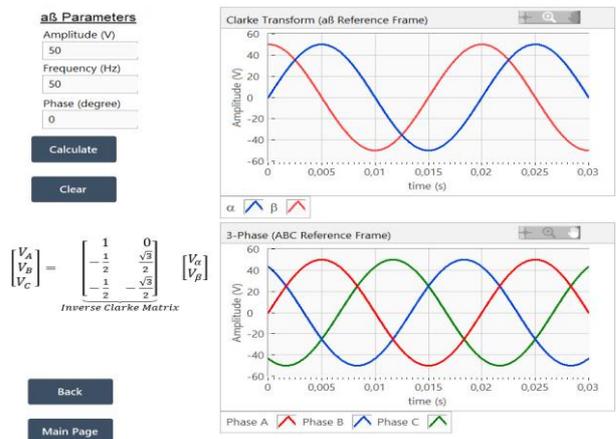


Figure 8. Inverse Clarke transform

The Park transform for $V = 110 V, f = 60 Hz$ values is shown in Figure 9. In Figure 9, the V_α and V_β voltages obtained as a result of Clarke transform is given. It has been shown that these voltages, whose direction and value change over time, are transformed into fixed voltage values with Park transform. The main purpose of this transform is to realize the asynchronous motor more easily.



Figure 9. Park transform

On the other hand, Figure 9 illustrates the Inverse Park transform obtained for $V_d = 110\text{ V}$, $V_q = 0\text{ V}$, $f = 60\text{ Hz}$ selection.

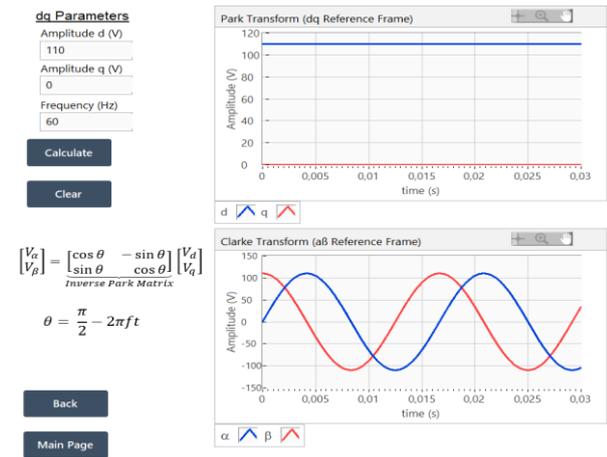


Figure 10. Inverse Park transform

In Figure 10, the result of the Inverse Park transform of the voltage values obtained as a result of the Park transform is shown.

Figure 11 shows the results of selecting $V = 380\text{ V}$, $f = 50\text{ Hz}$ for Clarke Park transform, in which 3 phase voltages transferred to the dq axis.

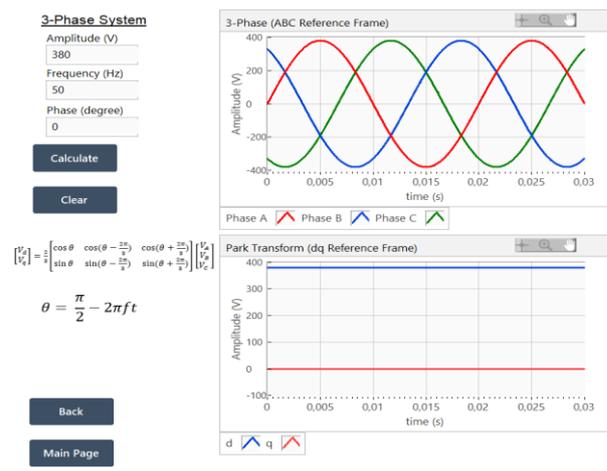


Figure 11. Clarke-Park transforms

Finally, if $V_d = 380\text{ V}$, $V_q = 0\text{ V}$, $f = 50\text{ Hz}$ is selected, the transform is shown in Figure 12.

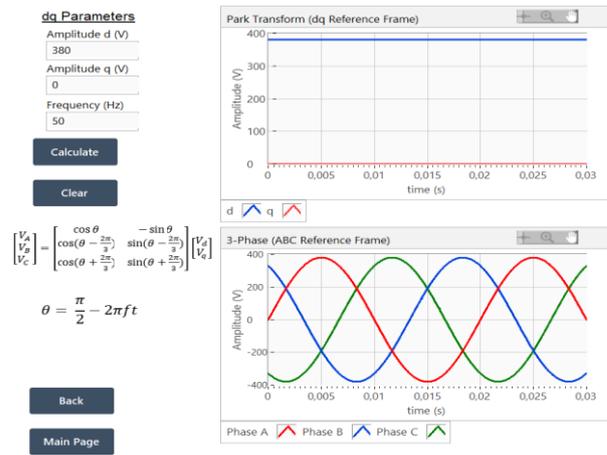


Figure 12. Inverse Clarke-Park transforms

In Figure 12, the transform of the voltage values given on the dq reference axis to the 3 phase ABC axis is shown.

The basic mathematical transform equations are given in Figure 13. Figure 13 shows Clarke matrix, Park matrix, Inverse Clarke matrix, Inverse Park matrix, Clarke-Park matrix and Inverse Clarke-Park matrix equations together.

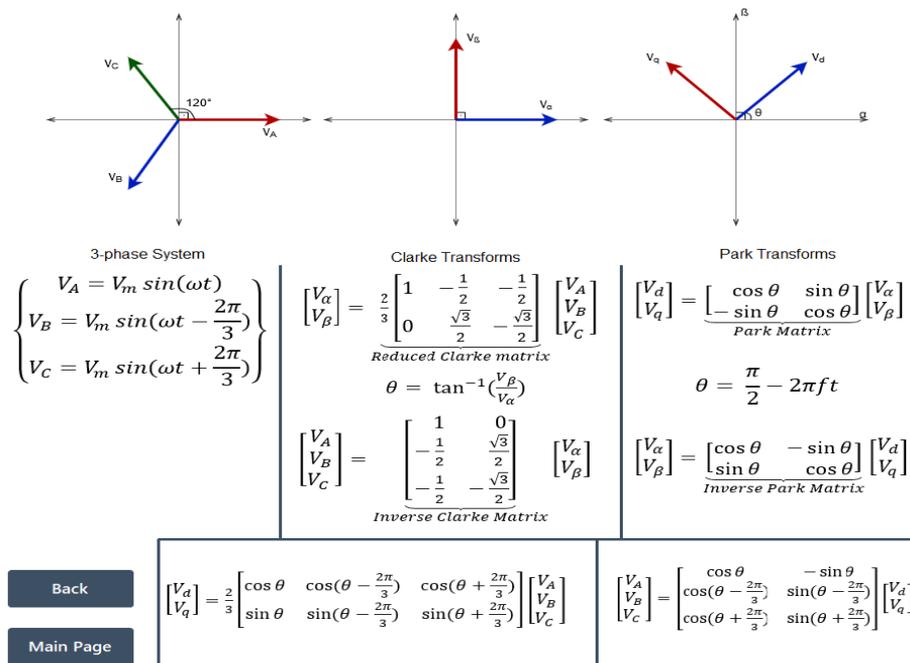


Figure 13. Mathematical transform matrix

4. Conclusion

Clarke-Park transforms are generally used in the dynamic analysis of three-phase induction motors with the time-varying current and voltage. In this study, a visual interface has been prepared in order to see the effects of voltage, frequency and angle value parameters on Clarke-Park transforms. Thanks to the interactive interface of the standalone executable program, users will be able to change parameters easily and see the changes visually. Graphically, LabVIEW presents more user-friendly interfaces than other programming languages. Users can graphically observe the transforms of $(abc \text{ to } \alpha\beta)$, $(\alpha\beta \text{ to } dq)$, $(abc \text{ to } dq)$, $(dq \text{ to } abc)$, $(dq \text{ to } \alpha\beta)$ and $(\alpha\beta \text{ to } abc)$. Moreover, there are theoretical information about transforms in the interface. Through this interface, we manage to teach transforms by the help of visual illustrations. Mathematical models of the transforms and the interface are generated using LabVIEW. This interface can be used in electrical machines related subjects. We are aiming to give users a graphically enhanced experience about the subject. This interface will be useful for understanding Clarke-Park transforms used in asynchronous motors especially for undergraduate and postgraduate students.

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