THE REPUBLIC OF TURKEY

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HIGH-IMPEDANCE FAULTS DETECTION BY USING WAVELET TRANSFORM

Master's Thesis

WASEEM KHALID IBRAHIM AL-KES

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This is to certify that we have read this thesis and we find it fully adequate in scope, quality and content, as a thesis for the degree of Master of Science.

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ABSTRACT

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The power system is protected from different types of faults. Especially single phase to ground fault is the most popular one in terms of frequency of occurrence. High impedance fault is one of single phase to ground fault types. Because of the small high impedance fault current, the detection of this type of fault has always been difficult in distribution power system. In this thesis, high impedance faults (HIFs) detection in distribution power system is investigated. An algorithm is proposed to detect HIF by using discrete wavelet transform. The characteristic of wavelet transform has been used for extracting fault signal feature. The Matlab Simulink software environment is preferred for modeling the power system and high impedance fault. Moreover, the wavelet toolbox in Matlab is used to extract the signal feature. In the algorithm, the discrete wavelet transform is applied to three phase signals. Then the signals have been analyzed by debauches wavelet as mother wavelet with 6 levels of details. The main part of algorithm depends on energy of details. The HIF is separated from the other faults by using energy of details. The limit for energy percentage was chosen in the algorithm depending on the simulation results. In order to show the effectiveness, different fault parameters with different fault location were tested. All test results show that the proposed algorithm is found the faulty phase when the fault in distribution power system is HIF.

Keywords: Distribution System, Fault Detection, Wavelet Transform.

ÖZET

DALGACIK DÖNÜŞÜMÜ İLE YÜKSEK EMPEDANCE HATALARI BELİRLENMESİ

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Elektrik güç sistemi farklı arıza tiplerinden korunmaktadır. Arızaların meydana gelme sıklığı bakımından en çok görülen arıza tipi tek faz toprak arızasıdır. Tek faz toprak arıza tiplerinden bir tanesi de yüksek empedans arızası olarak tanımlanır. Yüksek empedans arızasındaki akımın küçük olmasından dolayı bu tip arızaların dağıtım sisteminde tespit edilmesi daima zordur. Bu tez çalışmasında, dağıtım sisteminde meydana gelen yüksek empedans arızaların belirlenmesi araştırılmıştır. Ayrık dalgacık dönüşümü tekniği kullanılarak HIF tespiti yapabilen bir algoritma önerilmiştir. Arızalı sinyalin özelliğini elde etmek için dalgacık dönüşümünün karakteristiği kullanılır. Güç sisteminin ve yüksek empedans arızanın modellenmesi için Matlab Simulink yazılım ortamı tercih edilmiştir. Ayrıca sinyal özelliğini elde etmek için Matlab içinde bulunan dalgacık araç kutusu kullanılmaktadır. Algoritmada ayrık parçacık dönüşümü üç fazlı dalgaya uygulanmaktadır. Sinyaller 6. Seviyeden detaylara sahip ana dalgacık olarak Debauches dalgacık yöntemi ile incelenmiştir. Algoritmanın ana kısmı elde edilen detayların enerjisine bağlıdır. HIF diğer arıza türlerinden detayların enerji bilgisi kullanılarak ayrılmaktadır. Algoritma içinde enerji seviyesinin yüzdesi benzetim sonuçlarına bağlı olarak seçilmiştir. Algoritmanın etkisini göstermek için farklı arıza noktalarında yaratılacak farklı arızalar ile testler yapılmıştır. Bütün test sonuçları dağıtım sisteminde bir HIF arızası olduğu zaman önerilen algoritmanın sistemdeki arızalı fazı bulduğunu göstermiştir.

Keywords: Dağıtım Sistemi, Arıza Tespiti, Dalgacık Dönüşümü.

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ABBREVIATIONS

ANN	:	Artificial neural network
db4	:	Daubechies 4
DL	:	Distribution Line
DWT	:	Discrete Wavelet Transformation
ED6	:	Energy of detail six
FFNN	:	Feed-Forward Neural Network
HIF	:	High Impedance Fault
NN	:	Neural Network
WT	:	Wavelet Transform

SYMBOLS

Complex value	:	J
Current of phase (A)	:	Ia
Current of phase (B)	:	Ib
Current of phase (C)	:	Ic
Delta	:	δ
Father wavelet	:	φ
Hilbert space	:	$L^2(R)$
Index	:	K
Mother function	:	ϕ
Real positive	:	R^{+*}
Real positive for n value	:	R^n
Subgroup	:	Λ
Wavelet	:	ψ

1. INTRODUCTION

1.1 BACKGROUND

Fault detection in electrical power systems plays an important role in the correct operation of a protective relay. When a fault happens in power system, the fault current is always higher than the rated load current. Several methods and conventional digital techniques were proposed and used for fault detection (Baqui, Zamora, Mazón, & Buigues, 2011).

The unbalanced system operation could be result in an otherwise balanced system due to unsymmetrical fault like line to ground fault or line to line fault. These types of fault are in fact, of common occurrence than the symmetrical (three-phase) fault. When loads are unbalanced as in the presence of the large single phase loads, the system operation will lead to become unbalanced.

The unbalanced conditions analyzing would be carried out on a three-phase basis. Otherwise, a more suitable method of analyzing unbalanced power system operation is through symmetrical components where the three–phase (voltages and currents) which may be unbalanced are transformed in to three sets of balanced (voltage and current) called symmetrical components.

Fortunately, in such a transformation the impedances presented by various power system elements (synchronous generators, transformers, lines) to symmetrical components are decoupled from to each other resulting in independent system network for each component (eg. balanced set) (Kothari & Nagrath, 2003).

The fault can be occurred in any part of power system such as generation, transmission and distribution. In the literature, researchers study on different the fault types on the necessary action should be done on the protection level. The most dangerous fault is high impedance fault (HIF), HIF happens when an energized conductor breaks and falls to the ground without solid ground and this type of fault makes an ionization around the fallen place that is made more difficulty to detect it.

The frequencies of occurrence various faults in the transmission and distribution system are given below:

a) Three phase faults :5 percentage
b) Double line-to-ground faults :10 percentage
c) Double line faults :15 percentage
d) Single line-to-ground faults :75 percentage

1.2 LITERATURE REVIEW

High impedance faults (HIFs) are difficult to be detected through traditional protection relay such as distance relays, when a conductor makes a contact with a poor conductive surface, such as asphalt, sand etc.

In the last thirty years of 20_{th} century, many researchers have presented results aimed at more effective detection of HIF. Now the algorithms developed up to the current rate method (Aucoin & Russell, 1987; Lee & Bishop, 1983), a high-frequency method (Aucoin & Russell, 1987), the off-harmonic current method (Jeerings & Linders, 1991), neural network and Kalman filtering method (Girgis, Chang, & Makram, 1990; Mohamed & Rao, 1995; Sultan, Swift, & Fedirchuk, 1992).

S. J. Huang (Huang & Hsieh, 1999) introduced HIF detection technique with wavelet transform delivery systems using a Morlet (Emanuel, Cyganski, Orr, Shiller, & Gulachenski, 1990; Wai & Yibin, 1998). Though, each of these techniques increases the detection of fault until a definite degree, but each has its own disadvantages. Until now, there are subject to a number of different systems and techniques rather extensive testing to determine the effectiveness of fault conditions. This HIF other relay adjustment imposed by very low levels of fault currents and limitations are due mainly to the relay insensitivity. Such a failure typically occurs when a high impedance conductive ground contact with broken branches of a tree touch. In case of overload relay, the relay sensitivity settings associated with the current low level of HIF is as follows. In the distance relay case based on an estimate of the impedance based on the measured voltage and current fault, the accuracy of the estimates may be affected quite high impedance faults (Mamishev, Russell, & Benner, 1995; Sultan et al., 1992).

Wavelet other hand transmission-line faults and transient phenomena that are associated with switching operation is useful to analyze transform. Unlike Fourier analysis, by a signal variable window length to use providing time information (such as widespread power systems encountered in the network), low and high frequency components formed a very effective life attribute of non-stationary signals (Strang & Nguyen, 1996). A wavelet transform, has marked the time and frequency information, and one of these techniques (especially in terms of increased credibility and reliability) advantages of this type of subject.

The wavelet analysis to the other signal processing techniques, through more complex, ideally it should be noted that is appropriate to deal with non-stationary signals such as those encountered under the high impedance fault. This error detection accuracy and increases the reliability and features that affect error location techniques (Chen, 2005) to be applied.

In the S-transform property, feature a number of conversion is obtained by the various features press or using a digital signal processing means such as ripple voltage and current signals (Akorede & Katende, 2010; Etemadi & Sanaye-Pasand, 2008). Fourier Transform (Chen, 2005), Prony analysis transformation (Dash, Panigrahi, & Panda, 2003; Li & Wu, 2008; Suja & Jerome, 2010).

The HIF is insufficient fault current because of that the conventional protection devices in electric distribution systems have not able to detect it. One of the chief characteristic of high impedance fault is the low magnitude of current (Torres, Ruiz, & Hector, 2011).

In last years, several methods have been highlighted to detect the high impedance fault (HIF) such as using the wavelet, then, the Feed-Forward Neural Network (FFNN) for detection and classification (HIF) respectively (Narasimharao, 2012). The major problem in utilizing the FFNN is that it requires additional data for training, which means more time consuming. In addition, many Neural Network (NN) algorithms, including the FFNN, are struggling from the local error problem. That is the algorithm may consider the local error as a global error during the training stage, which could lead to a false classification during the testing stage.

Moreover, in (Zanjani, Kargar, & Zanjani, 2012) a strong method has been suggested to detect the HIF based on the phasor measurement unit. However, in that study, one phase has been considered to test the algorithm.

The currents of three phases have been combined by using the summation operation rule in (Jannati, Keivanian, & Eslami, 2015). So, the main deficiency of that proposed solution with this thesis is that in (Jannati et al., 2015) the exact phase, which causes the fault, cannot be detected. Due to the fact that combining the three phases together according to the summation operation will merge the values together and will waste detectıng the phase type where the fault can be found

Previously low impedance fault (LIF) has been tested in several research location. In (H Mokhlis, Li, & Khalid, 2010; H Mokhlis, Li, Mohamad, & Bakar, 2010; H Mokhlis, Mohamad, Bakarl, & Li, 2011; Hazlie Mokhlis, Mohamad, Li, & Bakar, 2011), the LIF is the most common fault by high current faults and low impedance fault which are easily recognizable by traditional protection relay.

Recently digital distance protection has replaced the conventional relaying practices. The one of the most important parts of the operation in digital distance protection is signal processing. Until recently, Fourier analysis was the main tool in signal processing. In the distribution system, the main form of single-phase electricity network failure, and even many of the fault phase to phase fault evolution. Single phase earth fault type can be divided into three groups:

a. Base metal.
b. High impedance base.
c. Clamp Base.

Fault detection, through the extraction of the residual voltage and current characteristics when HIF happened, using discrete wavelet detail coefficients of residual voltage and current. When one of them, high-impedance ground fault occurs, it is difficult to accurately extract the characteristic value according to the most symmetrical three-phase line voltage. Small error and fault current unobvious features increase the difficulty of high impedance fault detection (Jannati et al., 2015).

1.3 AIM OF THE THESIS

The aim of this study is to propose an algorithm to detect any high impedance fault in power distribution system by using the Matlab Simulink environment. In the algorithm, the discrete wavelet transform will be used to find the faulty phase in the system. The algorithm allows to detect different types of faults in electrical distribution line. It takes the current signals as inputs to the wavelet transform. The fault detection process is accomplished through decomposition of the current signals, thresholding of percentage of energy for wavelet transform details, and the difference between the energy of normal case with faulty case to detect HIF.

In this thesis, the high impedance fault is implemented on distribution system and then with it is detected by wavelet transform. Different types of faults were tested and were detected. Daubechies wavelet is used for mother wavelet. In chapter 2, the power system is discussed. In third chapter, the wavelet transform is briefly explained. The proposed algorithm and simulations are given in chapter 4. the conclusion is presented in chapter 5.

2. POWER SYSTEMS

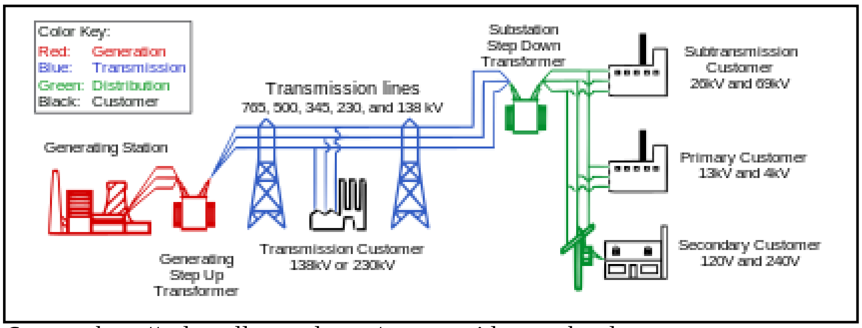
2.1 POWER GENERATION

Much of our daily energy available is provided as electric energy in power plants. Various types of energy sources (eg. uranium, coal, gas, water, wind or the sun) to be converted into useful energy (eg. light, heat, cold). The demand in a power system is strongly influenced by seasonal fluctuations.

The generation and consumption in any power system must always be in balance. This leads to a complex and expensive control of the network and the power stations. Because of this, energy storage is important issue to operate the power system easily. Variations in power generation and the need for regional power grids are compensated for by a number of regional power grids that are interconnected and different energy technologies that are used as an energy buffer.

Depending on the purpose of the power plant, there are three different type power plants: base load power plant, medium load power plant, peak load power plant. Especially, the renewable energy based power plants cannot use as a baseload power plant in any power system. Figure 2.1 represent the electric power system diagram from generation to consumer.

Figure 2.1: An electric power system diagram



Source: http://solarcellcentral.com/smart_grid_page.html.

2.2 POWER TRANSMISSION

Electrical power is transferred from generation station to power distribution through the overhead lines and underground cables by increasing the voltage value used to step up transformer. Transmission lines are characterized by four parameters:

a. Series Resistance (R)
b. Shunt Conductive (G)
c. Series Inductance (L)
d. Shunt Capacitance (C)

There are three models of power transmission depending on the length :

a. Short lines is that length less than 50(miles) in the other meaning the maximum length is 80(km).
b. Medium lines is that length higher than 50 (miles) and less than 150(miles) in the other meaning the maximum length of that type of line is (250 km).
c. Long lines is that length higher than 150(miles).

2.3 POWER DISTRIBUTION

The main part of the power distribution system is the distribution line. A distribution line is used for transporting the signal from the transmission system to a power load. It must be considered a pair of conductors as a distribution line when a length of the same order of magnitude or more than the wavelength of the highest frequency of the signal to be transmitted. It can be shown that the line can carry the load fictitiously close to the signal source. The most common distribution lines are overhead lines and underground cables.
A distribution line is characterized by its characteristic impedance, the attenuation constant (which specifies the losses in the line), and the signal propagation speed which depends on the dielectric used to make the line.

2.4 POWER SYSTEM FAULTS

The power system ground fault is created from contact between ground and an energized conductor. This ground fault has unleashed large amount of electrical energy. These faults are dangerous to equipment of power system and people. Depending on the amount of fault impedance, the one of them is high impedance fault. The electrical fault including high impedance faults and are stochastic in nature and depend on factors such as:

a. Location of fault.
b. Impedance of fault.
c. Inception angle of fault.
d. Other electrical loads.

2.4.1 High Impedance Fault

High impedance faults (HIFs) when an energized primary conductor interacts with a semi protecting object, such as a tree, structure or equipment, or falls to the ground. The hugeness of these beforehand imperceptible faults is that they speak to a genuine open wellbeing peril as well as a danger of arcing ignition of flames. High impedance fault is so complex occurrence and exhibits a very highly nonlinear behavior. The greatest feature characteristics of high impedance fault are:

a. Build up
b. Shoulder
c. Nonlinearity
d. Asymmetry

The detection of HIFs is difficult by traditional protection relays such as, distance or overcurrent relays (Baqui et al., 2011; Etemadi & Sanaye-Pasand, 2008).

HIFs, although rare, still it must be determined precisely and should be separated from other faults. This apart from threatening the reliability of electric power supply, which may pose a risk of fire and electric shock with the possibility of these faults is much more in view of the fact that life in danger. HIF most conventional fault detection techniques require mainly post-HIF current and voltage feature extraction based computing. HIF also realistic nonlinear simulation model (Lee & Bishop, 1983; Mamishev et al., 1995) comprises an arrangement. Relay performance is examined for different systems encountered in practice and then HIF fault signals under various conditions.

This error detection accuracy and increases the reliability and features that affect error location techniques (Sultan et al., 1992) to be applied. In this paper, a new fault detection techniques including (HIFs) under a distribution line that captures the current signals generated are described. This technique increases the absolute DWT based HIF detection performance using the total value is shown.

In last decade, many researchers have offered results aimed at more effective detection of HIF. Now the algorithms developed up to the current rate method (Sarlak & Shahrtash, 2011), a high-frequency method (Akorede & Katende, 2010), the method of off-harmonic current (Chen, 2005), Kalman filtering method and the method of neural network (Baqui et al., 2011), (Avdakovic & Nuhanovic, 2010; Dash et al., 2003; Suja & Jerome, 2010).

S. J. Huang (Li & Wu, 2008) approach (H Mokhlis et al., 2011) HIF detection technique for a wavelet transform delivery systems using a Morlet (H Mokhlis, Li, & Khalid, 2010; H Mokhlis, Li, Mohamad, et al., 2010) he has proposed. Until now, the (some available as commercial products) are subject to a number of different systems and techniques rather extensive testing to determine the effectiveness of fault conditions.

As known, the traditional Fourier transform-based techniques (for example, those which rely completely transform Fourier spectrum analysis) error is known to have inherent knowledge on how to start time. Wavelet other hand transmission-line faults and transient phenomena that are associated with switching operation is useful to analyze, transform. Unlike Fourier analysis, by a signal, low and high frequency components formed a very effective life attribute of non-stationary signals (Hazlie Mokhlis et al., 2011).

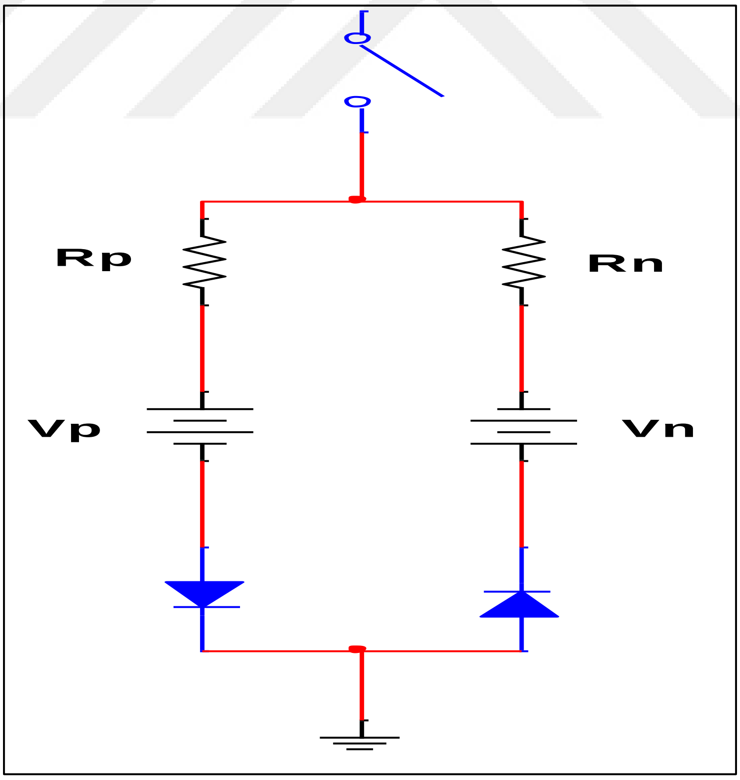
Through decomposition, thresholding WT coefficients and time of the signal accomplish the signal detection process.

Threshold moving window layout is noted by the weighted sum of the absolute value for a period, and this system is the basis of a complexed decision logic for a trip to the limitations of the decision.

In past, there are some model of HIF have been proposed and depended on arc theory and distribution voltage level and will present two of them on this thesis:

a. A first version (HIF) two diodes (DP and DN) is formed, two resistances (RP and RN) and two DC voltage sources (VN and VP) and the arc of HIF in sandy soils provided. Two DC voltage source, VP and VN, which represents air in the soil arc voltage and / or between trees and lines. RP and RN between diodes and DC voltage represents the resistance of trees and / or ground resistance. The current asymmetric in order to simulate different amounts of RP and RN used. When the line voltage is greater than the positive voltage DC Department, fault current starts flowing towards the ground. Now reverse fault back from the ground when the line voltage is less than negative voltage DC VN. If the line voltage value between VP and VN, anti-voltage line is balanced by VP and VN. So that no fault current flows (Eldin, Aboul-Zahab, & Saleh, 2009. The fault model of HIFs for two diodes Simplified as shown on figure 2.2 that is used on this thesis.

Figure 2.2: The fault model of HIFs for two diodes simplified



Source: (Eldin, Aboul-Zahab, & Saleh, 2009)

b. Second HIF model is characterized by two resistances related in series and takes from equation (2.1):

$$R(t) = R_1(t) + R_2(t) \quad (2.1)$$

When $R_1(t)$ has periodic characteristic and is used to denote the nonlinearity and asymmetry. The amount of $R_1(t)$ is taken from the voltage and current characteristics during the steady state. When the voltage of faulted branch (V(t)) is in the range $V_n < V(t) < V_{n+1}$ and corresponding current is i(t), $R_1(t)$ is given in equation (2.2).

$$R_1(t) = \frac{V(t)}{I(t)} = \frac{V(t)}{i_n + \frac{i_{n+1} - i_n}{V_{n+1} - V_n} + (V(t) - V_n)} \quad (2.2)$$

Which n is the point number on the V-I (eg. voltage and current) characteristics curve. $R_2(t)$ is used to simulate such characteristics by assigning a very large value at the beginning of the high impedance fault then regularly decreases that value in the transient state and finally becomes zero in steady-state. The value of $R_2(t)$ for the no shoulder case is introduced by equation (2.3):

$$R_2(t) = \frac{1600}{1 + 65t} - 135t \quad (2.3)$$

There are such a large number of strategies to gauge the High impedance faults:

a. The first strategies created to distinguish high impedance arcing faults depended on the direct measurement of the fundamental electric parameters, for example, voltage and current, examining their varieties or their harmonic components and utilizing distinctive techniques or mixes of them. Nonetheless, these strategies now and again mistrip because of likeness between frequency domain information delivered by HIFs and ordinary normal system switching events. In this manner, it is hard to discover maybe a couple basic critical harmonic components that can segregate one aggravation from another. Along these lines, the HIF discovery algorithms that are just taking into account the power frequency or on some current harmonics (ignoring other high frequency parts that exist in the fault current) are not dependable algorithms. Hence, new techniques must be produced.

b. The extra strategies utilized for the portrayal of these faults can be founded on the infusion of low frequency signal analysis, ANN, WT and intelligent systems. Regarding to the techniques in view of utilizing just WT to HIF discovery, they have been frequently criticized because the data set of registered faults do not agree with other published. Then again, the ANN algorithms have been tried by many research groups, however the ideal segregation of capacitor switching and high impedance faults is still an unsolved issue. In this way, in light of the disadvantages of utilizing WT or ANN independently, the mix of both WT and ANN is exhibited as a superior answer for the issue of HIF detection in distribution power systems (Eldin, Aboul-Zahab, & Saleh, 2009).

3. WAVELETE TRANSFORM

3.1 INTRODUCTION OF WAVELET TRANSFORM

Wavelet transform is a tool that is used to analyze any signal, the results of the analysis are given in the time and frequency domain. Wavelets have emerged when some subjects of study required an analysis in frequency and time. In the nineteenth century, the only way to analyze Fourier analysis of the signal without loss of information. Unfortunately, it provides time-frequency analysis but the position does not allow sudden changes, such as the appearance of a second musical note after a first note was played.

In 1909, Alfréd Haar defines a function composed of a short negative pulse followed by a short positive pulse, known as the first wavelet (Haar wavelet). In 1946, Dennis Gabor, Hungarian mathematician invented transformation a function similar to that of Joseph Fourier, applied to a time window expressed by a Gaussian function. Finally, the term wavelet was introduced into mathematical language by Jean Morlet and Alex Grossmann in 1984. Term originally French, it was translated into English by wavelet, from the terms wave (wave) and let the diminutive (small).

Yves Meyer, recognized as one of the founders of wavelet theory, gathered in 1986 all previous discoveries (it numbered 16) then defines orthogonal wavelets. In the same year, Stéphane Mallat made the connection between wavelets and multiresolution analysis. Finally, Ingrid Daubechies devised in 1987 orthogonal wavelets called Daubechies wavelets easily implementable, and used in the JPEG 2000 standard (Strang & Nguyen, 1996).

3.2 MATHEMATICAL DEFINITION OF WAVELET TRANSFORM

In mathematics, a wavelet ψ is a square integral function of the Hilbert space $L^2(R)$, usually oscillating and zero mean, chosen as an analytical tool and reconstruction multi-ladder.

Wavelets are usually found in families consisting of a mother wavelet and all of this images by the elements of a subgroup Λ group of affine transformations of R^n. This defines a wavelet family $\psi_{s,\tau}(\varphi(s,\tau) \in R^{+*} \times R)$ from the mother wavelet:

$$\forall t \in R, \psi_{s,\tau}(t) = \frac{1}{\sqrt{s}} \psi(\frac{t-\tau}{s}) \tag{3.1}$$

By extension, the families of functions on sub manifolds of R^n invariant under a group of locally isomorphic to the group affine transformation can also be described as wavelet families (Strang & Nguyen, 1996).

3.3 WAVELET TRANSFORM TYPES

Depending on the types of wavelet decomposition, there are two types of wavelet transform: discrete and continuous wavelet transform.

In continuous wavelet transform (CWT), Analyze a square sum able function wavelet is to calculate all its scalar products with the wavelet family. Numbers obtained are called wavelet coefficients, and combining the transaction to a function its wavelet coefficients is called wavelet transform (Strang & Nguyen, 1996).

In discrete wavelet transform (DWT), this technique is used in the compression of any signal, with or without loss. Compression is achieved by successive approximations of the initial information from coarser to finer. One then reduces the size of the information by selecting a level of detail (Strang & Nguyen, 1996).

One-dimensional (1D) signals such as voltage and current signals could be analyzed with wavelet transform. It is well known that wavelet transforms are widely used to compress data and to suppress noise. In the literature, this process is known as wavelet de-noising. The wavelet transform of one dimensional signal encloses the information regarding the low-frequency content of any signal. This low-frequency content is called the approximation coefficients, while the information regarding the high-frequency content of any signal is called the detail coefficients. The WT of the any signal with using the matrix method is described in the following sections.

3.4 THE CONTINUOUS WAVELET TRANSFORM

Let $\Psi(t) \in L^2(R)$ is a continuous-time mother wavelet function and the set of functions, obtained by shifting and scaling the mother wavelets.

$$\psi_{a,b} = \frac{1}{\sqrt{a}}\psi(\frac{t-b}{a}) \tag{3.2}$$

are orthonormal wavelet basis in the $L^2(R)$. That is

$$\int_{-\infty}^{\infty}\psi_{a,b}(t)\tilde{\psi}_{a',b'}(t)dt = \delta(a-a')\delta(b-b') \tag{3.3}$$

In the wavelet, *a* and *b* variables are real and the integral value indicate the closeness of the signal to a particular basis function. Dividing $\Psi_{a,b}(t)$ by $\sqrt{a}$ insures the unity in the L^2 norm of the set $\Psi_{a,b}(t)$.

The main disadvantages of the CWT are computational complexity and redundancy. The mother wavelet has to satisfy the following properties.

A wavelet must have finite energy

$$\int\left|\Psi(t)\right|^2 dt < \infty \tag{3.4}$$

$\Psi(t)$ integrates over time to zero (It's Fourier transform Y(*w*) equals to zero at *w*= 0).

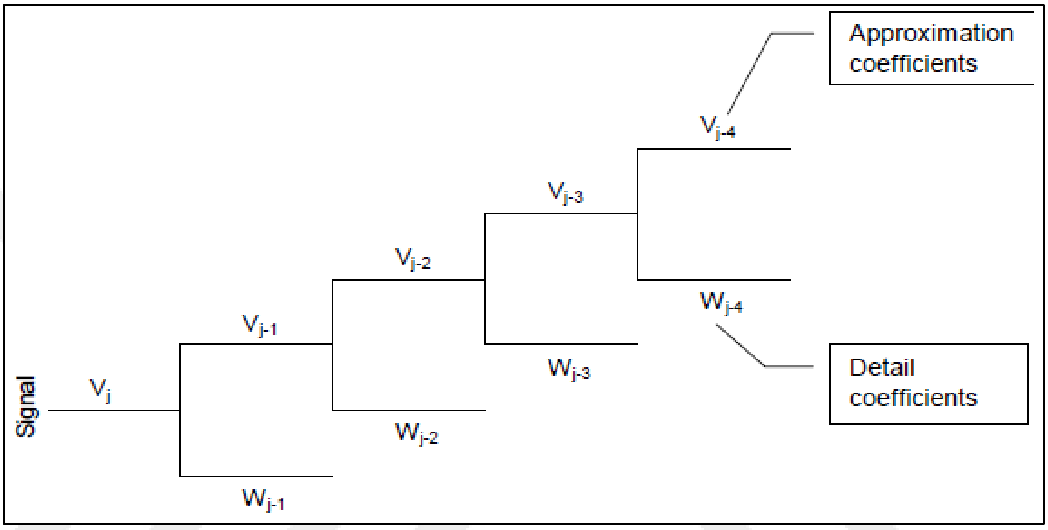
$$\Psi(w=0) = \int_{-\infty}^{\infty}\psi(t)dt = 0 \tag{3.5}$$

The connection between the signal and the wavelet is defined as the integral of their product.

3.5 THE DISCRETE WAVELET TRANSFORM

DWT is generally obtained by sampling the continuous wavelet transform. Discrete CWT, a wavelet analysis function that generates orthogonal (or orthogonal) basis for favorite space is required. Many of CWT there may be discrete, but DWT routine use of dual network, in which $a = 2^{-j}$ and $b = 2^{-j}k$. In DWT is used two types of filters low pass filter and high pass filter while low pass filter is named approximation (A) and high pass filter is named detail (D). The wavelet decomposition process can be represented schematically in figure 3.1.

Figure 3.1: The representation of wavelet decomposition of signals schematic



Source: (Strang & Nguyen, 1996)

Below the properties multiresolution analysis is summarized. A multiresolution analysis or system should have the following properties or conditions. A multiresolution analysis of $L^2(R)$ is sequence subspaces of $L^2(R)$.

3.6 DAUBECHIES DISCRETE WAVELET TRANSFORM

For the purposes of functional analysis generates the wavelet function, together with its integer shifts, and the compressions / dilations of these functions with powers of a factor, an orthonormal basis of the Hilbert space L^2 (IR), ie. every square integrable function can be decomposed into parts that the wavelet function similar see. Since 1909 was the Haar wavelet, a piecewise constant function, known with this property. It was the merit of I. Daubechies, to have constructed the first is a continuous function with this property. There are two finite sequences of real numbers, which can be used as a digital low and high pass filters in a filter bank, which is part of the filter bank wavelet transform for each wavelet. The length N of these filters, referred to as a number of taps, is part of name the individual Daubechies wavelets. In practice, usually the Daubechies wavelets with the names D2-D20 are used. On theoretical grounds only just N = 2A occur. Each wavelet this class has the maximum number of A vanishing moments. The wavelet function is normal (within the meaning of L^2 (IR), ie the integral of the product of both functions is zero) to each polynomial of degree at most A-1. For example, D2 (the Haar wavelet) a vanishing moment and is perpendicular to all of constant functions, D4 has two such moments and is perpendicular to all linear functions, etc. The number A of vanishing moments is a measure of the quality of a scaling function. Also in this thesis this wavelet is used for implementation. Because this wavelet is robust technique for finding of HIF in transmission and distribution lines. In this thesis after simulation in model and getting the result for current the signal is loaded in wavelet and after analyzing of the signal the fault will be detected HIF. Also the multi-level is tested in this thesis and these result are illustrated in chapter 4.

4. PROPOSED METHOD

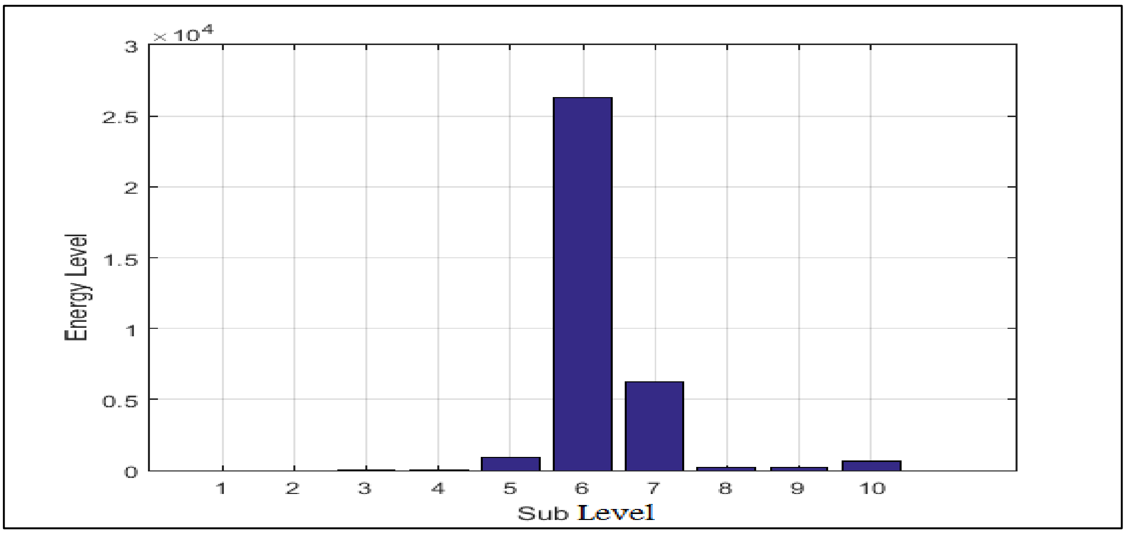
4.1 PROPOSED ALGORITHM

In this thesis, a new algorithm for detecting the high impedance fault has been suggested. The algorithm is based on the discrete wavelet transform (DWT) and the energy calculations. The flowchart of the suggested algorithm is given in figure. 4.2. First of all, the current signals at the end of the distribution networks will be analyzed according to the DWT technique. It has been cited that the DWT type (db4) has attained the best performance compared with the other DWT types as described in (Narasimharao, 2012). Secondly, the energy of every sub-band signal will be calculated according to Eq. (4.1):

$$ED_n = \frac{1}{n}\sum_{i=1}^{n} D_i^2 \tag{4.1}$$

In this equation D is represent the details signal of the DWT, n is the length of the *D* signal, also ED is the energy value and i is the level number. The reason of choosing the details energy of level 6 (ED6) for the current signals is that it holds the maximum energy comparing with the other levels. Figure 4.1 shows the relationship between the energy level of each DWT level up to level10 (ED10).

Figure 4.1: Represent the relationship between the energy of sub band with energy level on the HIF case



Then, the energy percentage (*PER)* can be easily computed by dividing the minimum value of ED_6 in the faulty case by its maximum value in fault case by the equation (4.2).

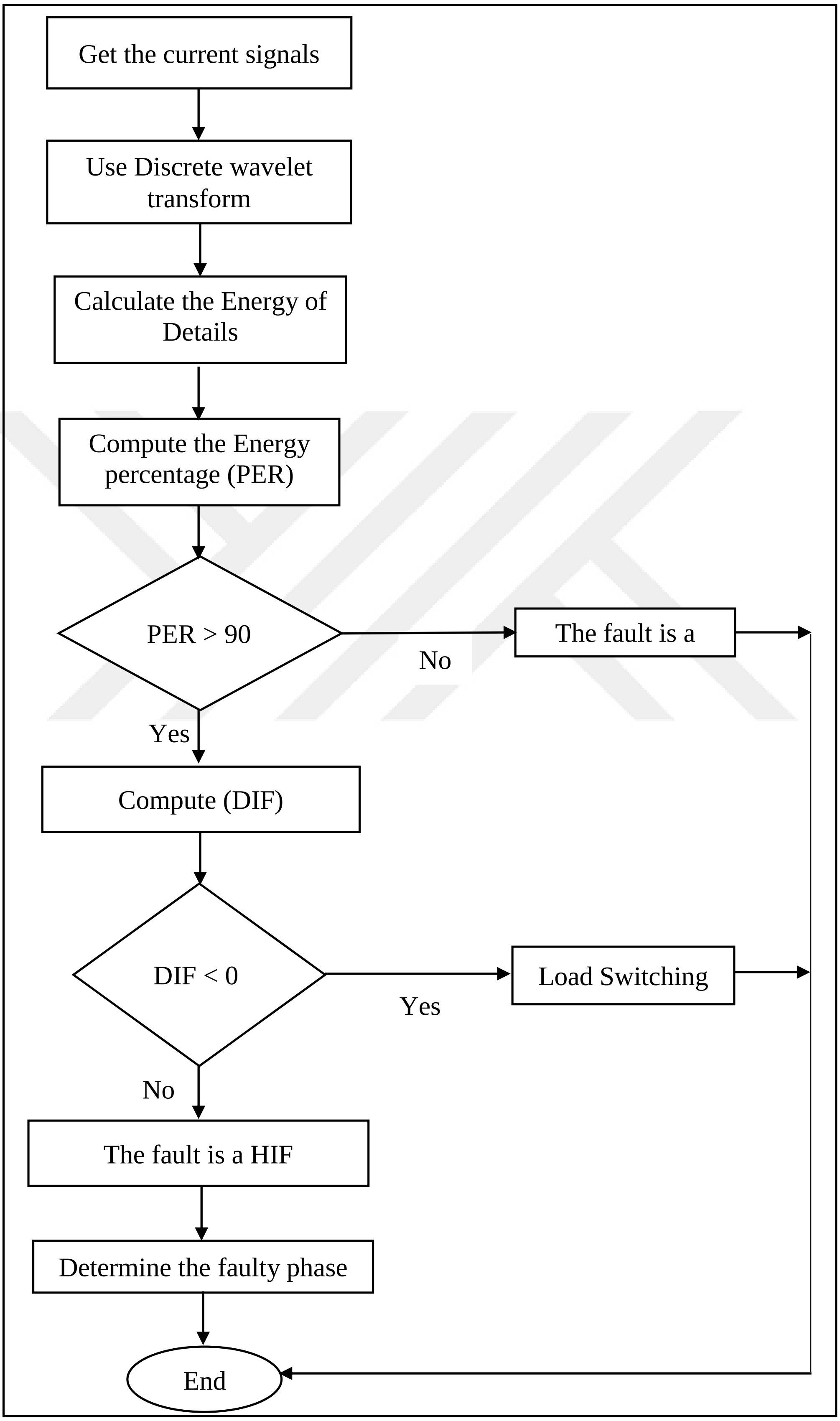
$$PER = \frac{\mathrm{Min}(\mathrm{ED}_{6\_F})}{\mathrm{Max}(\mathrm{ED}_{6\_F})} * 100 \qquad (4.2)$$

Hence, the *PER* is less than 90, then the fault is considered as the Low Impedance Fault (LIF). If PER is greater than 90, the algorithm checks the difference (DIF) between the energy level of unfaulty current signal and the energy level of faulty current signal. It is calculated by the equation (4.3).

$$\mathrm{DIF} = ED_{6\_N} - ED_{6\_F} \qquad (4.3)$$

If the *DIF* is less than zero, the problem is about the load switching. If not so, the case is called as the High Impedance Fault (HIF). After that, the faulty phase is determined according to which phase has the maximum value of *DIF*. Finally, after detecting the HIF and determining the faulty phase, the faulty point of the system is forced to be turned off.

Figure 4.2: The flowchart of detecting a HIF



4.2 SIMULATION TEST SYSTEM

In order to evaluate the proposed algorithm, a basic distribution network is used as the simulation test system in this study. The properties of the distribution system are given below.

a. The system frequency is 50 Hz
b. The length of the lines is 20 km
c. The system voltage level is 20 kV
d. The load is 800 kW
e. The sample frequency is 5 kHz
f. Distribution line parameters as shown on table 4.1.

Table 4.1: The distributed network parameters

Parameter	Value	Unit
R1,R2 and R3	0.01273	Ω/km
L1,L2 and L3	0.9337	mH/km

The simulation test system is given in figure 4.3. Matlab-Simulink is used as the test environment for the simulation. The test system is represented simply in figure 4.4. It was modelled in Matlab2015a.

Figure 4.3: The simulation test system on Matlab-Simulink

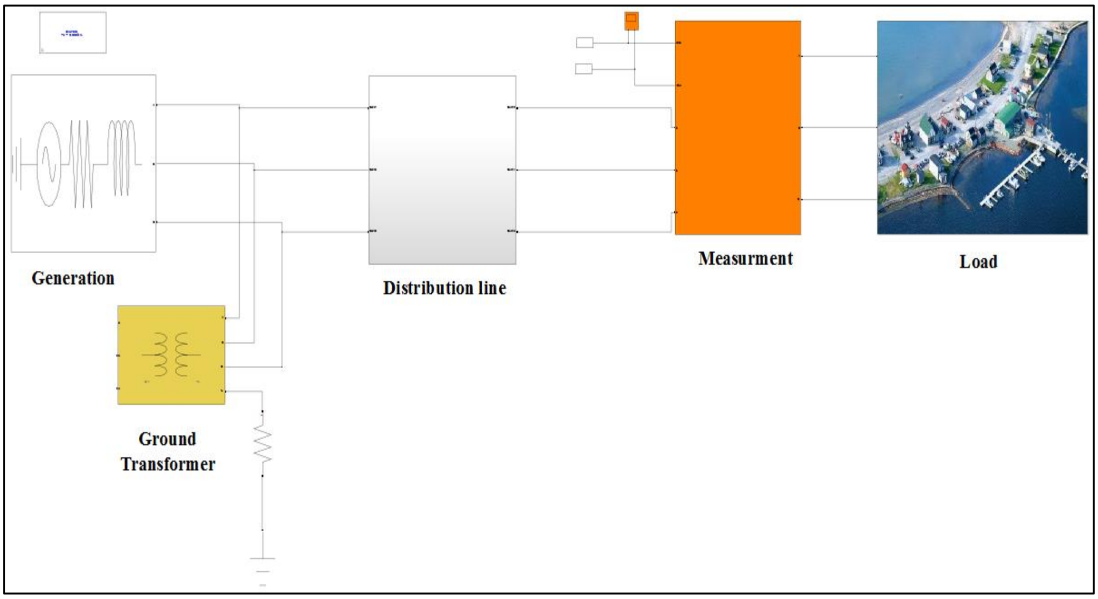


Figure 4.4: The distribution network model

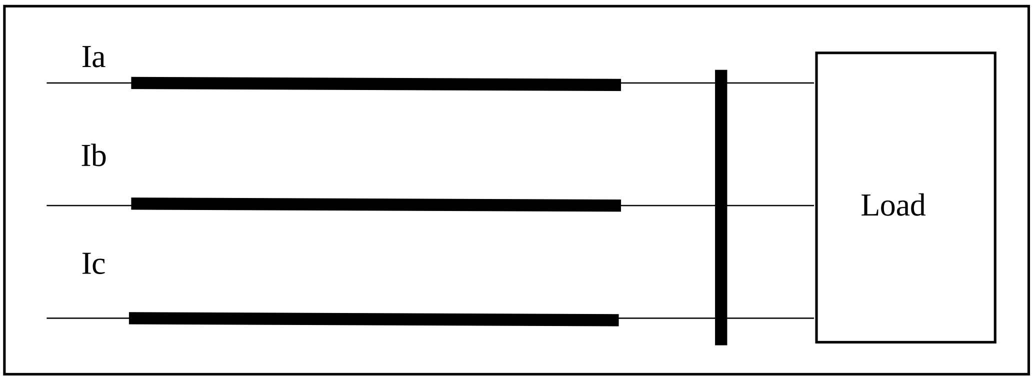
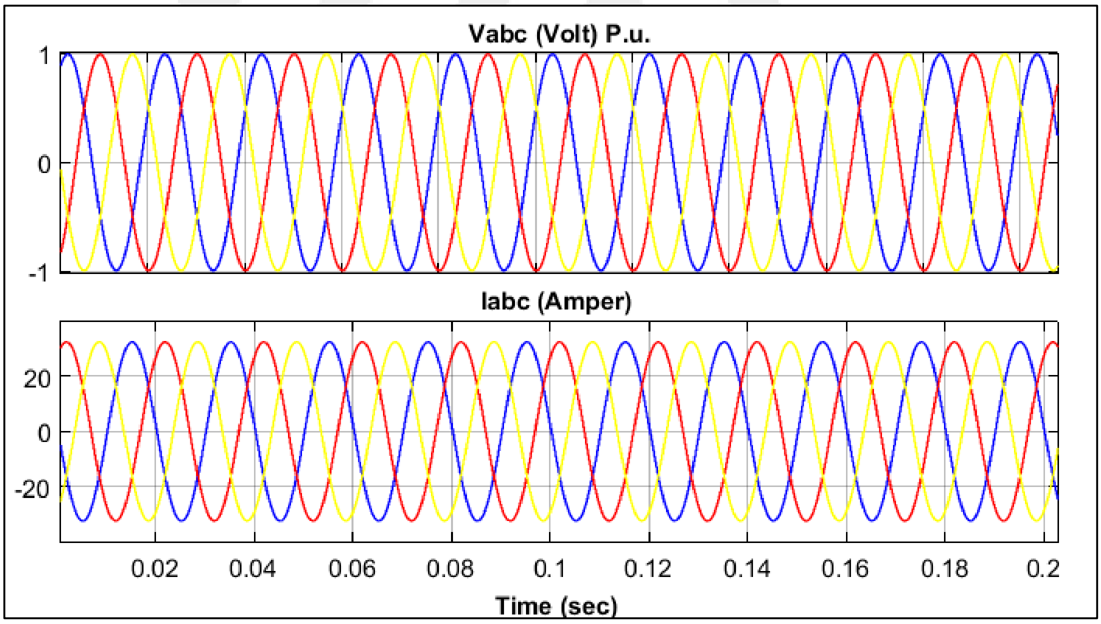


Figure 4.5 shows the 3-phase voltages and currents for the bus measurement of the unfaulty case.

Figure 4.5: 3-Phase voltages and current for the unfaulty case



The HIF model, that is the most popular model, is used in this thesis. It was developed depending on Emanuel model in 2003 (Jannati et al., 2015). The details of HIF model was given in figure 2.2. It reflects the arcing in the sand soil.

The three-line diagrams of a 50-Hz distributed system are given in figure. 4.6, 4.7 and 4.8. A length of 20-km distributed network with the linear load of (800kW) has been employed in this thesis. Different faults have been applied such as HIF, LIF and load switching.

The HIF model can be considered as the most difficult fault in the HIF. Due to the fact that highest impedance fault phenomena contain arcing, that has not been accurately modelled so far. Some recent scientists have accepted that high impedance fault is nonlinear and asymmetric phenomena. Also, the modelling must include random and dynamic qualities of arcing.

Figure 4.6: Distribution network model with HIF on phase (A)

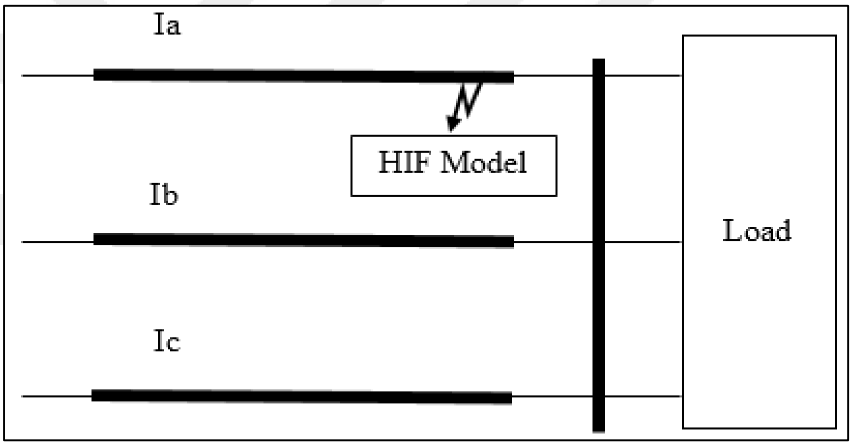


Figure 4.7: Distribution network model with HIF on phase (B)

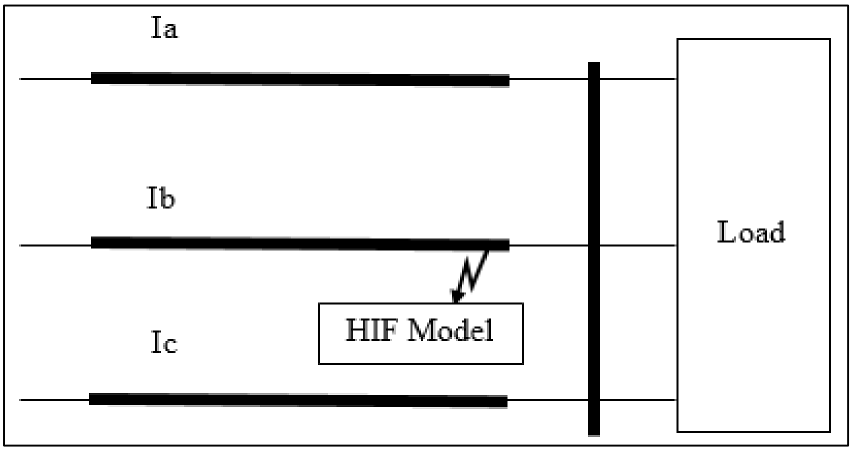


Figure 4.8: Distribution network model with HIF on phase (C)

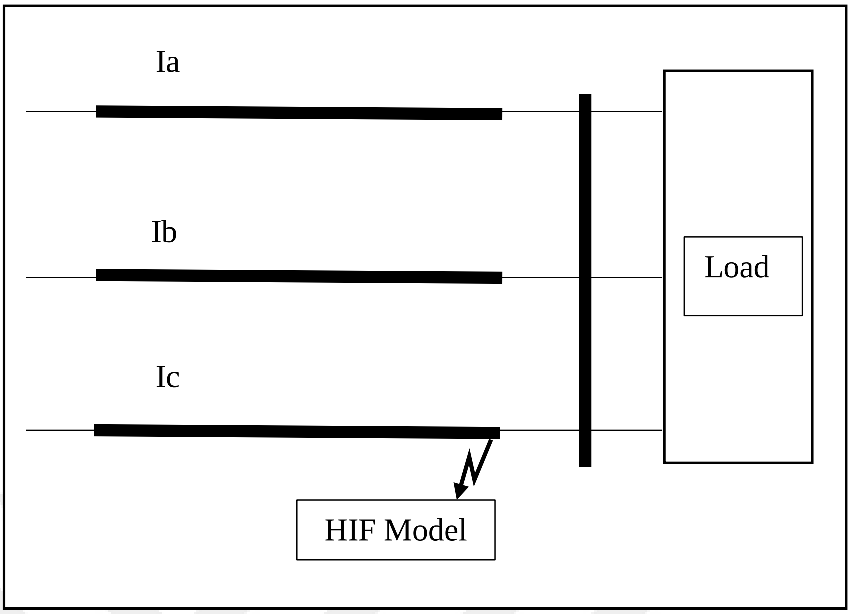
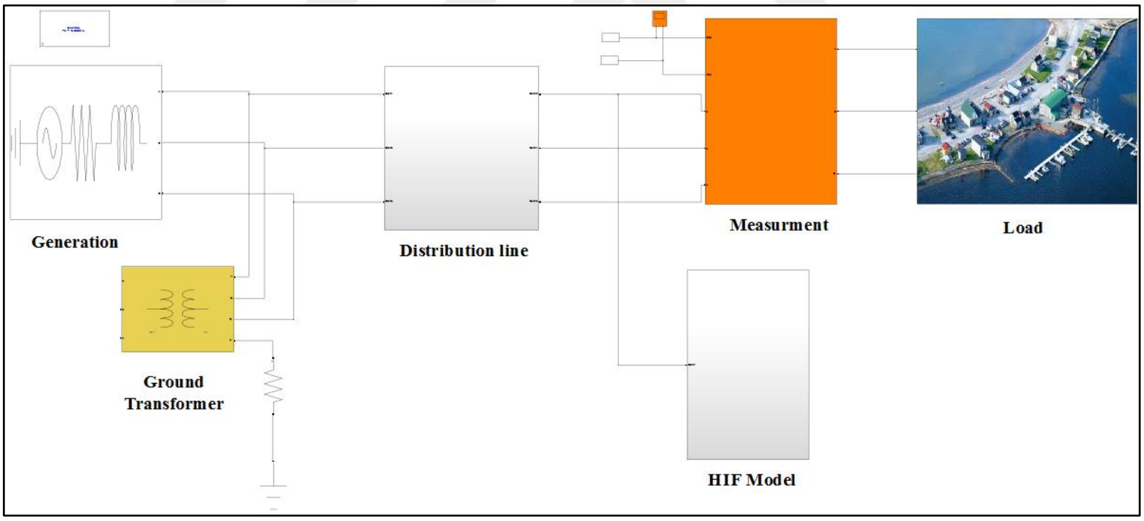


Figure 4.9: The simulation test system with HIF on Matlab-Simulink



4.3 TEST CASES

4.3.1 The Case of HIF Situation

When the phase voltage is greater than the positive DC voltage (VP), high impedance fault (HIF) occurs and the fault current flowing toward the ground. Also, when line voltage is less than negative DC voltage (VN), the reverse fault will happen. Finally, there is not any fault current flows, when the amount of phase voltage between VP and VN. Figure 4.10 shows the typical fault current and voltage.

Figure 4.10: Typical current and voltage for HIF on faulty phase

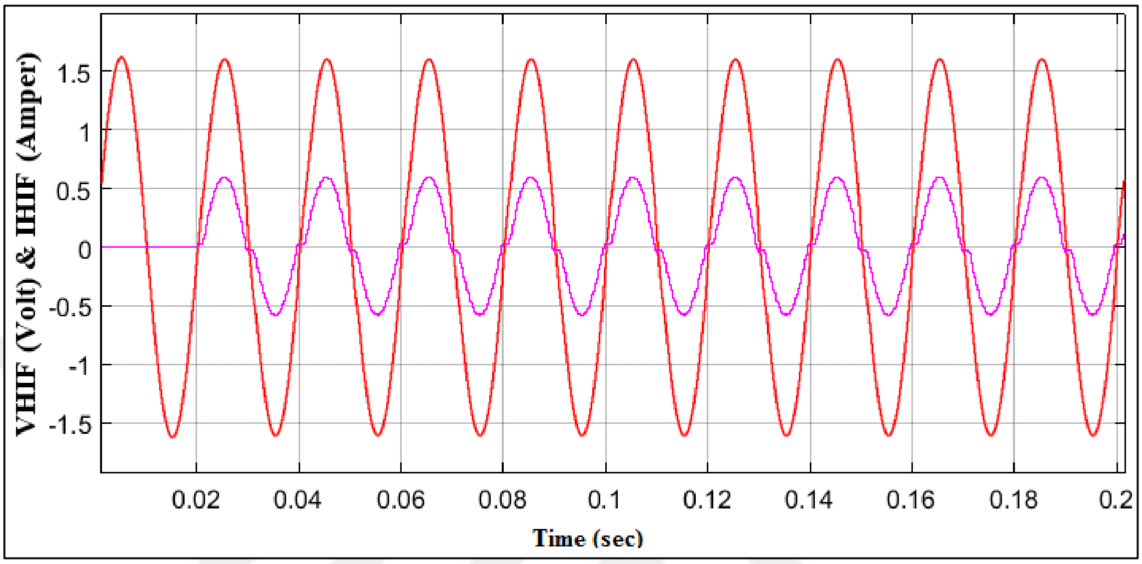
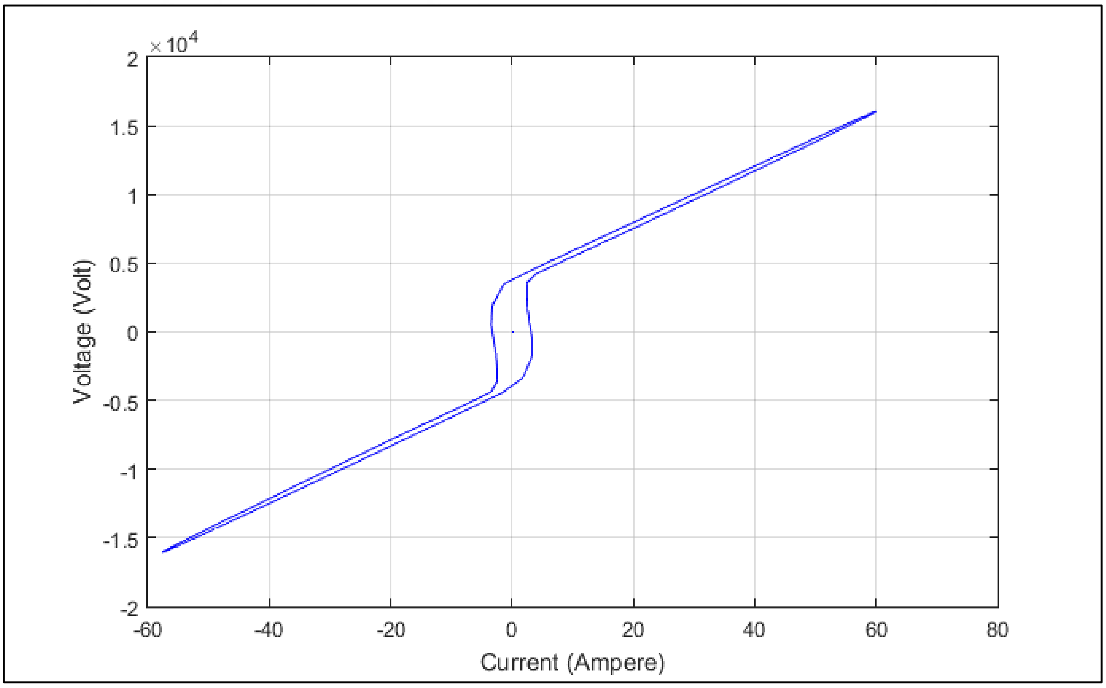
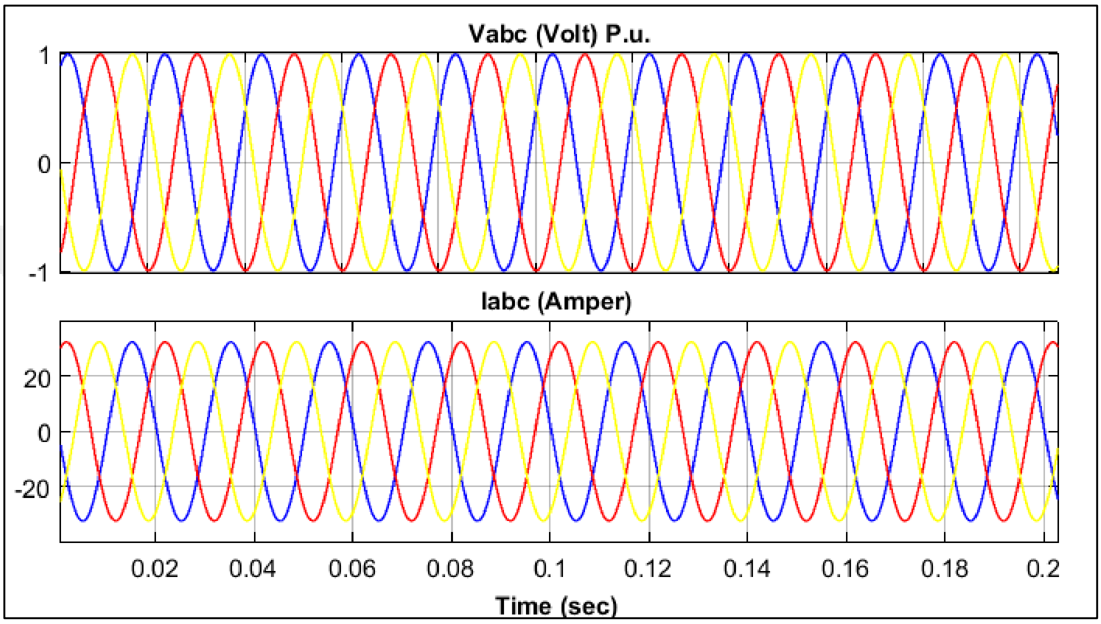


Figure 4.11: The relationship between the current and the voltage for HIF



It is clear from figure 4.11 that the relationship between the voltage and current for the high impedance fault is non-linear behavior. The high impedance faults have two main characteristics: the low fault currents and arcing. In figure 4.12 depicts the 3-phase voltages and currents on the bus measurement for HIF case.

Figure 4.12: 3-phase voltages and currents for HIF case



The first characteristic of HIFs faults produce little or no fault current. This fault current will be further reduced during winter in cold countries. Therefore, the diagnosis of this type of fault is more challenging because of the trees. In this thesis, the fault that occurred in 0.02 seconds simulation time of 1.0 seconds. The second feature high-impedance faults near the arc phenomena as a result of the air gap due to poor contact, which can be caused by a tree or a ground object. This creates a high potential short-distance air gap and that gap breaks down the arc is produced. In any case, the current level stable enough for reliable arc is not detected. Accordingly, a desired electrical performance of the characteristics associated with (HIFs) (Narasimharao, 2012). The model of HIF values are acquired from as shown in Table 4.2.

Table 4.2: The values of parameters on HIF model

Cases	Rp (Ω)	Rn (Ω)	Vp (volt)	Vn (volt)
1	208	212	3588	3847
2	215	223	4075	4626
3	235	225	5472	4783
4	244	227	6092	4911
5	245	245	6180	6155
6	247	271	6348	8011
7	255	280	6883	8634
8	267	286	7729	9059
9	269	289	7894	9249
10	272	290	8092	9358

The figures.4.13, 4.14 and 4.15 represent the relationship between the energy of the detail signal in level six (ED6) for the current phases of the unfaulty case with HIF case for the HIF parameters (Rp=208 ohm, Rn=212 ohm, Vp=3588 Volt, Vn=3847 Volt).

Figure 4.13: Relationship between (ED6) of normal case and HIF case on phase (A)

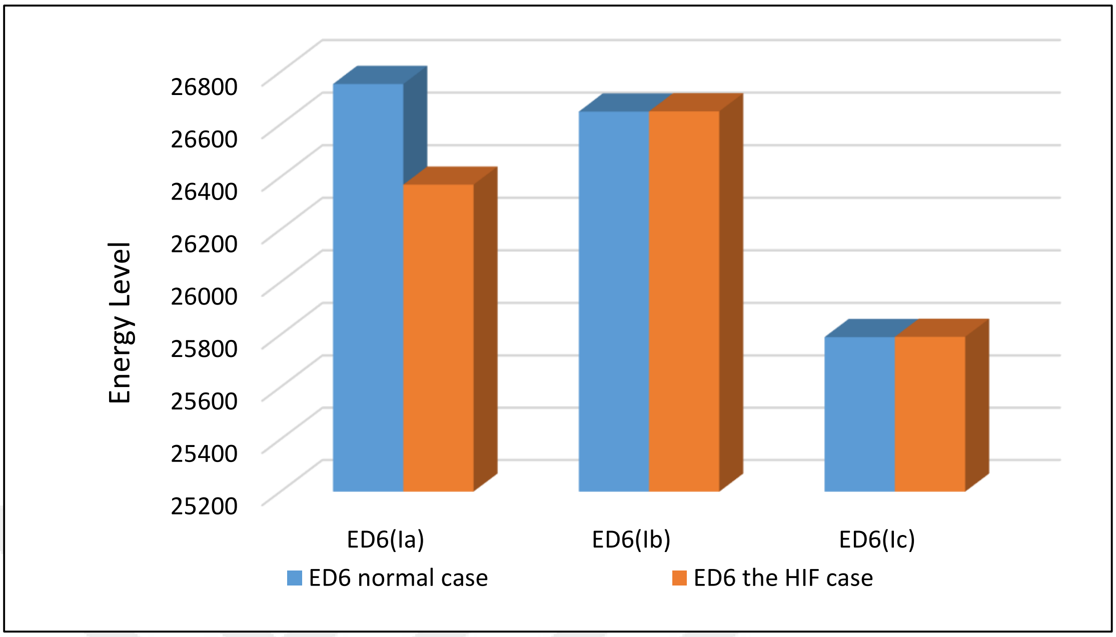


Figure 4.14: Relationship between (ED6) of normal case and HIF case on phase (B)

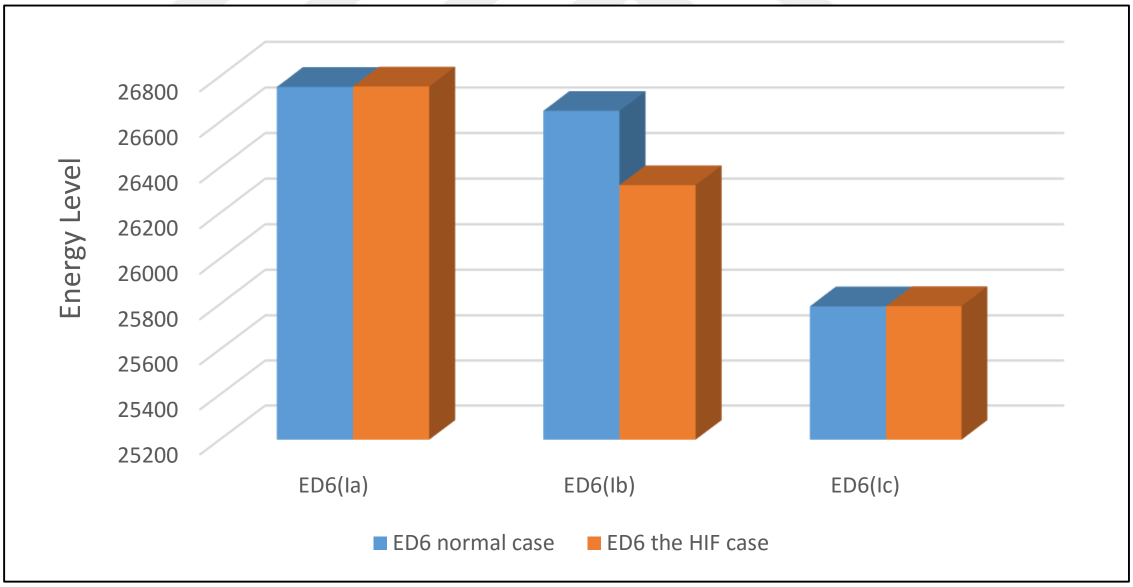
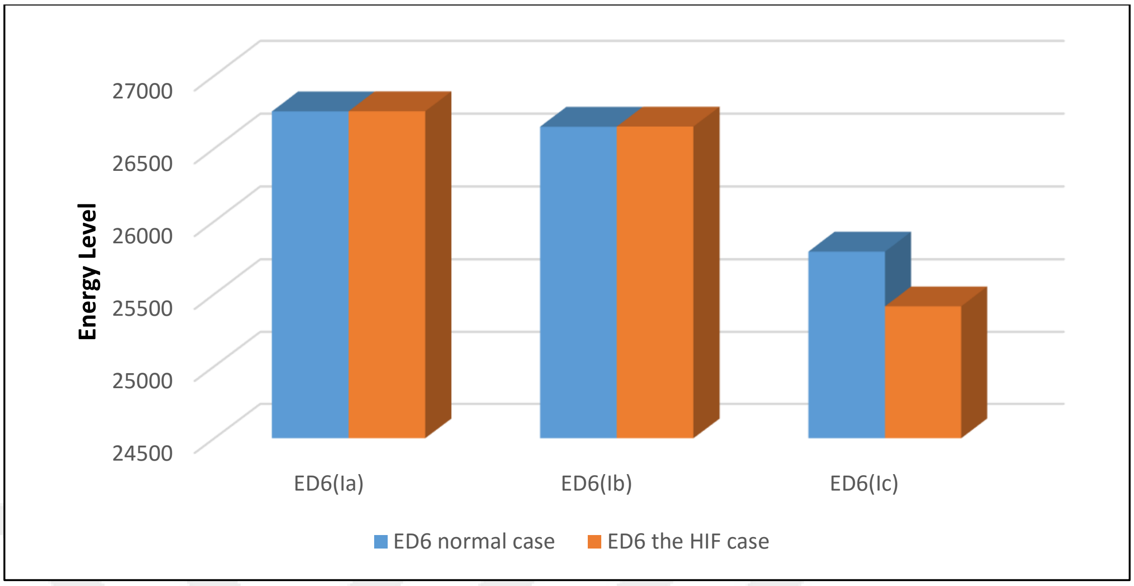


Figure 4.15: Relationship between (ED6) of normal case and HIF case on phase (C)



In figures 4.13, 4.14 and 4.15, the orange color shows the faulty signal. While, the blue color shows the normal signal (unfaulty signal). Also, in figures 4.13, 4.14 and 4.15 the faulty phase holds a fault in all simulation. In addition, it can be seen that the orange color has lower height values than the blue one. But in other signals the both color have the same height of amplitudes.

The figures.4.16, 4.17 and 4.18 represent the relationship between the energy of the detail signal in level six (ED6) for the current phases of the unfaulty case with HIF case for the HIF parameters (Rp=244 ohm, Rn=227 ohm, Vp=6092 Volt, Vn=4911 Volt).

Figure 4.16: Relationship between (ED6) of normal case and HIF case on phase (A)

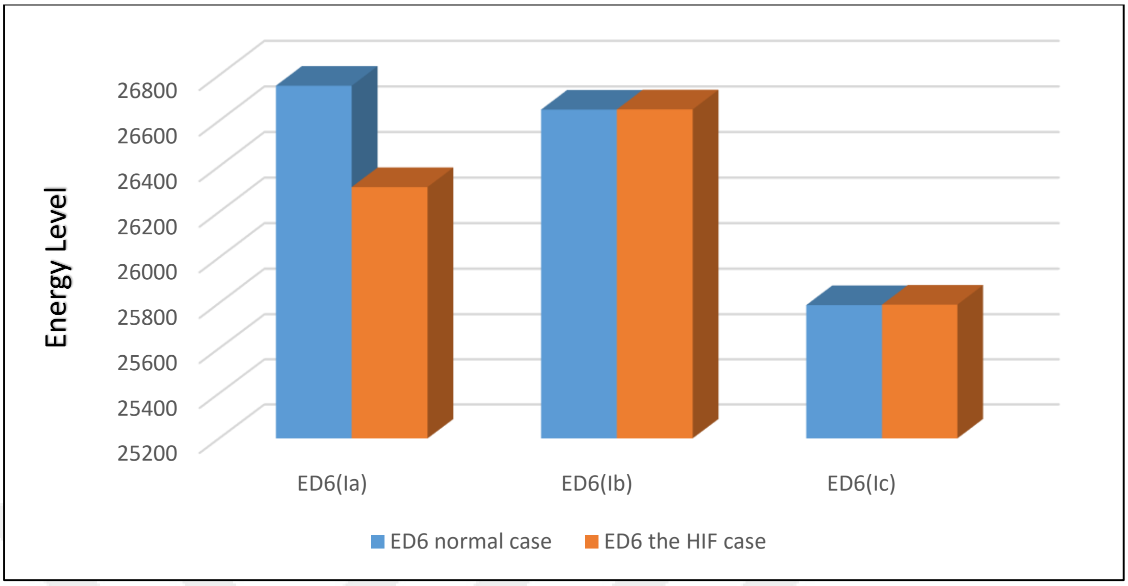


Figure 4.17: Relationship between (ED6) of normal case and HIF case on phase (B)

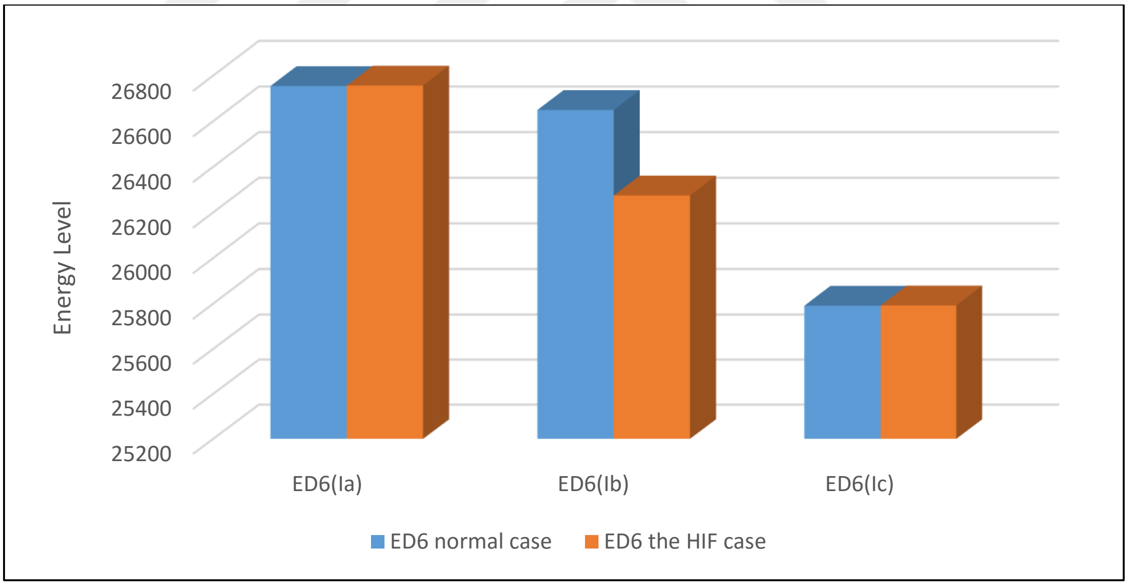
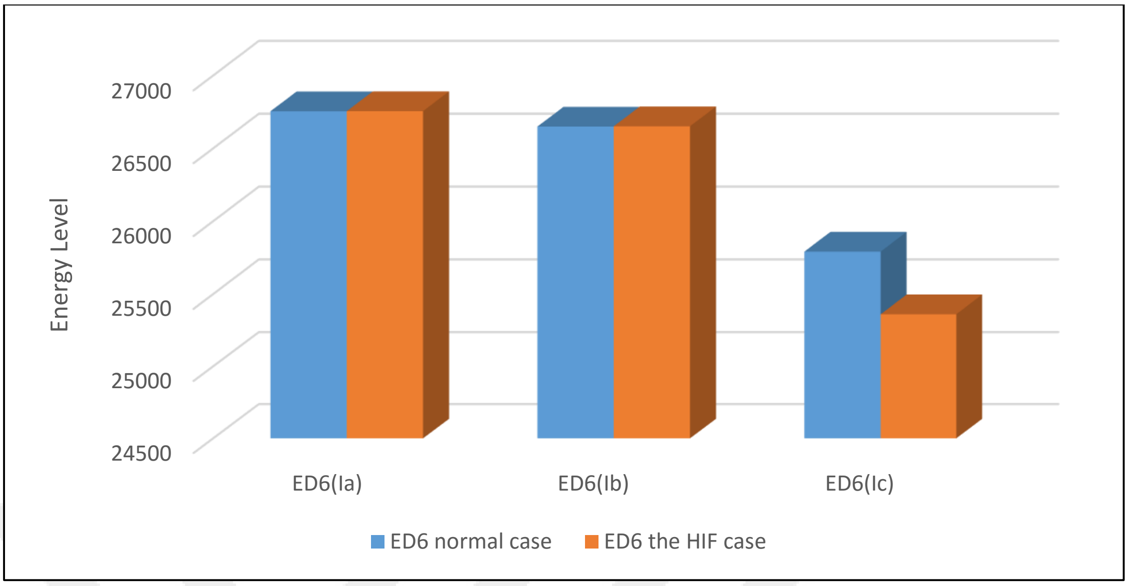


Figure 4.18: Relationship between (ED6) of normal case and HIF case on phase (C)



In figures 4.16, 4.17 and 4.18, the orange color shows the faulty signal. While, the blue color shows the normal signal (unfaulty signal). Also, in figures 4.16, 4.17 and 4.18 the faulty phase holds a fault in all simulation. In addition, it can be seen that the orange color has lower height values than the blue one. But in other signals the both color have the same height of amplitudes.

The figures.4.19, 4.20 and 4.21 represent the relationship between the energy of the detail signal in level six (ED6) for the current phases of the unfaulty case with HIF case for the HIF parameters (Rp=267 ohm, Rn=286 ohm, Vp=7729 Volt, Vn=9059 Volt).

Figure 4.19: Relationship between (ED6) of normal case and HIF case on phase (A)

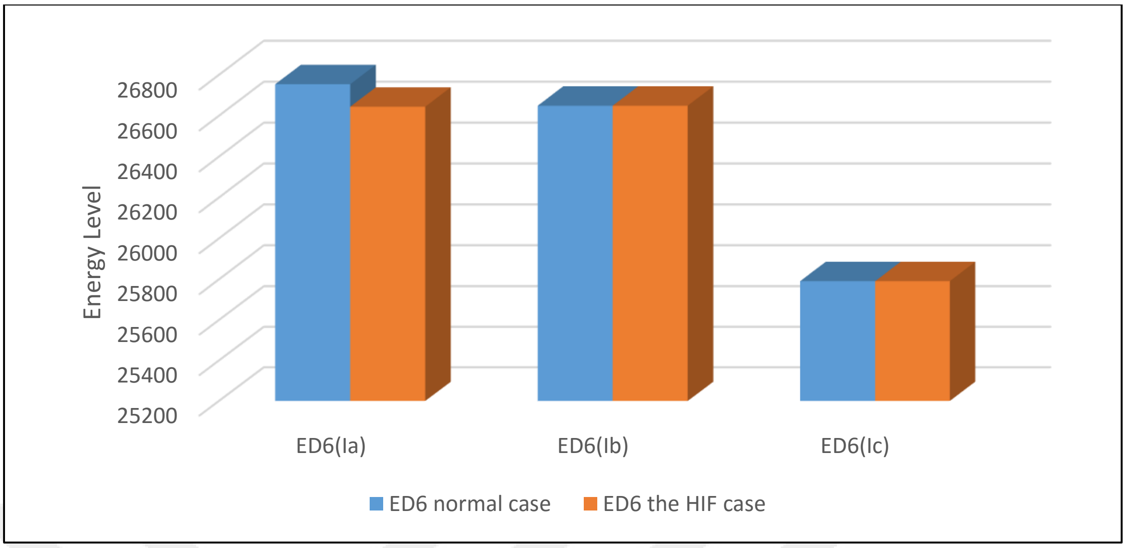


Figure 4.20: Relationship between (ED6) of normal case and HIF case on phase (B)

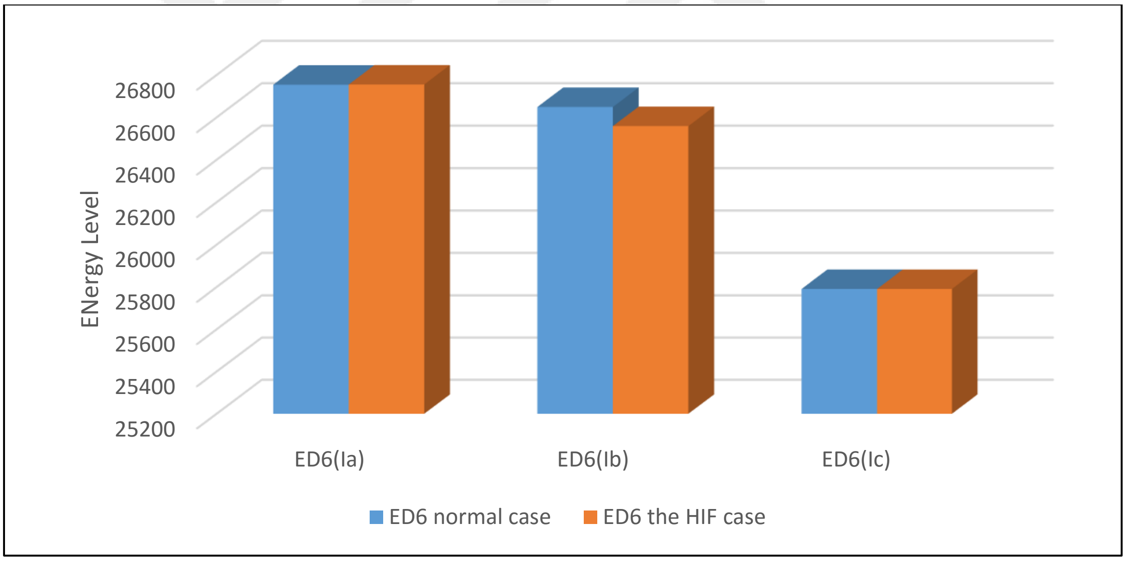
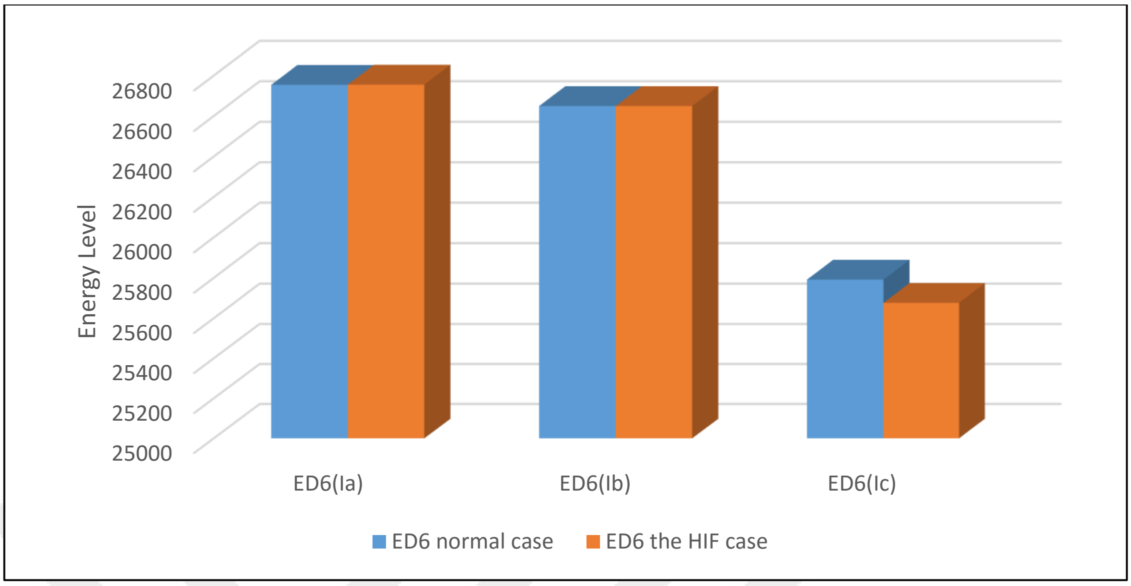


Figure 4.21: Relationship between (ED6) of normal case and HIF case on phase (C)



In figures 4.19, 4.20 and 4.21, the orange color shows the faulty signal. While, the blue color shows the normal signal (unfaulty signal). Also, in figures 4.19, 4.20 and 4.21 the faulty phase holds a fault in all simulation. In addition, it can be seen that the orange color has lower height values than the blue one. But in other signals the both color have the same height of amplitudes.

The figures.4.22, 4.23 and 4.24 represent the relationship between the energy of the detail signal in level six (ED6) for the current phases of the unfaulty case with HIF case for the HIF parameters (Rp=269 ohm, Rn=289 ohm, Vp=7894 Volt, Vn=9249 Volt).

Figure 4.22: Relationship between (ED6) of normal case and HIF case on phase (A)

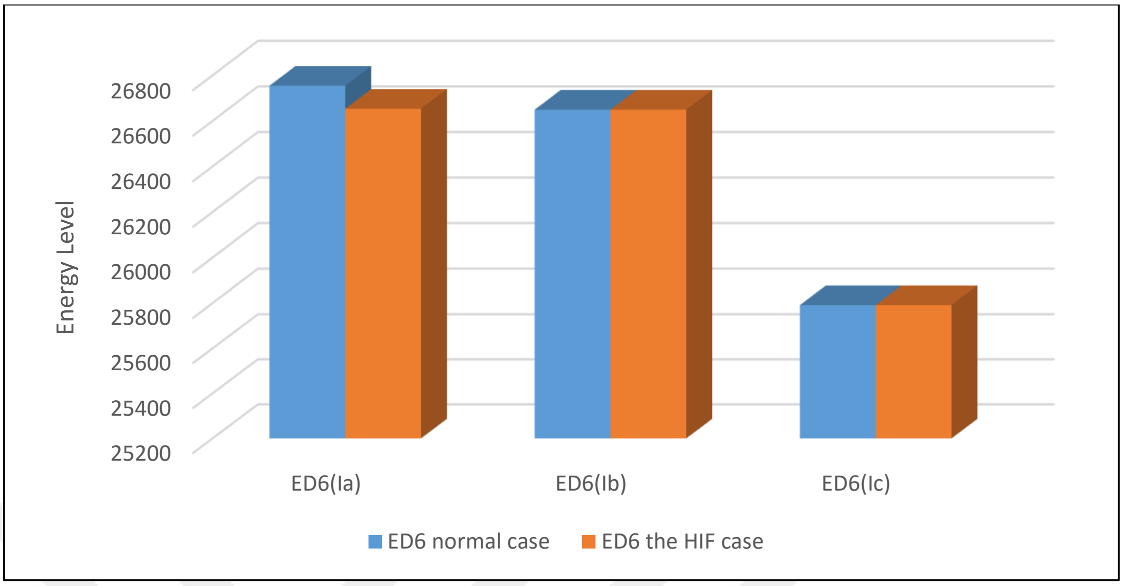


Figure 4.23: Relationship between (ED6) of normal case and HIF case on phase (B)

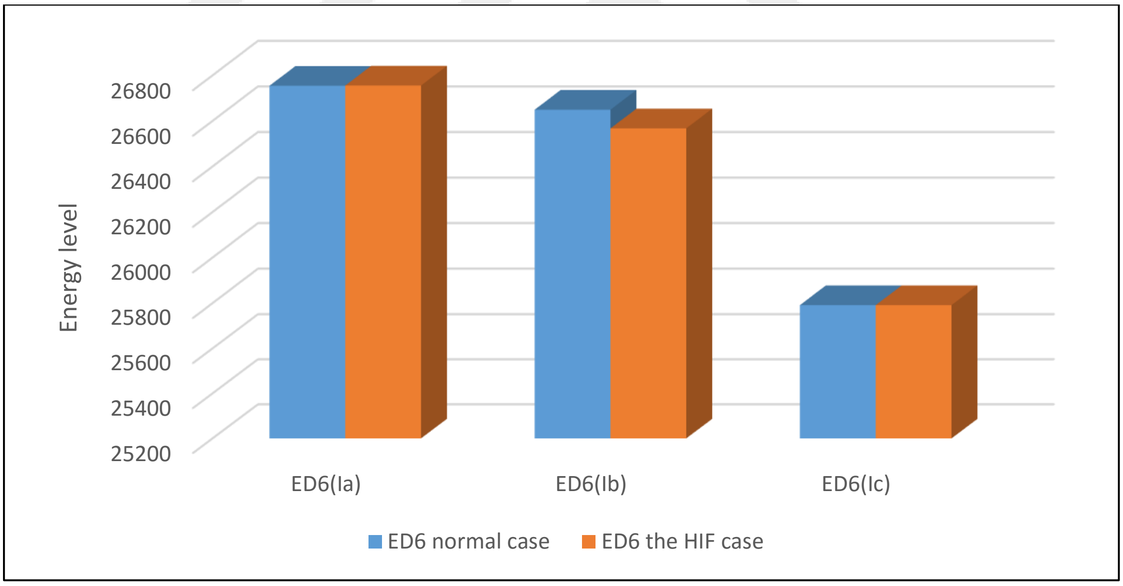
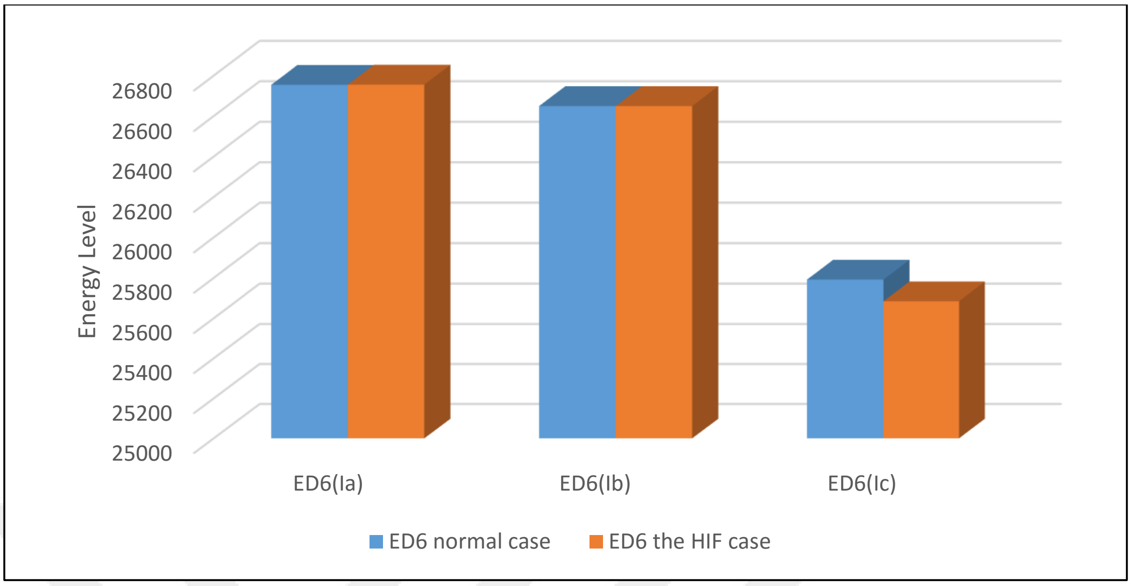


Figure 4.24: Relationship between (ED6) of normal case and HIF case on phase (C)



In figures 4.22, 4.23 and 4.24, the orange color shows the faulty signal. While, the blue color shows the normal signal (unfaulty signal). Also, in figures 4.22, 4.23 and 4.24 the faulty phase holds a fault in all simulation. In addition, it can be seen that the orange color has lower height values than the blue one. But in other signals the both color have the same height of amplitudes.

In another case of HIF, when the line is divided into two parts and each part is equal to (10km). If the fault is happened in the middle of the distribution line figures 4.25, 4.26, 4.27,4.28,4.29,4.30,4.31,4.32,4.33,4.34,4.35 and 4.36 show the relationship between the normal case and HIF case for different arcing fault values.

The figures.4.25, 4.26 and 4.27 represent the relationship between the energy of the detail signal in level six (ED6) for the current phases of the unfaulty case with HIF case for the HIF parameters (Rp=208 ohm, Rn=212 ohm, Vp=3588 Volt, Vn=3847 Volt).

Figure 4.25: Relationship between (ED6) of normal case and HIF case on phase (A)

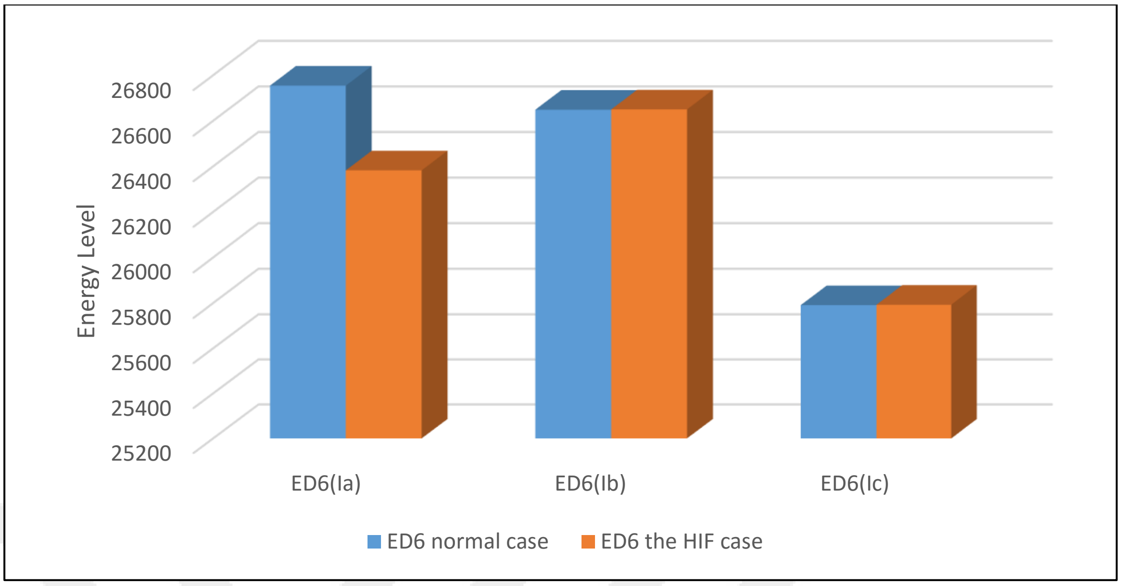


Figure 4.26: Relationship between (ED6) of normal case and HIF case on phase (B)

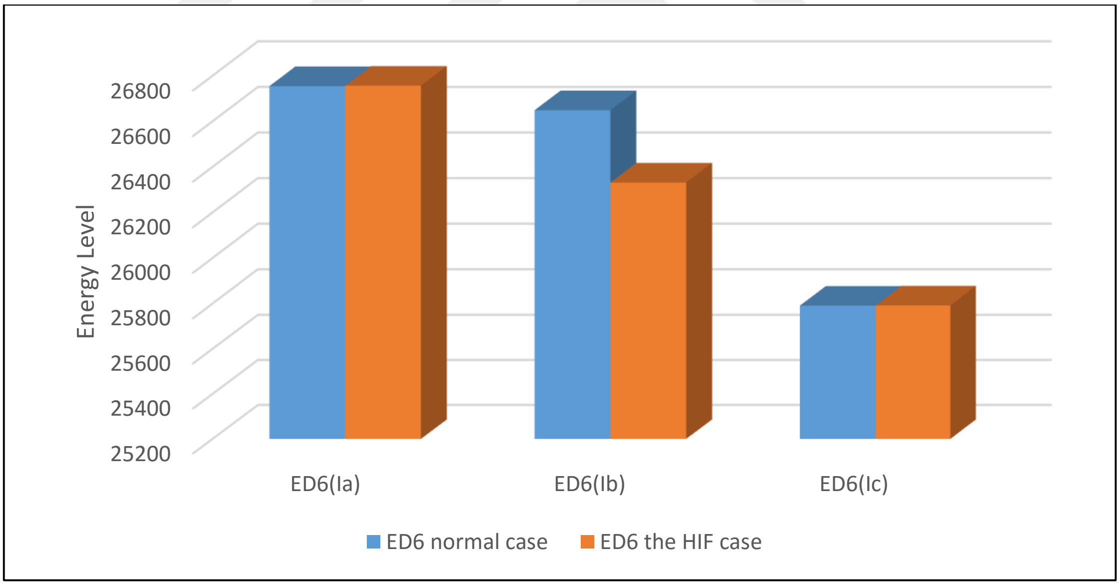
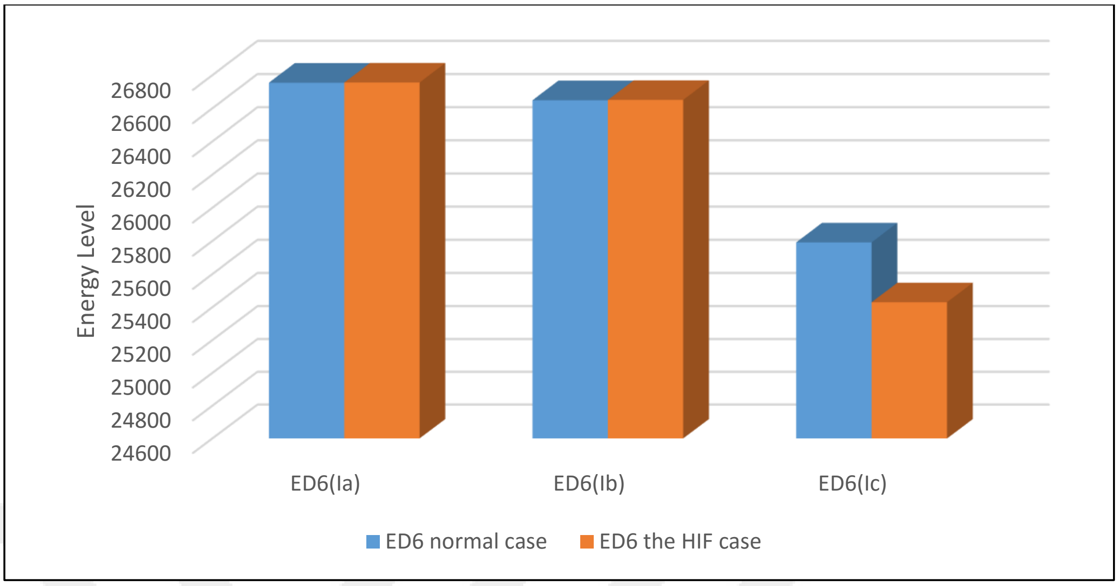


Figure 4.27: Relationship between (ED6) of normal case and HIF case on phase (C)



In figures 4.25, 4.26 and 4.27, the orange color shows the faulty signal. While, the blue color shows the normal signal (unfaulty signal). Also, in figures 4.25, 4.26 and 4.27 the faulty phase holds a fault in all simulation. In addition, it can be seen that the orange color has lower height values than the blue one. But in other signals the both color have the same height of amplitudes.

The figures.4.28, 4.29 and 4.30 represent the relationship between the energy of the detail signal in level six (ED6) for the current phases of the unfaulty case with HIF case for the HIF parameters (Rp=244 ohm, Rn=227ohm, Vp=6092 Volt, Vn=4911 Volt).

Figure 4.28: Relationship between (ED6) of normal case and HIF case on phase (A)

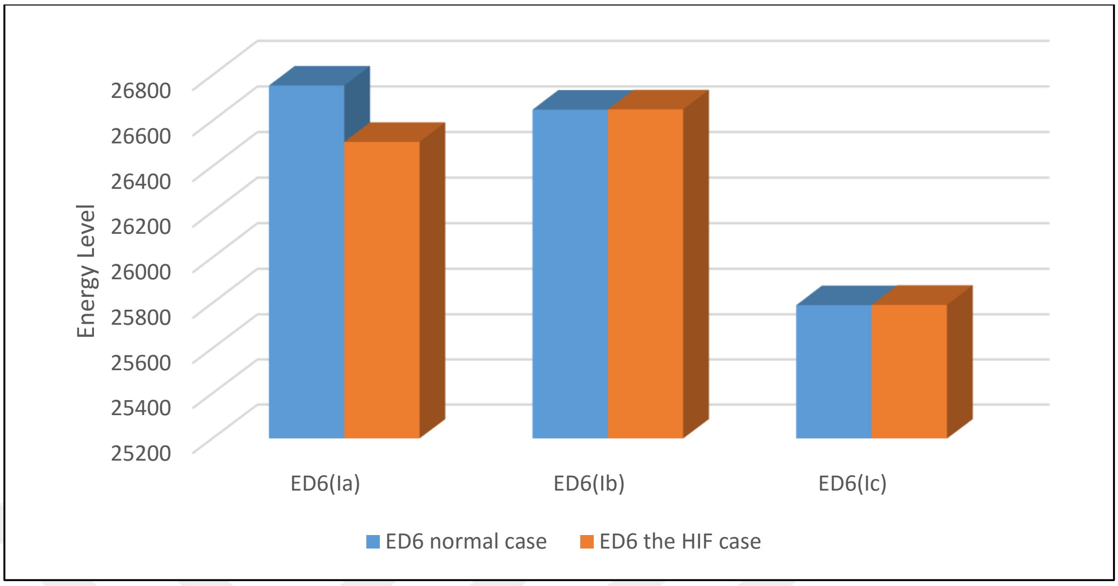


Figure 4.29: Relationship between (ED6) of normal case and HIF case on phase (B)

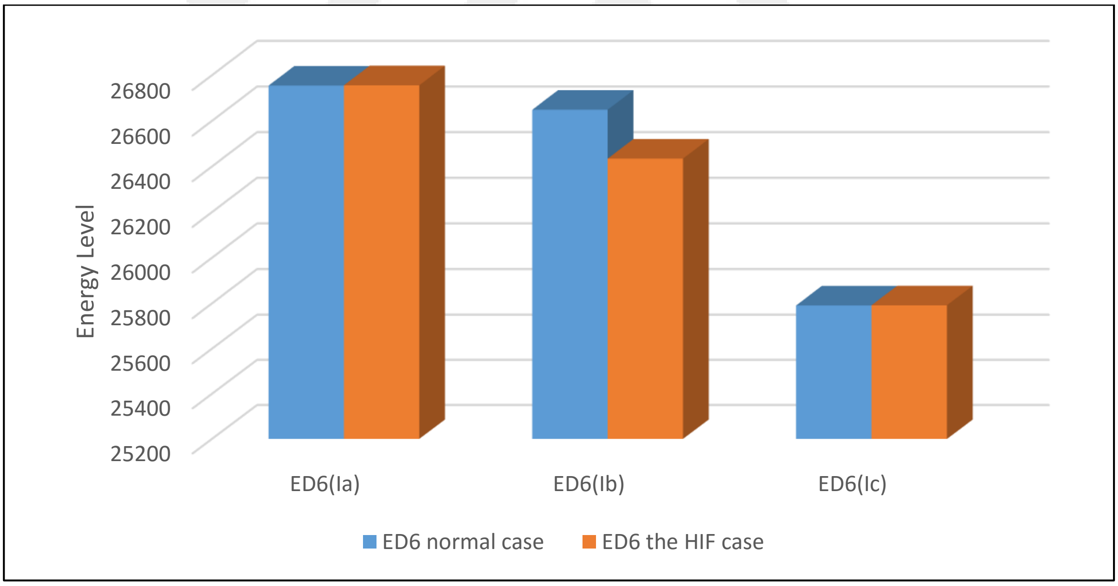
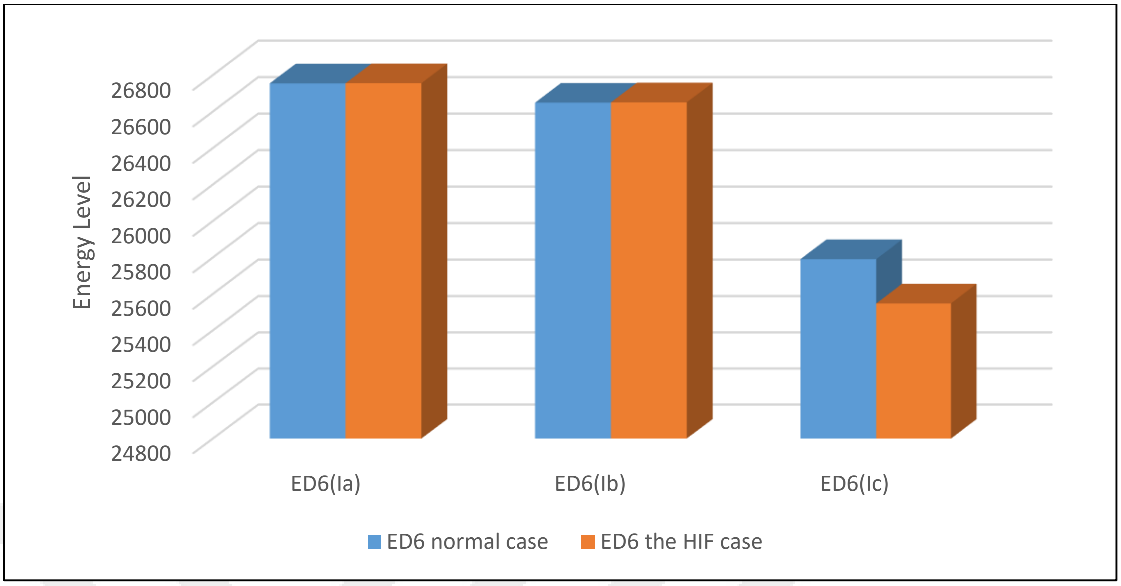


Figure 4.30: Relationship between (ED6) of normal case and HIF case on phase (C)



In figures 4.28, 4.29 and 4.30, the orange color shows the faulty signal. While, the blue color shows the normal signal (unfaulty signal). Also, in figures 4.28, 4.29 and 4.30 the faulty phase holds a fault in all simulation. In addition, it can be seen that the orange color has lower height values than the blue one. But in other signals the both color have the same height of amplitudes.

The figures.4.31, 4.32 and 4.33 represent the relationship between the energy of the detail signal in level six (ED6) for the current phases of the unfaulty case with HIF case for the HIF parameters (Rp=267 ohm, Rn=286 ohm, Vp=7729 Volt, Vn=9059 Volt).

Figure 4.31: Relationship between (ED6) of normal case and HIF case on phase (A)

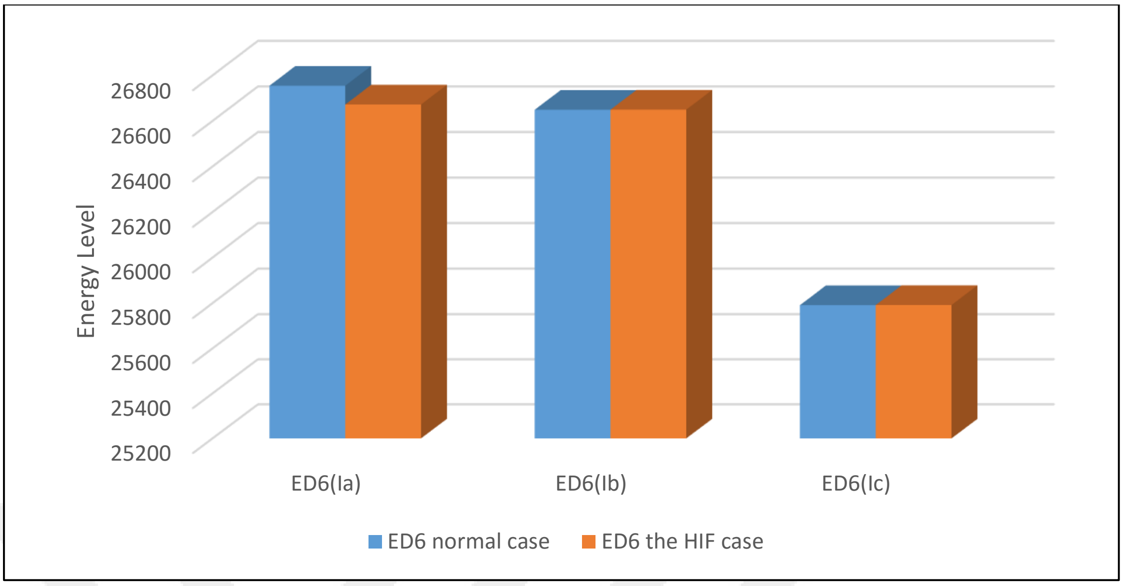


Figure 4.32: Relationship between (ED6) of normal case and HIF case on phase (B)

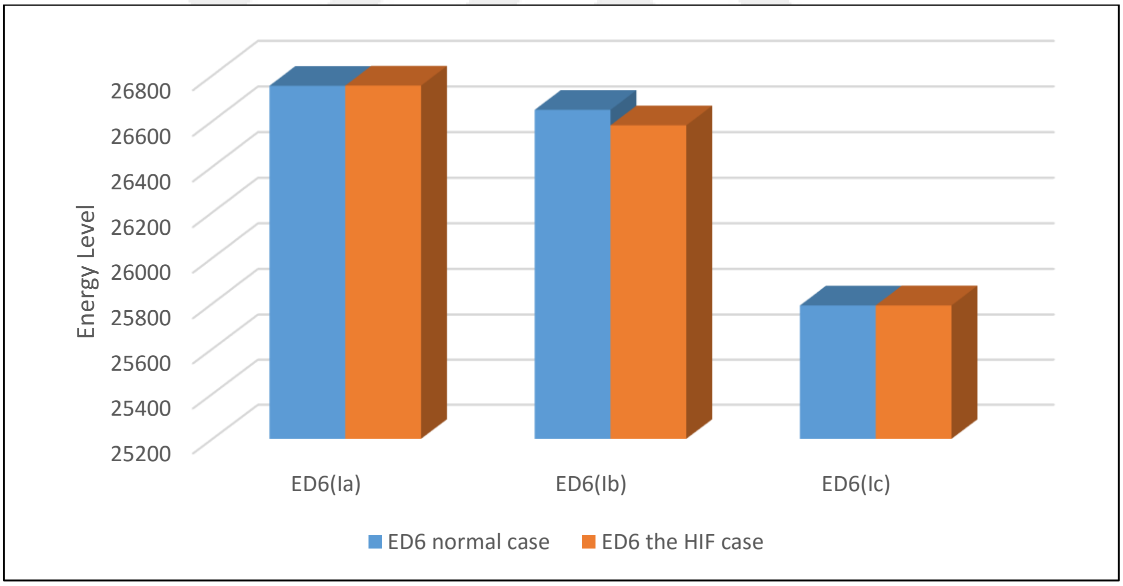
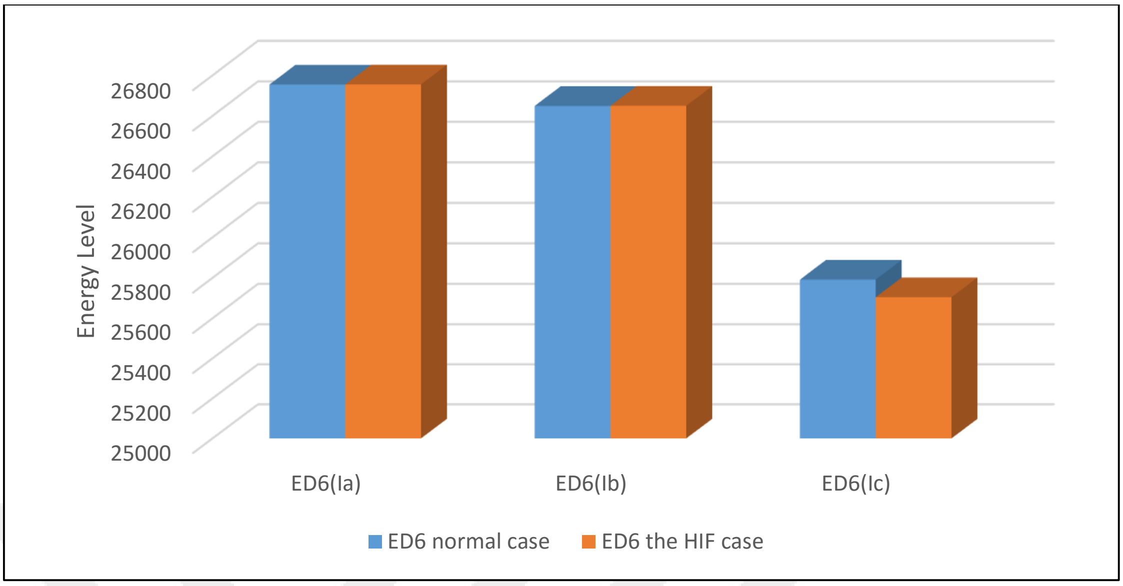


Figure 4.33: Relationship between (ED6) of normal case and HIF case on phase (C)



In figures 4.31, 4.32 and 4.33, the orange color shows the faulty signal. While, the blue color shows the normal signal (unfaulty signal). Also, in figures 4.31, 4.32 and 4.33 the faulty phase holds a fault in all simulation. In addition, it can be seen that the orange color has lower height values than the blue one. But in other signals the both color have the same height of amplitudes.

The figures.4.34, 4.35 and 4.36 represent the relationship between the energy of the detail signal in level six (ED6) for the current phases of the unfaulty case with HIF case for the HIF parameters (Rp=269 ohm, Rn=289 ohm, Vp=7894 Volt, Vn=9249 Volt).

Figure 4.34: Relationship between (ED6) of normal case and HIF case on phase (A)

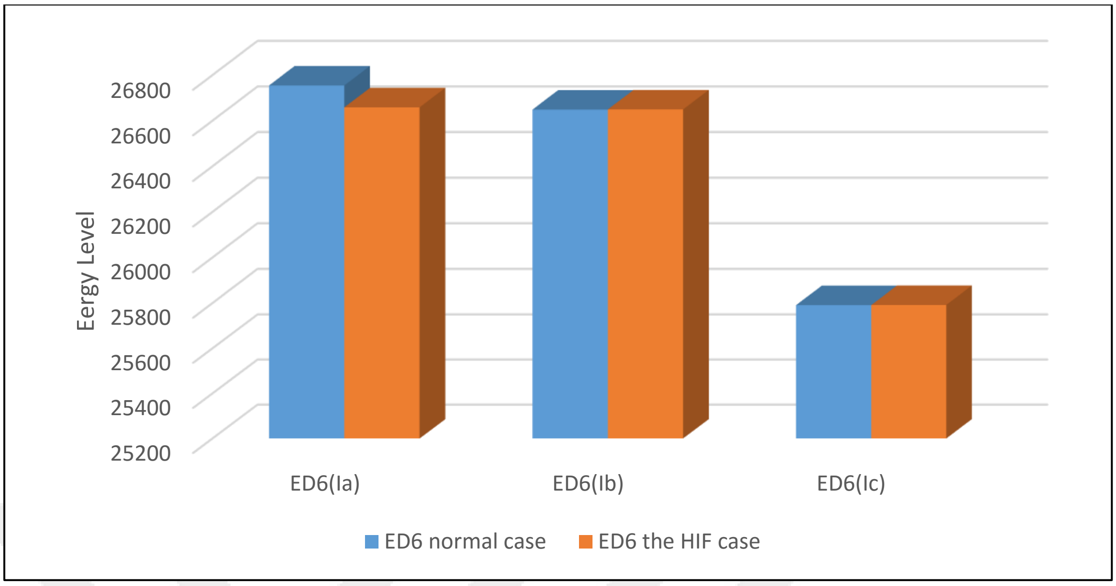


Figure 4.35: Relationship between (ED6) of normal case and HIF case on phase (B)

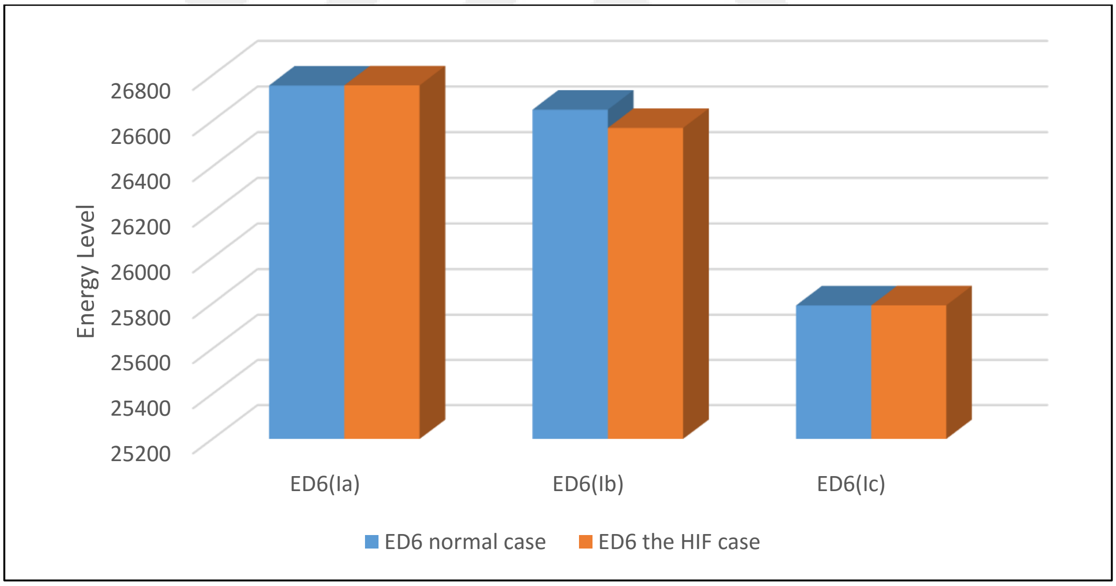
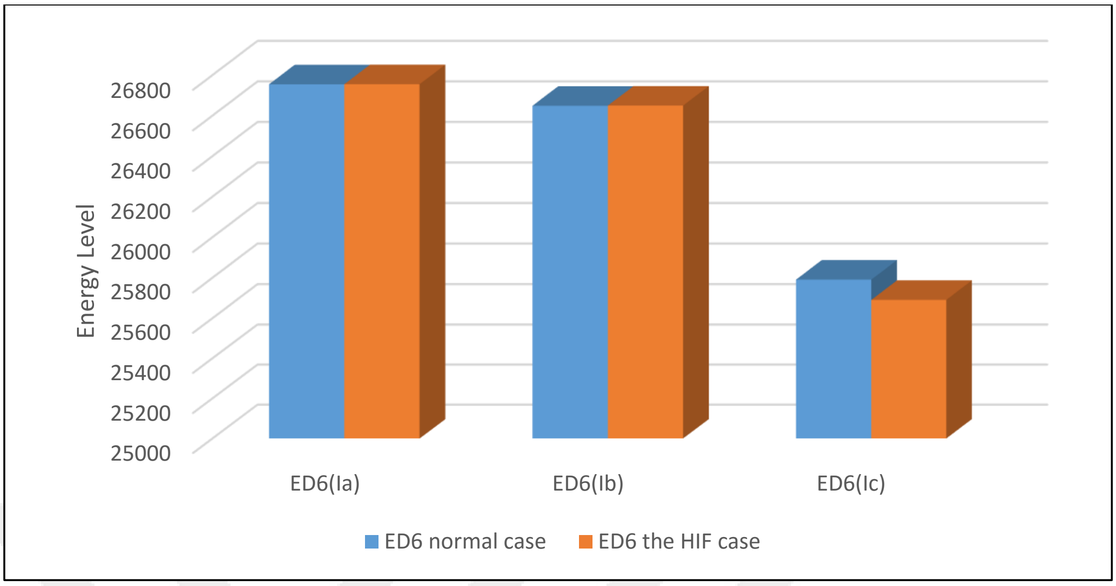


Figure 4.36: Relationship between (ED6) of normal case and HIF case on phase (C)



In figures 4.34, 4.35 and 4.36, the orange color shows the faulty signal. While, the blue color shows the normal signal (unfaulty signal). Also, in figures 4.34, 4.35 and 4.36 the faulty phase holds a fault in all simulation. In addition, it can be seen that the orange color has lower height values than the blue one. But in other signals the both color have the same height of amplitudes.

4.3.2 Low Impedance Fault (LIF)

LIF is a short circuit, which include relatively large fault currents and are readily detectable by conventional overcurrent protection. The model of LIF includes the appropriate fault resistance switched at the fault location in the end of distribution line. Table 4.3 shows the values of the fault resistance (Rf) and the ground resistance (Rg).

Table 4.3: The values of LIF model parameters

Cases	Rf (Ω)	Rg(Ω)
1	1	0.1
2	2.5	0.1
3	5	0.1
4	7.5	0.1
5	10	0.1
6	1	0.2
7	1	0.4
8	1	0.6
9	1	0.8
10	1	1

The figures.4.37, 4.38 and 4.39 represent the relationship between the energy of the detail signal in level six (ED6) for the current phases of the unfaulty case with LIF case for the LIF parameters (Rf=1 ohm, Rg=0.1 ohm).

Figure 4.37: Relationship between (ED6) of normal case and LIF case on phase (A)

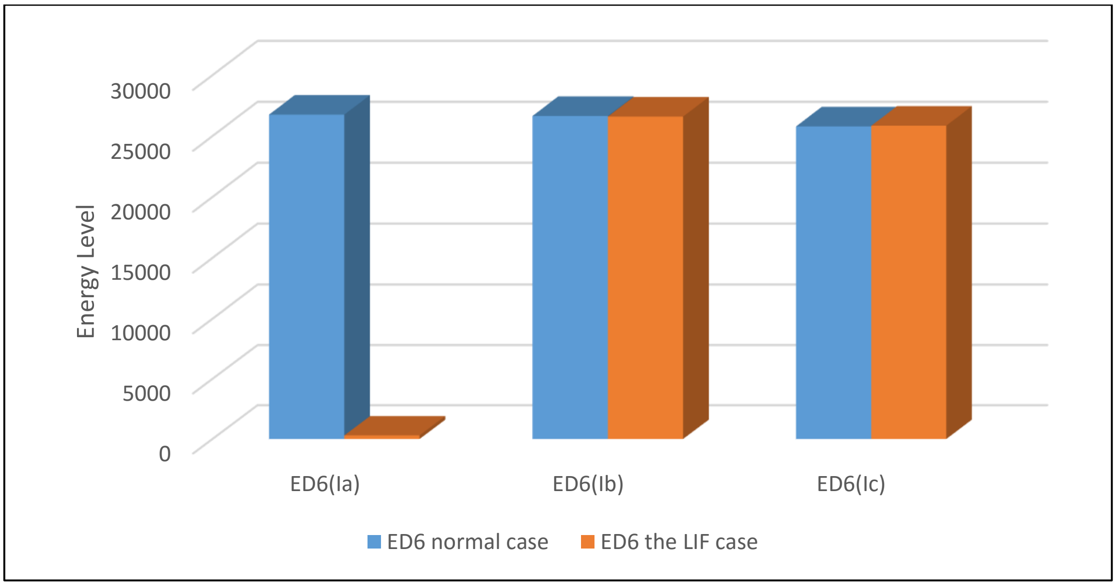


Figure 4.38: Relationship between (ED6) of normal case and LIF case on phase (B)

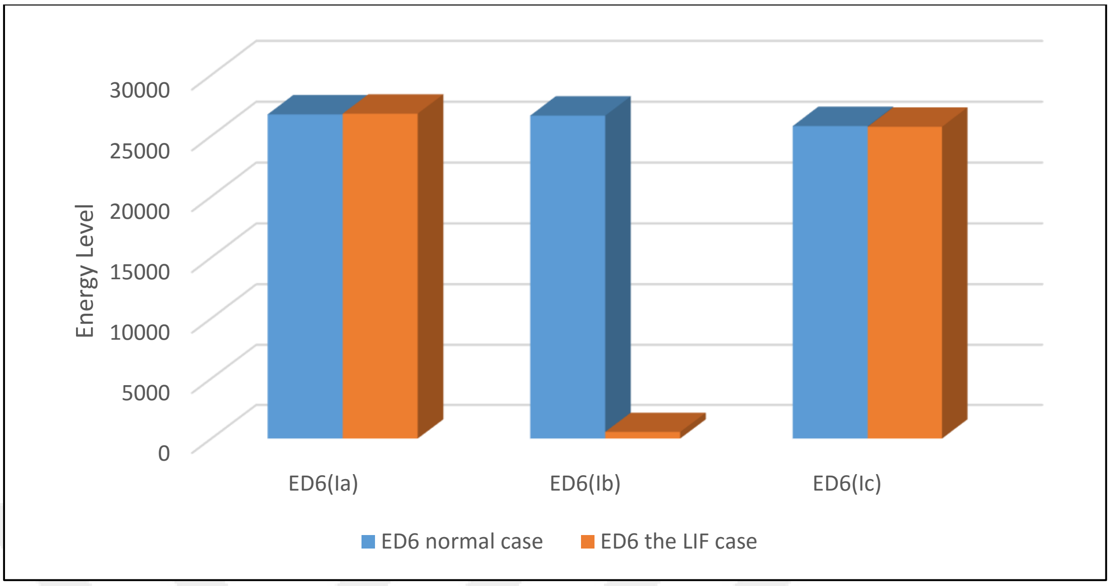
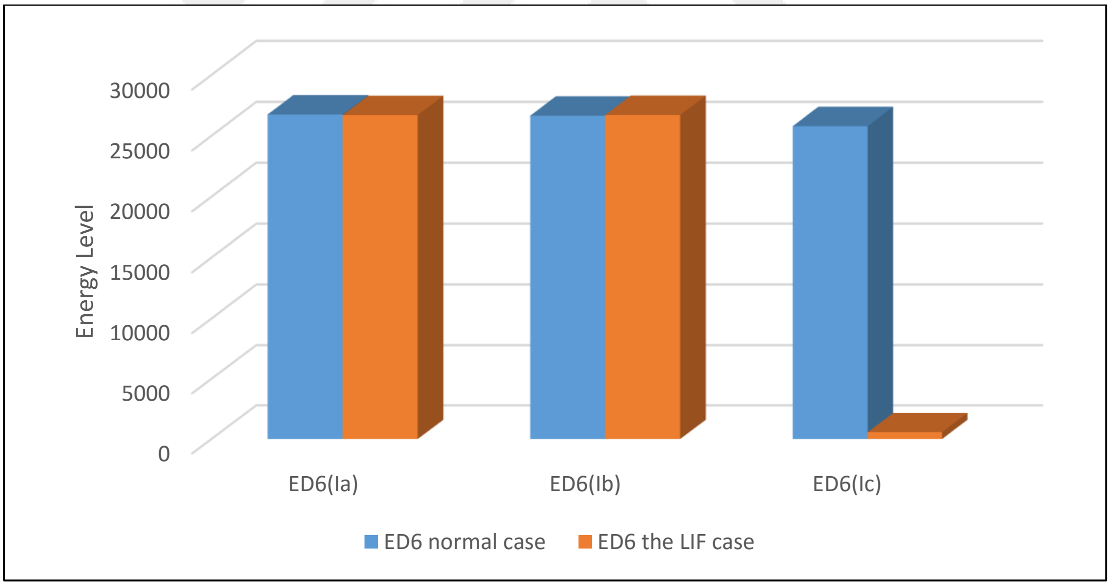


Figure 4.39: Relationship between (ED6) of normal case and LIF case on phase (C)



In figures 4.37, 4.38 and 4.39, the orange color shows the faulty signal. While, the blue color shows the normal signal (unfaulty signal). Also, in figures 4.37, 4.38 and 4.39 the faulty phase holds a fault in all simulation. In addition, it can be seen that the orange color has lower height values than the blue one. But in other signals the both color have the same height of amplitudes.

The figures.4.40, 4.41 and 4.42 represent the relationship between the energy of the detail signal in level six (ED6) for the current phases of the unfaulty case with LIF case for the LIF parameters (Rf=7.5 ohm, Rg=0.1 ohm).

Figure 4.40: Relationship between (ED6) of normal case and LIF case on phase (A)

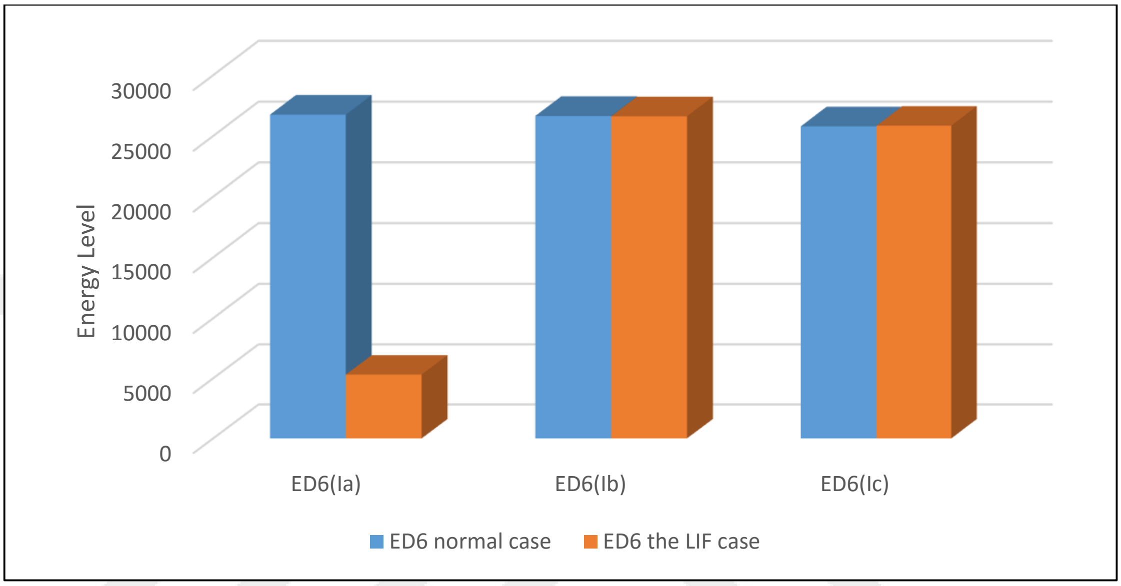


Figure 4.41: Relationship between (ED6) of normal case and LIF case on phase (B)

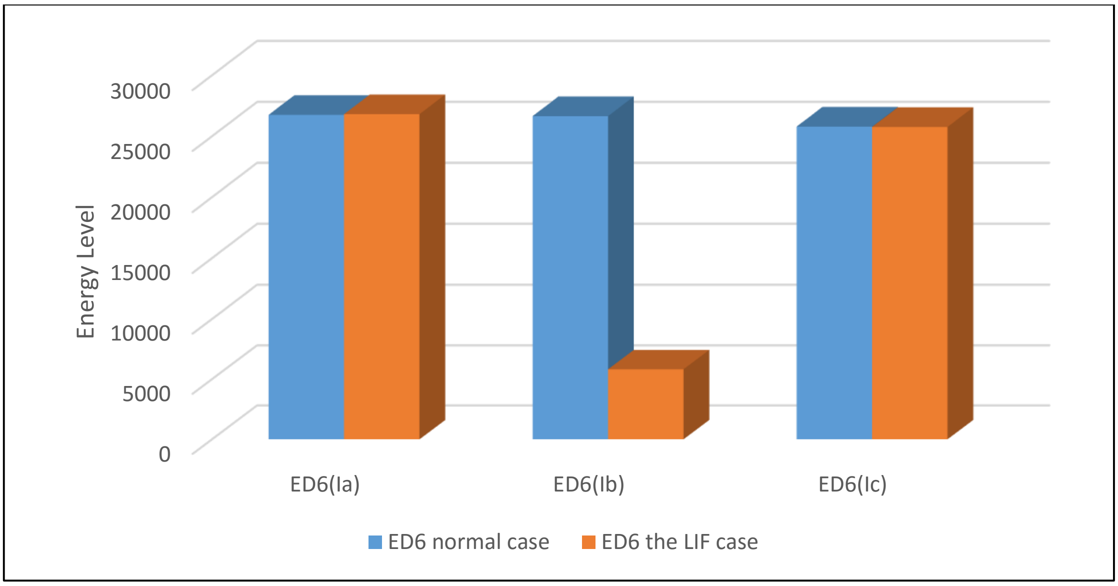
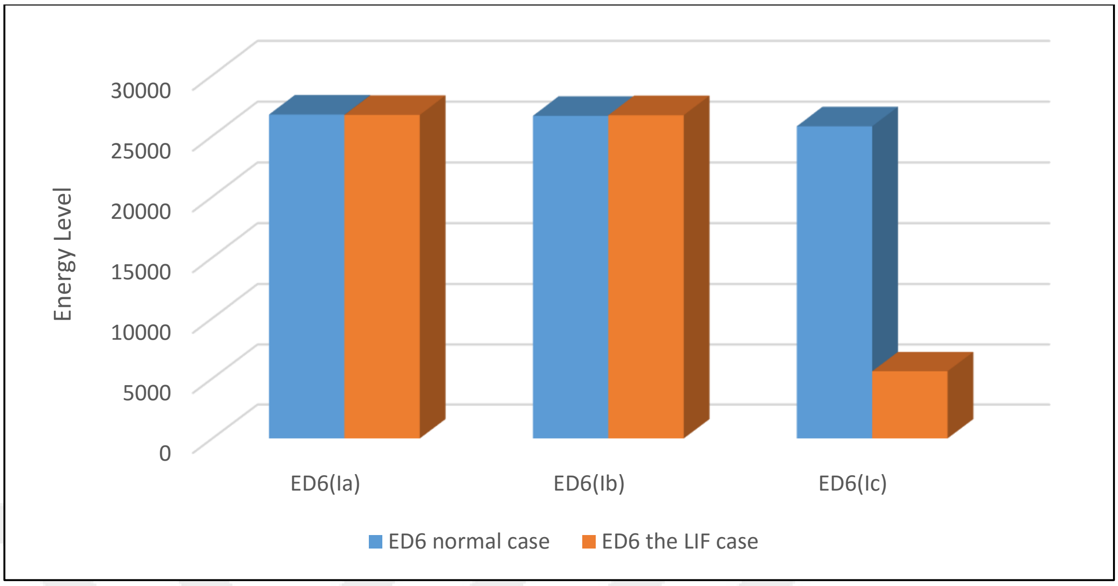


Figure 4.42: Relationship between (ED6) of normal case and LIF case on phase (C)



In figures 4.40, 4.41 and 4.42, the orange color shows the faulty signal. While, the blue color shows the normal signal (unfaulty signal). Also, in figures 4.40, 4.41 and 4.42 the faulty phase holds a fault in all simulation. In addition, it can be seen that the orange color has lower height values than the blue one. But in other signals the both color have the same height of amplitudes.

The figures.4.43, 4.44 and 4.45 represent the relationship between the energy of the detail signal in level six (ED6) for the current phases of the unfaulty case with HIF case for the HIF parameters (Rf=1 ohm, Rg=0.6 ohm).

Figure 4.43: Relationship between (ED6) of normal case and LIF case on phase (A)

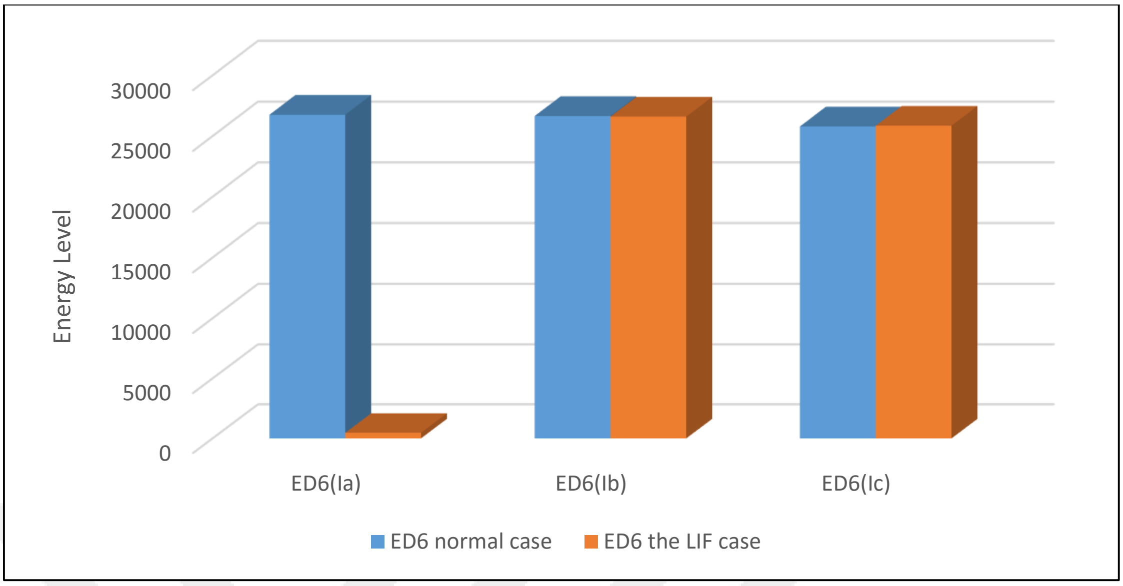


Figure 4.44: Relationship between (ED6) of normal case and LIF case on phase (B)

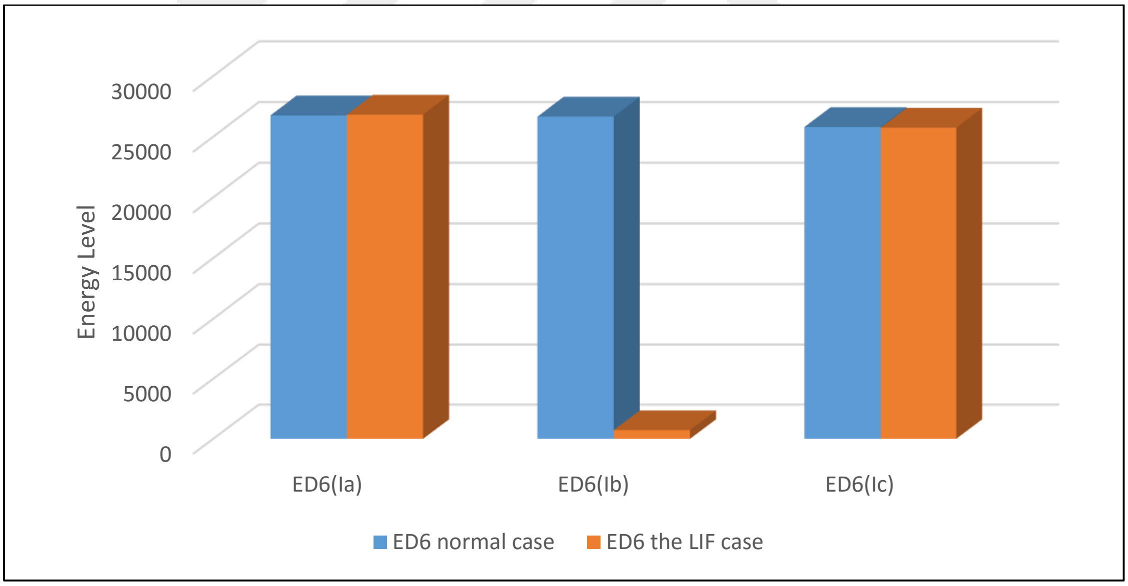
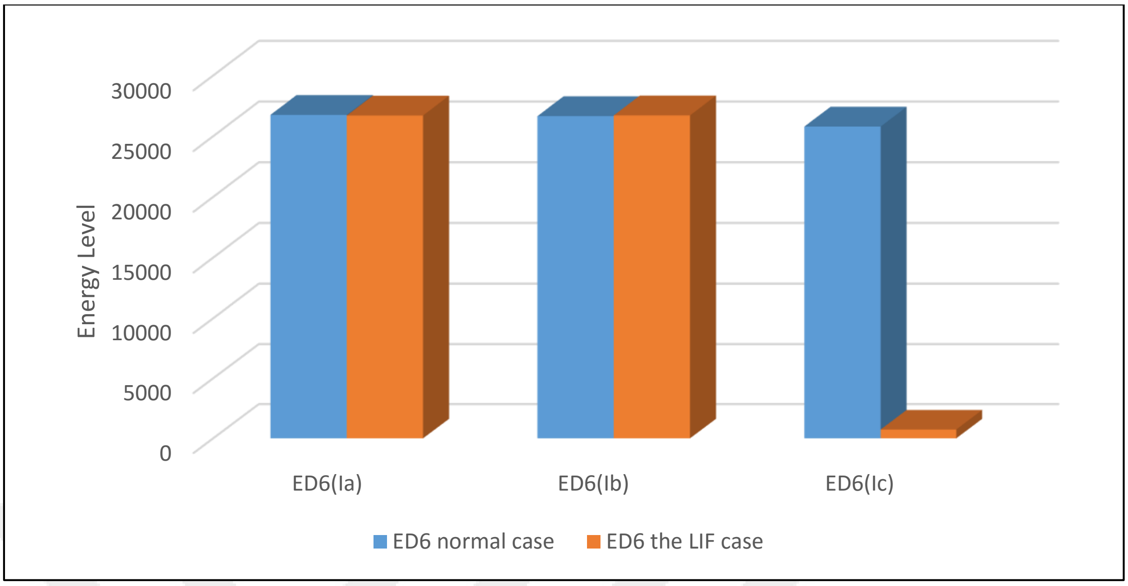


Figure 4.45: Relationship between (ED6) of normal case and LIF case on phase (C)



In figures 4.43, 4.44 and 4.45, the orange color shows the faulty signal. While, the blue color shows the normal signal (unfaulty signal). Also, in figures 4.43, 4.44 and 4.45 the faulty phase holds a fault in all simulation. In addition, it can be seen that the orange color has lower height values than the blue one. But in other signals the both color have the same height of amplitudes.

The figures.4.46, 4.47 and 4.48 represent the relationship between the energy of the detail signal in level six (ED6) for the current phases of the unfaulty case with HIF case for the HIF parameters (Rf=1 ohm, Rg=1 ohm).

Figure 4.46: Relationship between (ED6) of normal case and LIF case on phase (A)

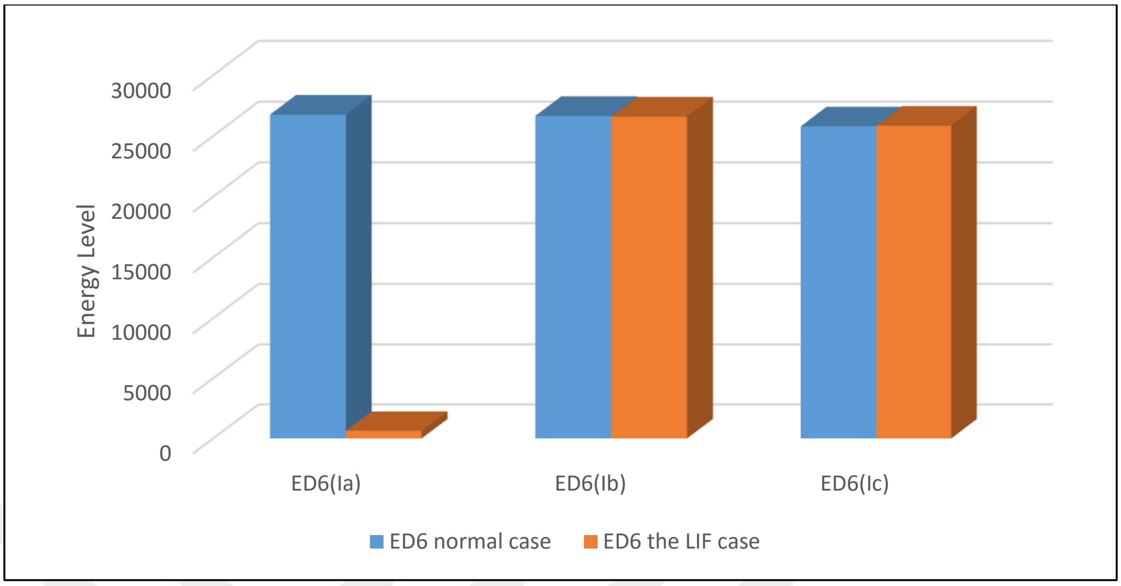


Figure 4.47: Relationship between (ED6) of normal case and LIF case on phase (B)

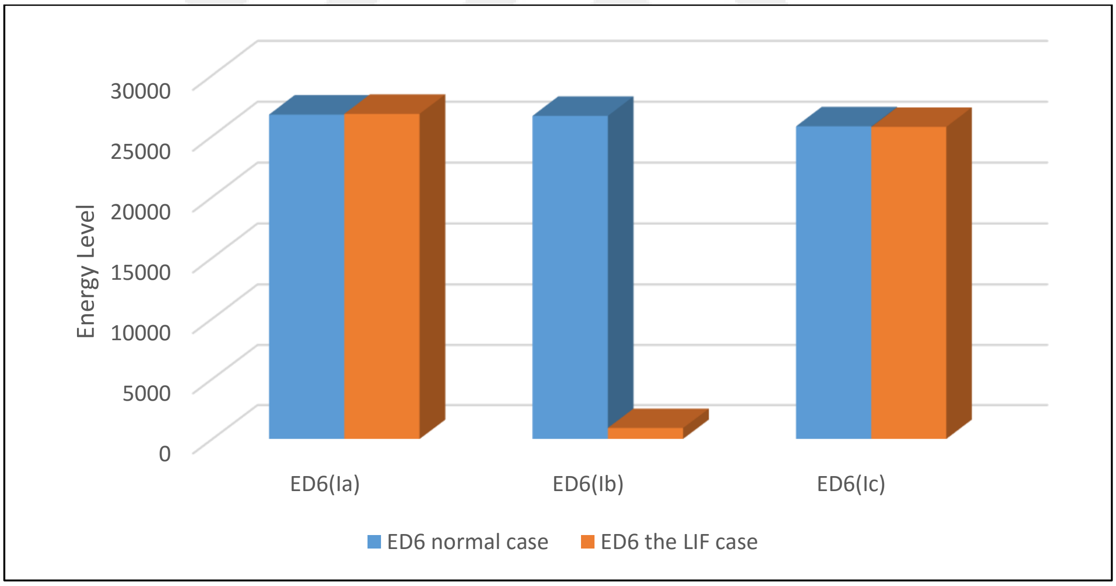
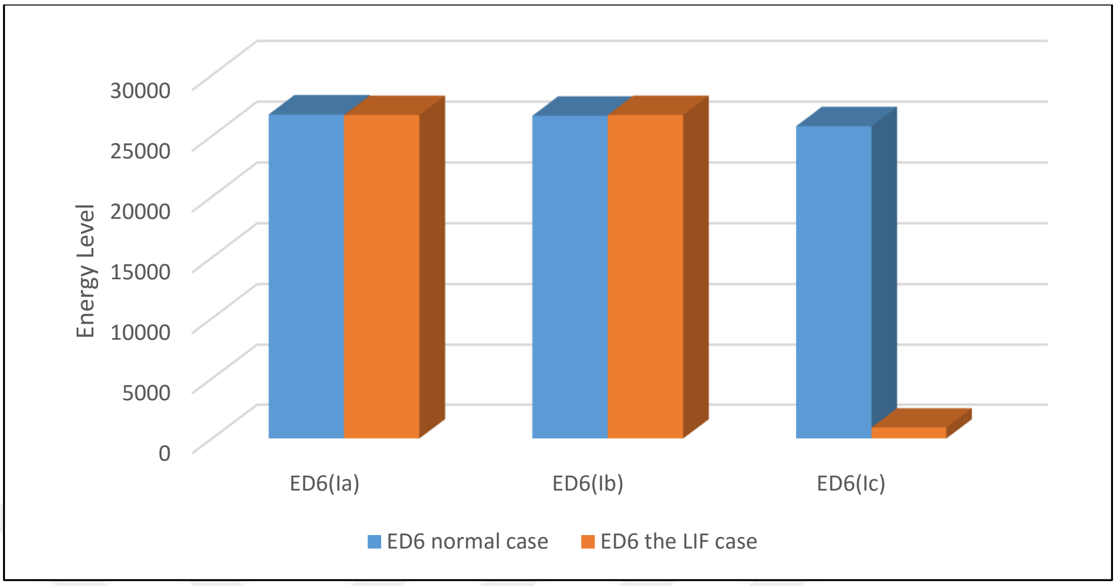


Figure 4.48: Relationship between (ED6) of normal case and LIF case on phase (C)



In figures 4.46, 4.47 and 4.48, the orange color shows the faulty signal. While, the blue color shows the normal signal (unfaulty signal). Also, in figures 4.46, 4.47 and 4.48 the faulty phase holds a fault in all simulation. In addition, it can be seen that the orange color has lower height values than the blue one. But in other signals the both color have the same height of amplitudes.

4.3.3. Load Switching

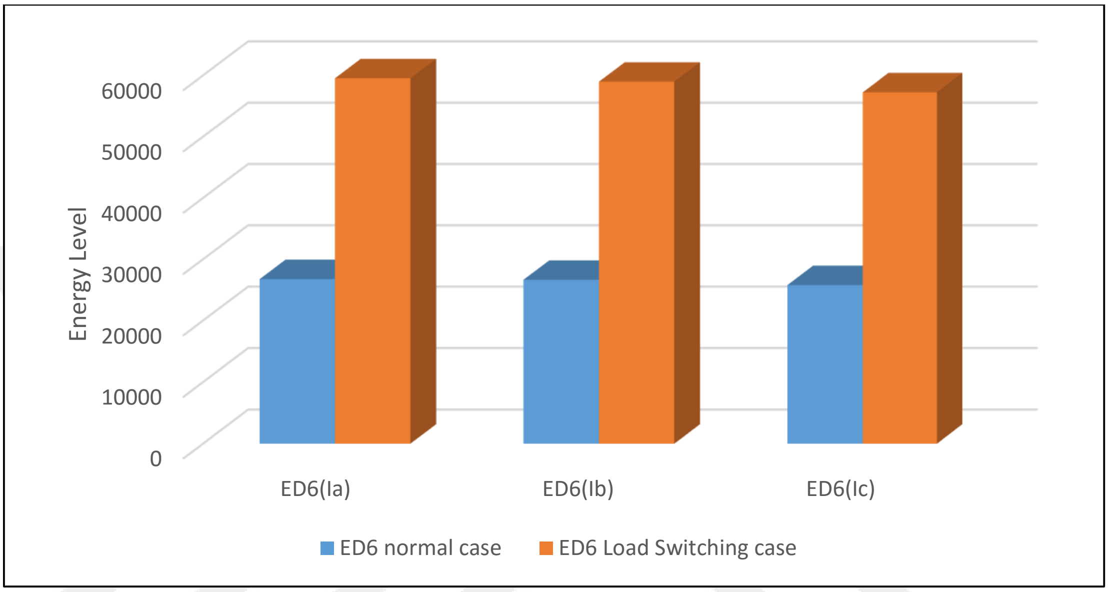
Load switching is the case that when the load is suddenly increased in the distribution network and that will affect clearly in the loading current. The cases of the load switching are given in Table 4.4.

Table 4.4: Load switching values

Cases	Load1 (kW)	Load2(kW)
1	800	400
2	800	600
3	800	1000

The relationship between the energy of the detail signal in level six (ED6) for the current phases of the unfaulty case with load switching case is shown in figure. 4.49 with the load parameters (load1=800 kW, load2=400 kW).

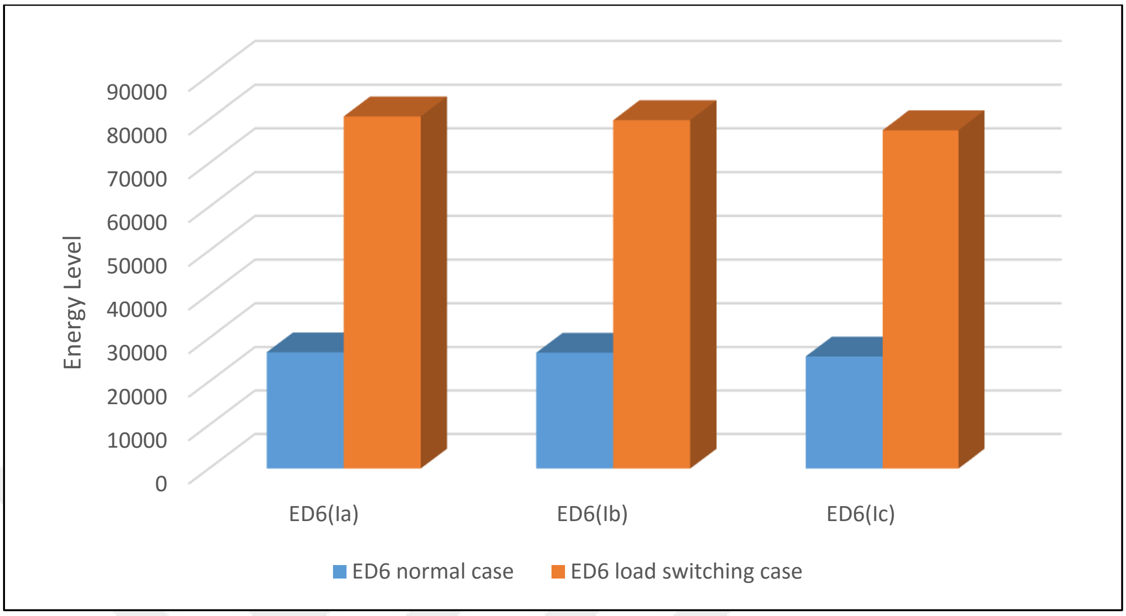
Figure 4.49: Relationship between (ED6) of normal case and load switching case with 400kW.



As shown in figure 4.49, the orange color shows the load switching signal. The blue color shows the normal signal. Also the load switching hold on a 3-phase at the same time. In addition, it can be seen that the orange colors have height values than the blue one of amplitudes because of increasing on load current values as compared with normal case.

The relationship between the energy of the detail signal in level six (ED6) for the current phases of the unfaulty case with load switching case is shown in figure. 4.50 with the load parameters (load1=800(kW), load2=600(kW)).

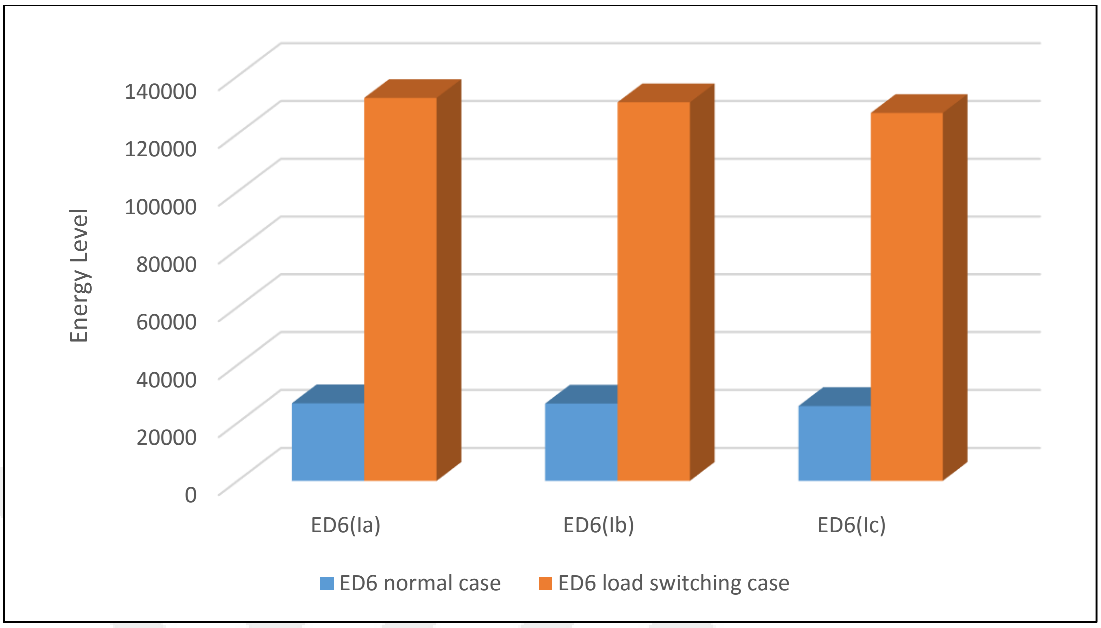
Figure 4.50: Relationship between (ED6) of normal case and load switching case with 600kW.



As shown in figure 4.50, the orange color shows the load switching signal. The blue color shows the normal signal. Also the load switching hold on a 3-phase at the same time. In addition, it can be seen that the orange colors have height values than the blue one of amplitudes because of increasing on load current values as compared with normal case.

The relationship between the energy of the detail signal in level six (ED6) for the current phases of the unfaulty case with load switching case is shown in figure. 4.51 with the load parameters (load1=800(kW), load2=1000(kW)).

Figure 4.51: Relationship between (ED6) of normal case and load switching case with 1000kW.



As shown in figure 4.51, the orange color shows the load switching signal. The blue color shows the normal signal. Also the load switching hold on a 3-phase at the same time. In addition, it can be seen that the orange colors have height values than the blue one of amplitudes because of increasing on load current values as compared with normal case.

In table 4.5, HIF model parameters are (Rp=245 ohm, Rn=245 ohm, Vp=6180 Volt, Vn=6155 Volt) and LIF model parameters are (Rf=10 ohm, Rg=0.1ohm) for load switching cases will be used the same load in table 4.4.

Table 4.5: Detection fault type for 22 cases by using proposed algorithm.

Case	Length (km)	Load (kW)	Simulation time (sec)	Type of fault	Detection of faulty phase
1	10	800	1	HIF	(A)
2	10	800	0.5	HIF	(A)
3	30	800	1	HIF	(A)
4	30	800	0.5	HIF	(A)
5	20	400	1	HIF	(A)
6	20	400	0.5	HIF	(A)
7	20	1000	1	HIF	(A)
8	20	1000	0.5	HIF	(A)
9	10	800	1	LIF	-
10	10	800	0.5	LIF	-
11	30	800	1	LIF	-
12	30	800	0.5	LIF	-
13	20	400	1	LIF	-
14	20	400	0.5	LIF	-
15	20	1000	1	LIF	-
16	20	1000	0.5	LIF	-
17	10	800,400	0.5	Load Switching	-
18	10	800,600	0.5	Load Switching	-
19	10	800,1000	0.5	Load Switching	-
20	30	800,400	0.5	Load Switching	-
21	30	800,600	0.5	Load Switching	-
22	30	800,1000	0.5	Load Switching	-

5. CONCLUSION

In this study, an energy model depending on wavelet transform for HIFs detection in distribution system was presented. The specification of wavelet transform has more facilities for detecting the features of a voltage or current signal and has been so convenient in characterizing the cause of fault in the power system. Therefore, the discrete wavelet transform is used for multiresolution analysis for compression of the signals which are gotten from the simulation measurement.

In the proposed algorithm, discrete wavelet transform with debauches wavelet as mother wavelet is handled the signal decomposition. By using the debauches 4 wavelet decomposition of six layers of the measured data, the details coefficients are obtained. They are used to calculate energy percentage for any input signal. The difference in percentage value and the difference between energy of detail six (ED6) helps to detect HIFs. The high impedance fault is modelled by using the Matlab-Simulink software and the wavelet toolbox is preferred to handle discrete wavelet transform which is used on compression of the signals resulted from the power system simulation. In first step the faulty signal and healthy signal is got from model. Then the discrete wavelet transform with Debauches 4 (db4) is taken for 6 levels. By using energy of details, the faulty phase is determined.

Matlab Simulink software is used for simulating the modeled power system and testing the proposed algorithm on three-phase system. The proposed detecting algorithm was tested with different scenarios. They consist of the different length of distribution line, different simulation times, different fault location, different fault types and different fault data. The test results show that the proposed algorithm detects high impedance fault case (HIF) and the faulty phase easily. Other types of faults just are determined as a low impedance fault (LIF) and load switching.

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