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The Technical Revisions Required to Prevent Electricity Theft

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Abstract

Electricity theft is a comprehensive problem in both developing and developed countries. Although the theft causes great economic losses and reduces reliability of power grids, the problem continues to grow. In this study, the revisions required to prevent electricity theft are specified and a new distribution grid configuration with revisions is presented. Distorted distribution voltage is the most significant revision in the new configuration since traditional distribution voltage is directly consumable in electric powered devices and facilitates the theft. But, dishonest customers utilize various theft techniques such as power meter tampering, illegal connections to the streetlights line and manipulation of power control panel. Therefore, the proposed grid configuration was designed by considering widely used electricity theft techniques.

Keywords: Electricity theft, Distorted distribution voltage, Harmonic filters

Elektrik Kaçırmayı Engellemek için Gerekli Olan Teknik Revizyonlar

Öz

Elektrik kaçırma gelişen ve gelişmekte olan birçok ülkede etraflı bir problemdir. Elektrik kaçırma büyük ekonomik kayıplara neden olmasına ve güç şebekelerinin güvenirliliğini azaltmasına rağmen bu problem büyümeye devam etmektedir. Bu çalışmada, elektrik kaçırmayı engellemek için gerekli olan revizyonlar belirtilmekte ve bu revizyonları içeren yeni dağıtım şebekesi konfigürasyonu gösterilmektedir. Geleneksel şebekelerde dağıtım gerilimi elektrikli cihazlarda doğrudan kullanılabilirdir. Kullanılabilir dağıtım gerilimi elektrik kaçırmayı kolaylaştırdığından önerilen konfigürasyonda en önemli revizyon bozuk dağıtım gerilimidir. Ancak, dürüst olmayan tüketiciler sayaç kurcalama, kanunsuz bağlantı, aydınlatma hattını kullanma ev kontrol paneline müdahale gibi çeşitli elektrik kaçırma teknikleri kullanmaktadır. Bu yüzden, önerilen şebeke konfigürasyonu yaygın olarak kullanılan elektrik kaçırma teknikleri göz önüne alınarak tasarlanmıştır.

Anahtar Kelimeler: Elektrik kaçırma, Bozuk dağıtım gerilimi, Harmonik filtreler

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1. INTRODUCTION

Electricity theft is a comprehensive problem in both developing and developed countries. The problem adversely affects energy sector in terms of total energy consumption, electricity prices, economic injustice, power quality, utility grid reliability etc. [1]. The illegal customers don't pay electricity bills accurately and don't need energy saving so they wastefully consume utility electricity. Therefore, utility services increase electricity prices to cover the unpaid consumptions. Furthermore, the excessive consumptions cause technical problems such as frequent and long-term power outages. Although electricity theft aggrieves genuine costumers and it is accepted as a crime [2-3], the problem is growing all over the world. It is estimated that emerging markets lose $58.7bn per year and the rest of the markets, including the largest economies, lose $30.6bn per year because of electricity theft. The total cost of electricity theft for three countries that are on top of the list is about $31.8bn per year; $16.2bn in India, $10.5bn in Brazil and $5.1bn in Russia, respectively [4].

The rate of electricity theft is small (1-2%) in some developed countries but the financial losses caused by electricity theft are high because the electric consumption of the developed countries is much more compared to other countries. For instance, in the US, the theft rate between 0.5% and 3.5% causes serious financial losses between $1 and $10 billion worth per year [3]. However, electricity loss of Bangladesh is about one-third of the total generation and the cost of the loss is around $247 million per year [5]. This figure shows that electricity theft is an enormous economic problem even if its rate is small. The governments, which are suffered from the theft, fund smart grid projects to control the theft. The most interesting among these projects is presented in India. Indian government develops a project worth $4bn for improving smart meters and upgrading the distribution grids to combat electricity theft [6].

In generally, distribution losses obtained from electricity marketing data are used to calculate electricity theft rate and its adverse effects on the economy [7]. This method facilitates the calculation and enables rough data about costly consequences of the theft. But, in fact, the theft is associated with various economic losses. Lewis classifies costly consequences of electricity theft at four groups as follows: Rise in power prices, low power quality, reduction in re-investment and hazardous fire for human life [8]. The number of these groups can be increased by adding new issues such as maintenance cost, the use of more expensive and polluted energy sources, economic losses caused by power outages etc. The topics increase complexity of the problem so they are ignored to ease the calculation of adverse cost effects of the theft. However, authorities know that the problem is more harmful than it is reported.

There are few technical solutions that can be used to eliminate the theft problem in the literature and they can be divided into two groups: Theft detection [9-13] and theft control methods [14-15]. The detection methods aim to find illegal consumers without any technical intervention to prevent the theft. The detection methods can be effective for customers with high consumption (commercial and industrial customers) in central settlements. However, in rural areas, even if the illegal costumers are known, utility services ignore them because of various reasons such as politic atmosphere and mafia oppression [1]. The theft control methods are more promising than the detection methods to prevent the theft for all type of costumers in every residential area. The control methods include technical interventions (power system control or utility stuff operation) to prevent the electricity theft. However, as far we know there is no theoretical and practical control method used to solve the electricity theft problem completely.

In this study, the technical revisions required to prevent the electricity theft are specified and a new theft control method including the revisions is presented by a simulation model in Matlab/Simulink simulation environment. In the proposed model, distribution voltage is intentionally distorted by a harmonic supply in power distribution center in order to eliminate illegal connections between the distribution center and power meters. A passive harmonic filter group embedded in the power meter clears the harmonics of the distorted voltage to protect the legal consumers from adverse effects of the harmonics. The distorted distribution voltage has a key role in the proposed theft control method, because it cannot be used without the formal power meter. After this revision, dishonest customers can easily find a new theft technique such as deactivating the harmonic supply or using informal power meters. Therefore, the probable electricity theft techniques and technological revisions to prevent them are presented in the next section.

2. THE TECHNICAL REVISIONS

The power losses occurred in power grids are divided into two groups: Technical and nontechnical losses. The technical losses are mechanical, electrostatic and electromagnetic losses occurring in the generation, transmission, distribution and conversion of energy in electric power grids. The nontechnical losses can be defined as illegal electricity consumption or electricity theft, which is made consciously by dishonest customers. The dishonest customers use several theft techniques such as illegal connection, misreading, power meter tampering and unpaid bills [3]. The following sections describe revisions required for existing power grids to solve the theft problem by considering known and probable electricity theft techniques. The revisions should be handled as a whole and zero tolerance policy must be applied against electricity theft.

2.1. Unusable Distribution Voltage

Distribution transformers step down high transmission voltage to low distribution voltage, which is directly consumable in electric powered devices. Therefore, utility customers can use utility electricity with a power meter and there is no need for an additional power converter. The power meters have no impact on utility power quality and they are only used to protect the cost benefits of utilities and their customers. Dishonest customers can use utility electricity by tampering or bypassing the power meter [16-17]. These theft techniques are easy particularly from overhead lines in rural areas since theft detections, which are made by utility staff, are impossible in every time. However, dishonest customers cannot use utility electricity without power meter in the case distribution voltage is harmful or insufficient for electric powered devices and it is safely used only with the power meter.

Using an external harmonic source in electric distribution centers is a practical and efficient way to distort the distribution voltage because of the following advantages. Firstly, the harmonics can be easily cleaned by a passive harmonic filter group, which is embedded in new power meters; hence, genuine customers are not adversely affected by distorted distribution voltage. Secondly, the distortion characteristic of the distribution voltage can be controlled by changing frequency and amplitude of the harmonic voltage. Therefore, different harmonic characteristics can be used for different customer types and regions. Thirdly, there is no need to change power architecture of existing distribution grids because only distribution transformers and power meters must be changed to implement the method. Finally, the harmonic voltage source needs no extra much power since harmonic voltage with low current is enough to distort the distribution voltage. These advantages reveal that use of an external harmonic voltage source is an easy and effective recyclable way for distribution voltage distortion.

2.2. Unusable Distribution Voltage for Street Lighting

Distribution voltage of street lighting systems has same electrical characteristics with usable home voltage, so overhead street lighting lines can also be used for electricity theft. In fact, there is no power in the street lighting lines at daylight hours owing to photocell sensors. However, dishonest customers deactivate the sensors to employ the lines for the theft, in which distribution voltage has low power quality because of overload. This theft technique also leads to street lights working during the whole day rather than only evening hours. Therefore, distribution voltage of street lighting system must be inconsumable for conventional electric powered devices to prevent this theft technique.

DC distribution voltage is more reliable and efficient for street lighting systems owing to improved led and power conversion technologies [18-20]. This is the reason why DC distribution voltage can be preferred to change traditional AC voltage of street lighting systems. Dishonest customers, who know DC voltage is insufficient for conventional electric devices, give up using street lighting lines to meet their electricity needs. DC distribution voltage of street light system can be used only with a DC/AC power converter by establishing an illegal connection. However, the use of a power converter is not a practical way to employ the lighting lines for the theft since the converters are expensive electronics equipment. Even so, this way must be considered as a risk for the theft and an effective precaution should be taken against it. Electricity consumption of street lights is generally stable and limited. If the lighting power characteristic is abnormally changed, there is a theft attempt. In these cases, the lighting energy must be automatically cut for a short time by power control center. After this short time period, if the characteristic abnormality of the lighting power continues, the time of energy cutting is gradually increased until utility staff interfere the lighting system.

2.3. The Monopolized Power Meters

Almost all electricity theft techniques are related to power meters such as power meter tampering, bypass power meter and misreading. This fact shows that the power meters have a vital role in electric distribution grids to prevent the theft. As we stated in the first revision, dishonest costumers avoid illegal electrical connections when distribution voltage is harmful for electrical devices. In case the power meters convert the harmful voltage to the usable voltage by filtering harmonics of distorted distribution voltage, the use of power meters will be the only way to have reliable energy. Thus, utility customers have to use power meters to benefit from energy of utility grids; hence, their electric consumptions are recorded accurately.

Power meter burning is another electricity theft technique. Sometimes, when electric consumption bill exceeds the price of a power meter, dishonest customers intentionally burn the meter by making incorrect electrical connections to zero the bill. This theft technique also provides free utility energy for the customers until new power meter is installed. To prevent this theft technique, new power meters must be expensive and monopolized by utility services. In the proposed electric distribution grids, dishonest costumers cannot use utility electricity when their power meters are burned due to distribution voltage is harmful for electrical devices. However, dishonest costumers will want to tamper new power meters to find a new theft technique hence the cost of power meters must be an inhibitive amount for them. It should be noted that the power meters are renewed by utility services without any charge when the burned is based on manufacturer defects or natural causes.

3. CONFIGURATION MODEL

Harmonics are produced by nonlinear loads such as power converters, adjustable speed drivers, electronic equipment, rotating machines and transformers. The harmonics have adverse effects on the energy systems in terms of power losses, thermal overloading, equipment heating and damage [21]. Passive [22], active [23] and hybrid [24] harmonic filters are employed to eliminate the harmonics and protect the energy systems from these adverse effects. Furthermore, the harmonic filters, which are located near electrical loads, improve power factor by providing reactive energy to the loads. Among the harmonic filters, passive harmonic filters are widely used in practice due to their lower cost and simplicity.

Electric distribution voltage can be directly utilized in electric powered devices, so it facilitates electricity theft. Dishonest costumers can easily make illegal connection to the distribution line and use utility power without any charge. However, if the distribution voltage is unusable and harmful for electric powered devices, the dishonest costumers would give up making illegal connections to the power grid. The harmonics can be employed to distort the distribution voltage in traditional power grids. Figure 1 shows the proposed method configuration, in which the distribution voltages of houses and street lights are unusable for conventional electric powered devices. The distribution voltage of the houses is distorted by an external harmonic source in the power distribution center. The power meter includes harmonic filters to eliminate harmonics of the distorted distribution voltage and provide reliable energy to domestic loads. 400 V DC voltage is utilized for the distribution voltage of street lights to make it unusable for traditional electric powered devices.

Figure 2 shows power components configuration of the power distribution center. Power distribution center includes a conventional transformer and power converters. The transformer steps down high transmission voltage to low distribution voltage to provide usable energy for residential areas. The AC/DC converter is utilized to produce 400 V DC, which is the suitable voltage level for DC distribution grids. The DC voltage is employed to supply street lights and the DC/AC inverter. The DC/AC inverter is serially connected to the distribution line of houses to distort its voltage characteristics with harmonics. In this configuration, power distribution center has a compact structure with a high transmission voltage as the input and its outputs are 400 V DC and distorted distribution voltages. Therefore, utility staffs can cut energy of the distribution grid, but they cannot repair or control power components of the distribution center.

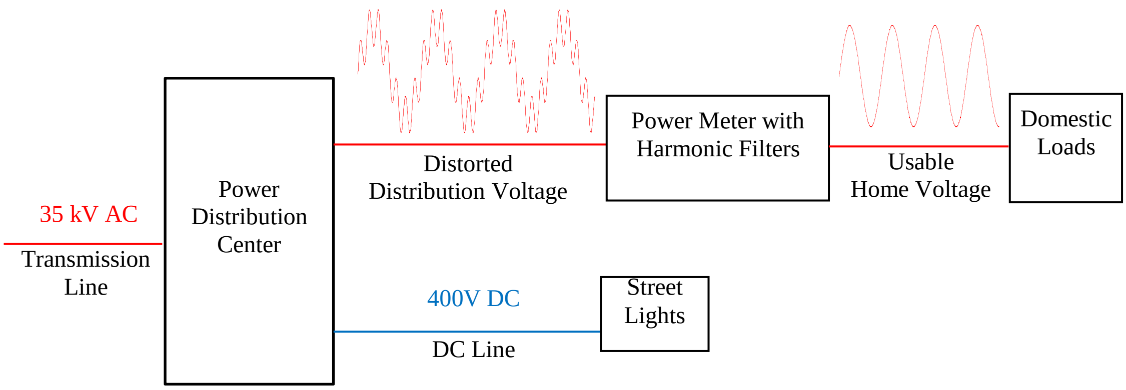

Figure 1. Use of distorted distribution voltage in an electric power grid

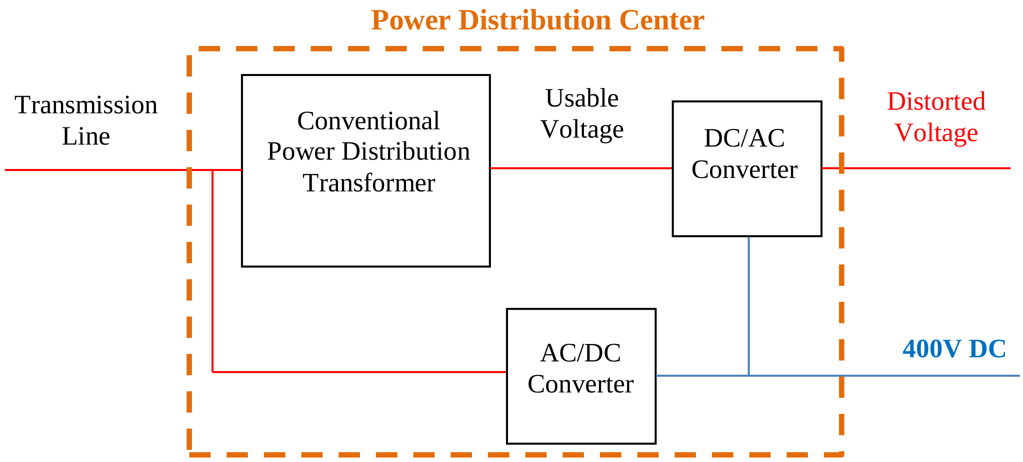

Figure 2. Power components configuration of the power distribution center

519-2014-IEEE standard recommends limiting total harmonic distortion (THD) with 8% in electric distribution grids [25]. If THD of the distribution voltage is over the recommended limit, utility energy can be unreliable for traditional electrical devices. In fact, each electrical device is differently affected from THD. However, we classified THD in three groups as low, medium and high in order to define distortion of the distribution voltage. If THD is low, distribution voltage is reliable for all electrical devices. If THD is medium, the distribution voltage is unusable, but not harmful for a lot of electrical devices. If THD is high, the distribution voltage can be harmful for all electrical devices. THD can be controlled by the DC/AC converter by using a harmonic control method.

The power meters of houses include passive harmonic filters that are compatible with distorted distribution voltage. Distortion characteristic of the distribution voltage can be changeable depending on passive filters. For instance, if the power meter has harmonic filters for 3^{rd}, 5^{th} and 7^{th} harmonics, the DC/AC converter produces the harmonics just in these orders and control the distortion characteristics by changing amplitude and phase angle of these harmonics. Thus, the distortion of distribution voltage can be controlled to prevent the illegal connections and honest costumers have reliable energy.

4. RESULTS

Figure 3 shows Matlab/Simulink model of the proposed method within an electric power distribution grid. The blocks of the high voltage power source and the distribution transformer were taken from Simulink/Library and the blocks of the power converters and electrical loads were designed by the authors for smart grid studies [26]. As it is in traditional electric grids, the distribution transformer steps down high transmission voltage to low distribution voltage, which is directly usable in electric powered devices. An AC/DC converter is utilized to produce 400 V DC voltage that is needed for harmonic production and street light power distribution. A DC/AC power converter is employed as a harmonic supply, whose output is serially connected to the distribution line to distort the distribution voltage with the harmonics. The distribution grid has a formal costumer and a street light that are supplied from unusual distribution voltage. The power meter of the costumer has passive harmonic filters, which are compatible with produced harmonics in the power distribution center. Therefore, the distorted distribution voltage has no adverse effects on the costumer's loads since the filters eliminate the harmonics.

THD of the distorted distribution voltage depends on frequency and amplitude of the produced harmonic voltage. Therefore, THD can be controlled by changing frequency and amplitude of the harmonic voltage. A reference signal composed of several sinusoidal signals can be used to determine voltage and frequency of the harmonics. For instance, if the reference signal is composed of two sinusoidal signals with a frequency of 250 and 350 Hz, the harmonic supply distorts the distribution voltage with 5^{th} and 7^{th} harmonics. In this case, the power meter must have harmonic filters for 5^{th} and 7^{th} harmonics. Otherwise, the harmonics of distorted distribution cannot be eliminated by the power meter and they can be harmful for the costumer' loads. Therefore, the frequency of the harmonics must have fix values and THD of the distorted distribution voltage must be controlled by adjusting the amplitude of harmonics.

Figure 4 shows circuit topology of the power meter that includes harmonic passive filters and a wattmeter. The harmonic filters were designed for 5^{th} and 7^{th} harmonics and their common resistance was serially connected to the phase line. The indices of capacitors and inductors show harmonic order of the filters with inductors L_5 and L_7=4 mH, the capacitor C_5=100 μF and C_7=50 μF and the resistance R=4 Ω. The wattmeter measures active and reactive power by using resistance voltage and load current. The power meter uses only phase line for the measurement and it works free from the neutral line. Therefore, deactivation of neutral line for electricity theft has no affects for measurement accuracy of the power meter.

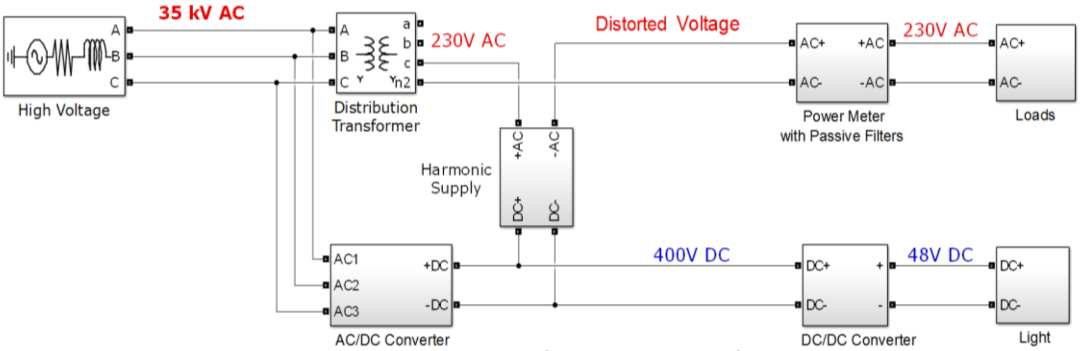

Figure 3. Matlab/Simulink model of the proposed theft control method

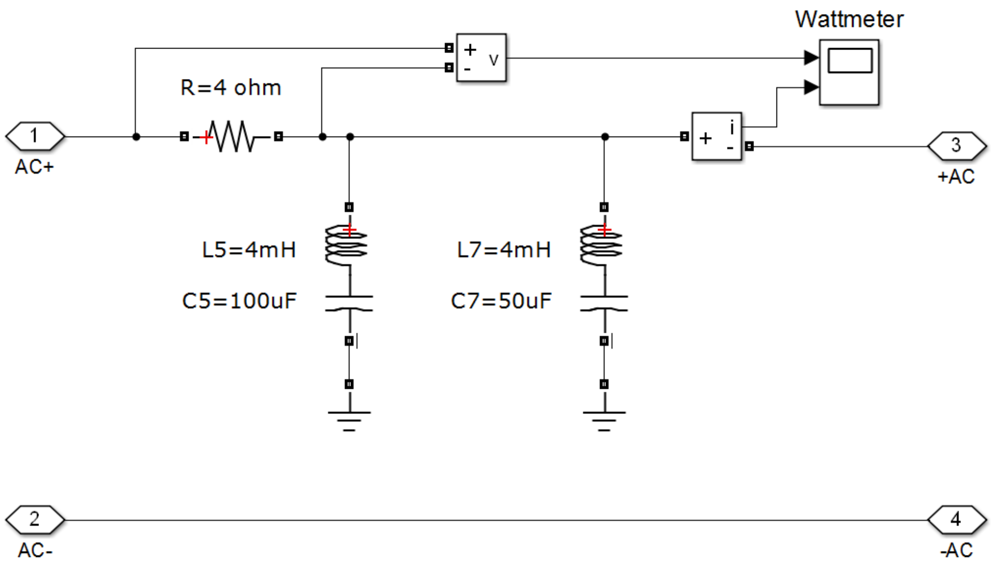

Figure 4. Matlab/Simulink model of the power meter

Power distribution voltage has a pure sinusoidal characteristic within 230 volt and 50 Hz in most countries. In this study, the pure distribution voltage is intentionally distorted with various harmonics to obtain unusable distribution voltage. Figure 5 shows distorted distribution voltage that is composed of pure distribution voltage and 5^{th} and 7^{th} harmonics. The nominal voltage of the 5^{th} and 7^{th} harmonics is 50 V and their phase angles are 0^{o} and 180^{o} leading from the pure voltage, respectively. The distribution voltage has an insufficient and hazardous sinusoidal waveform for electric powered devices. THD of distribution voltage is 31% which is significantly higher than THD limit (8%) recommended by 519-2014-IEEE standard. Furthermore, peak value of the distribution voltage (V_{peak}) can reach 330 V instead of 230 V. These high THD and maximum voltage values show that the distorted distribution voltage cannot be directly utilized for electrical devices. On the other hand, house voltage is usable and reliable for electrical loads during the simulation time since the harmonics are eliminated by the harmonic filters of the power meter.

V_{peak} of the distorted distribution voltage can be controlled by changing phase angle and amplitude of the harmonics. Figure 6 shows distorted distribution voltage, which was distorted by 5^{th} and 7^{th} harmonics that are 50 volt and 180^{o} leading. In this case, although only phase angle of the 5^{th} harmonic was leaded 180^{o} according to the previous case, V_{peak} was reduced to 235 V from 330 V. The new V_{peak} value of the distribution voltage is not hazardous for electrical devices, because it is almost equal to Vpeak of the pure distribution voltage. However, many electrical devices based on electronic circuits do not work correctly with this distorted voltage since THD is same with previous case and it is very high for reliable energy. This result shows that phase angle of the harmonics can be employed to adjust the Vpeak, but it has no effects on THD.

The harmonic distortion will cause extra power losses in electric power distribution grids. These losses are negligible in the grids that have high electricity theft. However, the losses are unnecessary if the electricity theft is very low or zero. Therefore, the harmonic distortion must be controlled to prevent wasted energy consumption. Figure 7 shows electrical characteristics of controlled distribution voltage, which is intentionally distorted with the harmonics between 0.2 and 0.4 seconds. This intermittent harmonic distortion can be utilized to control electricity theft with energy saving. When an electricity theft is detected in the distribution gird, the theft can be prevented by increasing time, V_{peak} and THD values of the intermittent harmonic distortion. In other times, the intermittent harmonic voltage with low distortion can be used as a caution signal to keep away dishonest costumers from the electricity theft. Thus, the use of harmonic distortion decreases as long as electricity theft is low in the distribution grids.

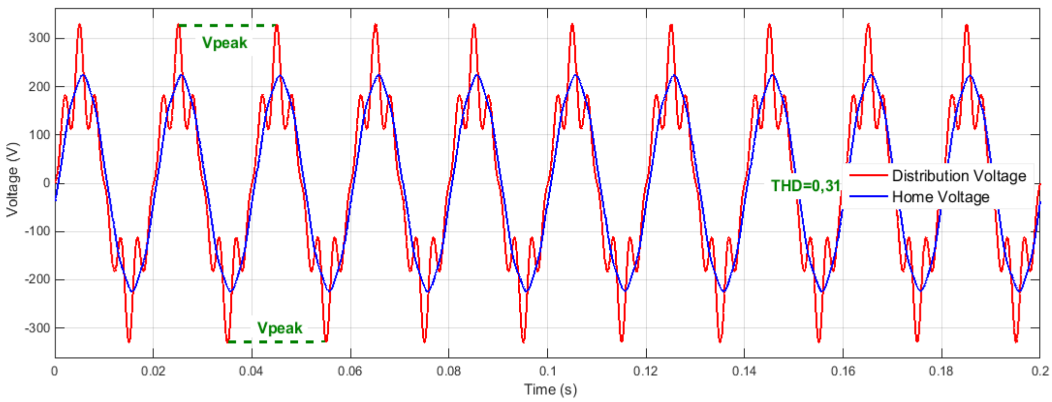

Figure 5. The characteristic of distorted distribution voltage (5^{th} 0° and 7^{th} 180° leading)

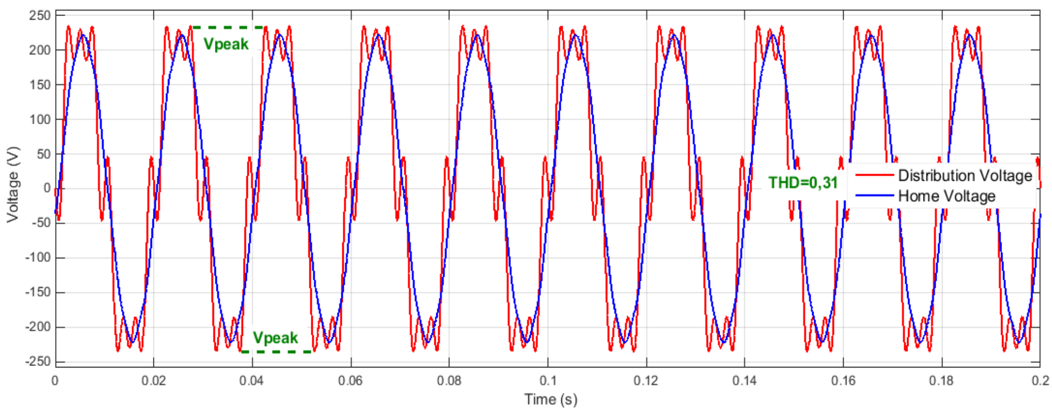

Figure 6. The characteristic of distorted distribution voltage (5^{th} and 7^{th} 180° leading)

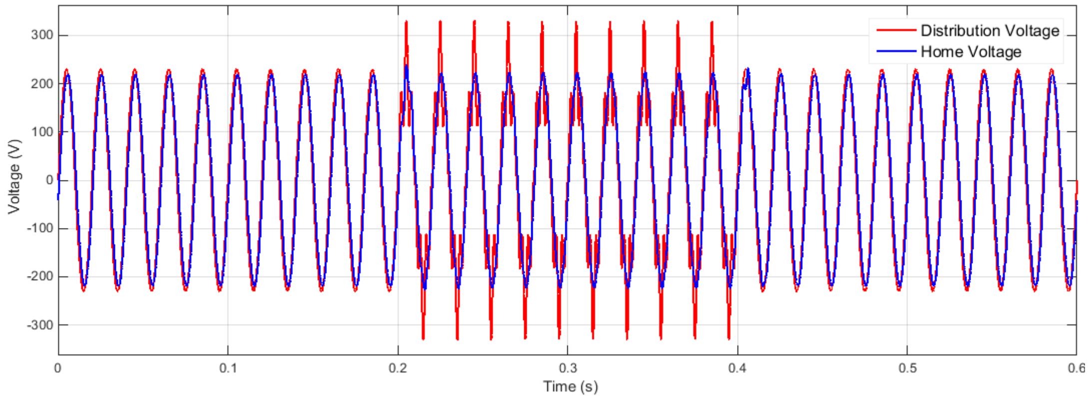

Figure 7. Intermittent harmonic distortion in electric distribution voltage

In the proposed power distribution architecture, the power meters have several harmonic filters that are compatible with produced harmonics in power distribution center. Thus, honest costumers using power meters are not adversely affected by the harmonics and utilize reliable energy all the time. The harmonic filters have extra advantages such as providing reactive power for the costumers and filtering existent harmonics produced by nonlinear electrical loads for improving power quality of electric distribution grids. Therefore, when the harmonics used to distort distribution voltage are determined, the common harmonics that are occurred in electric distribution grids must be considered to be filtered in power meters.

5. CONCLUSION

This paper investigates the technical revisions required to prevent electricity theft and presents a new electric distribution grid model including the revisions. The revisions are determined by considering widely used electricity theft technics and included appropriate technological solutions against the theft technics. In the new model, inconsumable distribution voltage has a key role since consumable distribution voltage facilitates the theft. The proposed distribution grid architecture is modeled in Matlab/Simulink simulation environment and tested for various inconsumable distribution voltages which are distorted by 5^{th} and 7^{th} harmonics. The simulation results show that the distortion of distribution voltage can be controlled as a reliable, insufficient or harmful voltage for electrical equipment by using an external harmonic voltage source. Furthermore, genuine costumers have robust energy during the simulation time owing to the passive harmonic filters embedded new power meters. These results reveal that the proposed method can be safely employed in existing electric distribution grids to prevent electricity theft.

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