Advanced Metering Infrastructure's Measurement of Working, Reflected, and Detrimental Active Power in Microgrids

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***Abstract*— With the increasing popularity of renewable energy sources and harmonic generating loads, issues with power quality can be addressed with the help of the advanced metering infra- structure (AMI). Power quality is a major issue with microgrids because they tend to have low short circuit power with higher levels of harmonic distortion and asymmetry than major power grids. Energy delivered to the customer by distorted and asymmetrical voltages and currents can be composed of a useful component and a component that can be harmful to customers and/or the utility. Unfortunately, traditional analog based energy meters are incapable of distinguishing these components and billing for them appropriately. Using a new concept of working, detrimental, and reflected active power, via the advanced metering infrastructure, sources of degradation can be pinpointed so entities responsible for harmonic distortion and asymmetry can be made aware of the issue. A model of a microgrid bus will demonstrate the con- sequences of distortion and asymmetry. Enforcing penalties can result in better voltage and current profiles thus increasing the overall efficiency of the microgrid for a minimal cost of software updates to AMI meters.**

***Index Terms*—AMI; Advanced Metering Infrastructure; CPC, Current's Physical Components; distortion; asymmetry; harmonics; microgrid**

I. INTRODUCTION

Renewable energies, microgrids, and new age power electronic devices are fast approaching widespread adoption. While new technologies are certainly beneficial to the overall quality of a microgrid; one must not forget the most important concept of power engineering, economics. Rising fuel costs, strict regulations on nuclear entities, and high capital cost of renewable sources leads to a high cost for utilities. This leads us to take a look at the power quality of the grid and customer billing in terms of economics.

In today's microgrids, there are a large number of harmonic generating loads (HGLs) such as compact fluorescent light (CFL) bulbs, variable speed drives (VSDs), and other power electronic devices [1]. These devices contribute to high levels of distortion on the grid, especially in low MVA systems such as microgrids. This harmonic distortion and asymmetry in the power system causes additional system losses and load efficiency issues. Several methods have been proposed to pinpoint the sources of distortion [2] with additional regards to economics [3-6]. Thus, economic incentives, similar to power factor penalties, are needed to lower distortion and asymmetry.

In the power system, the majority of revenue meters are the older mechanical type. Unfortunately, these mechanical meters are incapable of distinguishing harmonic and negative sequenced components of the active power. To create the economic incentives mentioned above, newer digital signal processing (DSP) based meters are needed. Fortunately, the power industry is slowly accepting newer microprocessor based revenue meters. This will enable the calculation of a new concept of working, detrimental and reflected active power based on the idea of categorizing active power into useful and useless components based on the point of origin.

II. ADVANCED METERING INFRASTRUCTURE

In the power system, relays and meters are installed as an essential part in maintaining reliability. New electronic meters are capable of sampling voltages and currents that will be processed via their digital signal processor (DSP) and shared to the rest of the AMI via network. AMI enhances the microgrid by having a network of meters installed in the distribution system to relay critical information to the rest of the network in real time. With the AMI's network, microgrids and the present power system can benefit with improved grid efficiencies and moderating energy usage [7].

The AMI has many capabilities that will enhance the power system and microgrids for distribution operations. With the automotive industry showing signs of interest in hybrid plug-in vehicles, AMI serves as the access point for charging electric vehicles from the power grid [8,9]. With an ever growing infrastructure in size and technology, load forecasting becomes more complicated, in which detailed hourly load forecasting available by the AMI system will be utilized [10-12]. Furthermore, transformer load modeling and management on the distribution system can be possible with AMI [13,14].

Additionally, AMI is capable for enhancing billing and power quality. Two way communication with revenue meters and central control stations can relay information billing and distributed generation units [15,16]. Even the ability to control individual household loads is possible; scaling power usage for the distribution system [17,18]. Lastly, with AMI's digital processing power, power quality can be addressed in terms of harmonic content and asymmetry identification [7,19,20].

This paper is mainly interested in the power quality component that will economically distinguish harmful components of the active power and pinpoint the sources. Using the AMI's DSP capabilities, an economic incentive can be quantified to penalize the entities that inject harmonics and/or unbalanced currents into the system. In addition, other entities can get a refund for the additional loss of energy and wear on their equipment that is a result of the harmful currents injected by the previous "bad" entities. This will convince entities as a whole to clean up their loading profile that will increase the efficiency of the power gird or microgrid.

III. WORKING AND REFLECTED ACTIVE POWERS

The main component of a monthly bill for energy usage is the cost of energy delivered to the customer over a month. This active power has clear physical meaning, the average rate of energy transfer. This energy is referred to as **active energy** in this paper. This is a fundamental power quantity used for billing, equipment design, and performance evaluation.

Active energy is useful energy if it is deliberately converted to heat, light, or work; such as resistive heaters, incandescent light bulbs, and motors. On the other hand, energy conveyed by voltage and current harmonics and negative sequence components can disturb and overheat loads with the exception of purely resistive loads. Another example is a three-phase induction motor because energy conveyed by harmonics or negative sequences are not useful energy. Therefore, active power is not synonymous to "useful power" and should be considered a composite power of useful and useless powers.

Assume a simple distribution system with a purely resistive internal impedance that provides sinusoidal voltage *e*, and the load is a purely resistive source of current harmonics without any dc component shown in Fig 1. The load current is,

$$i(t)=\sum_{n=1}^{\infty} i_n(t)=i_1(t)+i_{\mathrm{h}}(t), \tag{1}$$

where *n* denotes harmonic order. The load current harmonics flow in the supply source impedance and as a result, load voltage has distortion in the form,

$$u(t)=\sum_{n=1}^{\infty} u_n(t)=u_1(t)+u_{\mathrm{h}}(t), \tag{2}$$

Therefore, the active power at the load terminals is equal to

$$P=U_1 I_1\cos\theta_1+U_2 I_2\cos\theta_2+U_3 I_3\cos\theta_3+... \tag{3}$$

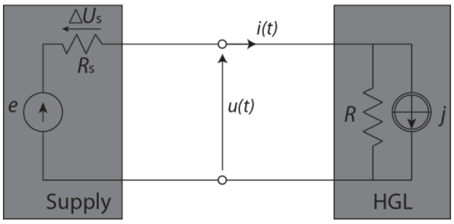

Fig. 1. Single phase sinusoidal supply with resistive harmonic generating load.

Because the internal voltage is sinusoidal, the load voltage harmonics are a response to the voltage drop across the source impedance via the current harmonics. Remember, the source is absent at higher order harmonics. So, the harmonic energy is then a function of the harmonic generating current source on the load side. Thus, higher order harmonic energy flows from the load to the supply and dissipates off the supply impedance. Therefore, the active power of harmonics of the order $n > 1$ is negative. This power is referred to as **reflected active power**, P_{r}, which is the sum of all harmonic active powers P_{n},

$$P_{\mathrm{r}}=-\sum_{n=2}^{\infty} P_n=-\sum_{n=2}^{\infty} R_{\mathrm{s}} I_n^2 \tag{4}$$

The only positive term on the right side of formula (3) is the active power of the fundamental harmonic, P_1. Since the load current harmonics causes energy to flow from the load back to the source, the load needs to draw additional energy from the source to supply this reflected active power, P_{r}. Because the source is sinusoidal, this additional energy flow has to be supplied from the active fundamental power P_1. Therefore, HGLs operating with active power *P* must be supplied with the fundamental power P_1 which is higher than active power *P*. This power is referred to as **working active power**, P_{w}. Such that, active power of HGLs can be written as such,

$$P=P_{\mathrm{w}}-P_{\mathrm{r}}. \tag{5}$$

Components of active powers are represented in Fig. 2.

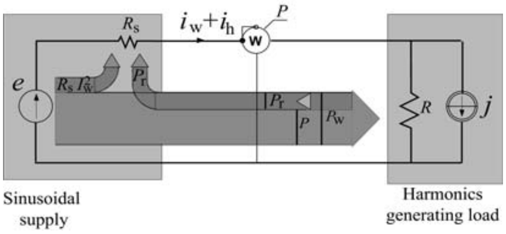

Fig. 2. Diagram of energy flow in a resistive system with harmonics generating load.

An illustration of a single phase rectifier supplying a DC motor from a 120V rms source referenced in [5] with active power P = 2097 W calculates the working active power P_{w} = 2235.8 W and reflected active power P_{r} = 138.8 W.

The same reasoning for single phase can be extended to three phase, three wire systems with HGLs. Similarly to the single phase systems, the only positive harmonic power is the active power of the fundamental harmonic, P_1. The HGLs require extra energy flow from the source for the reflected active power P_{r}, which is supplied from the fundamental active power, P_1. Therefore, the fundamental active power, P_1 is higher than the active power *P*. As a result, the power equation (5) is valid for three wire, three phase systems with sinusoidal and symmetrical supply voltages with balanced, resistive HGL. To support this conclusion, an illustration of a three-phase rectifier supplying a dc motor of active power P = 10 kW is referenced in [6] that calculates the working active power P_{w} = 10,376 W and reflected active power P_{r} = 376 W.

This reasoning was obtained under the assumption that the system is purely resistive. When the system is not purely resistive, these conclusions are still valid for in-phase components of voltages and currents. However, the relation between the components of active power is shadowed by other energy flow phenomena, mainly reactive current.

IV. REFLECTED ACTIVE POWER IN UNBALANCED LOADS

Now consider a three phase three wire system with symmetrical sinusoidal supply voltage but with a purely resistive unbalanced load as shown in Fig. 3.

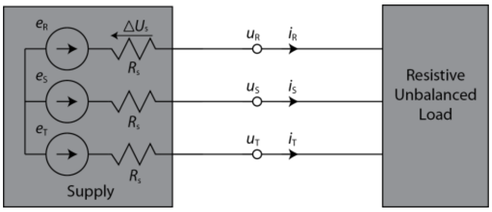

Fig. 3. Three-phase system with resistive unbalanced load supplied with symmetrical sinusoidal voltage.

The load currents of the system can be decomposed into symmetrical components. The load current is composed of positive and negative sequence components, namely,

$$\boldsymbol{I}^{\mathrm{p}} = \frac{1}{3}(\boldsymbol{I}_{\mathrm{R}} + \alpha \boldsymbol{I}_{\mathrm{S}} + \alpha^2 \boldsymbol{I}_{\mathrm{T}}) \tag{6}$$

$$\boldsymbol{I}^{\mathrm{n}} = \frac{1}{3}(\boldsymbol{I}_{\mathrm{R}} + \alpha^2 \boldsymbol{I}_{\mathrm{S}} + \alpha \boldsymbol{I}_{\mathrm{T}}) \tag{7}$$

$$\boldsymbol{X} = Xe^{j\beta}, \alpha = 1e^{j\frac{2}{3}\pi}$$

Since the load current is asymmetrical, the load voltage will be composed of positive and negative sequence components

$$\boldsymbol{U}^{\mathrm{p}} = \frac{1}{3}(\boldsymbol{U}_{\mathrm{R}} + \alpha \boldsymbol{U}_{\mathrm{S}} + \alpha^2 \boldsymbol{U}_{\mathrm{T}}) \tag{8}$$

$$\boldsymbol{U}^{\mathrm{n}} = \frac{1}{3}(\boldsymbol{U}_{\mathrm{R}} + \alpha^2 \boldsymbol{U}_{\mathrm{S}} + \alpha \boldsymbol{U}_{\mathrm{T}}) \tag{9}$$

The positive sequence components produce the positive sequence power and the negative sequence components produce negative sequenced power.

$$P^{\mathrm{p}} = 3U^{\mathrm{p}} I^{\mathrm{p}} \cos\theta^{\mathrm{p}}, \tag{10}$$

$$P^{\mathrm{n}} = 3U^{\mathrm{n}} I^{\mathrm{n}} \cos\theta^{\mathrm{n}}, \tag{11}$$

Since the positive sequence and negative sequence components are mutually orthogonal, they transfer energy independently of each other [5]. Thus, active power is

$$P = P^{\mathrm{n}} + P^{\mathrm{p}} \tag{12}$$

Similar to the harmonic case previously, since the supply voltage e is assumed to be symmetrical, the negative sequence voltage component at the load terminals is a result of the voltage drop across the source resistance from the negative sequence current. Thus, active power of the negative sequence P^{n} is negative. This average rate of energy dissipation on the supply source resistance is the product of the negative sequence current produced by load imbalance. The negative sign represents the energy delivery from the load to the supply source resistance. Thus, this negative power can be regarded as reflected active power, i.e. $P_{\mathrm{r}} = -P^{\mathrm{n}}$.

Consequently, the active power of the positive sequence component P^{p} is greater than the active power of the load P. The unbalanced load must be supplied with the positive sequence power P^{p} to be able to deliver the energy back to the supply source resistance. This power has the same interpretation as the active power of the fundamental harmonic in the HGL system. Therefore, this positive sequence active power P^{p} can be regarded as the working active power, i.e. $P_{\mathrm{w}} = P^{\mathrm{p}}$. An illustration of a three-phase purely resistive unbalanced load with active power P = 100 kW calculated the working active power P_{w} = 105.6 kW and reflected active power P_{r} = 5.48 kW [5].

V. DETRIMENTAL ACTIVE POWER

So far the relation between active power and working active power was analyzed for systems where the supply voltage was sinusoidal and in three phase systems, symmetrical. The load was responsible for the current harmonic and asymmetry. Now consider the situation where the supply voltage contains harmonics and asymmetry while the load does not. Since induction motors are a majority of loads in power systems and susceptible to voltage distortion and asymmetry, details in terms of working active power could prove beneficial.

Assume that the induction motor in Fig. 4 is supplied by a sinusoidal yet asymmetrical source with internal voltage e, which composes of both positive and negative sequence components, specifically $e^{\mathrm{p}}(t)$ and $e^{\mathrm{n}}(t)$.

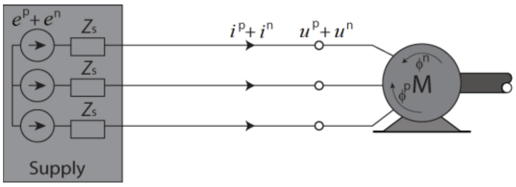

Fig. 4. Induction motor supplied with asymmetrical voltage.

In response to the asymmetrical supply voltage, the motor current $i(t)$ contains both positive and negative sequence components, specifically $i^{\mathrm{p}}(t)$ and $i^{\mathrm{n}}(t)$. Therefore, the active power at the motor terminals consist of,

$$P = P^{\mathrm{p}} + P^{\mathrm{n}}. \tag{13}$$

In induction motors, only the active power of the positive sequence component P^{p} converts into mechanical power on the motor shaft, minus some losses. The negative sequence current creates a rotating magnetic field Φ^{n} which rotates in the opposite direction of the shaft rotation reducing motor torque, T. The energy delivered to the motor by the negative sequence voltages and currents eventually dissipates in the motor as heat that raises temperatures and reduces life span. Thus, the active power of the negative sequence component P^{n} should be noted as **detrimental active power** denoted by P_{d}.

Only the active power of the positive sequence component provides useful energy to the mechanical loads. Therefore, only the positive sequence component of the active power P can be classified as working active power, i.e.,

$$P_{\mathrm{w}} = P^{\mathrm{p}}. \tag{14}$$

The active power measured by a revenue meter at the motor terminals is the sum of the working and detrimental powers,

$$P = P^{\mathrm{p}} + P^{\mathrm{n}} = P_{\mathrm{w}} + P_{\mathrm{d}}. \tag{15}$$

If the distribution voltage contains a harmonic of the n^{th} order that is of positive sequence, this harmonic creates a magnetic field rotating at an angular velocity approximately equal to $(n-1)\omega_1$ with respect to the rotor's angular velocity approximately equal to ω_1. This fast rotating magnetic field inside the rotor behaves similar to a locked rotor of an induction machine. For example, the energy from the 7th order harmonic is dissipated into the motor windings as heat.

Conversely, if the distribution voltage contains a harmonic of the n^{th} order that is negative sequence such as the 5th order harmonic, the magnetic field rotates in the opposite direction with angular velocity approximately equal to $(n+1)\omega_1$ with respect to the rotor. The energy of the negative sequence harmonic converts entirely into heat which dissipates into the motor windings, thus raising the motor temperature. Therefore, the active power P_n of the supply voltage harmonic contributes to the detrimental active power P_{d} rather than the working active power P_{w}. If P_{h} denotes the active power of harmonics of $n > 1$, then the detrimental active power of the motor is,

$$P_{\mathrm{d}} = P^{\mathrm{n}} + P_{\mathrm{h}} \tag{16}$$

VI. MODELING INTERACTIONS OF ACTIVE POWER P AND WORKING ACTIVE POWER P_{W} BETWEEN LOADS

To quantify the concept of working active power, a Matlab model using Simulink's power module will be used. There will be three loads that will be observed; rectifier with capacitive filter, a three phase resistive heater, and an auxiliary induction motor. Calculating the working active power will show how distortion and unbalance affect the induction motor.

The source consists of a three phase symmetrical and sinusoidal voltage source of 480 V rms. The supply impedance is modeled as resistors with a 5% voltage drop of the supply voltage. The three phase rectifier's diodes are considered lossless and the capacitive filter keeps the DC voltage ripple at 5%. Next, the induction motor is rated at 10 HP at 1760 rpm at 460V. Lastly, meter points are at the load and before the bus.

There are a total of four scenarios to test. The first is the control test in which all devices are running at near sinusoidal and balanced conditions. The second test has the rectifier and the induction motor running to test the effects of distortion. The third test has the resistive load only connected to two phases creating an unbalanced load to test the effects of asymmetry. Finally, the last test has all three devices on with the rectifier's distortion and the unbalanced load's asymmetry.

A. *Experiment #1: Control Test*

The control experiment tests that all loads are running at a near sinusoidal and symmetrical mode. Meaning, the rectifier has the capacitive filter turned off to reduce distortion, the resistive load is perfectly balanced, and the induction motor is fully loaded. The active power for each device is chosen to reflect a scaled scenario of industrial loads such as a DC drive and/or unbalanced load with a small auxiliary induction motor. The auxiliary motor in this case is 1/10th of main load's power. The magnitudes of the active powers are much less than a real life scenario which was chosen so that the experiment can be tested in a laboratory environment on a later date.

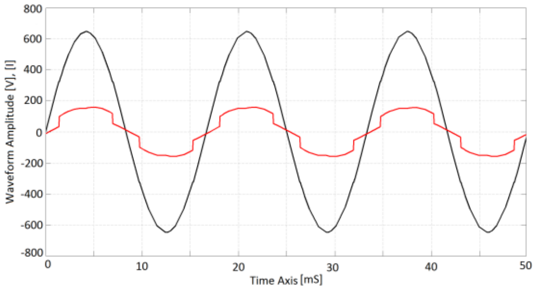

Fig. 5. Exp #1 Voltage and current waveforms for A phase.

Results for the control test are shown as the source's voltage and current waveforms for A phase. The voltages for all three phases are $V_{\mathrm{a}} = 456.6$ V, $V_{\mathrm{b}} = 455.7$ V, $V_{\mathrm{c}} = 457.6$ V, and the currents for all three phases are $I_{\mathrm{a}} = I_{\mathrm{b}} = I_{\mathrm{c}} = 62.2$ A. The active, working active, and reflected/detrimental active powers are shown in Table I.

TABLE I
MEASUREMENT RESULTS FOR EXPERIMENT #1

Exp. 1	P [W]	P_{w} [W]	$P_{\mathrm{w}} - P$ [W]	$\Delta P/P$
Bus	83,514	83,594	80	0.1%
Rectifier	37,750	37,830	80	0.2%
Resistors	37,960	37,960	0	0.0%
Ind. Motor	7,804	7,804	0	0.0%

B. *Experiment #2: Rectifier and Induction Motor*

The second experiment tests the effects of the rectifier's harmonic distorted current on the voltage supplying the induction motor. Meaning, how badly is the motor's operations degraded due to distortion. The total harmonic distortion (THD) of the load current of the rectifier is 70%.

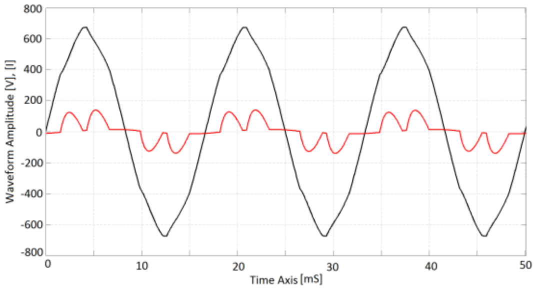

Fig. 6. Exp #2 Voltage and current waveforms for A phase.

Results of the experiments show that the voltages for all three phases are the same from the control experiment. Phase A voltage of the bus has a THD of 3.56%. In Fig. 6, the phase A current distortion is quite apparent, while the voltage distortion is barely noticeable. The low voltage THD stems from the fact that the voltage drop across the resistor is only 5% of the supply. This 5% voltage drop is due to the current flowing to the bus which has a 70% THD. Therefore, 5% of the 70% current THD produces the 3.5% voltage THD. As a result, the induction motor did not suffer much degradation. Line currents are $I_{\mathrm{a}} = 73.87$ A, $I_{\mathrm{b}} = 74.01$ A, $I_{\mathrm{c}} = 74.01$ A.

TABLE II
MEASUREMENT RESULTS FOR EXPERIMENT #2

Exp. 2	P [W]	P_w [W]	$P_w - P$ [W]	$\Delta P/P$
Source	83,704	85,571	1,867	2.2%
Rectifier	75,380	77,250	1,870	2.5%
Ind. Motor	8324	8321	-3	0.04%

C. Experiment #3: Unbalanced Resistive Load and Induction Motor

The third experiment tests the effects of unbalanced current on the voltage supplying the induction motor. Meaning, how badly is the motor's operations degraded due to asymmetry. The resistive load has $R_a = 3.4\ \Omega$, $R_b = 3.4\ \Omega$, and R_c is open.

Results of the experiments show that the currents for all the phases are $I_a = 96.37$ A, $I_b = 110.8$ A, $I_c = 16.9$ A and voltages are $V_a = 445.8$ V, $V_b = 450.7$ V, $V_c = 477.6$ V. Since R_c is open, only the current from the induction motor causes a voltage drop on A phase supply impedance. At the motor terminals, the currents are $I_a = 7.28$ A, $I_b = 10.28$ A, $I_c = 16.9$ A. This shows that even a small amount of voltage asymmetry can cause significant current imbalance in the motor windings.

TABLE III
MEASUREMENT RESULTS FOR EXPERIMENT #3

Exp. 3	P [W]	P_w [W]	$P_w - P$ [W]	$\Delta P/P$
Source	83,628	87,380	3,752	4.5%
Unbal. Res.	75,650	79,541	3,891	5.1%
Ind. Motor	7,978	7,839	-139	1.74%

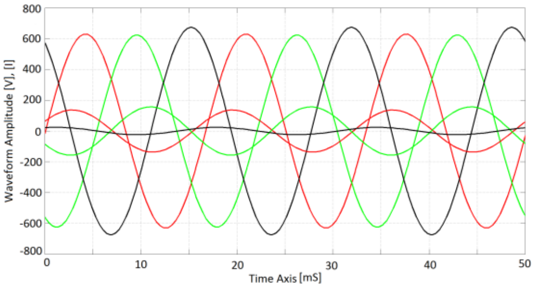

Fig. 7. Exp #3 Voltage and current waveforms for three phases.

D. Experiment #4: Rectifier, Unbalanced Resistive Load and Induction Motor

The fourth experiment tests the effects of both the harmonic distorted current and current asymmetry on the voltage supplying the induction motor. This will show the aggregated effects of both loads on the induction motor.

Results of the experiments show that the currents for all the phases are $I_a = 80.65$ A, $I_b = 81.02$ A, $I_c = 49.66$ A and voltages are $V_a = 450.3$ V, $V_b = 450.8$ V, $V_c = 464.5$ V. Additionally, THD for the current equals 35.6% and 2.3% for the voltage. Because the individual loads are smaller than the previous experiments, the distortion and asymmetry have less effect on the voltage supply individually. Fig. 8 shows the current waveforms are more sinusoidal and symmetrical than on the previous two experiments respectively. Thus, with a smaller asymmetrical bus voltage component, the degradation to the motor performance is lessened.

TABLE IV
MEASUREMENT RESULTS FOR EXPERIMENT #4

Exp. 4	P [W]	P_w [W]	$P_w - P$ [W]	$\Delta P/P$
Source	83,730	85,225	1,495	1.8%
Rectifier	38,590	39,360	770	2.0%
Unbal. Res.	37,290	38,040	750	2.0%
Ind. Motor	7,850	7,825	-25	0.3%

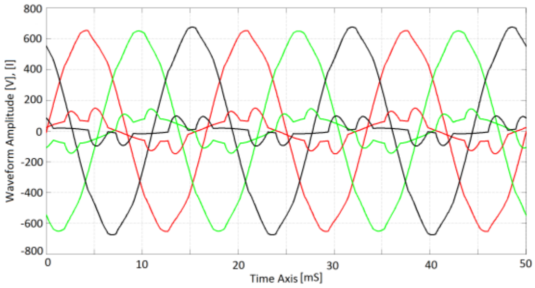

Fig. 8. Exp #4 Voltage and current waveforms for three phases.

E. Experimental Results and Analysis

Results of the experiments show that adding a HGL or unbalanced load on a bus affects other loads except for purely resistive loads. That is because the distorted and/or unbalanced current results in a voltage drop across the system impedance. This appears as a small component of distortion and/or asymmetry on the bus voltage.

In experiment #2, the rectifier's current load contained distortion that did not degrade the induction motor's performance noticeably. The rectifier's current distortion resulted in the working active power, P_w to be greater than the active power, P. The difference of 2.5% is the reflected active power, P_r which means that the rectifier is injecting a harmful component back into the system and is not being billed for it. This resulted in the bus voltage being affected with a 3.6% THD. Since the THD level on the voltage is so low, the harmonic current flow is minimal. Therefore, the motor's performance did not suffer noticeable degradation.

In experiment #3, the unbalanced load's current caused a more noticeable degradation on the induction motor's performance. The unbalanced C phase load being left open resulted in the working active power, P_w to be greater than the active power, P. The difference of 5.1% is the reflected active power, P_r. This means that the unbalanced load is injecting a harmful component back into the system and not being billed for it.

The load current on the incoming source for the bus resulted in a voltage drop across the system impedance that resulted in the phase C bus voltage, V_c having a 31.8 V higher rms than A phase and 26.9 V higher rms than B phase. Thus, the motor's current magnitude suffered drastic imbalance. Meaning, the working active power, P_w was less than the active power, P. Thus, the difference of 1.8% is detrimental active power, P_d that is billed and degrades the motor.

In experiment #4 both the rectifier and unbalanced load current's resulted in degrading the motor's performance, but at a much less combined rate. As in the previous experiments, both the rectifier and unbalanced load produced reflected power, P_r. This in turn affected the bus voltage in the form of distortion and asymmetry, but at a lower magnitude than the previous experiments. The main difference now is that phase C is loaded with current from the rectifier, albeit with some distortion giving the difference of the phase voltages as 14.2 V. This drastically reduced the amount of unbalanced current in the motor compared to experiment #3 reducing the detrimental active power, P_d to 0.3% of the active power, P.

VII. CONCLUSION

With the industry moving towards microgrids and new technologies, comes new challenges. These challenges consist of more power electronic devices that could potentially cause more distortion in the system, a greater number of HGLs, and higher generation costs. Thus, economics, power quality, and subsequently, efficiency becomes more important than ever.

The advent of smart grid technologies brings about AMI's DSP based revenue meters. Some of the benefits include enhancements to the network and distribution operations, tying in plug in hybrid vehicles easily, load forecasting, and greater capabilities for billing and power quality. In this paper, the added technology of the AMI meter gives the opportunity to take a look at active power with respects to economics.

With respects to economics, the working active power concept can be applied to energy metering. This takes into account harmonic generating and/or asymmetrical loads on the power system. Such loads consist of power electronic converters for renewable energies and converters for electric vehicles that are becoming popular with the push for microgrids and renewable sources of energy.

Currently, the utility pays for any system losses. Thus, when an unbalanced and/or HGL is energized from the system, the utility does not get fully compensated for the costs to send energy to the load. Of course, the utility will ultimately push this extra cost across the majority of customers as a surcharge or increased billing rate which is not fair for the rest of the customers. Therefore, energy accounts based on working active power can pinpoint the customers at fault and bill them accordingly. This will naturally give an incentive for the customer to reduce the amount of harmonic injection they are causing. Ultimately, this results in a power system with reduced harmonic distortion and asymmetrical components.

On the other hand, customers with loads susceptible to harmonic distortion and asymmetry in the voltage are overcharged for the energy sent to them by these distorted and asymmetrical sources. This detrimental energy ends up being useless. Therefore, energy accounts based on working active power can identify the detrimental active power so the customer will not get billed for useless energy sent to them.

In conclusion, energy accounts based on working active power is a new and fair way to pinpoint sources of distortion and asymmetry. This concept can be used as a billing method for both the customers and the utility. As seen, the economic difference is few percentage per load, but spread across a large customer base can add up to significant losses. This new concept will fit well with the growing trends of better supply and loading quality, shifting to micro grid and AMI technologies, and the need to update current billing standards.

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