OPERATION OF THE ABET-2201 POWER CONDITIONING UNIT

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December 12, 2004

1. Introduction

With the advent of electricity and technological breakthroughs, electrical energy has been made available at a reasonable cost through an elaborate and efficient distribution grid system to households and businesses alike operating various kinds of appliances that run on electricity. The local distributors of electrical energy charges the consumers based on the consumers' rate of electrical energy consumption called "power" expressed in numbers of thousands of watts, i.e., kilowatts (kW). The electrical quantity kW that represents the rate of energy consumed can be minimized if the circuitry is optimized in a way that there is less "spurious" energy lost. The ABET 2201 product, if incorporated into the electrical circuit, is able to achieve such minimization. In addition, the ABET-2201 brings about a number of other benefits to the consumer without introducing any adverse effects, or "side effects." A good understanding of various aspects of how electrical power is consumed in a circuit is therefore essential to understand how this product works. The principle of operation of the ABET-2201, based on theoretical concepts which are substantiated by measurement evidences, is presented in the following.

2. Types of loads and their electrical behavior

Theoretically, there are three basic types of loads in an electrical system, e.g., resistive, inductive, and capacitive. While electrical energy is <u>expended</u> in pure resistive loads, electrical energy is <u>not expended</u> but <u>stored</u> in ideally inductive and capacitive loads. Although all practical loads and appliances at a consumer's site incorporate these three types of ideal loads, it is appropriate to categorize them as mostly resistive, inductive or capacitive. The following is an example of common practical loads that are used in a household.

   a. Resistive: Oven, light bulbs, iron, electric heaters, etc.
   b. Inductive: Appliances with motors and transformers are examples of inductive loads which include air-conditioners, washers, dryers, refrigerators, induction motor, power transformer, lighting ballasts, welder or induction furnace, etc.
   c. Capacitive: Rechargeable batteries, etc.

Since the currents flowing in inductive and capacitive loads are half a cycle out of phase, it is possible to make their sum zero at any particular time by adjusting their magnitudes, consequently reducing the total current magnitude flowing through the Energy-meter (kW-hour meter) installed by the local distributors to monitor energy consumed by a subscriber. This is the essence of "power factor correction," where power factor refers to cosine of the phase angle between the voltage and the total current. The phase angle $\theta = \omega t$, where t = time and $\omega = 2\pi/T$ is the angular frequency of power supply and T = 1/f, where the principle frequency f of the power being delivered is usually 60 Hz. For purely resistive load, $\theta = 0^o$, hence power factor for resistive load = cosine 0° = 1. For purely inductive and capacitive loads, power factor = cosine $(\pm 90^o)$ = 0. Power factor correction implies to the situation where the inductive load current is balanced by capacitive load current thus reducing the total current to a minimum and the phase angle between the voltage and the total current representing the algebraic sum of the individual

load currents approaches 0°, i.e., cosine $0^o = 1$. At lower power factor, the total current is larger and vice versa.

The current passing through the current coil of the Energy-meter installed by the power distributor to monitor power consumption is the algebraic aggregate of the individual resistive, inductive, and capacitive currents flowing in different loads of the household. Power distributors require the industrial consumers to keep the power factor of the household read at the Energy-meter above say, 0.8, since power factors below 0.8 would require the distributors supply larger currents, therefore running larger generators which in turn would cost them more. Also, smaller current associated with higher power factor will minimize various resistive losses in the distribution system. Therefore, industrial consumers are charged a penalty at a predetermined rate based on their operating power factor.

The ABET-2201 is capable of correcting the power factor toward various benefits of the consumer as explained below.

3. The Role of the Capacitor in the Electrical Power System

Capacitor is a device that stores energy in the electric field established between a pair of conductors on which equal but opposite electric charges have been induced. Historically, capacitors have taken the form of a pair of thin metal plates, whether flat or tightly coiled up in a cylinder (like a sushi roll), but every multi-conductor geometry exhibits the phenomenon of capacitance.

The capacitance of a traditional flat-plate capacitor--and, resultantly, the amount of energy that can be stored in the capacitor--is proportional to the surface area of the conducting plate and inversely proportional to the distance between the plates. It is also proportional to the permittivity of the dielectric substance that separates the plates, whether vacuum, air, or specially engineered materials chosen for their high electrical permittivity.

In a direct-current (DC) circuit, a capacitor acts like an open circuit: no current flows through it, though the potential difference initially induced between its conductors can serve as an exponentially decaying energy source for the circuit. In an alternating-current (AC) circuit, a capacitor cyclically stores and releases energy at twice the frequency of the forcing source.

3.1. Power Factor Correction

ABET-2201 brings the advantages of the power factor correction capacitor to household use. Figure 1 shows a typical connection of the ABET unit in a household. This unit is usually connected to the fuse panel where the electricity is distributed to different locations in the house.

As mentioned above, the current passing through the current coil of the Energy-meter installed

by the power distributor to monitor power consumption is the algebraic aggregate of the individual resistive, inductive, and capacitive currents flowing in different loads of the household, as shown in Fig. 1. Since the currents flowing in inductive and capacitive loads are half a cycle out of phase, it is possible to make their sum zero at any particular time by adjusting their magnitudes, consequently reducing the total current magnitude flowing through the Energy-meter.
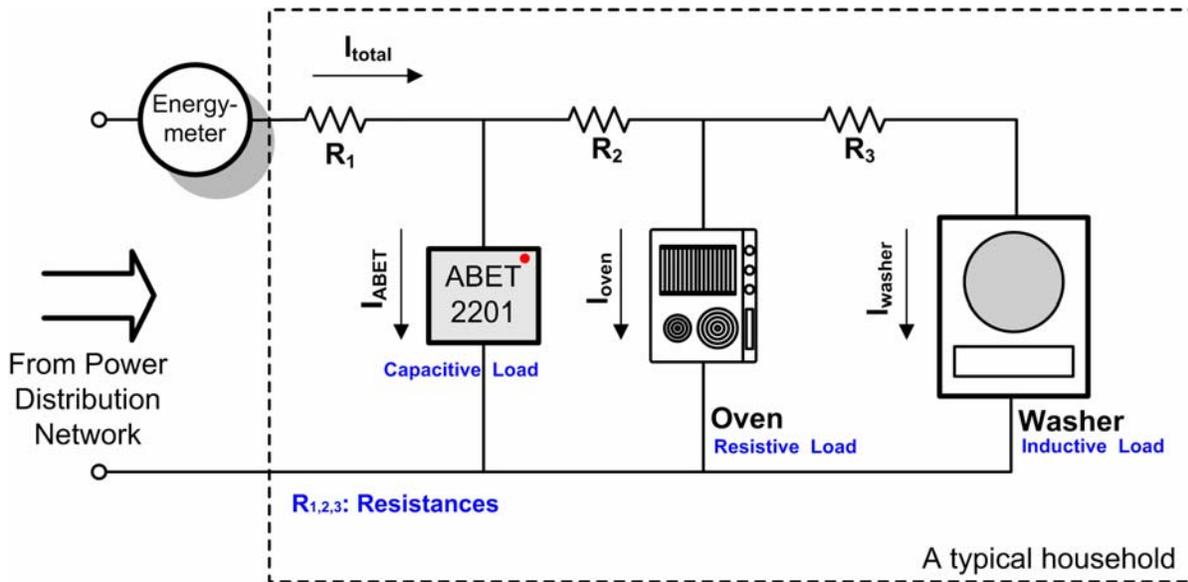

Fig. 1. An example ABET-2201 installation in a typical household.

Figure 2 (a) illustrates the instantaneous supply voltage, and currents in resistive, inductive, capacitive loads. It can be clearly seen that while the current in the resistive load is in phase with the supply voltage ($\theta = 0^o$), the current through the inductive load lags the supply voltage by a quarter of a cycle ($\theta = -90^o$), and the current through the capacitive load leads the supply voltage by a quarter of a cycle ($\theta = +90^o$). Figure 2 (b) displays the instantaneous supply voltage and the total current with and without the ABET-2201 capacitive load. Figure 3 is an exploded view of a section of Fig. 2 (b) showing clearly the reduction of the phase angle between the supply voltage and the total current when ABET-2201 is connected to the system, thus improving the power factor and consequently, reducing the total current magnitude. Due to the reduction in the total current, the power loss ($I^2_{total} \times R_1$) in the resistance R_1, between the wattmeter and the ABET-2201, which varies from house to house, is also reduced. This is the instantaneous power saving that is achieved by installing the ABET-2201. It is important to note that i) the resistance R_1 will depend on the locations of the Energy-meter and ABET-2201, and ii) the power saving is proportional to the square of the reduction in the current brought about by the ABET-2201. Figure 4 presents average voltage, current, power, and power factor measured over a period of one hour in an actual household. It is clearly observed that the power consumption is reduced along with the improved power factor and reduced current.
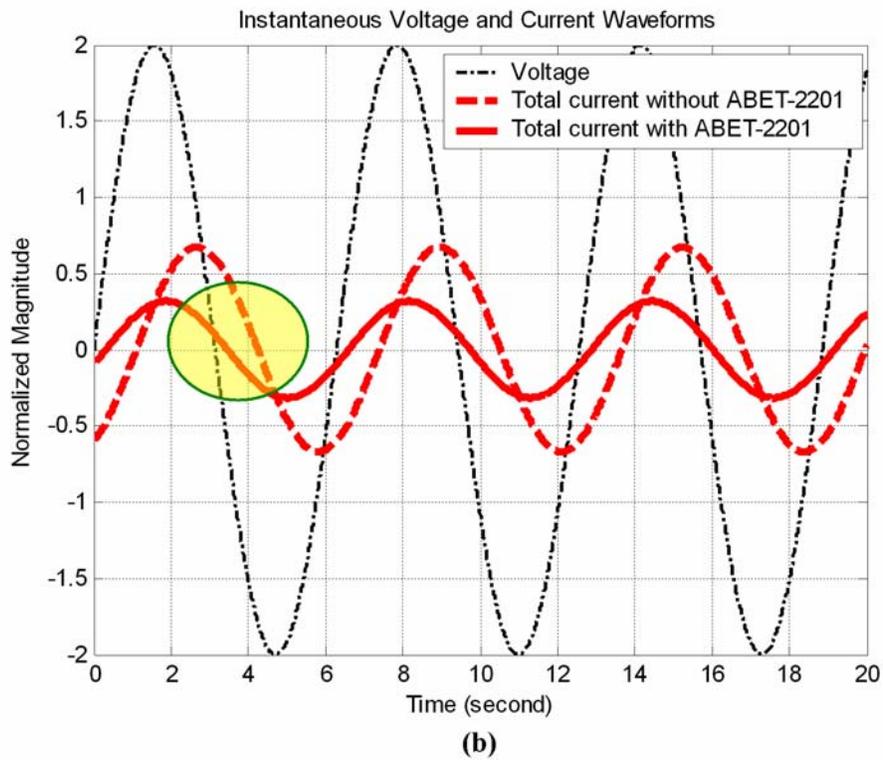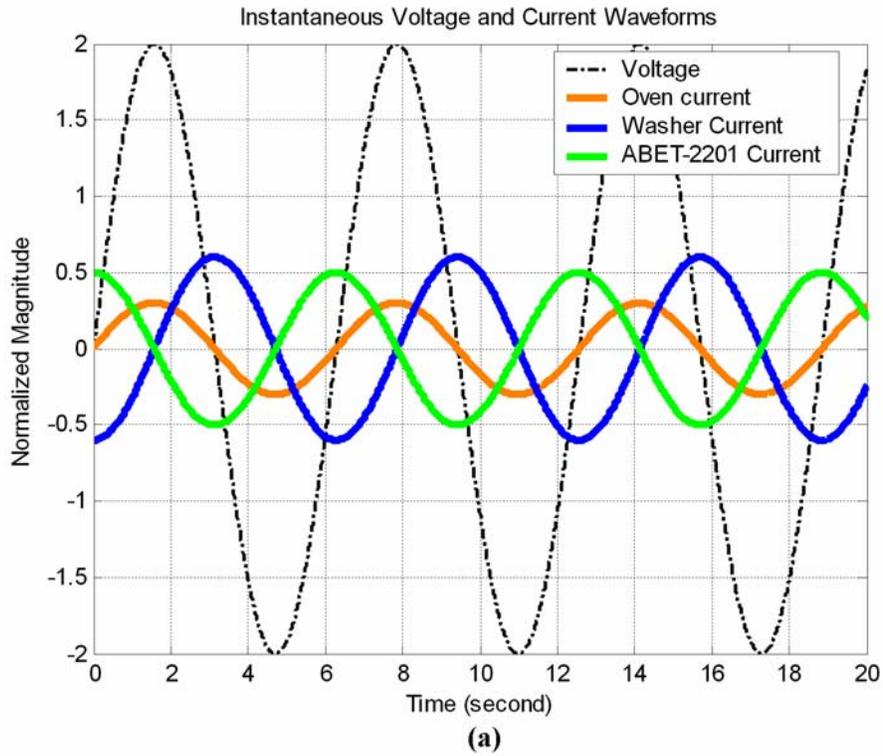
Fig. 2. (a) Instantaneous voltage and current waveforms of individual components, (b) Instantaneous voltage and total current waveforms before and after ABET-2201.
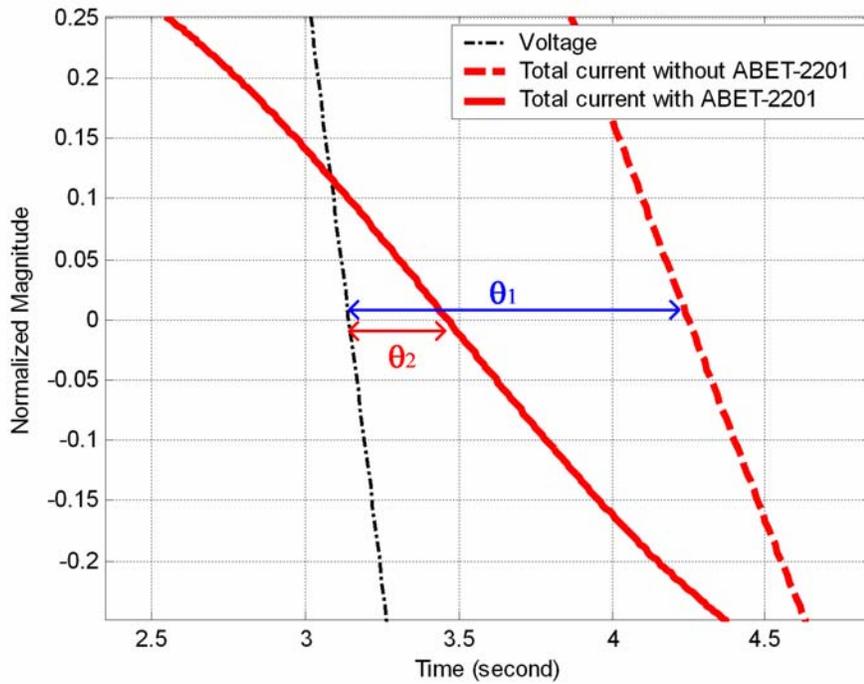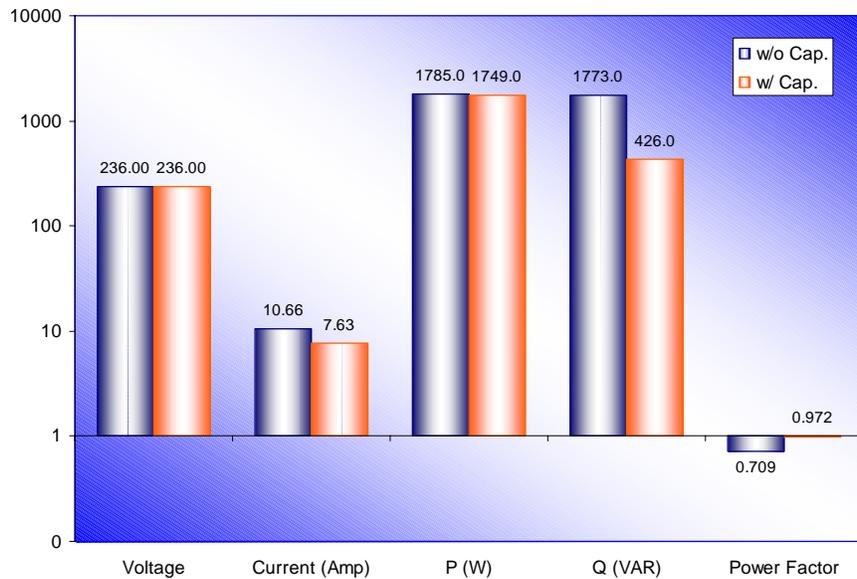
Fig. 3. Phase angle reduction (power factor correction) with the addition of ABET-2201 to the system. (Circled part of Fig. 2(b) zoomed in.)

House	Voltage	Current (Amp)	P (W)	Q (VAR)	Power Factor
w/o Cap.	236.00	10.66	1785.0	1773.0	0.709
w/ Cap.	236.00	7.63	1749.0	426.0	0.972
% Change	0.00%	28.42%	2.02%	75.97%	-36.96%

Fig. 4. Measurement results of average voltage, current, power and power factor in a household.

3.2 Motor Inrush Current

When the power switch is turned on, a stationary motor acts as short circuit causing a much higher than normal current to flow. As time passes the magnetic field builds up and the motor starts to rotate and reaches steady state rpm and the current drops down to normal values. This high current is called "inrush current" which has minimal impact on the total power consumption of the motor but may adversely affect motor lifetime by stressing out its wiring. The magnitude of this current is a function of the motor horsepower and design characteristics.

Our experiments have shown that adding ABET-2201 has reduced the peak inrush current of the tested motor by about 5%. Also, when the motor was under full load, the unit has reduced the inrush current time about 15%.
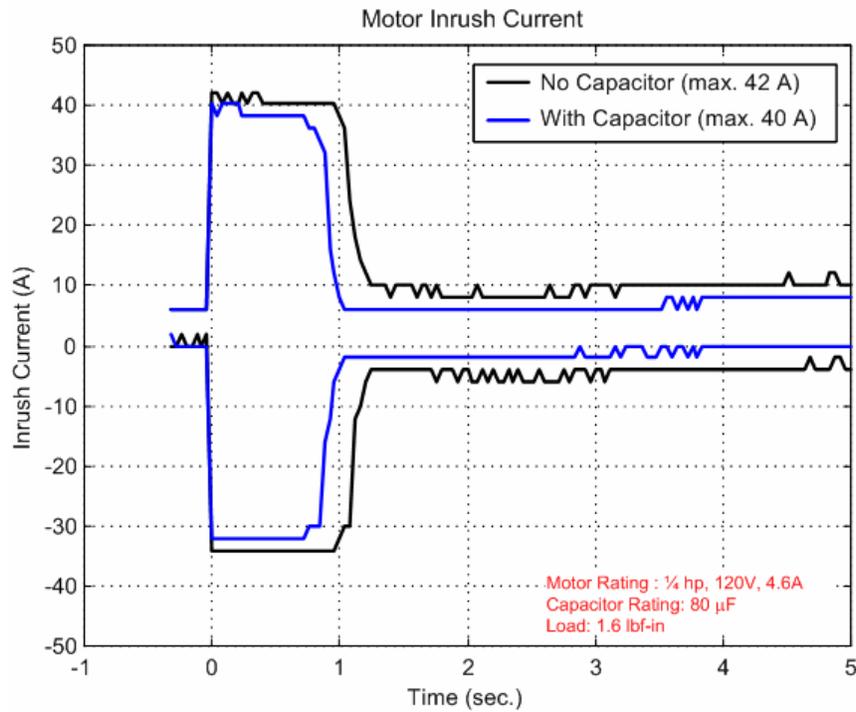

Fig. 5. Motor inrush current with and without ABET-2201 capacitor unit at 1.6 lbf-in dynamometer load.

3.3. Voltage Sags

The current i, and the voltage V, in a capacitor C, is related to each other by the following equation,

$$i = C \frac{dV}{dt}$$

where dV/dt is the time rate of change of the voltage across the capacitor. Therefore, the voltage

across the capacitor cannot change instantaneously (i.e., $dt = 0$) because it will then need an infinite amount of current to do so. As a consequence, whenever the capacitor is subjected to a sudden voltage surge or sag, the capacitor tends to reduce it to certain extent depending on its size. This behavior of capacitors have lead to applications where these are connected in parallel with the power circuits of most electronic devices and larger systems (such as factories) to shunt away and conceal voltage and current fluctuations from the primary power source to provide a "clean" power supply for signal or control circuits. Such effects in capacitors can also be interpreted to act as a local reserve for the DC power source, to smooth out fluctuations by charging and discharging each cycle. Figure 6 presents the effects of ABET-2201 capacitor on voltage sag due to an induction motor switching in a household.
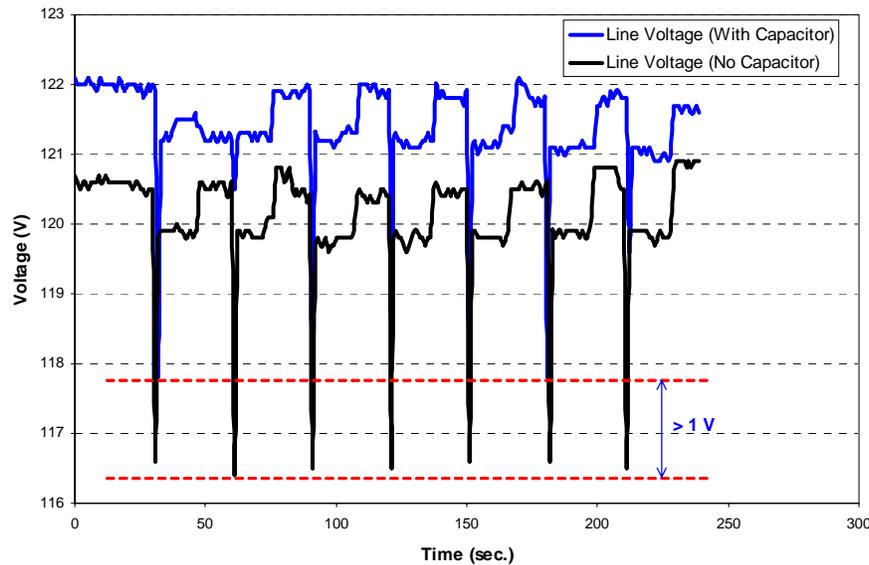

Fig. 6. The effects of ABET-2201 capacitor on voltage sag due to an induction motor switching in a household.

3.4. Harmonics and Temperature

Harmonic distortion is the deviation in the waveform of the supply voltage from its ideal sinusoidal waveform due to inclusion of higher frequency components in addition to the fundamental frequency. The major adverse effect of the harmonics is heating of induction motors and transformers in the household leading to reduced lifetime of the motor. It has been known that a reduction of 10 $^{\circ}$C in the operating temperature of a motor essentially doubles its lifetime. The ABET-2201 in conjunction with the resistance of the household wiring forms a low-pass filter which prohibits higher frequency components from the incoming supply into household loads. Consequently, motors are subjected to less heating as illustrated in Fig. 7.
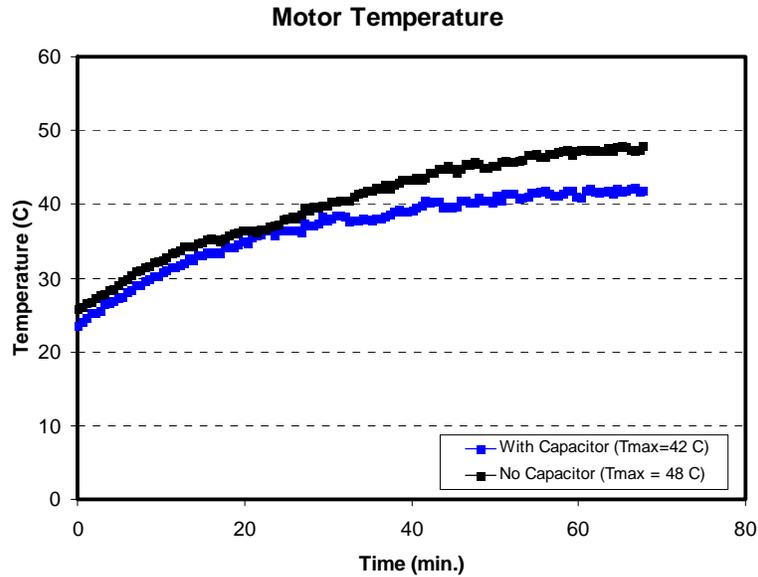
Motor Temperature

Fig. 7. The effect of ABET-2201 capacitor on the temperature of a motor running under dynamometer load.

4. The power distribution panel installed by distributor

The distributor of electrical energy installs a power distribution panel outside a household so that their personnel can monitor the total energy consumed by the household by reading the Energy-meter installed in the panel. Two wires with 220 V across them are brought in from the locality supply grid into the distribution panel. All loads in the house which run on 220 V are connected across these two wires. Loads which run on 120 V are connected across one of these two wires and the ground terminal which is fabricated in each household by inserting a solid copper rod deep into the soil. All 120 V loads are divided into two circuits, each consisting of one the above mentioned two wires and the ground terminal. Figure 8 shows these two different configurations.
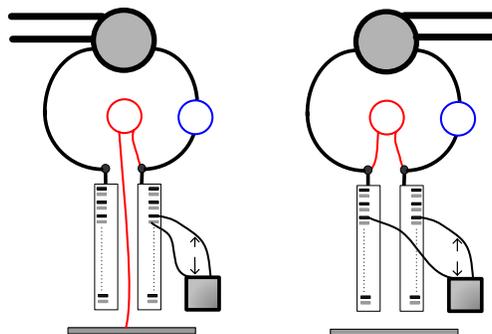
Fig. 8. Distribution panel configurations in a household

5. Conclusion

An attempt has been made to elucidate the principle of operation of the ABET-2201 Power Conditioning Unit in offering significant benefits in the areas of reduced power usage, decreased motor temperature, improved power factor, reduced inrush current and suppression of voltage sags. Investigations are being continued to understand and explain other effects that may have implications on the ABET-2201 such as
i) Harmonics generated in the household loads,
ii) Impact of the unit to the distribution system during non-peak hours (i.e., nights).

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