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Reduction of Harmonic Distortion in Off-Grid Renewable Energy Systems
Problem Definition and Initial Research

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1. Problem Definition

Off grid energy is frequently used in remote locations where it would be prohibitively expensive to connect to a conventional power grid. However, many of these systems experience problems when nonlinear electrical devices that use pulse width modulation (PWM) to deliver power are connected to the system. Even when off grid systems use pure sine wave DC to AC inverters, PWM devices often create harmonic distortion in the voltage and current on the system's power lines. This distortion is also present in grid-connected power systems, but is much less apparent, as the strength of the grid often forces the signals back to near sine wave operation.

Since many inverters produce a sinusoidal waveform which is roughly 60 Hz, the 2nd harmonic component is 120 Hz, the 3rd harmonic component is 180 Hz, and the nth harmonic component is n*60 Hz. Ideally a power supply produces an undistorted 60 Hz pure sinusoidal voltage waveform, but several common household appliances, such as computer switched –mode power supplies and laser printers, draw power in brief pulses thereby distorting both current and voltage waveforms. Said another way, many common household loads (particularly those that use PWM) will create harmonics on the voltage and current waveforms when they draw power. Total harmonic Distortion (THD) is used to quantify the amount by which a voltage signal is distorted. A large THD value indicates that a large portion of the voltage or current is not operating at the fundamental frequency, but rather an integer multiple of it.

Total harmonic distortion is an important concept to consider when designing electrical systems, as a high THD can cause increased temperatures in electronics thereby shortening their lifespan. Other consequences of a high THD include lower efficiency, an increase in core temperature of electrical motors (causing damage), damage to power systems, and potential interference with telecommunication devices if the harmonics exist at the same frequency as the transmission frequency. Thus, understanding and mitigating THD levels is essential if one wants to get the most from an off grid system. To this end, the team will be creating a device which reduces the voltage and current harmonics produced by a load. The device must work reliably with all common household appliances, be easy to use, and be safe for households with pets and children. Such a device would save the user money and benefit any off grid home by reducing THD, thereby increasing the lifespan of electrical devices and increasing power quality and efficiency in the off-grid system.

Figures 1, 2, and 3 show how the system will reduce THD on the power lines in the off-grid system.

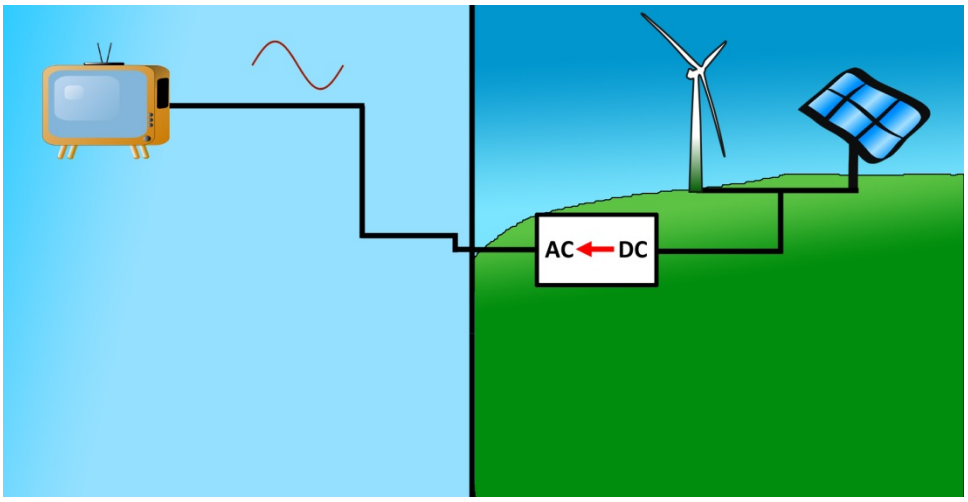

Figure 1: In normal operation, off grid inverters supply a pure sine wave to electronic devices.

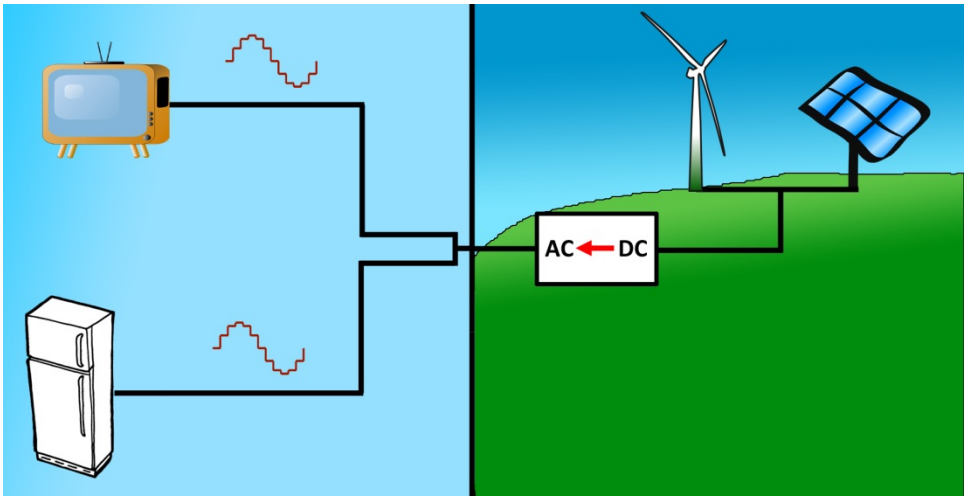

Figure 2: When PWM devices are connected to the lines, the sine wave is distorted, resulting in diminished efficiency for other devices.

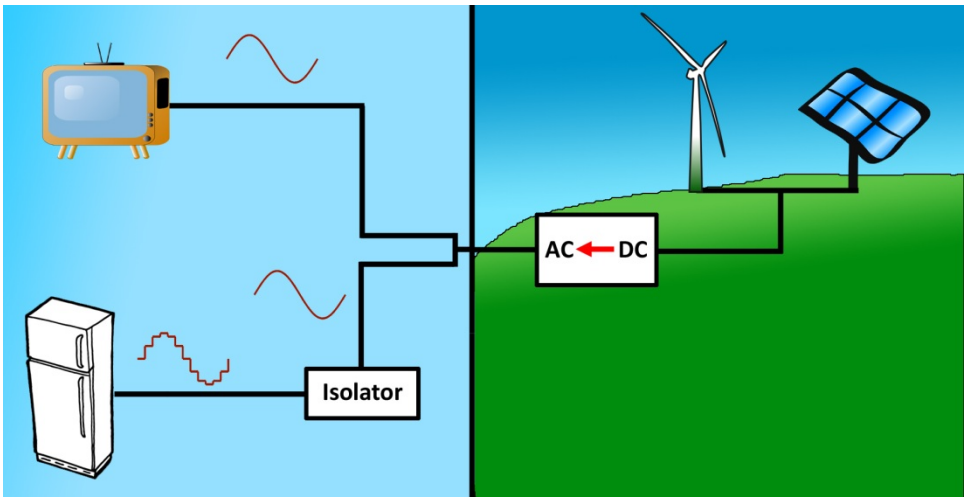

Figure 3: By adding an intermediate circuit, the PWM devices are isolated from the rest of the system, ensuring that they operate properly.

2. Research Survey

Although the voltage signals generated by power sources have always had harmonic components, the magnitudes of these harmonics were generally minimal, and their effects negligible, until the use of non-linear loads became common place in the 1960s. Non-linear loads draw current from the power source in a way which is not proportional to the voltage of the supplied waveform, often times drawing energy in short bursts, or pulses, of varying width instead [1]. A common technique for drawing power in such pulses is called pulse width modulation (PWM). It is noted, however, "An unfortunate side effect of their [PWM devices] usage however, is the introduction of harmonic distortion in the power system... These harmonics flow through the power system where they can distort the supply voltage, overload electrical distribution equipment (such as transformers) and resonate with power factor correction capacitors among other issues" [2].

The tendency for devices utilizing pulse width modulation to distort the voltage waveform supplied by a power source is well known, and the issue is addressed by several sources. IEEE standard 519 suggests that a voltage signal's total harmonic distortion (THD) is less than or equal to 5% , and that the largest single harmonic is less than or equal to 3% of the fundamental voltage. IEEE provides a partial justification of these limits, stating "Higher levels of harmonics result in erratic, sometimes subtle, malfunctions of the equipment that can, in some cases, have serious consequences " [2]. Although compliance with this standard is voluntary, many efforts have been made to reduce the THD of systems. A simple observation provides an easy-to-implement method for controlling THD: "The key to controlling harmonic distortion is limiting the current pulses. This has been accomplished through the use of inductor coils, which may also be called reactors or chokes, on the input of the drive. The inductance of a coil creates a back electromotive force (emf), or voltage, as the current pulse passes through it. This reduces the rate of the current pulse" [3]. While the effects of this simple technique can be significant, and the improvement can be made without impacting the performance of the load, the THD of a system may still be well above those recommended by IEEE [3].

In addition to these DC link reactors, other techniques are used to reduce THD. The use of a 12 pulse transformer (12 pulse drive) design can reduce THD by approximately 90% by eliminating the 5th and 7th harmonics in the transforming windings [4]. This harmonic elimination holds in theory, but can be difficult to implement practically, as this elimination requires two rectifiers sharing current exactly [5]. If exact matching is impossible or impractical, research shows “a standard six-pulse drive fed from a low pass Matrix Filter provides superior harmonic performance to a twelve-pulse drive in applications with variable loads and line voltage unbalances ranging from 0% to 3%” [5]. It may also be possible to eliminate specific harmonics using trap filters, but these filters “may cause random circuit breaker tripping and blown fuses” [4]. Alternative, situation specific THD reducing techniques also exist, but they may not provide the functionality desired for this project.

Bibliography

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