Narrow Band Power Line Communication (NB-PLC) frequency band review under residential load noise

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Abstract. Advanced Metering Infrastructure (AMI) is the foundation of the Smart Grid system. One of the most important parts of AMI is smart meter communication. Power Line Communication (PLC) technology utilizes the existing power line network for communication media between smart meters and Data Collector Units (DCU). One of the biggest challenges of communication using PLC is the noise level due to residential loads. In this study, laboratory test set up to measure noise caused by PV rooftop and residential loads are observed. Each PLC frequency band was measured and observed to determine the suitable frequency for PLC communication which was the low noise level. Some experiments in the field were conducted to determine the performance of the PLC. Laboratory test measurement result shows the FCC band (150-490 kHz) was outside the range of PV rooftop and residential load noise. On the other hand, the Cenelec A (35-90 kHz) frequency range was in the range of noise signal. Therefore, NB-PLC G3 using FCC frequency band was proposed to achieve robust data communication and lower noise level. G3 PLC FCC band was tested in the real field residential area, the experimental results showed 97.62% successful rate within one-week data collection.

1. Introduction

Advanced metering infrastructure (AMI) is the foundation of the smart grid [1]. One of the most important parts of AMI is the smart meter technology. Smart meter has bidirectional communication to receive and send data. The smart meter has to send the recorded electrical data into data center through data collector unit (DCU). Additionally, smart meter has to responding the command sent by the data center through DCU. The communication between smart meter and DCU is called as subnetwork. There are 3 communication technology choices that can be used for smart meter communication, Cellular technology, Radio Frequency (RF) and Power Line Communication. Cellular and RF both use air as communication media. For electrical utility point of view, cellular might be the most expensive choice for operational cost aspect. Cellular needs monthly cost to use the cellular provider services. On the other hand, both RF and Cellular have line of sight issues. Moreover, RF has to build and invest some equipment as RF infrastructure. The most commonly used communication technology for AMI subnetwork is power line communication (PLC) [2]. Figure 1 shows the topology design of AMI using PLC as subnetwork. The biggest benefit especially for electrical utility company is PLC technology utilizes the existing power line network for communication media between smart meters and DCU.
Based on the frequency band there are two types of PLC, Broad band PLC (BB-PLC) and Narrow band PLC (NB-PLC). BB-PLC has high bandwidth and data rate thus usually used for high data rate data transmission such as internet services, TV cable, and others. NB-PLC technology have less data rate but sufficient enough for smart meter data necessity. Narrow frequency bands also benefit for longer data transmit distance. NB-PLC most commonly used protocol is PRIME and G3 PLC. The difference is mainly the robustness level depend on modulation technique and forward error correction to defense against the network noise. More detail PLC technology review will be explained in this study. Basically, power line is not designed for transmitting communication data. The characteristic of distribution grid including power line conductor and load characteristic are varying with time and are frequency dependent. The most major challenge of PLC system is network noise and attenuation. Residential load is one of the sources of noise in PLC system. Long network distance makes high signal attenuation. Attenuated signal is susceptible to noise. The biggest noise sources of distribution grid are the residential load noise. Noise is affected by harmonic distortion of residential device [3]. Therefore, residential load which potentially generating high noise signals has to be considered. Moreover, the frequency band of the residential noise is recommended to be avoided.

The rest of the paper is organized as follows. Section II is overview of NB-PLC choice for AMI smart meter communication technology. Section III, the methodology to measure residential load noise is described. Section IV, measured noise signal is analyzed to find the band frequency of residential load noise. Section V, field test using PLC G3 FCC band is conducted. Finally, a conclusion is given in Section VI.

2. Narrow Band PLC overview

Based on the frequency band, there are 2 types of PLC technology, Broadband PLC (BB-PLC) and Narrowband PLC (NB-PLC). BB-PLC frequency band is range in between 2-12 MHz. Wide frequency band of BB-PLC, allows a high data rate of 0.5–2 Mbps. BB-PLC have flexibility to choose the working frequency, so that easier to avoid frequency band with high noise level. But BB-PLC has some attenuation issues over the underground LV power lines [4-5]. Moreover, high band frequency generates high impedance that limit the data transmit distance. Higher frequency band is resulting shorter distance compare with lower frequency band in the same transmitting power [6]. On the other hand, NB-PLC frequency band is around 3-500 kHz. The data rate is slower than BB-PLC. But, the data rate of NB-PLC is sufficient enough to carry on smart meter data. With a lower data rate, NB-PLC has low power consumption. Moreover, lower frequency band allows NB-PLC to have a longer data transmit distance. In addition, NB-PLC is appropriate over underground LV power lines. Therefore, based on smart meter data size requirement, long data transmit distance, and low power consumption, NB-PLC is chosen in this study as communication technology between the smart meter and DCU [7].
There are two protocols NB-PLC technology commonly used in smart meter application, G3 and PRIME PLC. The differences between both of them are mainly the robust mode and modulation technique. The robust mode is depending on the interleave and repetition code of the protocol. The data rate that can be generated is the result of the modulation technique. G3 PLC is using Reed Solomon and convolution code as the mandatory in forward error correction (FEC) technique. While PRIME does not have mandatory FEC. PRIME can deactivate the FEC to increase the data rate. Both G3 and PRIME data rate are capable to transmit the required smart meter recorded data [8]. Although the G3 robust mode has less data rate, it is sufficient enough for transmitting data of smart meter communication. The benefit of robust characteristic of G3 PLC allows a better performance against residential noise load as the distribution network challenge [8].

3. Residential load noise test
In this study, laboratory test set up to measure noise caused by PV rooftop and residential loads are described. The measured signal is analyzed to find out the PLC frequency band with a low noise level. Spectrum analyzer is used to capture the communication signal and noise signal that occur between DCU and Smart meter. PLC sniffer helps to confirm the packet data sent and determine whether the communication is success. The measured signal is captured and analyzed in peak hold mode. Peak hold is the spectrum view shows a rolling maximum of the spectra calculated from all the waveforms in the buffer. In this mode, the amplitude of any frequency band in the spectrum view will either stay the same or increase, but never decrease, over time. So that, the noise can be captured if there is noise signal higher than the PLC signal and inside the frequency band of the PLC signal. Figure 2 shows the laboratory set up for the noise test in this study. The objective is to find the noise frequency band of the residential load and respond of both Cenelec A and FCC band G3 PLC. Experiments in the field are also conducted to determine the performance of the PLC.

![Figure 2](image_url). AMI topology using PLC subnetwork.

4. Noise signal analysis
Figure 3 shows the measured signal of the distribution grid using spectrum analyzer. The signal is called as the background noise of the distribution grid. The background noise frequency is dominantly happening under 15 kHz. In this study, frequency higher than 15 kHz is the noise that possibly disturbs the PLC signal thus frequency above 15 kHz will be analyzed further. Figure 4 shows the NB-PLC signal using FCC frequency band generated by the communication process between DCU and smart meter. As shown in Figure 4, the FCC band is range in between 150–450 kHz [9]. Figure 5 shows the NB-PLC signal using Cenelec A frequency band generated by the communication process between DCU and smart meter. As shown in Figure 5, the Cenelec A band is range in between 30–90 kHz [9].
Figure 3. Distribution grid background noise.

Figure 4. PLC FCC signal amplitude and frequency band.

Figure 5. PLC Cenelec A signal amplitude and frequency band.

Figure 6 shows the measured signal of residential load and PLC signal using the laboratory test set up as explained before. The grey line shows the PLC FCC band signal data that generated by DCU and smart meter communication. The communication signal ranges between 150–490 kHz. The orange line shows the PLC Cenelec A band signal data generated by DCU and smart meter communication. As shown in the Figure 6, the communication of PLC Cenelec A band signal is range in between 30–90 kHz. The other color signals are the signals generated by some residential load including tube TV, microwave, refrigerator (inverter based), cutting wheel and fan. The source of noise signal for NB-PLC comes from residential loads. The signal with amplitude above -30 dBu is mainly happen between 5-67 kHz. In addition, microwave and tube TV are also generating some noise in range 94–119 kHz. From the sniffer report data, both PLC FCC and PLC Cenelec A are successfully communicated with the DCU while each residential load is turned on. However, the PLC signals needs to avoid the frequency band where the noise signal could possibly happen. As shown in Figure 6 noise from household appliances appears inside the PLC Cenelec A frequency band. On the other hand, PLC FCC frequency band operates outside the residential load noise signal.
There are some issues NB-PLC applied in residential area which install PV Rooftop. PV rooftop is variable renewable energy (VRE) which converts solar energy into electricity. The output of PV rooftop is direct current (DC) power so it can’t directly connect to the grid. PV rooftop needs inverter to convert the DC signal to AC signal. The output of the inverter is synchronized to connect to the grid. Therefore, the device that directly connects to the grid is inverter. Nowadays, Inverter consists of power electronic devices. Inverter main component is switching devices such as IGBT and MOSFET. The switching devices commonly operate at high switching frequency which can generate harmonic signal. The harmonic becomes noise signal for the NB-PLC when the frequency band of the communication signal is the same with the harmonic. Figure 7 shows the signal of PLC FCC (blue line), PLC Cenelec A (green line), and PV rooftop inverter signal (red line). The maximum noise amplitude is 1dBu detected in 19 kHz and -22 dBu inside the frequency band of Cenelec A.

5. Discussion
The Residential load is one of the biggest noise sources for NB-PLC communication. Experimental results show, the signal with amplitude above -30 dBu is mainly happening between 0-15 kHz. This signal is determined as the background noise of the grid (no load condition). The residential load noise is dominant happen in frequency range between 15-148.5 kHz including tube TV, microwave, refrigerator, gerinda, fan & electric Stove. Moreover, PV rooftop that using inverter which directly connects to the grid, is dominant happen in frequency range between 15-80 kHz. The maximum noise amplitude is 1dBu detected in 19 kHz and -22 dBu inside the frequency band of Cenelec A. From the laboratory experiment, both Smart meter using PLC FCC and PLC Cenelec A were successfully communicated with the DCU while each residential load was turned on. However, the PLC signal needs to avoid the frequency band where the noise signal could possibly happen. Laboratory test measurement result shows the FCC band (150-490 kHz) was outside the range of PV rooftop and residential load noise. On the other hand, the Cenelec A (35-90 kHz) frequency range was in the range of noise signal. Therefore, NB-PLC G3 using FCC frequency band is proposed to achieve robust data communication and lower noise level. G3 PLC FCC band are tested in the real field residential area; the experimental results show 97.62% successful rate within one-week data collection.

Based on the laboratory experiment, smart meter and DCU using G3 PLC FCC band were chosen to be tested in the real field residential area. G3 PLC technology is mesh topology based. The smart meter can act as the repeater for the other smart meter where located farther to the DCU. The configuration of the field test can be shown in Figure 6. There are 8 smart meter and 1 DCU, The DCU is placed in the low voltage substation, one smart meter is placed 70m near the DCU and the other 7 meters are placed in the residential houses.
6. Conclusion

PLC G3 as NB-PLC technology choice for AMI has been described. There were 2 frequency bands commonly used for G3 PLC, FCC band (150-490kHz) and Cenelec A band (35-90kHz). Laboratory test measurement result showed the FCC band operates outside the range of PV rooftop and residential load noise. On the other hand, the Cenelec A frequency range operates inside the range of noise signal. Therefore, NB-PLC G3 using FCC frequency band is proposed to avoid noise frequency band thus robust data communication and lower noise level can be achieved. G3 PLC FCC band are tested in the real field residential area; the experimental results show 97.62% success rate within one-week data collection.

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