COMPARISON OF COUPLING METHODS IN MV EQUIPMENT FOR POWERLINE COMMUNICATIONS

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ABSTRACT

With the current interest in the smart grid, communication between various elements of the grid is a key factor. Among the various communication methods available there exists a renewed growing interest in power line communications (PLC) over the medium voltage (MV) distribution network. There are various methods for coupling communications signals to the MV network, the best of which is still open to debate. Here we investigate various coupling methods and locations within MV GIS equipment to introduce communications signals over the MV network. Using commercially available MV PLC modems, the communications parameters: transmission and reception speeds; channel frequency response, and signal-to-noise ratio, have been measured under different capacitive and inductive coupling regimes. Capacitive coupling elements developed by Ormazabal have been introduced by plugging them into T-junctions at the end of the MV cables in the switchgear. Capacitive coupling via the inherent capacitance of the bushings of the switchgear have also been used. Inductive coupling has been made by using a ferrite element over the earth of the MV cable and also the voltage presence indicator cables running from the bushing screen. It has been observed that each coupling method has its own characteristic channel frequency response and that the largest theoretical distance required between nodes is achieved using the capacitive coupling method for PLC communications. One must also take into account the practicalities of each coupling method not only in terms of quality of communications, but also interruption of service for the introduction of each unit and the effect over other elements within the MV GIS equipment.

INTRODUCTION

The broadband PLC or Broadband over Powerline (BPL) technology used in these tests is a commercially available Orthogonal Frequency Division Multiplexing (OFDM) system based on chipset designs from DS2[1]. It is similar in concept to broadband DSL technology[2] on telephony lines in that it exploits unused power line spectrum by overlaying the low frequency 50/60 Hz AC power signal with 1536 high frequency data carriers over a frequency range of 1 to 34MHz depending on configured signal mode. As the signal could be transported over unshielded overhead lines it also incorporates power masking to attenuate the PLC signal at user definable frequencies to reduce interference with other technologies operating at that part of the spectrum.

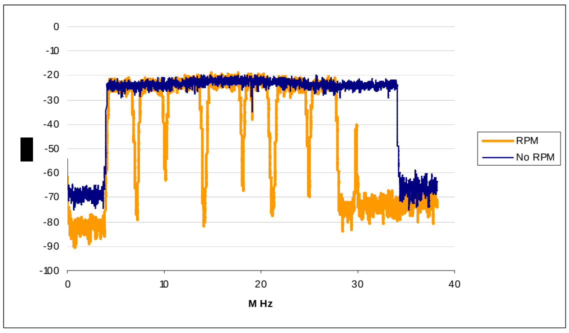


Figure 1 – PLC Mode 6, with and without regulation power mask, 19.0625MHz central frequency, 30 MHz bandwidth.

Theoretically the system can deliver up to 200mbps shared symmetric channel bit rate on MV electrical supply lines up to a kilometer in length and is an effective broadband access solution over MV and LV lines requiring no new wiring or expensive infrastructure to reach or deploy within homes. Figure 1 shows the OFDM spectrum of the PLC mode used in the coupler tests. The modem was configured to use Mode 6 having a predetermined central frequency of 19.0625MHz and a 30MHz bandwidth with and without regulation power mask (RPM) enabled. The default RPM in the modems under test had notched frequencies as shown.

EXPERIMENTAL SETUP

Two main tests were carried out. The first on the individual couplers to see the effect on resulting signals from each type. The second using the couplers in an end to end configuration in circuit with MV cable representing a possible field scenario. Measurements were made using software supplied with the PLC modems.

Couplers

Figure 2 shows the principal couplers tested in situ within Ormazabal switchgear. The ekorEVTC capacitive coupler, which integrates a 1.8nF high voltage capacitor as well as a quadripole for separating high and low frequency signals, is shown plugged into a T-junction at the cable termination in the cubicle.

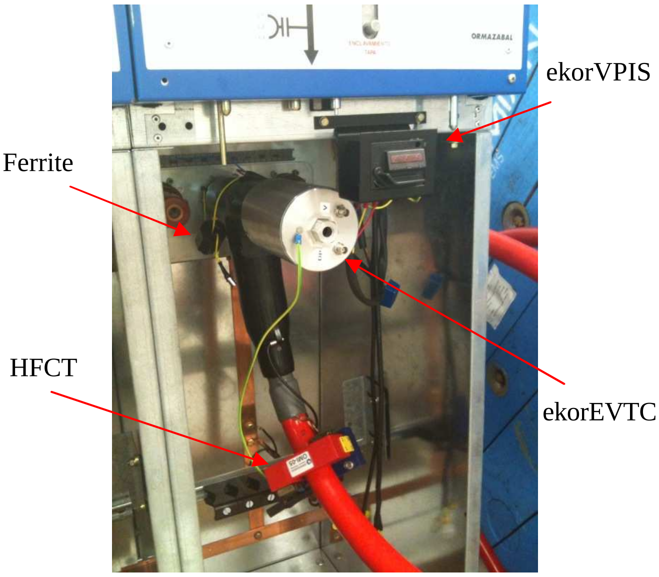


Figure 2 – Couplers located in-situ.

The High Frequency Current Transformer (HFCT) inductive coupler is also shown located around the cable close to the cable termination at the T-junction. Both of these couplers can be used as sensors for high frequency partial discharge signals and/or as a PLC injection point through the high frequency BNC connection. Two other coupling sites are also shown. The ekorVPIS Voltage Presence Indicator System is a visual indicator of voltage on the line and is connected via an unshielded cable directly to the bushing with an inherent capacitance of 22pF. The ferrite also wraps around this unshielded cable as shown with a single loop also connected to a BNC connector.

Circuit Setup

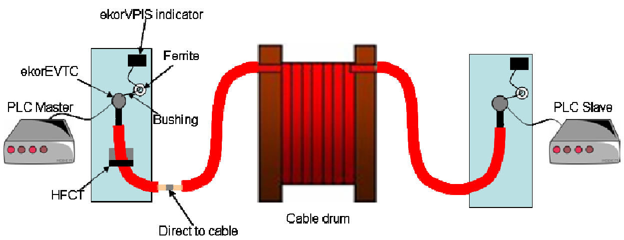


Figure 3 – End to End setup.

To measure the PLC performance over a power cable link for each coupling method measurements were made on an end to end setup using approximately 95m of MV cable and configured as in Figure 3. As previous work had shown little variation in PLC performance when cable was energized to full operating voltage the following tests were carried out on the cable with no voltage applied.

Due to practicalities of modem location and existing cable arrangements, different couplers were tested at one end of the link with the other side using a fixed ekorEVTC coupler. Several potentially lossy components were also inherent in the setup. These included long (several metre length) BNC cables from modem coupling device and an unshielded cable joint on near side of cable drum. Also there was potential for crosstalk in this setup as the long cable on the drum was not unrolled. These factors were common for all tested couplers.

RESULTS

Coupling method effects

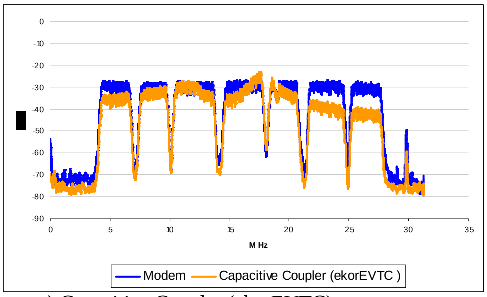
Figure 4 shows the signal level on the cable immediately after each coupling method under test with the source signal as reference in each case. The PLC regulation power mask was also present for these measurements showing notched frequencies. Figure 4(a) shows the coupled signal level immediately after the ekorEVTC coupler with some attenuation particularly after 20MHz but otherwise a good signal level over a wide frequency range. Figure 4(b) shows the same result for the HFCT coupler with more attenuation throughout the range. Figure 4(c) shows the result for the ekorVPIS voltage indicator showing considerable attenuation particularly above 10MHz. Figure 4(d) shows the signal level for the Ferrite + bushing method showing some attenuation but less than for the ekorVPIS coupling options. All methods couple the high frequency PLC signal well but the capacitive ekorEVTC coupler shows the least attenuation over the entire frequency range.

Coupling in circuit (end-to-end)

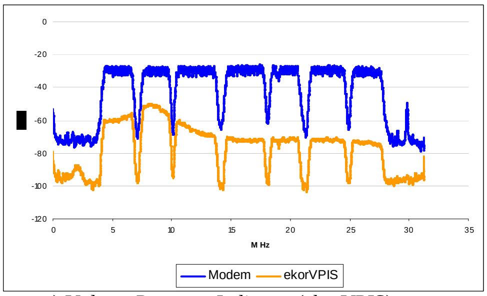
The circuit test results are summarised in Figure 5 and Table 1 with each coupling method discussed below. The channel frequency response charts in Figure 5 show the attenuation over frequency after receiver gain has been applied. An optimal response here would be a flat response over the entire spectrum and a low receiver gain requirement.

Direct to Cable

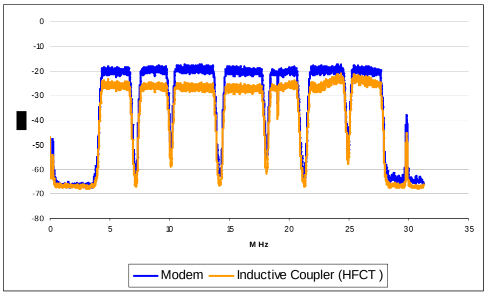
Connecting directly is not an option when the cable is operating at full voltage, as there is no electrical isolation between modem and power cable but was included here as a reference for the various end to end coupling methods. A direct galvanic connection was made from the modem to the cable at the unshielded joint as seen in figure 3. For the end to end measurements the slave was connected to an ekorEVTC capacitive coupler. An average receiver gain of 6dB was applied by the automatic gain control process for this test. Much of the attenuation here can be attributed to the impedance mismatch between the modem output (50Ω) and the power cable (~20Ω).



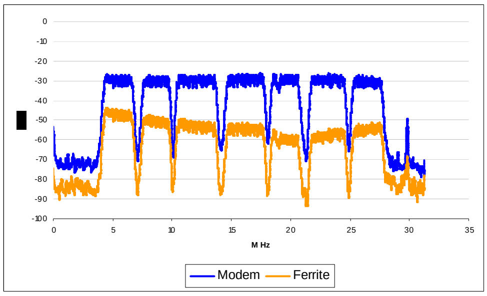
a) Capacitive Coupler (ekorEVTC)



c) Voltage Presence Indicator (ekorVPIS)

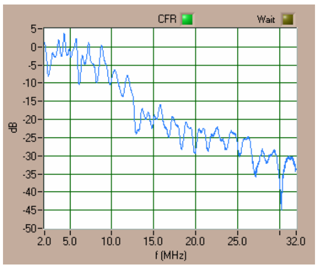


b) High Frequency Current Transformer

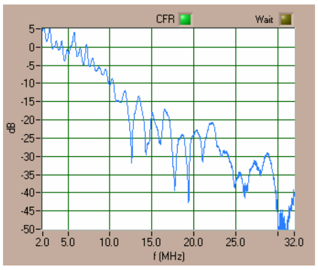


d) Ferrite + Bushing

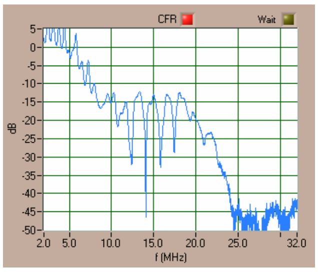
Figure 4 – Coupled PLC Signal Level with various coupling methods.



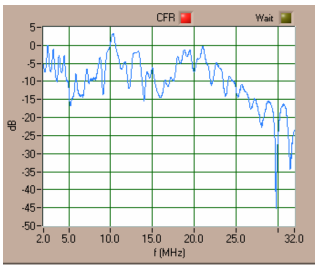
a) Direct (AGC=6dB, SNR=30.6)



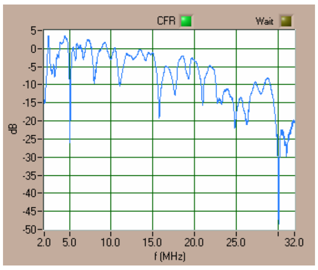
b) ekorEVTC (AGC=6dB, SNR=29.7dB)



c) HFCT (AGC=11.2dB, SNR= 27dB)



d) Ferrite (AGC=36dB, SNR=32.9dB)



e) ekorVPIS (AGC=41.5dB, SNR=31.6 dB)

Figure 5 – Circuit channel frequency response after automatic gain control with various local end coupling methods.

Master (Local) coupling method	Slave (Remote) coupling method	Avg. SNR (Local) (dB)	Avg. SNR (Remote) (dB)	Avg. Rx Gain (Local) (dB)	Avg. Rx Gain (Remote) (dB)	Uplink Speed (mbps)	Downlink Speed (mbps)	Theoretic Propagation Length (km)
direct	ekorEVTC	30.6	31.8	6	6	126	128	1.34
ekorEVTC	ekorEVTC	29.7	30.2	6	6	117	123	1.34
HFCT	ekorEVTC	27	26	11.2	12	97	94	0.67
HFCT	HFCT	25	25.4	18	18	96	99	0.45
Ferrite	ekorEVTC	32.9	22.9	36	35.6	157	86	0.22
ekorVPIS	ekorEVTC	31.6	20.4	41.5	39	109	58	0.2

Table 1 – Summary of channel measurements with various coupling methods.

Capacitive Sensor (ekorEVTC)
This coupling method uses a high voltage 1.8nF capacitive coupler suitable for use on cables operating at up to 24kV. The coupler can be used as a sensor for high frequency partial discharges signal measurements as well as the injection point for a PLC system. For the end to end test, the slave was connected as before to an identical ekorEVTC capacitive coupler.

The lowest average receiver gain of 6 dB, similar to the result for direct galvanic connection, was recorded for this method with average SNR of 29.7 dB. Sustained symmetric data rates of ~120 mbps with instantaneous rates of up to 145 mbps were also observed over the 95m cable.

High Frequency Current Transformer (HFCT)
This coupling method is an inductive coupler that is clamped directly around the unshielded earth of an existing cable. The sensor can also be used as a sensor for partial discharge detection. For the end to end test the slave was connected as before to an ekorEVTC capacitive coupler. An average receiver gain of 12dB and SNR of 27dB was recorded for this setup yielding 96mpbs over the 95m cable.

An additional test using HFCT transformers on both ends of the link was also performed resulting in an average receiver gain of 18 dB and SNR of 25dB also delivering 97 – 98 mbps of sustained throughput.

Voltage Presence Indicator (ekorVPIS)
This coupling method uses the ekorVPIS voltage presence indicator system present on Ormazabal switchgear. This indicator system is capacitively coupled to the power cable through the bushing screen with an inherent capacitance there of approximately 22 pF. For the circuit test the slave modem was connected as before to the ekorEVTC capacitive coupler. The highest average receiver gain of 41.5 dB was recorded for this method. However the flatter channel frequency response, relative to the HFCT and ekorEVTC and due to the smaller coupling capacitance yields good average SNR of 31.6dB and data rates of 109mbps uplink and 58mbps downlink.

Ferrite
This coupling method is an inductive coupling of the PLC signal using a small ferrite cylinder clamped around the unshielded ekorVPIS indicator line cable. A BNC connector was connected to a single loop also passing through the ferrite. This then is a combined inductive / capacitive coupling - inductive through the ferrite and capacitive through the final connection to the bushing screen.

For the end to end test, the slave was connected as before to the ekorEVTC capacitive coupler. A high average receiver gain requirement of 36 dB was recorded for this method. The flatter channel frequency response, relative to the HFCT and ekorEVTC, yields the highest average SNR recorded of 32.9 dB and data rates and 157mpbs uplink and 86 mbps downlink.

Comparitive Propagation Length

The modems were observed to be unable to maintain synchronization with signal attenuation greater than 85dB. Based on the average receiver gain measurements made earlier over the 95m cable length for each coupling arrangement the theoretical signal propagation distances were calculated as shown in Table 1 and Figure 6.

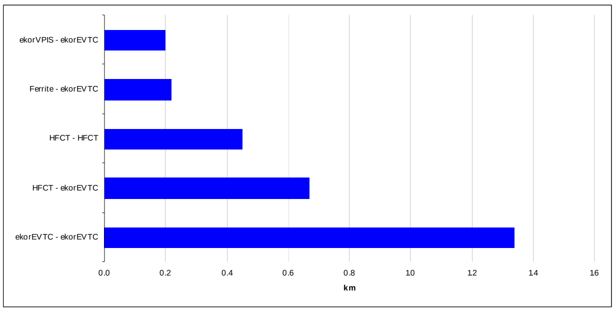


Figure 6 – Theoretical PLC propagation distance for various end coupling options.

CONCLUSIONS

For its much lower attenuation of the PLC signal, greater estimated range and best combined uplink/downlink of all the practical options, the high voltage capacitive coupler is the best performing overall of the signal coupling options tested. However, if distance is not the main factor than a number of other options with good performance at short range are available. The use of other methods strongly depends on capacity, speed requirements and practicalities of coupling unit installation.

REFERENCES

[1] DS2 "How it works", Online reference - http://www.ds2.es/subsecciones-web/subsecciones-web.aspx?ID=3
[2] ANSI T1.413-1998 , "Network and Customer Installation Interfaces – Asymmetric Digital Subscriber Line (ADSL) Metallic Interface." (American National Standards Institute 1998)