CONFIGURATIONS TO INTRODUCE CARRIER SIGNALS INTO
THE ELECTRICAL POWER SYSTEM

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SUMMARY

Transmission and distribution lines are becoming a medium to transmit information. A spare bandwidth, a group of rules sets in laws and coupling equipments have been necessaries to have several practical applications. Thus, this paper is centered in the analysis of different coupling circuits. Besides, special attention has been made in the empiric results obtained in the research carried out to study the single high impedance fault, with a superimposing tone over a carrier that is synchronized with the main signal of the power system.

INTRODUCTION

Years ago carried tones were introduced into electric power transmission systems to be used as control data by utilities. Soon, more complex information were added to the single control signals [1-3]. The use of existing electrical lines for transmitting data and voice is particularly interesting since it would provide customers of electrical utilities an alternative to traditional networks. Besides, they enable public electrical utilities to tap new lucrative business in fast Internet access, telephone service, and home automation at an attractive price. Power line communication, a new technology that sends data through existing electrical lines alongside electrical current, is set to turn the largest existing network in the world, the electricity distribution grid, into a data transmission network. This power line communication will make it possible to both industrial control and home automation over power lines with economical and reliable solutions. The benefits are obvious: valuable additional uses without the need for expensive infrastructure investments. Several configurations can be used to do it and a classification can be done when the voltage or the current is shown as parameter:

- Voltage addition (superimposed tone). A voltage signal is introduced in the power system to be added to the main signal. That signal can have the same or different frequency from the industrial one. Thus, it can be seen as a superimposed signal on the 50 Hz signal or a fully different signal in other frequencies. The bigger problem is that electromagnetic noise can affect the information or sensibility in the phenomena to be studied.

- Current injection. The carrier or data are introduced in the line as current loop. The information can be seen in the other end. This mode of operation protect the information against electromagnetic perturbations but means the stop of the whole system when the coupler fails.

Another classification is made about the coupling mode. Two ways can be used to introduce the signal in the distribution network, a serial mode between the main generator and loads and a parallel mode in relation with the main signal:

- The serial coupling introduce the data or tones in the series loop between the main generator and the load. The voltage level of the main signal diminished because of series self-inductions. Also, it is necessary to stop the main service when the coupler fail or the maintenance service have to check it.

- Parallel mode is used to introduce signals in the power system without stopping the main service. It is necessary to take into account that a special tuning or synchronization is mandatory to avoid the main signal to cause damages in the tone generator circuits.

The electrical utilities were the first in owning a physical network that connect everybody (with spare bandwidth) and, also, in introducing tones and data [4]. In this paper, technical problems to introduce a carrier with modulated information are analyzed and new configurations proposed. These new configurations are intended to detect high impedance faults in power systems [5].

TUNED OPERATION

In a first step, tests have been developed in laboratory enclosed environments, based on models of distributed parameters. The network model has been built with several stages. Each stage has been designed with the values of the electrical parameters that represent ten, five or one km, of a single-phase network. The possibility of connecting diverse modules gives a big flexibility. The use of the distributed parameter model has been very useful to obtain the appropriate circuit values. The loads, as well as the line length, have been chosen. Also, it has been able to work with wide ranges of frequencies.

The first tests were carried out in the range of 3 kHz. This range of frequencies had been previously though to be from 100 Hz to 1 kHz to avoid the problems that the real components in the power system produces. Finally the frequencies of the test were expanded into superior and inferior ranges, because of the possibility of use the circuit to transmit data and voice [6]. The chosen model is shown in
This circuit model is widely used for transmission and distribution lines. The model is completely adjustable to the requirements of the test.

Figure 1. Pi-model of transmission/distribution lines

Tapped-Capacitor

The tapped–capacitor configuration is a divider built with two capacitors which is useful to obtain a sample of voltage from the Electrical Power System. But historically, this topology has also been used to introduce carriers into transmission lines [7]. For this application, some resonant circuits have to be added.

Figure 2. Tapped-Capacitor Diagram

The diagram shown in figure 2 is composed by three differenced parts:
- The tone generator with three resonant circuits and a resistor R1 as the output resistance of the generator. This resistor is used to analyze the load influence.
- The taped capacitor.
- The Power System, composed by a pi model circuit with distributed parameters, a load and the voltage source.

Numerical values the components are shown in table I.

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>600 Ω</td>
</tr>
<tr>
<td>L4</td>
<td>10 mH</td>
</tr>
<tr>
<td>C5</td>
<td>1 mF</td>
</tr>
<tr>
<td>L5</td>
<td>10 mF</td>
</tr>
<tr>
<td>C2</td>
<td>100 µF</td>
</tr>
<tr>
<td>L1</td>
<td>1.57 H</td>
</tr>
<tr>
<td>C4</td>
<td>20 nF</td>
</tr>
<tr>
<td>C3</td>
<td>20 nF</td>
</tr>
<tr>
<td>R2</td>
<td>3.3 Ω</td>
</tr>
<tr>
<td>L3</td>
<td>15 mH</td>
</tr>
</tbody>
</table>

Table I. Numerical values of R, L and C. Tapped-capacitor

Having the load resistor as parameter whose value change from 50 kΩ to 200 Ω, more power is demanded from the tone generator when the value of the resistor decreases, as it was expected. So, a higher level of voltage is watched in R1.

Results are similar if two models of distributed parameters are connected in series and the load is placed in the join point. But changes happen if the voltage source is connected in other points of the line. The power consumption increases.

Inductive Coupling

The inductive coupling configuration contains one or more inductors, each one with one or several associated windings, and most of the cases with a magnetic core. Historically, it has been used as transformer, to sense currents or voltages and to introduce signals into the transmission line. Power in the output side is always lower than power in the input side but voltage or current can be increased or decreased.

Inductive couplers exists with and without magnetic cores. The former are the usual devices when the low frequencies of Power System signals are considered and several kind are available:
- Isolated magnetic coupling is used when non electrical connection is needed. This connection is quite usual, in order to obtain a more safe environment to work. However, it can result in a lose in precision because of the electromagnetic noise that dive into the coils.
- Autotransformers are used when no electrical isolation is required and a big power quantity have to be introduce into the Power System.

The inductive couplers can work in two ways: injecting a current signal into the network or superimposing a voltage signal. Different circuit topologies are needed.

Serial topology is recommended when currents must flow throw the line. The effect is usually watched in voltage parameters.

Figure 3. Serial Inductive Coupled Diagram

The diagram shown in figure 3 is composed by three differenced parts:
- The tone generator. This device is similar to the one described above but the primary of a current transformer is connected in series configuration.
- A current transformer to introduce the carrier into the network. The main characteristics of this transformer are a high isolation between the two coils and a low
impedance to be introduced into the Power System.
- A pi model of the line with distributed parameters. This line is charged with the load in one side and feed with two sinusoidal signals: the main voltage and the tone introduced through the current transformer (a resonant circuit with frequency f=3 kHz is placed between both points).

Numerical values of the components are shown in table II.

| Table II. Numerical values of R, L and C. Serial inductive couplers |
|-----------------------------|-------------|-------------|
| R1 | 600 Ω | L18 | 10 mH | C19 | 1 mH |
| L6 | 10 mH | C5 | 1 mF | L8 | 10 mH |
| C6 | 1 mF | L2 | 2 H | L1 | 4 mH |
| L7 | 1 mH | C3 | 2.8 µF | L4 | 1.57 H |
| L5 | 5.1 H | C2 | 20 nF | C1 | 20 nF |
| R3 | 3.3 Ω | L3 | 15 mH | |

When the load changes from 50 kΩ to 200 Ω (a decrease toward 0.4%), the power demanded to the tone circuit increases only 5%. So this circuits is steady in power consumption when load changes. The results are similar if two models of distributed parameters are connected in series and the load is placed in the join point.

The diagram in figure 4 shows a configuration of parallel inductive coupled circuit. There are two resonant circuits to reject the input of one signal into the other generator. Both signals are magnetic coupled and join through the capacitor C1=100 nF. L3 protects the tone generator against the current that could flow from the main signal.

| Table III. Numerical values of R, L and C. Parallel inductive couplers |
|-----------------------------|-------------|-------------|
| L1 | 40 mH | L2 | 1 H | L8 | 10 mH |
| C5 | 1 mF | L3 | 281 mH | C1 | 18 nF |
| L7 | 1 mH | C4 | 2.8 µF | L4 | 1.57 H |
| L6 | 5.1 H | C2 | 20 nF | C3 | 20 nF |
| L5 | 15 mH | R3 | 3.3 Ω | R2 | 75 Ω |

When the load changes from 50 kΩ to 200 Ω (a decrease toward the 0.4%) the power demanded to the tone circuit increases about 33%. The results are similar if two models of distributed parameters are connected in series and the load is placed in the join point.

When either serial or parallel topology is going to be tried, a resonant circuit is mandatory.

SYNCHRONIZED OPERATION

The previous analysis shows that resonant circuits are necessary when a tone signal have to be introduce in the Power System. If they do not exist, the energy of one system flow throw the components of the other circuit and vice versa, and destruction or other damages can happen. However, there is another solution that avoid the use of resonant circuits. That is the synchronization.

Synchronizing a signal means to have the same signal in both systems (the generator circuit and the Power System) [8]. The equality is related to three aspect: phase, amplitude and frequency.
- Phase of both signals must match in the synchronization time and so on. The synchronization is going to last for long time after the main signal is locked if the frequency of both signals remains equal during the time.
- Frequency have to be steady with little variations. When a 50 Hz systems is thought and a variation of 5% in the value of both frequencies happens, a drift of 2 ms is produced. So, in 5 periods the two signals are in opposition
- Amplitude in both signals must be similar in order to avoid the transfer of energy in the 50 Hz frequency. From the Power System to the tone circuit and vice versa, because in both situations damages may happen in the circuits.

But two twins signals synchronized do not worth itself and other signal have to be added to be practical. So, it is necessary to introduce a modulated signal

PRACTICAL RESULTS

The signals detection has been carried out with an oscilloscope of two channels. In the instant of measurement, it is not known how the injected signal is. This fact introduces errors due to the temporary drifts of the injected signals. For this reason, it becomes necessary to design and implement an integral system of generation and measure of tones, so we know, in the moment to take the measure, how the generated signal is. Likewise, it will be necessary to measure all the signals at the same time.

Synchronized coupling between a carrier (with a superimposed tone) and the 50Hz signal in the Power System has been done. A circuit has been developed to obtain the carrier of 50 Hz and a tone of higher frequency.

Carrier signal has a nominal value of 135 Vrms that can be adjusted within the range of ±30%. The phase of this carrier can be shifted 180º to obtain the synchronization by means of a specific circuit.

Amplitude of the tone is about 5% of the carrier amplitude, and can be varied in a ±20% range of his nominal value. The
frequency of this tone is also adjustable from 200 Hz to 5 kHz.
Both, carrier and tone are driven separately through two different pre-amplifier to obtain the suitable amplitude in the inputs of the adder. The output of the adder is the superimposed signal (50 Hz + 3 kHz), which pass through a push-pull class AB power amplifier [9] to feed between 15 and 20 W into the load.

The Power System is considered to have a 50 Hz 127 Vrms reference signal and the carrier was set in 50 Hz and 122 Vrms. The voltage difference allows to study the power transferred, which is always lower than 15 W when both signals are synchronized. Power involved in the tone always flow toward the Power System and is about 5% of the average power considered in the main signal.

Several tests were carried out in order to study the high impedance faults. Some of the test were produced with non fully synchronized signals. The result of one of these tests can be seen in figure 5. The big trace represent the reference signal attached to the superimposed signal, the smallest one shows the difference between both signal when a shift in the synchronization is produced.

![Figure 5. Tone Superimposed to the Synchronized Carrier](image)

One of the most interesting conclusions obtained from these tests has been to determine the specifications that both, the injecting card of signals and the reception system must complete

CONCLUSIONS

Several ways to introduce a signal into the electric power system have been shown. Those couplers can be classify in two groups: the tuned ones and the synchronized ones. Tuned equipments are widely used because simple calculation are required. But there are practical problems to make them work because of the settings that have to be made in the resonant circuits, and because no full control is assured over the tone introduced.

More control over the signal is obtained if a synchronized equipment is used. Although more time is taken to develop it, no resonant circuits are used and the sensibility is improved.

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REFERENCES