# DEVICE FOR MV NETWORK INSPECTION VIA PULSE INJECTION

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## *ABSTRACT*

*This article describes the newest, portable instrument used in ENEL Distribuzione for the assessment of tuning condition and network parameters in MV Networks.*
*Either the instrument functions and performance are described as well as the in-field use and experiences.*
*The instrument, created in cooperation between ENEL and ARS, for the specific task of tuning condition monitoring, demonstrated the capability of estimating the zero sequence parameters and the prediction of the max earthfault current, even in case of neutral insulated (floating) MV network.*
*Implementing the new pulse injection method and some other related patents it is flexible and capable of estimating a rich set of parameters concerning either the network and the compensation systems. So it can be properly defined an* ***analyzer forMV zero sequence system*** *for estimating:*
- *detuning parameters*
- *coil parameters*
- *network parameters*

*All of this in a simple, safer, more accurate and faster manner than ever.*
*The instruments provides different insertion possibilities, depending on the accessibility and information looked for. Both mobile and fixed uses are suitable.*

## INTRODUCTION

In the last years the Italian MV network has been neutral compensated in excess of 75% of its extension.
The main benefits have been the improvement of the continuity of service (the present SAIDI of 48min) and the reduction of earthfault current values (resulting in a less demanding earthing system).
The excellent results have been achieved with the determinant contribution of a mix of neutral compensating devices: mobile coils, fixed coils, resistors. In order to guarantee the proper operating conditions and support the maintenance activity, some checks must be periodically performed. In particular, the grade of detuning must lie within the accepted range (depending on the protection system settings and the declared earthfault currents).
As this checks are imposed either by law and by operating activity, a dedicated instrument has been designed and carried out. A design-to-cost approach was followed as mentioned in [3] and several DMD are now used by maintenance crews.

## ENEL MV NEUTRAL STATUS

The ENEL MV neutral is generally grounded via extinction impedance (Petersen coil).
In relation to network capacitance, the compensation is provided by mobile coils (larger capacitance), fixed coils, and resistors (smaller networks). Under a defined threshold, no compensation or grounding is applied.

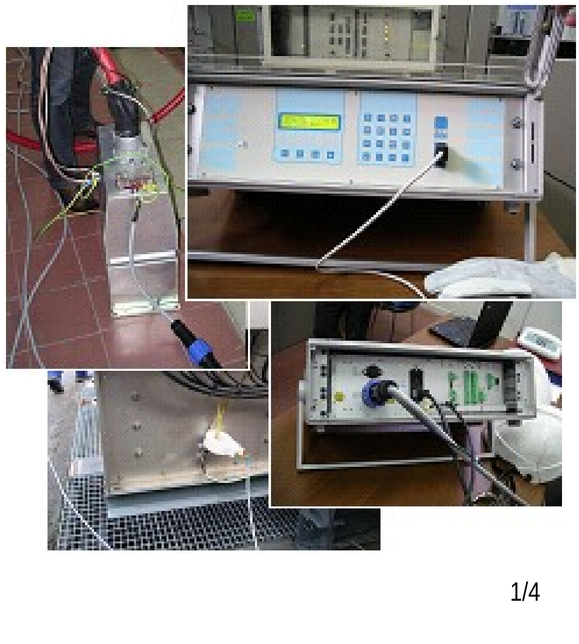
## MAINTENANCE OPERATION

The maintenance operation implies the estimation of the actual tuning degree and the estimation of the earthfault current either in compensated and insulated neutral.
Also the network capacitance, residual voltage, harmonics are evaluated.
The presence of harmonics can hinder the self-extinction of the fault as the tuning takes in account only the fundamental frequency (50 Hz in Europe). The knowledge of high order harmonics and circuit parameters will help in system analysis and corrective action definition.
In case of need, the instrument is kept in operation for long time in order to detect possible network or coil anomalies.

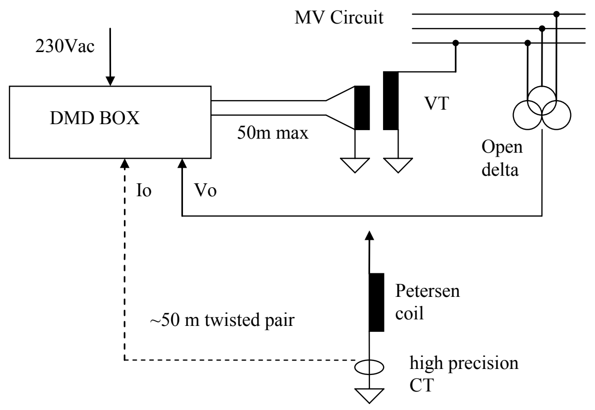
## DEVICE DESCRIPTION

The Detuning Monitor Device (refer as DMD) is a portable system composed by:
- central unit box, suitable for 19” rack mounting
- external high precision CT (Current Transformer) for measuring coil current
- external VT suitable for larger injection levels
- connection cables sets

The DMD is operable by a local keyboard and small LCD display A PC with MMI SW is used as a convenient interface and analysis.



The full insertion scheme is illustrated in the following picture:




**Full insertion scheme**

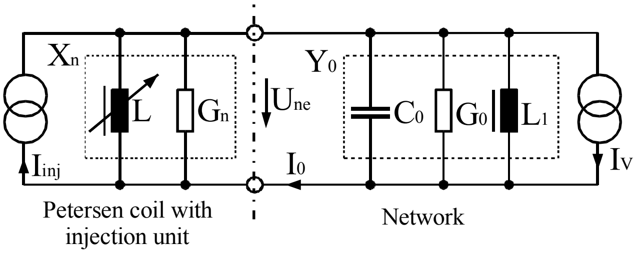
When using the protection busbar VT, the connections shall be provided on the marshalling that supplies the MV Protection System. Otherwise, in case of too small amplitudes of the zero sequence voltage change, an additional VT connected to a whichever phase on the system will be used.
Measurements can be performed one shot or cyclically with settable intervals (0…24h , step15min).

Measurements are displayed by a local LCD as well as MMI PC. The latter performs also the analysis functions.

## Algorithms

The DMD is a device that determinates the detuning and the parameters of the equivalent network zero sequence circuit through a pulse signal injection and the system response observation.
The injection take place through the MV/LV VT, while the system response is measured by Vo and/or Io inputs.

In principle, the device estimates the parameters of the equivalent zero sequence circuit.




**Equivalent Circuit Diagram for the Injection into the Zero Sequence System**

The main algorithms implemented inside the device have been described in [1] and [2].
The pulse-formed injection signal $I_{inj}(t)$ causes both a displacement in the zero sequence voltage signal $U_{NE}(t)$ and the zero sequence current signal $I_0(t)$ from the stationary (steady) state. Consequently, by difference is possible to observe the effect of the injection pulse signal $I_{inj}(t)$ into the zero sequence system, measuring the system response $\Delta U_{NE}(t)$ and $\Delta I_0(t)$ and eliminate the influence of the displacement current $I_v(t)$.
The parameters $G_0$, $C_0$, and $L_1$ of the zero sequence system of the network are calculated using a best-approximation method either in time or frequency domain.
The Petersen coil parameters L and $G_n$ and even the ohmic series resistance Rs consisting of the copper and the earthing resistance of the Petersen coil can be calculated in an analogous way.

## Device functions

All the functions are performed **with no or negligible impact on the normal operation** of the system, depending on the available or chosen insertion.
Four different operational modes are possible. The 4th mode returns the full and richest set of information, while modes 1 and 2 just return the grade of detuning.

| Operating MODE | Injection VT | Vo | Io | Estimated parameters |
|---|---|---|---|---|
| 1 - Voltage Mode | busbarVT / ext VT | Open delta | (Not used) | detuning |
| 2 - Current Mode | busbarVT / ext VT | (not used) | ferrite CT | detuning |
| 3 - Substation VT Mode | busbarVT / ext VT | Open delta | ferrite CT | detuning + coil param |
| 4 - Injection VT Mode | ext VT | Open delta | ferrite CT | detuning coil param net param |

The estimated parameters are listed in the following table:

**Detuning Results**
- Detuning by Network Parameters [%]
- Detuning by Resonant Frequency voltage [%]
- Detuning by Resonant Frequency coil current [%]

**Coil Parameters**
- IL : Normalized Inductive Current Coil [A]
- IWCOIL: Normalized Wattmetric Current Coil [A]
- RS : Ohmic Series Resistance of the coil [Ω]
- GP : Conductance of coil Parallel Resistance [mS]

**Network Parameters**
- ICLIN : Normalized Capacitive Current linear [A]
- ICNL : Normalized Capacitive Current nonlinear [A]
- IWNET: Normalized Wattmetric Current Network [A]
- IL1 : Normalized Inductive Curr of additional Coil [A]

**Additional functionalities**

Respect the original scope of the instrument, some important usages derived from the flexibility and easiness allowed by the device.
*Respect the* ***network*** it is possible to get the information

about:

- network capacitance and fault zero sequence current at insulated neutral;
- network insulation resistance
- presence of additional compensating coils on the network (f.i. in case of networks parallel)
- analysis of network frequency response. Normally linear (at lower frequencies), the frequency response can be useful for network diagnosis and earthfault current forecasting in presence of harmonics

*Respect the* ***grounding system*** it is possible to get the information about:

- the frequency response of coil
- the overall compensation effect considering the transformer impedance Zo effect (in series to the coil)
- the resulting series resistance useful to face the saturation effect on protection CT.

## Performance estimation

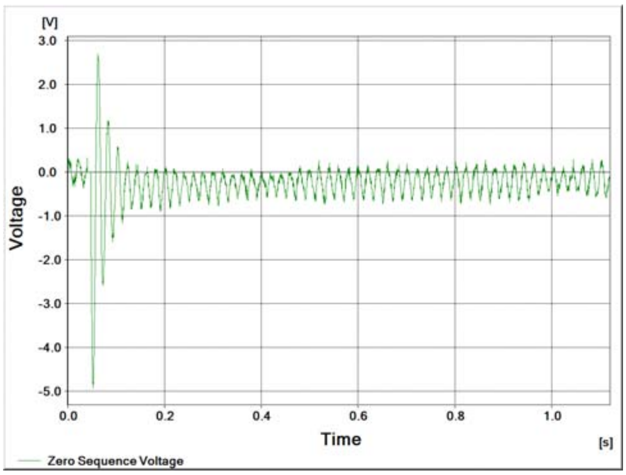
In order to validate the new instrument, several tests have been performed either in real field (HV/MV substations) and in laboratory. In particular, the laboratory tests have been performed with the RTDS (real time digital simulator) capable to emulate real world at the device's terminals. The RTDS implemented the network described in figure. Due to excessive complexity of emulation, only MODE1, MODE2 and MODE3 functionalities have been tested with RTDS. This allowed the simplification of the injection VT, replaced by a simple high ohmic resistor.
The field test demonstrated the correct operation respect all the busbar VT installed within the substation. It was always possible to estimate the detuning using all the available operating modes (MODE 1 to MODE 4). Performance results have been excellent.

| Parameter | Value | Unit |
|---|---|---|
| Peak amplitude voltage injection | 146,8846 | [V] |
| **Detuning Results:** | | |
| Grade of detuning (Uo Signal) | -5,462412 | [%] |
| Grade of detuning (Io Signal) | -5,48156 | [%] |
| Grade of detuning (network parameters) | -5,615431 | [%] |
| Damping factor (Uo Signal) | 0,211722 | |
| Damping factor (Io Signal) | 0,2124657 | |
| Resonant frequency (Uo Signal) | 48,61522 | [Hz] |
| Resonant frequency (Io Signal) | 48,61029 | [Hz] |
| **Coil Parameters:** | | |
| Serial resistance Petersen Coil | 2,5 | [OHM] |
| Parallel Reactance Coil | 2,247316 | [mS] |
| Normalized coil current | 131,4057 | [A] |
| Normalized wattmetric current coil | 29,47805 | [A] |
| **Network Parameters:** | | |
| Normalized wattmetric current network | 0 | [A] |
| Normalized Current Additional Coil | 0 | [A] |
| Normalized Capacitive Network Current (linear) | 138,7397 | [A] |
| Normalized Capacitive Network Current (nonlinear) | -0,3702096 | [A] |
| **Normalized Errors of estimation algorithms:** | | |
| Normalized Error (Uo Signal) | 0,3058099 | [%] |
| Normalized Error (Io Signal) | 0,350296 | [%] |
| Normalized Error (Network Parameters Real Part) | 8,188129 | [%] |
| Normalized Error (Network Parameters Imaginary Part) | 0,2191978 | [%] |
| Normalized Error (Coil parameter estimation) | 2,487852 | [%] |

**Parameters page from DMD visualization menu**

Several data records demonstrated the sensitivity of the instrument:

- dumped oscillation with a peak value of 5 volts (primary values, with Vn=15kV) superposed to the residual zero sequence voltage, have been sufficient for the correct detuning estimation in real network;
- tests with real time digital simulator (RTDS) have been successful even with dumped oscillation with a peak value of 3 volts (primary values, with Vn=20kV)
- with the external VT, the dumped oscillation reached easily 50 V peak value. This value, even negligible on the MV power system, is enough for the DMD to estimate correctly the whole set of parameters.




**Real data record from real field test**

**Measurement Precision and calibration needs**

Due to the fact that the measurement is fundamentally related to frequency domain, there is no need for detuning estimation, as the frequency stability is related to the internal clock precision produced by a quartz oscillator. Anyway a calibration procedure has been provided in order to control the precision of analog measurement.

The DMD works properly and estimates the network parameters even in case of isolated neutral (no coil or resistors connected). This is made possible by the parasitic component always present in the network which has proven to be sufficient for the correct operation. Actually, even the inductance of the busbar VT represents a very small inductance (sort of three-phase Petersen coil) contributing to the result.

A very useful functionality is the confidence indication associated to the estimated values: the DMD computes the estimation errors and displays the parameters with coloured fields in the visualization screen. Green, yellow, red are respectively associated to the relevant error estimation: very small error (excellent approximation), acceptable error (acceptable approximation), excessive error (poor approximation).

## Future developments

Some developments are already foreseen, but not applied up to now, because not considered necessary. Among them:

- possibility to use whichever commercial VT in place of dedicated VT for the functionality 4. This is achievable by means of the spare current input available. This input can be used for measuring the VT response in order to remove the VT effect on the measured voltage;
- transformation of the device in a Petersen coil controller just adding few digital I/O. This would be also a cheap solution due to the possibility to control two or more bus bars (or coils) at the same time;
- estimation of the real extinction efficiency, taking in account the presence of the higher order harmonics and the relative impedances
- possibility to implement the active injection with just an extra LV insulation transformer allowing the measurement even in case of powered off network or using auxiliary windings of Petersen coil.

## CONCLUSION

In consideration of all the measurements and network parameters it is able to elaborate, the device has to be considered a useful tool for network inspection, not necessarily connected to the extinction coil.

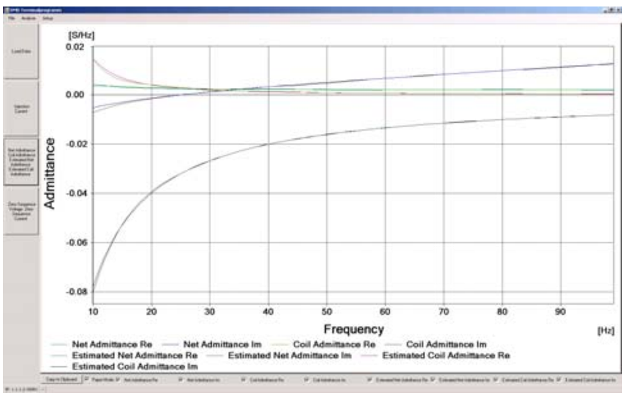
Its innovative approach make use of large integration with already installed components, reducing the overall cost and delivering unexpected performance.

As a first implementation of the recent algorithms and patents, many future developments can be foreseen.

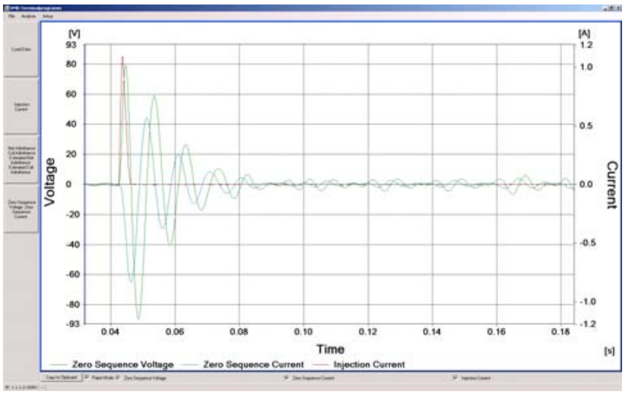
For instance, adding few digital I/O and a SW upgrade, the DMD can implement an automatic universal coil controller.

The instrument makes possible to inject and measure in whichever point of the network: even along the line, far from the substation, where it is possible to connect the injection VT and get the Vo from an open delta or an equivalent solution.

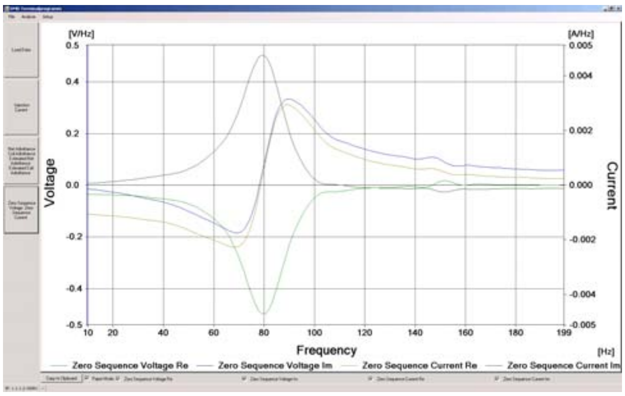
Using a DMD, even a client can easily measure the grade of detuning and estimate the operator max earthfault current.




**Admittance spectra from DMD visualization menu**




**Uo and Io signals from DMD visualization menu**




**Uo and Io signals spectra from DMD visualization menu**

## ACKNOWLEDGMENTS

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## REFERENCES

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[2] Francesco Ortolani, Albert Leikermoser, "Neutral compensation and network monitoring – Test field experience in determining resonant point and homopolar parameters with active and passive pulse injection" - *CIRED2009 Conference* – paper 0554

[3] Francesco Ortolani et alii, "Opex reduction in monitoring MV compensated network parameters" - *CIRED2010 Workshop* – paper 077