Coupling Capacitor Voltage Transformers as Harmonics Distortion Monitoring Devices in Transmission Systems

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Abstract—The proliferation of HVDC links in high voltage transmission systems and the growth of large industrial customers (with large non-linear loads) are increasing the need for harmonic distortion voltage measurements at transmission voltages.

This paper addresses the use of a Coupling Capacitor Voltage Transformer with built-in harmonic monitoring device (CCVTHM) to provide frequency response and accurate measurement of harmonic voltage distortions in a high voltage transmission system in an economical and effective way.

Keywords: Coupling Capacitor Voltage transformers (CCVT), Coupling Capacitor Voltage transformers with harmonic monitoring device (CCVTHM) , Harmonic distortion voltage measurement, frequency response, THD (Total harmonic distortion)

I. INTRODUCTION

Harmonic measurements are typically performed at the low voltage level at industrial customers using wire wound voltage transformers (VT's) and current transformers (CT's). The increase of large industrial customers directly connected to the high voltage transmission system has increased the need to accurately measure and monitor the harmonic distortion at transmission voltage levels. It is a very important to have an accurate and reliable measurement of the harmonics distortion (**THD**), in order to obtain parameters for functional filter design and for resolving eventual disputes between supplier and consumer of the power regarding **THD**. Though existing common design of CCVT provide many benefits, these CCVT's do not provide the linear, flat frequency response required to accurately measure harmonic voltage distortions across the most critical range of the harmonic frequency spectrums, thus requiring in the field calibration [1] that may have an adverse effect on the accuracy of the measurement. Trench Limited has developed a "special" CCVT design and / or "field installation kit" to solve this problem.

II. CCVT BASIC PRINCIPLE AND DESIGN

Coupling Capacitor Voltage Transformers (CCVT's) are designed to be applied on high voltage transmission systems to provide lower more manageable (approximately 57-115V) output voltage signals proportional to and in the phase with the primary line-to-ground voltage, power line carrier communication and transient recovery voltage (TRV) mitigation for circuit breakers during short line short circuit faults. The low voltage output signals are most often used for the following applications: metering/instrumentation, protection schemes and to act as a low-voltage and low-power supply. CCVT's are designed with an inherent margin of safety for the various in-service operating conditions, thus providing the customer with a highly reliable and economical instrument for the supervision and control of their power transmission lines.

The main components in the CCVT are:

- Capacitor Divider
- Step Down or Intermediate Transformer
- Series Compensation Reactor
- Ferroresonance damping circuit
- Carrier accessories

The capacitor divider is made up of many series connected capacitor elements, connected line to ground. A tap is brought out at an appropriate voltage level carefully coordinated with the intermediate transformer to provide the required output voltages. The capacitor elements on the high voltage side of the tap are called C1 and the capacitor elements on the low voltage side of the tap are called C2. To provide the reduced level tap voltage there are many more C1 capacitor elements than C2 capacitor elements. The capacitor elements are housed in hollow porcelain or composite insulators filled with an impregnating fluid.

The series reactor and primary windings of the step-down transformer are manufactured with taps to enable voltage ratio and phase angle adjustments. The step-down intermediate transformer, series compensating reactor and ferroresonance damping circuit are housed in the electromagnetic unit (EMU) and immersed in mineral oil.

Typical schematic diagram of common design Coupling Capacitor Voltage Transformer (CCVT) is shown in Fig.11 while Coupling Capacitor Voltage Transformer with Harmonic Monitoring terminals (CCVTHM) is shown in Fig.12.

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III. CCVT TEST AND MEASUREMENTS

Many papers, field and laboratory tests, digital simulations and ATP- EMTP models have been developed and performed on common design CCVT and other voltage transducers in order to evaluate, errors [1], transient response, [2] and frequency response characteristics [3]. To the author's knowledge, most of the existing research, measurements and simulations are focused on common design CCVT.

Using a modified Trench 145kV, 60Hz nominal voltage TEMP138 CCVT model built with tapped (115Vrms) secondary voltage terminals and special harmonic monitoring terminals (200Vrms), a frequency scan test was performed using the test circuit shown in Fig. 1. The objective was to take advantage of the capacitor divider as an integral part of CCVT as an "ideal" monitoring device for harmonics [4].

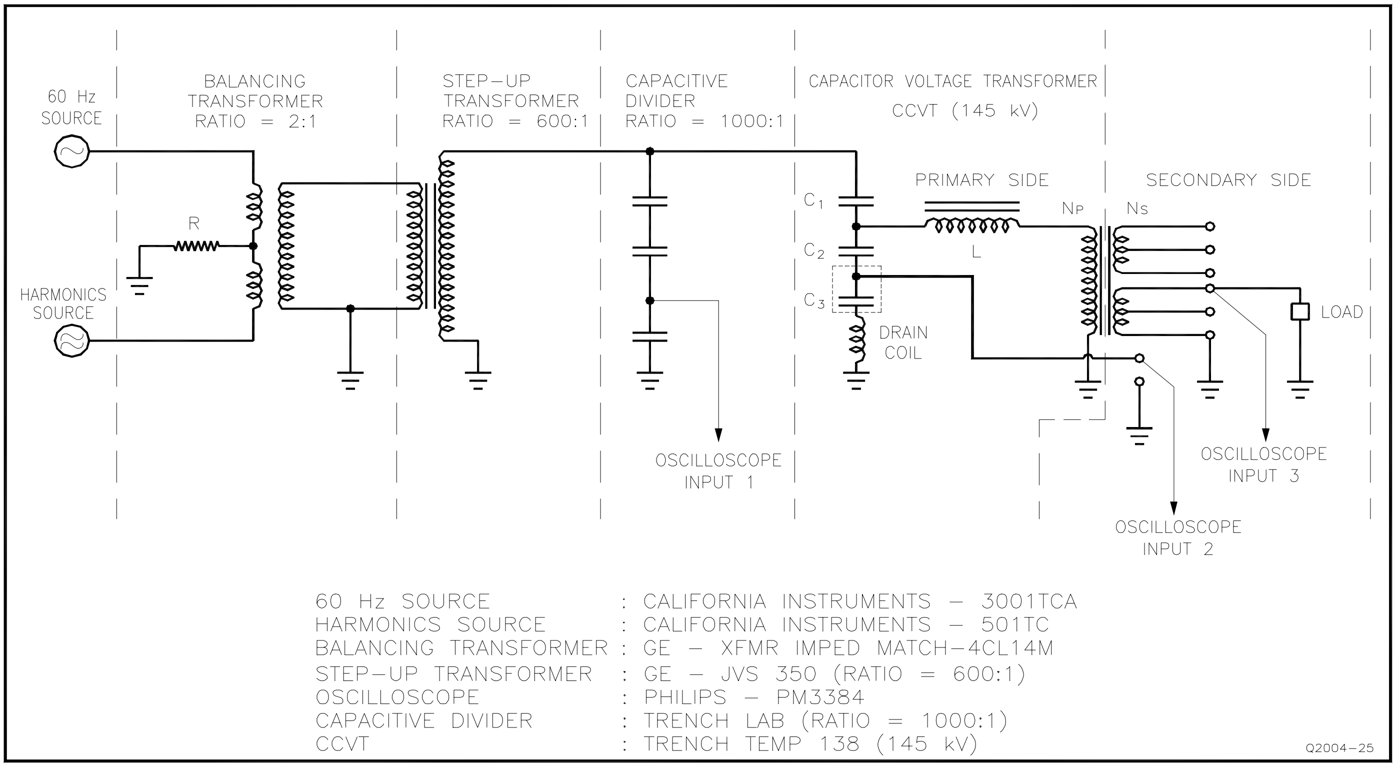


Fig. 1 Test circuit for frequency scan of CCVT with built-in harmonic monitoring terminals

Measurements were performed by using multi-input oscilloscope (PHILIPS-PM3384) to obtain and store data and waveforms for post-processing using ATP Analyzer. It is a very important to use proper cables (i.e. double-shielded) for cabling in order to eliminate any back ground noise. The premise of the test was to inject power frequency signal with harmonic content (measured as % of THD) (Input 1- Fig. 1.) and simultaneously measure % of THD across harmonic monitoring terminals (Input 2- Fig. 1.) and secondary terminals (Input 3- Fig. 1.). The same test was performed with CCVT being loaded with 200VA and without secondary load as well as with tap point (C1/C2) of electromagnetic unit (EMU) being disconnected from the capacitor divider of the CCVT.

Since total harmonics distortion (THD) is the most relevant information to be obtained from the power systems for further analysis, the accuracy of the monitoring device (VT/PT, CT, CCVT etc.) in the frequency spectrum of the interest is of the utmost importance. For this reason the test and measurements had been performed at relatively low voltage level (up to 1kVrms at 60 Hz), while accuracy of the transfer of THD from primary side to the secondary side (harmonic monitoring terminals) had been measured for harmonics up to 50th (3000 Hz).

IV. TEST RESULTS

The results of the laboratory frequency scan tests are shown in Tables I-III and corresponding Figures 2-4. It should be noticed how in agreement are THD values of CCVT input and what was measured across the harmonic monitoring terminals. At the same time THD values measured across secondary of the CCVT yields the typical frequency response for a common CCVT design. Note the large error around 500-800Hz.

Figures 5 to 10 show waveforms of different harmonics captured during frequency scan. Comparing waveforms (CCVT input vs. Harmonic terminals) there was no apparent phase shift noticed, while (CCVT input vs. sec. terminals) there is a phase shift.

Table I

No secondary load			
Fn	CCVT input	CCVT sec.term.	Harmonics mon. term.
(Hz)	Osc. Input1	Osc. Input3	Osc. Input2
	THD(%)	THD(%)	THD(%)
180	17.17	17.29	17.20
300	9.96	10.32	9.65
420	6.63	8.47	6.73
560	10.63	3.50	10.99
660	7.52	5.05	7.74
780	7.30	5.33	6.75
900	4.82	3.88	4.82
1020	4.37	3.16	4.40
1140	3.57	2.75	3.10
1260	3.91	3.31	4.03
1500	14.25	11.72	13.60
1620	11.30	9.30	11.17
1740	7.66	6.60	7.96
2000	5.06	4.25	4.90
3000	6.80	5.60	6.70

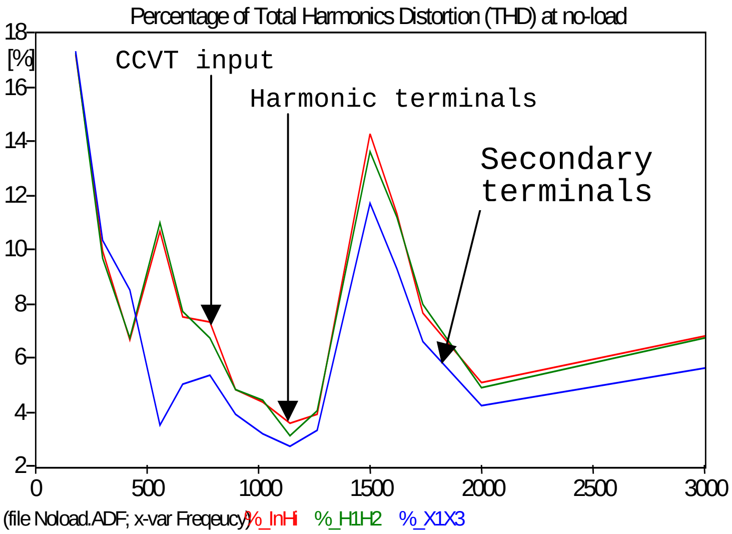


Fig.2. THD % at no secondary load

Table II

Secondary load - 200VA			
Fn	CCVT input	CCVT sec.term.	Harmonics mon. term.
(Hz)	Osc. Input1	Osc. Input3	Osc. Input2
	THD(%)	THD(%)	THD(%)
180	36.76	34.02	35.70
300	20.50	18.13	19.93
420	13.35	11.10	12.86
560	9.15	3.20	8.83
660	6.84	5.50	6.51
780	7.86	6.15	7.50
900	5.87	4.60	5.50
1020	3.99	2.70	3.87
1140	6.50	4.97	6.03
1260	5.29	4.39	5.03
1500	3.86	3.15	3.66
1620	3.80	3.99	3.46
1740	3.68	3.86	3.35
2000	3.56	3.74	3.24
3000	2.06	1.50	1.90

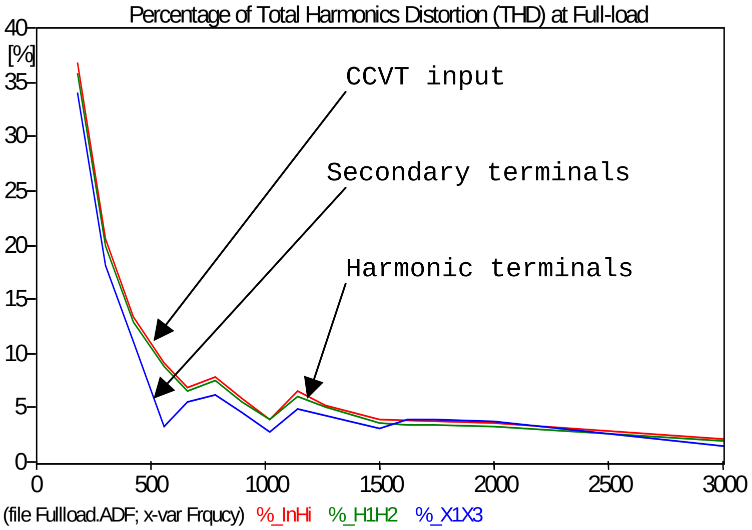


Fig.3. THD % at secondary load-200 VA

Table III

Elec.mag. unit (EMU) disconnected		
Fn	CCVT input	Harmonics mon. term.
(Hz)	Osc. Input1	Osc. Input2
	THD(%)	THD(%)
180	68.96	69.28
300	38.99	39.43
420	23.01	22.81
560	14.74	14.63
660	10.75	10.38
780	6.89	6.87
900	4.93	4.91
1020	9.08	8.81
1140	6.75	6.57
1260	5.40	5.03
1500	3.20	3.10
1620	3.18	3.08
1740	3.17	3.07
2000	3.15	3.10
3000	2.28	2.35

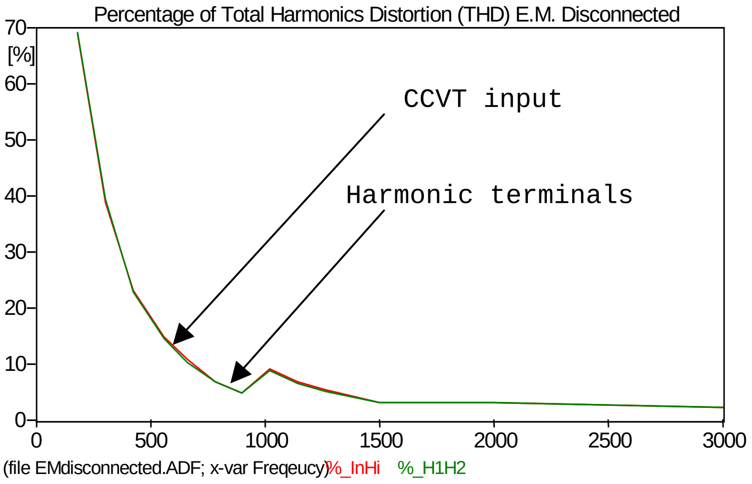


Fig.4. THD % Tap point (C1/C2) of (EMU) disconnected

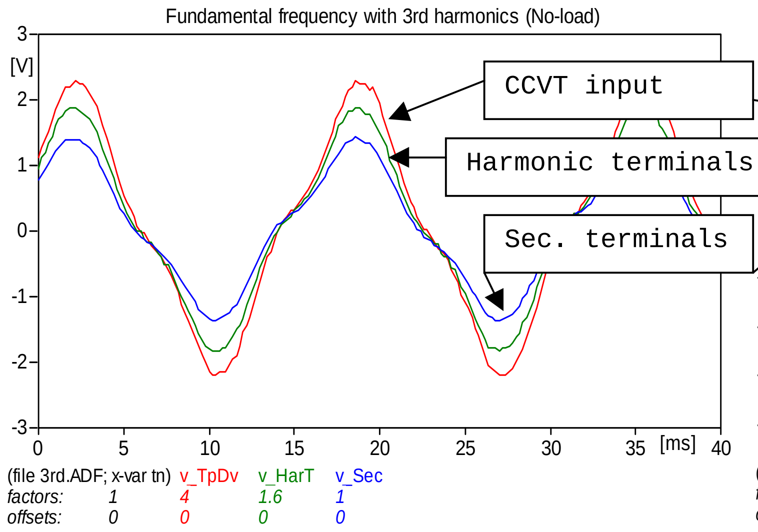


Fig.5. 3 th (180Hz) Harmonic waveform-no load

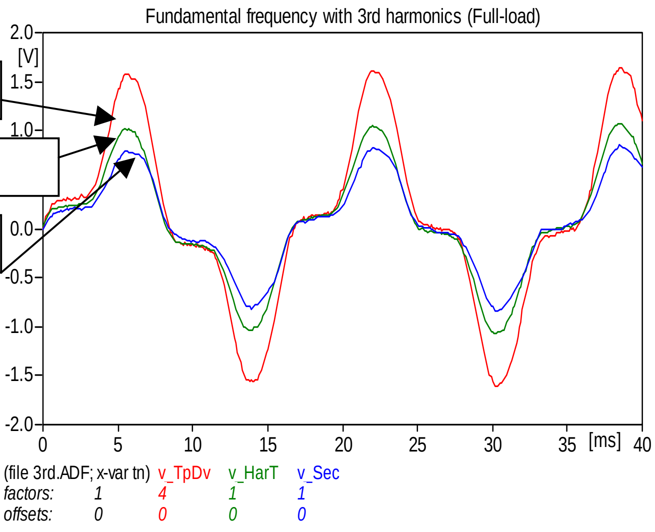


Fig.6. 3 th (180Hz) Harm. waveform- sec.load-200 VA

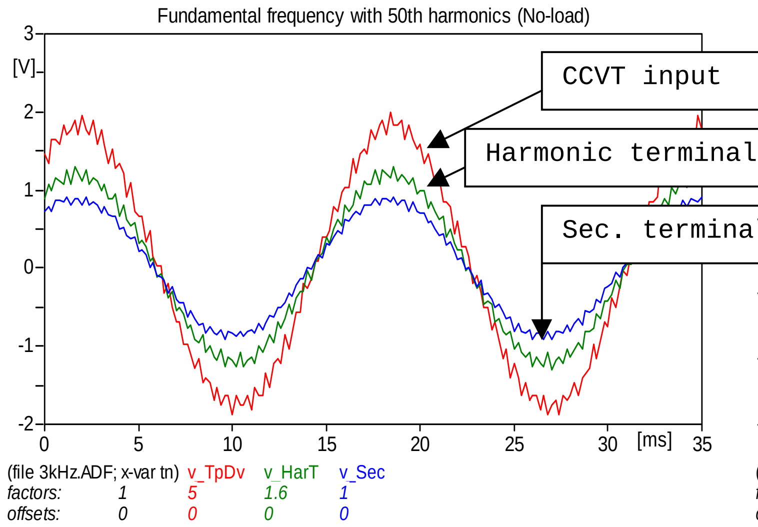


Fig.7. 50 th (3000Hz) Harmonic waveform-no load

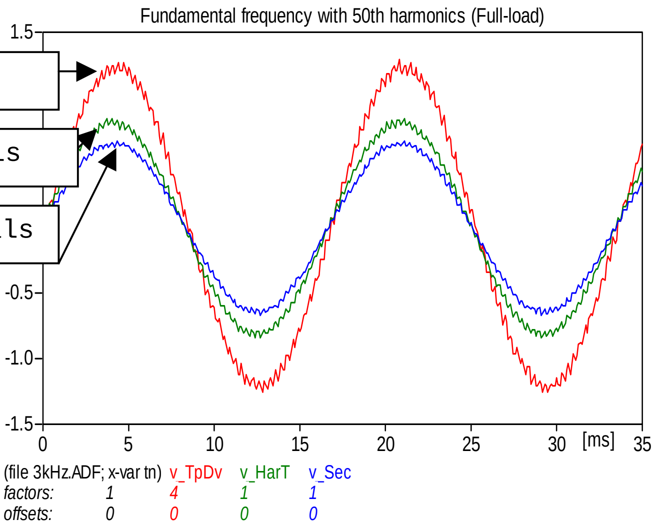


Fig.8. 50 th (3000Hz)Harm. waveform- sec. load-200 VA

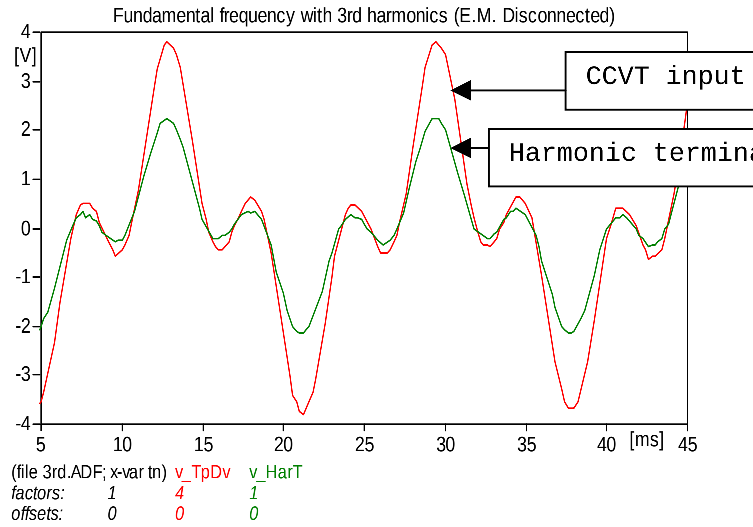


Fig.9. 3 th (180Hz) Harm. waveform- Tap point (C1/C2) of (EMU) disconnected

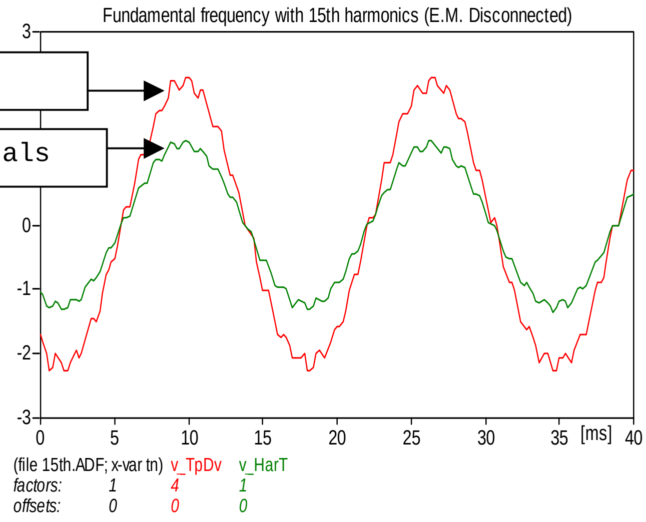
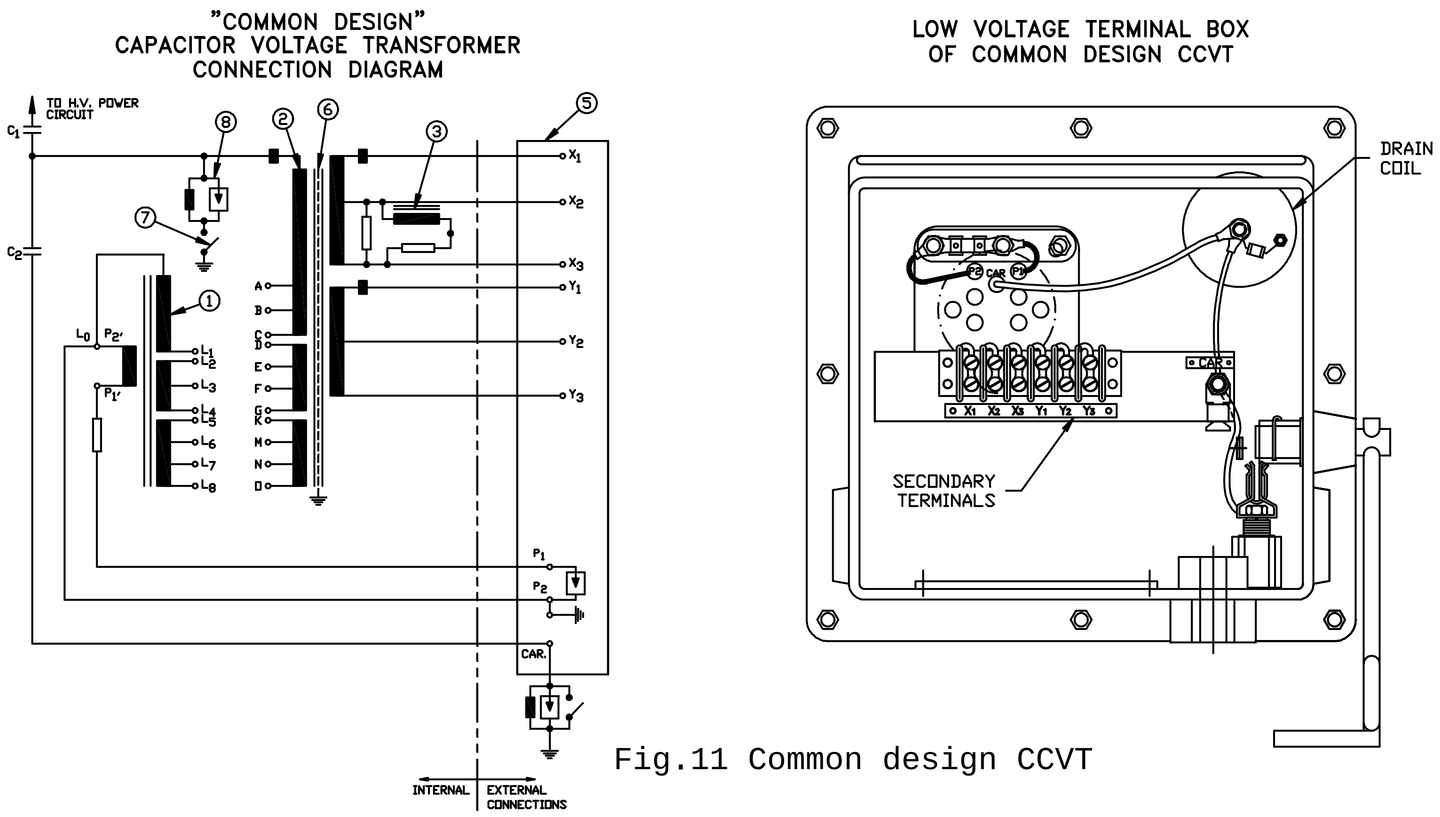


Fig.10. 15 th (900Hz) Harm. waveform- Tap point (C1/C2) of (EMU) disconnected



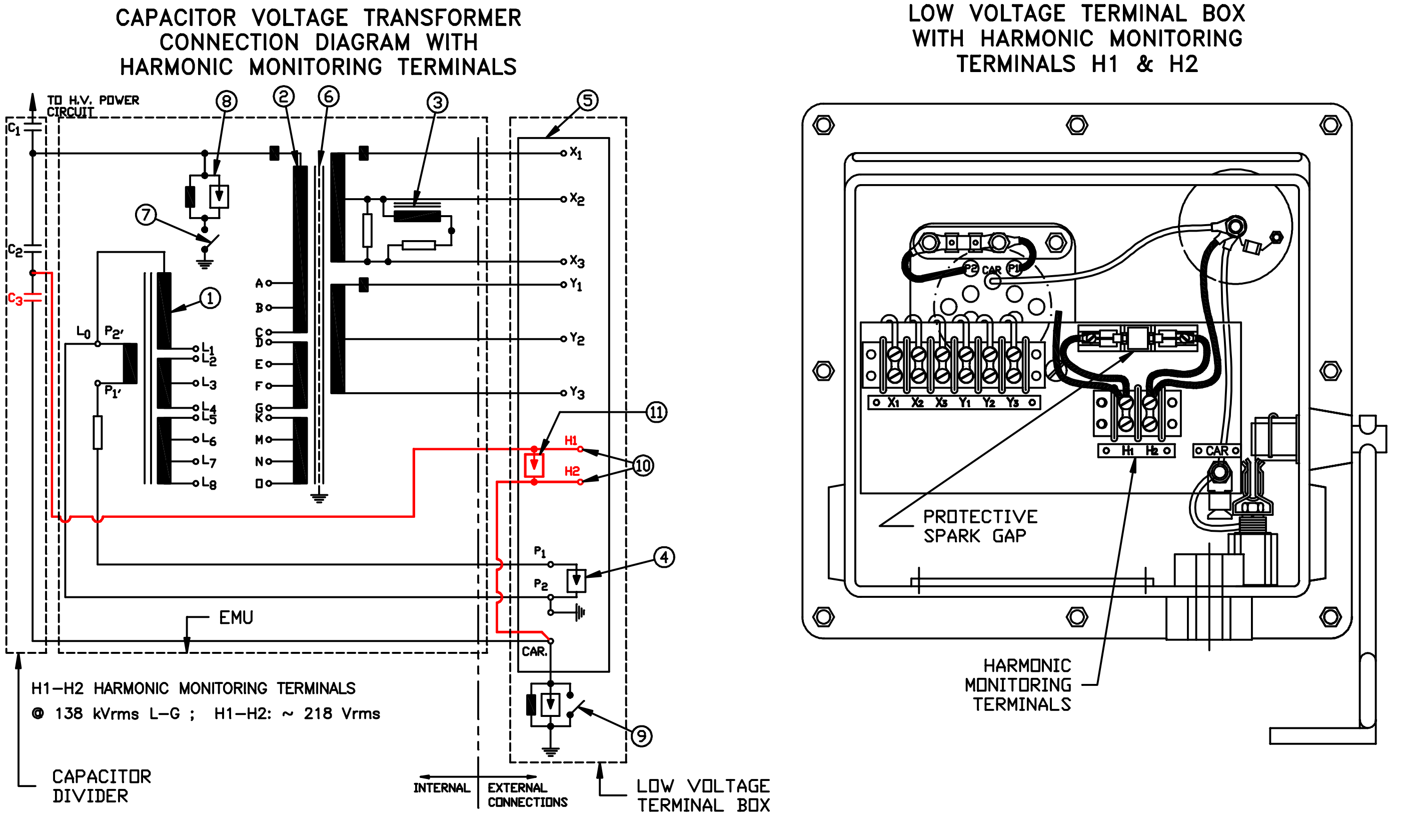
"COMMON DESIGN" CAPACITOR VOLTAGE TRANSFORMER CONNECTION DIAGRAM

LOW VOLTAGE TERMINAL BOX OF COMMON DESIGN CCVT

Fig.11 Common design CCVT

NOTE: CONNECTION BETWEEN INTERNAL TERMINALS L_1 … L_8 AND A, D … O ARE MADE AT THE FACTORY AS REQUIRED FOR EACH UNIT.

① SERIES REACTOR
② INTERMEDIATE VOLTAGE TRANSFORMER
③ FERRORESONANCE SUPPRESSOR CIRCUIT
④ PROTECTIVE GAP
⑤ SECONDARY TERMINAL BOARD
⑥ FARADAY SHIELD
⑦ POTENTIAL GROUND SWITCH
⑧ CHOKE COIL AND GAP ASSEMBLY
⑨ DRAIN COIL, GAP AND CARRIER GROUND SWITCH ASSEMBLY
⑩ HARMONIC MONITORING TERMINALS
⑪ PROTECTIVE SPARK GAP



CAPACITOR VOLTAGE TRANSFORMER CONNECTION DIAGRAM WITH HARMONIC MONITORING TERMINALS

LOW VOLTAGE TERMINAL BOX WITH HARMONIC MONITORING TERMINALS H1 & H2

Fig.12 Coupling Capacitor Voltage Transformer with Harmonic Monitoring terminals

V. CONCLUSIONS

As mentioned in [1], “The possibilities of using a high voltage CVT to measure harmonics depend on the design of the CVT”. In this specific case, it is shown that using slightly modified design of CCVT with special harmonic voltage monitoring terminals brought out from capacitor divider of the CCVT provides the frequency response that common design CCVT in most cases cannot provide. Based on the measurement of THD in wide frequency spectrum (up to 50 th harmonic), it is shown a very high accuracy of the measurement. For example the conventional CCVT shows errors as high as ~30% whereas the harmonic measurement output remains within 5-10% at worse, 1-3% typical. At the same time there is no phase shift that may be important if there is need for power measurement.

Special considerations must be taken in the design regarding the instrument being used to monitor and measure harmonics, (i.e. high input impedance of the instrument, >200kOhm).

CCVT’s (i.e.Trench product) installed in-field could be relatively easily retrofitted in order to be used for accurate harmonic monitoring and measurement.

The implementation of the harmonic monitoring terminals provides additional benefits to the user while maintaining all existing features and benefits of the CCVT as a voltage measurement device such as:

- Accurate voltage transformation
- Power Line Carrier Coupling
- Breaker TRV mitigation
- Accurate Harmonic Voltage measurement

VI. REFERENCES

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VII. BIOGRAPHIES

1. Miloje Tanaskovic received Bachelor of Science degree in Electrical Power Engineering from University of Sarajevo , Bosnia and Herzegovina in 1982.

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