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IEC 61850 Compatible Electronic CTs for MV Networks in Nuclear Power Plants

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1. Introduction

Electric power systems in power plant usually divided into 2 groups by voltage level. Medium voltage (1 KV to 100 kV) and low voltage (less than 1 kV) systems. For the medium voltage (MV) network integrated digital protective relays (IDPR) are provided in general. The digital protective relays perform not only protection function but also control and monitoring functions for electric power systems. Digital protective relays utilizing IEC61850 functionality have been developed for MV protection relays as well as low voltage (LV) circuit breakers recently. Together, these devices make it possible to design and operate a fully integrated protection and control system that spans the LV and MV networks.

One of the important devices of the electrical protection and control system is input device such as current transformers and voltage transformers. In this regard, this paper proposed to implement electronic current transformer (ECT) and IEC 61850 standard protocol to resolve the challenges in the existing current transformers of medium voltage switchgears and to improve the performance of nuclear power plant electrical protection and control systems. CT performance simulation has been performed to analyze saturation effect and measurement error. Then proposed the system configuration of the ECT and IEC 61850 based electrical protection and control system for nuclear power plants.

2. Conventional Current Transformer

The rated primary current (I_{pn}) of CT will always be greater than or equal to the service current. The rated thermal short-circuit current (I_{th}) is usually the short-circuit current of the installation and its duration is usually assumed to be 1 sec. All CTs must be able to resist the rated short-circuit current in the primary winding both thermally and dynamically until the malfunction induces shutdown. The secondary circuits of a CT must be suitable for the constraints related to its application for metering or protection purposes [1].

The accuracy class of a North American CT is given by a letter and secondary voltage rating. The accuracy voltage rating is the CT secondary voltage that the CT will deliver at 20 times the rated secondary current when connected to a standard burden without exceeding a 10% error.

2.1 An Example of MV Switchgear Design

Fig. 1 is a part of the 13.8kV switchgear single line diagram for an APR1400 nuclear power plant. In Fig. 1 short circuit withstand current of the switchgear and breakers is 50kA. Load is 750kVA and 1,000kVA transformers each. According to general practice for CT rating selection, appropriate CT rating and accuracy class are 50/5A, C20 for 750 kVA transformer feeder and 75/5A, C20 for 1,000 kVA transformer feeder [2]. But, in the example of Fig. 1, 13.8 kV switchgear, two parallel 400/5A, C100 CTs were applied for each feeder (See Fig.2).

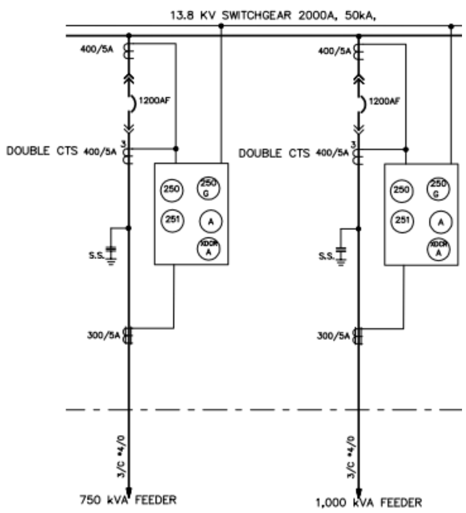


Fig. 1. Double CT Circuit in 13.8kV Switchgear Feeders

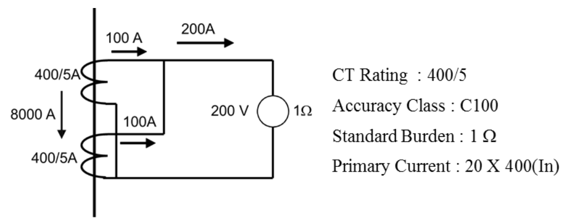


Fig. 2 Parallel Connection of Two CTs

CT saturation phenomenon caused by very high short circuit current can be mitigated by increasing CT primary current rating and accuracy class. On the other hand, normal load current of the transformer feeders is less than 10% of the CT primary rating. If demand factor of the 1,000kVA transformer is 0.8, load current is only 33.5A and 8.4% of the CT primary rating. That means CT's measurement error is uncertain. IEEE standard do not define accuracy between 0% and 10% of rated current. Current metering error is CT error plus meter error. By parallel connection of two CT effective CT current is doubled and meter error can be improved but CT error still exists. As a conclusion, parallel connection of high rating CTs can't be a satisfactory solution.

2.2 Simulation Results of Conventional CTs

CT performance was simulated by electromagnetic transient program revised version (EMTP-RV) for the branch circuits of Fig. 1. The ratings of CT and technical data of the circuit used in the simulation are as follows;

- CT Rating: 400/5A x 2 Parallel
- Accuracy Class: C100
- Standard Burden: 1.0 Ω
- Short circuit current (Symmetrical RMS): 45kA
- Short circuit current (Asymmetrical RMS): 65kA

Performance curve of 400/5A CT was assumed as Fig. 3[3] and estimated CT exciting current (I_E) and terminal voltage (V_S) are as Table I.

Table I: CT Excitation Current (Ie) and Terminal Voltage (Vs)

I_E (A)	0.02	0.04	0.07	0.1	0.2	0.3	1
Vs (V)	4	10	20	40	80	100	120

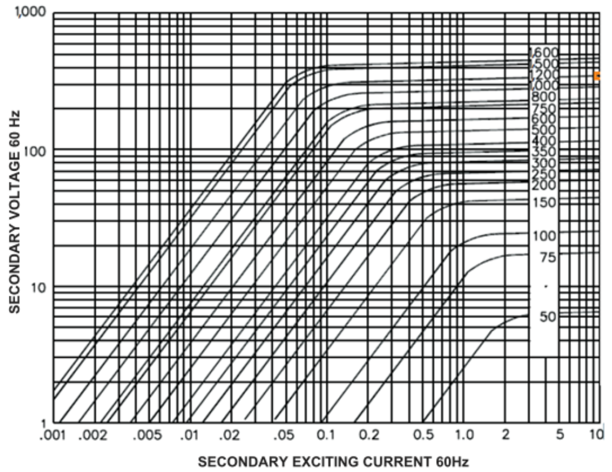
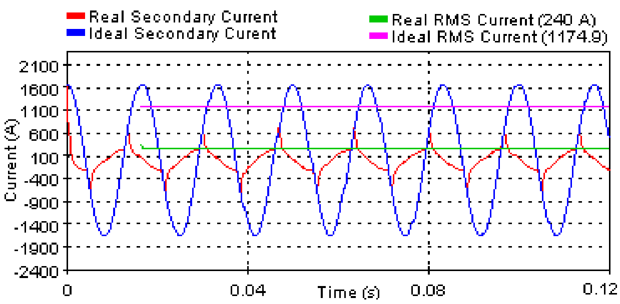
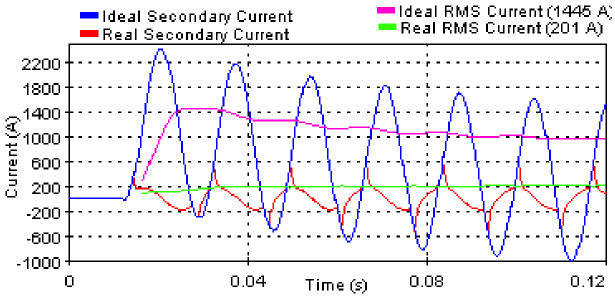


Fig. 3 CT excitation curves for multi-ratio C or K class current transformers with nongapped cores



(a) Short circuit fault state CT secondary current (Symmetrical)



(b) Short circuit fault state CT secondary current (Asymmetrical)

Fig. 4 CT secondary curves when short circuit fault occurs in the primary circuit.

3. Electronic Current Transformers

3.1 Electronic current transformer

Electronic current transformers intended for both measurement and protection should comply with all the clauses of IEC60044-8 standard and are called multipurpose electronic current transformers.

The ECT consists of an inductive current transformer with primary winding, small core and a secondary winding with minimized losses which is connected to a shunt resistor R_{sh}. The secondary current I_s causes a voltage drop U_s across the shunt resistor which is proportional to the primary current in amplitude and phase. Furthermore, the transformer becomes more ideal with respect to measuring range and accuracy the smaller the secondary power requirement of burden and internal losses becomes. The function of the ECT is as described as Fig. 5 where R_{sh} for example, is designed in a way, that U_{smax} corresponds with I_{th} [4].

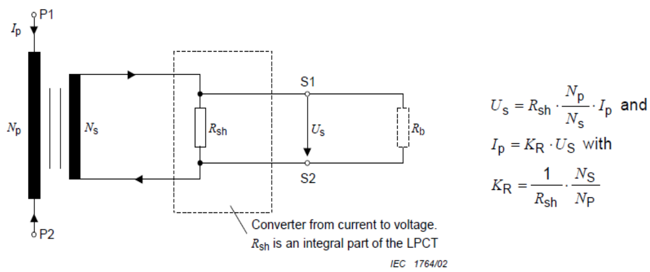


Fig. 5 Iron-core-coil current transformer

Because of the low input power requirement of modern electrical devices, the ECT can be dimensioned for high impedances R_b. Therefore, a substantial characteristic of the classical inductive current transformer, its saturation in case of very high (displaced) primary currents, is improved and in this way the measuring range is expanded enormously. The reduction in total power consumption enables a saturation-free measuring of overcurrents up to short-circuit currents with high accuracy.

"To use efficiently the advantages for electrical current and voltage transformers, the signals must be treated in a uniform way. A recommended way to do this is to combine the currents and voltages from one bay, i.e. the currents and voltages in the three phases and transmit them in one protocol. The physical unit doing this combination of currents and voltages is called the merging unit (MU)." [5] The structure of the measuring system is given in Fig. 6.

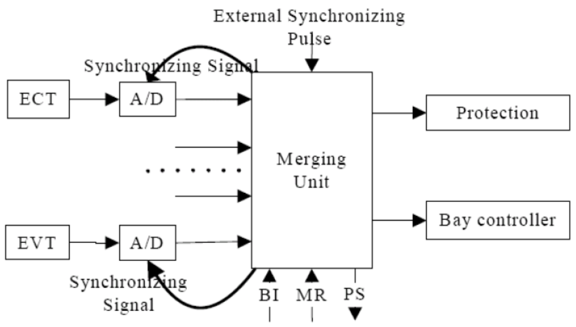


Fig. 6 Merging Unit Definition in IEC 60044-8

3.2 Simulation results of electronic current transformer

The simulation for an ECT was performed with the same conditions of conventional CT. Input data used in the simulation are as follows [6];

- Rated primary current (I_{pr}): 50 ~ 5,000A
- Secondary voltage(U_{sr}): 22.5 mV ` 2.25V
- Rated short circuit current: up to 63 kA/3 sec
- ECT performance curve: Table II and Fig. 7
- Accuracy: 0.2, 0.5 0r 1.0 and simultaneously class 5P up to 63kA
- Burden: 20 kΩ

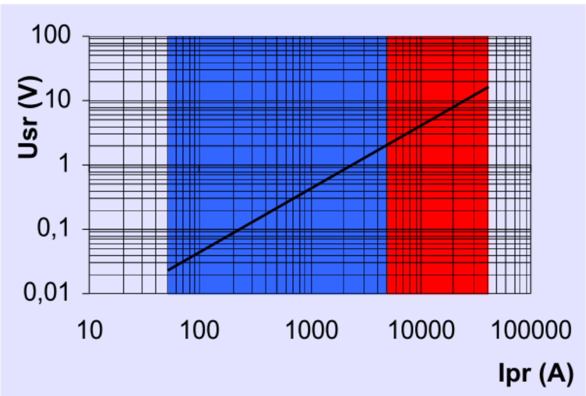
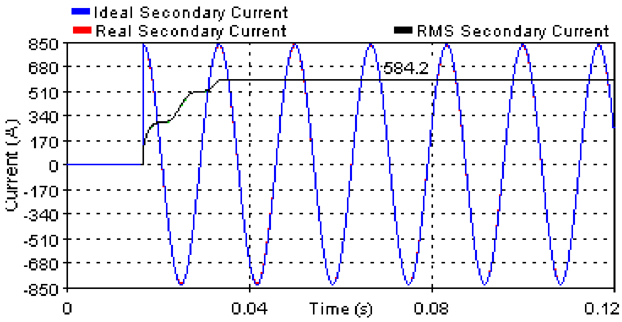


Fig. 7 Performance curve of the ECT

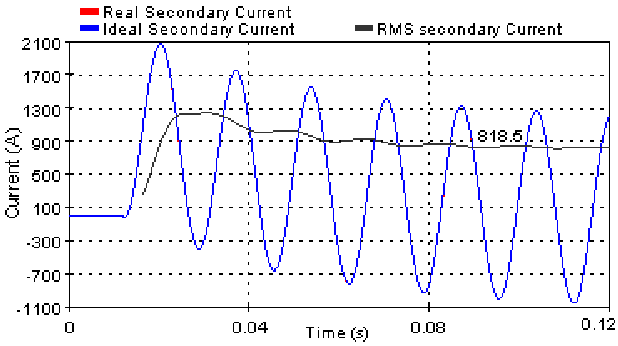
Table II: CT Primary Current (Ipr) and Terminal Voltage (Usr)

I_{pr} (A)	0.04	0.3	3	8
U_{sr} (V)	90	700	9000	20000

The ECT performance simulation results are shown in Fig. 8. It was assumed that ECT replace the conventional CTs in Fig. 1 and operation condition is the same. According to the simulation result, short circuit fault condition ECT produce clean sine wave secondary current without distortion.



(a) Short circuit fault state ECT secondary current (Symmetrical)



(b) Short circuit fault state ECT secondary current (Asymmetrical)

Fig. 8 ECT secondary curve when short circuit fault occurs in the primary circuit.

In Fig. 4, the conventional CT simulation curve, CT secondary symmetrical and asymmetrical current (rms) at primary circuit short circuit fault condition is only 20.42 % and 13.9 % of ideal secondary current respectively. It may cause the malfunction of instantaneous overcurrent relay (50) and fault current measuring error. But Fig. 8, the ECT simulation curve shows that no phase distortion occurs in the CT secondary current.

As a result, CT saturation in high fault current circuit and accuracy deterioration in low full load current circuit can be improved by replacing conventional CT to ECT. In addition, ECT with digital output can minimize metering errors as shown in Fig. 9[7].

If the ECTs and EVTs are digital output type, the error contribution from the purely digital signal transmission is eliminated. The meter is in this case a pure calculation from the digital values and thereby not adding any errors provided the precision in the calculation is properly chosen. All possibilities of temperature or long-term drift in the meter is also eliminated [5].

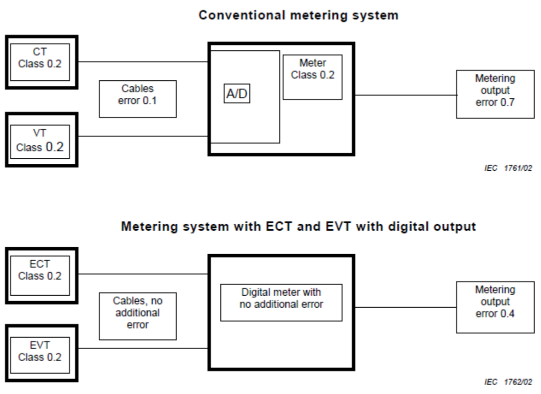
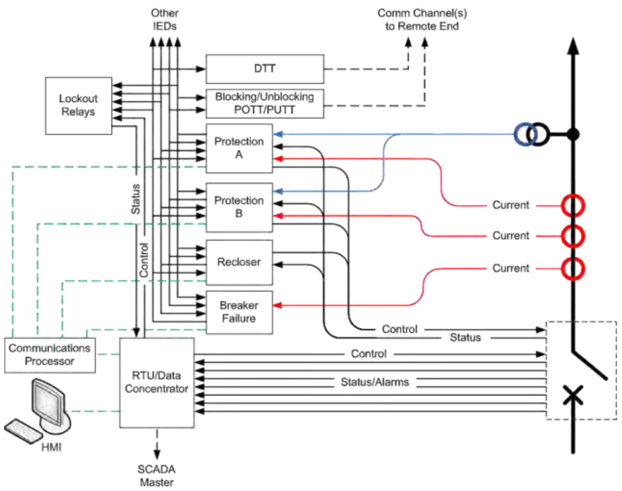


Fig. 9 Comparison of errors in conventional metering systems and systems based on ECTs and EVTs with digital output

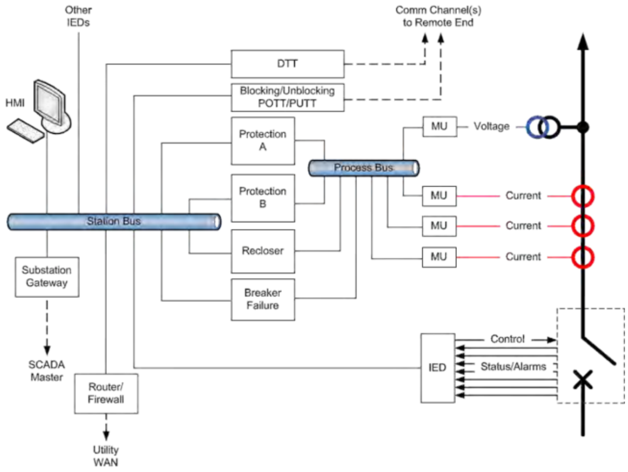
4. Compatibility of IEC 61850 and Electronic CT

IEC 61850 delivers an unprecedented amount of functionality that is simply not available from legacy communications protocols. These unique characteristics of IEC 61850 have a direct and positive impact on the cost to design, build, install, commission, and operate power systems. While legacy protocols on Ethernet enable the electrical engineer to do the same thing that was done 10-15 years ago using Ethernet, IEC 61850 enables fundamental improvements in the substation and distribution system automation process that is simply not possible with a legacy approach, with or without TCP/IP-Ethernet.

Fig. 10 [8] shows an example of the station and process bus architecture of the IEC 61850 based system and the traditional system. IEC 61850 based electrical protection and control system provides more plenty functions with more simple architecture.



(a) Traditional architectur



(b) IEC 61850 based system architecture

Fig. 10 Station and process bus architecture

If the ECTs and IEC 61850 standard are implemented together into the power distribution automation system, the CT saturation and accuracy deterioration problems of conventional CTs can be resolved and can take many other benefits as below;

- Reduce CT and switchgear design cost and time
- Save installation cost
- Reduce integration cost
- Implement new capability

5. Conclusions

IEC 61850 is a unique international standard for substation automation and assure device interoperability. Combination of IEC 61850 standard and the ECT can enhance interoperability and reliability of the protection, control and monitoring system in the medium voltage networks in nuclear power plants. This paper proposed how to implement ECT on the medium voltage networks in NPPs.

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