Proceedings of the 11th KACC, October 1996

Revenue Metering System Using Optical CPT

Hong Keun Cho, Seok Ku Kim, Won Bin Lee
Korea Electric Power Research Institute
103-16 Munji-dong Yusung-ku, Taejon Korea 305-380

1.Abstract

A new concept of 22.9kV class revenue metering system based on the optical sensing technique was designed and implemented.

This paper reports on the performance of a 22.9kV class three phase optical current / voltage metering scheme and three tariff metering system. This optoelectronic system was designed and developed to advance the state of the art in revenue metering. This paper deals with the characteristics of designed optical CPT (Current and Potential Transformer) and optoelectronic demand meter. The extensive field evaluation of the developed system with the existing oil filled transformer and solid state metering pair is undertaking. Upto now the operation of the optical revenue metering system under the field condition compares favorably with the existing system.

2. Introduction

The advent of an optoelectronics technology with fiber-optic link is creating a revolution in the field of power measurement. The existing inductive devices such as current/potential transformers being used have problems of the high insulation cost, heavy, bulky and especially susceptible to the surge or noise. In addition to these, there are distortion problems due to the magnetic saturation or the resonance phenomenon by harmonics.

To cope with above problems we developed optical CT(Current Transformer), PT (Potential Transformer) which triggered to develop optical metering outfit and demand meter that processing the modified optical signal. We adopted garnet films and BSO crystals to compose the optical CT(Current Transducer) and PT(Potential Transducer) sensors that have Faraday effect and Pockels effect respectively. For physical construction of robust and functional optical circuits of revenue metering logic, LED, PIN-PD and microprocessors that have the advantages of high power/sensitivity and a mature, well-characterized technology base were used.

Detected signals from metering outfit are transmitted through an optical fiber into the demand metering device that consists of light sources, detectors and signal processing modules.

This paper describes fundamental theory of optical sensors and circuitry for optical CT/PT and optical processing device for revenue metering. The main contents in this study are as follows.

- optical sensors for current and voltage measurement
- composition of optical metering outfit
- optoelectronic demand metering scheme
- installation and field trial
- results and further study

3. Optical Transducers

3.1 Optical Current Sensor

The magneto-optic current transducer is based on the Faraday effect, which states that a material, such as an iron garnet will become optically active when exposed to a strong magnetic field. Optically active means that when polarized light is transmitted through an iron garnet in a direction that is parallel to the applied magnetic field, the plane of light is rotated. The amount of rotation for any given substance is found experimentally to be proportional to the strength of the applied magnetic field and the distance the light travels through the medium. The rotation can be expressed by the relation,

$$\theta_F = \mu V N I \qquad (1)$$

where I is the current in amperes, N is the number of turns around the conductor, μ is the constant of permeability that equals unity in air, V is the Verdet constant, which is defined as the rotation per unit path per unit field strength, and θ_F is the angle of rotation in radians.

A current sensor is formed by looping an optical fiber around a conductor. Since Ampere's law,

$$\int H d\ell = I \qquad (2)$$

Since the application we are interested in is a single turn of the crystal in air, above formula can be reduced to

$$\theta_F = V I \qquad (3)$$

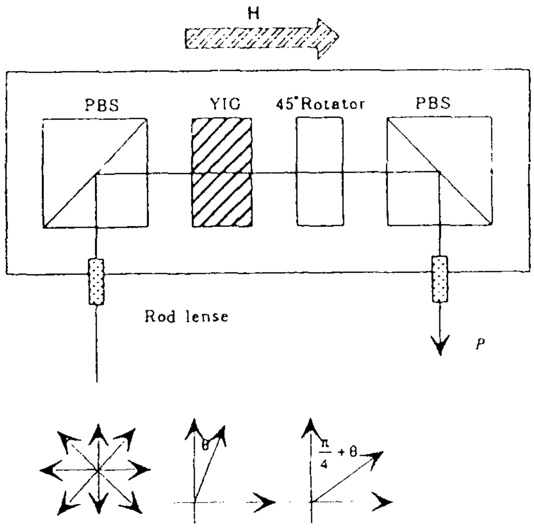

Fig.1 Configuration of Optical Sensor

3.2 Optical Voltage Sensor

The optical voltage transducer is based on the Pockels effect, which linearly polarized beam into a Pockels sensor causes the beam to be divided into two linearly polarized beams at different speeds and crossing each other at angles, becoming an elliptically polarized beam resulting from a phase difference between them at the sensor with the applied voltage. The light turned into a linearly polarized beam by a polarizer is injected into a Pockels sensor at a 45° angle to the crystal axes(X,Y) of the sensor. In the Pockels sensor, the light is given a phase difference γ by voltage application. Then the emitted light is passed through a quarter-wave retardation plate to be given a 90° optical bias, and further passed through an analyzer with the azimuth turned by 90° to be converted into an intensity signal P represented by

$$P = P_0(1 + \sin\delta) \qquad (4)$$

$$\gamma = \pi (V/V_\pi) \qquad (5)$$

4. Optical CPT(Current and Potential Transformer)

The present metering transformer being used has distortion problems due to the magnetic saturation or harmonics. In this respect, we designed the optical current and potential transformer based on the optical sensing technology as shown in Fig.2. The beam from the light sources(LED, λ =850nm) installed in a demand meter are guided through optical fibers(100/140μm, GI mode) to the optical current and voltage sensors located top and bottom inside of the insulator respectively. Capacitor-divided voltage of 132V is applied to the optical voltage sensor.

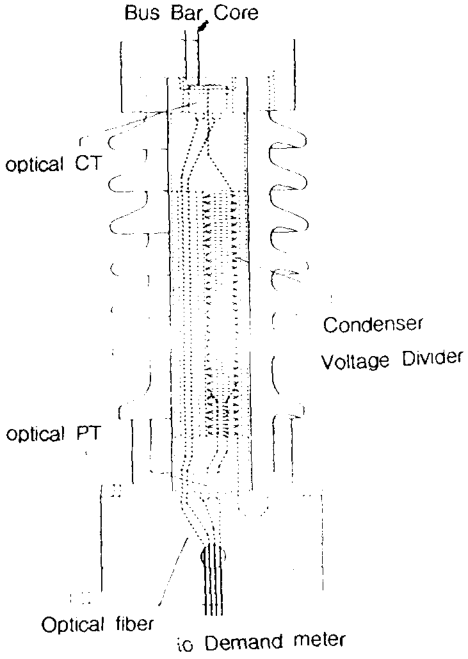

Fig.2 Crosssectional diagram of optical CPT

The beam modulated by the Pockels effect is guided through an optical fiber into the photo diode in the demand meter and signal processed. Twenty condensors are connected with serial for the primary voltage divide and five more condensors are hooked up with one of them parallel for the secondary dividing.

5. Optical Demand Metering Scheme

Fig.3 shows the demonstrantion of the optoelectronic demand metering system. The array of voltage sensor consists of polarizing beam splitter(PBS), BSO as a Pockels element, 1/4 wave plate and selfoc microlenses(SML). Garnet films are adopted as the Faraday element in the array for current sensors which are placed in the pure iron core to increase the magnetic field.

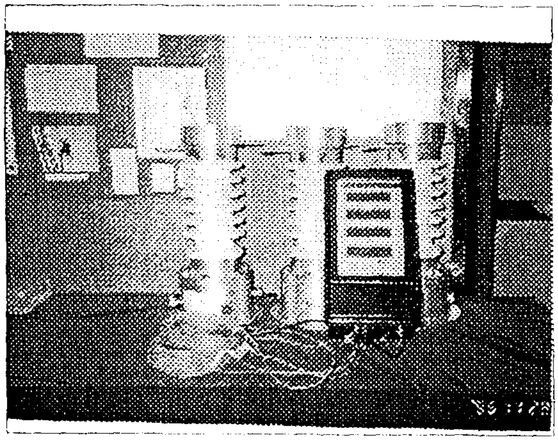

Fig.3 Appearance of optoelectronic demand metering system

Fig.4 shows the block diagram of the optical revenue metering system. Optical CT and PT with voltage divider are built in a insulator chamber and light sources with driver and signal processing units are composed in a optical demand meter.

Three insulators are usded for a three phase distribution line metering. Demand meter has 6 LEDs and 6 PIN-PDs for the 3 Φcurrent and 3Φ voltage. This can display the 3 different time watt-hour meter, peak value, VAR, cosΦ and current time, date, year.

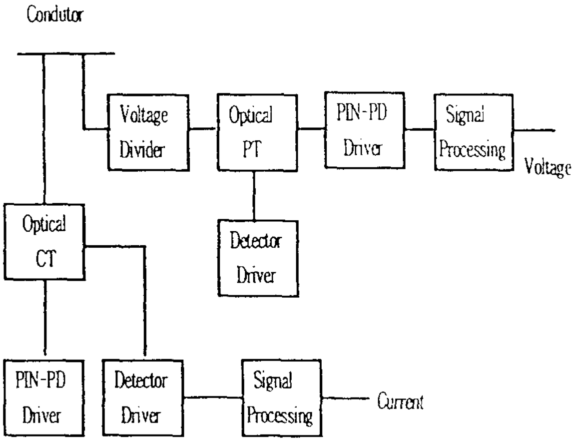

Fig.4 Schematic diagram of Optical metering outfit

6. Test Results and Operation

6.1 Characteristics of Optical CPT

Characteristics of the implemented optical CPT are as shown below. Six optical CTs and PTs were tested. Table 1 shows the output voltages along with the input current change from 0 to 400 amperes. Table 2 shows the output voltages along with the input voltage change from 0 to 450 volts. Both CTs and PTs showed below one tenth of a percent deviation at the range, in other words the characteristic curves showed good linearity.

Table 1. Out voltages at the various input current

Input Current I_{max} (A)	Output Voltage V_{rms} (V)					
	CT1	CT2	CT3	CT4	CT5	CT6
0	0.04	0.04	0.03	0.07	0.03	0.04
50	0.5	0.5	0.5	0.5	0.51	0.49
100	1.04	1.05	1.03	1.04	1.03	1.04
150	1.56	1.59	1.57	1.57	1.57	1.57
200	2.08	2.11	2.07	2.07	2.07	2.1
250	2.58	2.59	2.57	2.54	2.57	2.58
300	3.06	3.04	3.04	3.04	3.04	3.07
350	3.54	3.54	3.53	3.5	3.52	3.54
400	4.0	4.0	4.0	4.0	4.0	4.0

Table 2. Output voltages at the various input voltage

Input Voltage V_{max} (V)	Output Voltage V_{rms} (V)					
	PT1	PT2	PT3	PT4	PT5	PT6
0	0.04	0.04	0.04	0.04	0.04	0.05
50	0.51	0.55	0.53	0.51	0.53	0.53
100	1.04	1.01	1.047	1.07	0.98	1.08
150	1.49	1.56	1.53	1.56	1.49	1.58
200	1.98	2.02	2.08	2.09	1.94	2.06
250	2.52	2.59	2.55	2.56	2.36	2.61
300	3.01	3.05	3.02	3.07	2.78	3.04
350	3.52	3.56	3.55	3.54	3.41	3.57
400	3.99	4.04	4.03	4.05	3.99	4.07
450	4.5	4.5	4.5	4.5	4.5	4.5

6.2 Operation of Optical Demand Meter

The optical demand meter that hooked up to the optical CPT receives the optical signals from the sensors and convert those to the pulse trains to compute the quantities for billing and load analysis. The pulses of the watt-hour and var-hour are accumulated to give total kWh and kVARh. This demand quantities are calculated to give kW and kVAR for each interval. From the watt and VAR information kVA can be obtained for

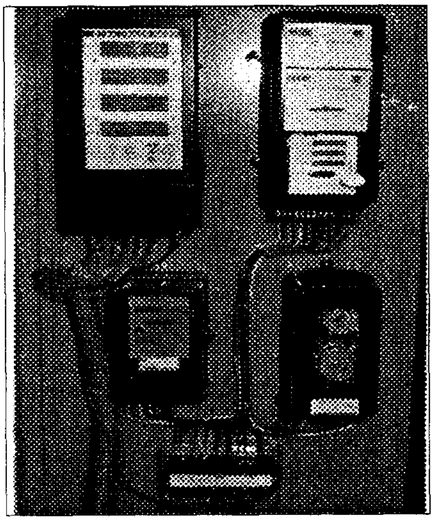

Fig.5 Site installation for comparison

each demand intervals. And power factor can be calculated also from the KVA computation. Designed circuit generate 10,000 pulses for each watt. This demand meter includes a built-in timer for the three tariff revenue metering. This metering system was calibrated against a standard watt-hour meter in the laboratory.

7. Conclusions

A successful implementation of 22kV class optical revenue metering system was developed and tested in the laboratory. This system was installed on the 22.9kV incoming power line of the research building to compare the oil filled conventional MOF (Metering Outfit) and Landis & Gear demand meter pair. This kind of technology could be a solution to the problems that engineers have endured with conventional metering transformers such as saturation under heavy fault current, burden, EMI, frequency response and high insulation etc..

The verification and comparison tests with the conventional metering system are continuing and will be reported in the near future.

References

[1] H.K.Cho et. al."154kV substation optical current measurement system" Proceedings of The International Conference on Electrical Engineering July 1995

[2] H.K.Cho et. al."Development of Optical CT and PT by using BSO Crystal" Preceeding of The Korean Institute of Electrical Engineers July 1992

[3] T. W. Cease, Paul Johnston "A Magneto-Optic Transducer" IEEE Transactions on Power Delivery, Vol.5, No.2, April 1990

[4] Edward F. Kelly, Robert E. Hebner, "Electro-Optic Measurement of the Electric Field Distribution in Transformer Oil" IEEE Transaction on Power Apparatus and System, Vol. PAS-102, No.7, July 1983

[5] Amnon Yariv, Pochi Yeh, "Optical Waves in Crystals" John Wiley & Sons, 1984

[6] Fiber Optic Sensors Working Group "Optical Current Transducers for power systems : A Review" IEEE Trans. on Power Delivery, Vol. 9, No.4, Oct. 1994