POWER QUALITY MONITORING ON DISTRIBUTION NETWORKS USING DISTRIBUTION AUTOMATION SYSTEM

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ABSTRACT

Distribution automation system provides remote supervision and control of switches, such as pole mounted switches and pad-mounted switchgears on medium voltage distribution networks. It can be remotely controlled either automatically or manually, so that it can provide automatic isolation of faulty sections, which enables quick and accurate recovery of a stable power supply, and also minimizes the out of service areas by unit of distribution sections. Recently KEPCO tries to add a new function, such as monitoring of power quality on distribution networks using distribution automation system. This paper describes the abstract of power quality problems, system configuration, monitoring points, monitoring items, and analysis program of power quality.

INTRODUCTION

KEPCO(Korea Electric Power Corporation) operates over 30,000 automated switches, such as SF6 Gas switch, auto-recloser, pad-mounted switchgear and pad-mounted breaker in 22.9kV distribution networks for distribution automation. Basic functions of DAS are remote monitoring, remote control, remote measuring, and remote setting. There are many application programs for feeder automation such as single line drawing program, protection coordination program, voltage drop calculation program, FLISR(fault location, isolation, and service restoration) program, optimal feeder reconfiguration program for loss minimization and load balancing, section load management program, data error detection program.
Recently KEPCO is adding a new function in DAS, which is the power quality monitoring at distribution networks such as primary substation, distribution substation, switching station, automated switches that was installed either overhead or underground distribution lines, high voltage customers and low voltage customers and distribution transformers.

TYPES OF POWER QUALITY PROBLEMS

In general, power quality problems contain several items such as interruptions, under voltage, over voltage, lightning and switching surges, sags, swells, harmonics, voltage unbalance, flicker and so on. This is the explanation of the types of power quality problems [1][2].

Voltage sags (dips)

Voltage sags are referred to voltage dips. IEEE defines voltage sags as a reduction in voltage for a short time. The duration of voltage sag is less than 1 minute but more than 8 milliseconds (0.5 cycle). The magnitude of the reduction is between 10 percent and 90 percent of the normal root mean square (rms) voltage at 60 Hz.

Voltage swells

Voltage swells, or momentary over-voltages, are rms voltage variations that exceed 110 percent of the nominal voltage and last for less than 1 minute. Voltage swells occur less frequently than voltage sags. Single-line to ground faults causes voltage swells. Long-duration over-voltages are close cousins to voltage swells, except lasting longer. The major cause of over-voltages is capacitor switching, the dropping of load and missetting of voltage taps on transformers.

Under voltage

Under-voltages occur when the voltage drops below 90 percent of the nominal voltage for more than 1 minute. They are sometimes referred to “brownouts,” although this is an imprecise nontechnical term that should be avoided. They are recognized by end users when their lights dim and their motors slow down.

Interruptions

Interruptions are a complete loss of voltage (a drop to less than 10 percent of nominal voltage) in one or more phases. IEEE defines three types of interruptions. They are categorized by the time that the interruptions occur: momentary, temporary, and long-duration interruptions.
Momentary interruptions are the complete loss of voltage on one or more phase conductors for a time period between 0.5 cycles, or 8 milliseconds, and 3 seconds. A temporary, or short-duration, interruption is a drop of voltage below 10 percent of the nominal voltage for a time period between 3 seconds and 1 minute. Long-duration, or sustained, interruptions last longer than 1 minute.

Voltage unbalance

Voltage unbalance is the deviation of each phase from the average voltage of all three phases. It can be calculated that voltage unbalance ratio equals maximum deviation from average voltage divided by average voltage multiples 100(%).

Voltage fluctuations

Voltage fluctuations are rapid changes in voltage within the allowable limits of voltage magnitude of 0.95 to 1.05 of nominal voltage. Voltage fluctuations can cause incandescent and fluorescent lights to blink rapidly. This blinking of lights is often referred to “flicker.” This change in light intensity occurs at frequencies of 6 to 8 Hz and is visible to the human eye.

Harmonics

Harmonics are the major source of sine waveform distortion. The increased use of nonlinear equipment have caused harmonics to become more common. Harmonics are integral multiples of the fundamental frequency of the sine wave, that is, harmonics are multiples of the 60 Hz fundamental voltage and current. They add to the fundamental 60 Hz waveform and distort it. They can be 2, 3, 4, 5, 6, 7, etc., times the fundamental. Harmonics are usually caused by nonlinear loads, like adjustable speed drives, solid-state heating controls, electronic ballasts for fluorescent lighting, switched-mode power supplies in computers, static UPS systems, electronic and medical test equipment, rectifiers, filters, and electronic office machines. The THD can be used to characterize distortion in both current and voltage waves.

$$V_{THD} = \frac{\sqrt{V_2^2 + V_3^2 + \ldots + V_n^2}}{V_1} = \frac{\sqrt{\sum_{n \geq 2} V_n^2}}{V_1} \times 100(\%)$$

TDD, on the other hand, deals with evaluating the current distortions caused by harmonic currents in the end-user facilities. TDD of the current I is calculated by the formula.

$$I_{TDD} = \frac{\sqrt{\sum_{n=1}^{n=\infty} (I_n)^2}}{I_L}$$

$I_L =$ rms value of demand load current
$n =$ harmonic order (1,2,3,4...)
$In =$ rms load current

RTU FOR PQ MONITORING

All RTUs(Remote terminal unit) should have the function of power quality. If RTU detects bad power quality, RTU sends the information that items went beyond setting value immediately, and operator can choose to command the data acquisition of waveform file of three phase voltage and current. In general, FRTU(Feeder RTU) is installed in control box of automated switch. It collects analog data such as current and voltage value of three phases, and transfers the digital data such as on/off status, fault indictor detection, voltage phase missing, and phase angle mismatch of automated switches.

Arithmetic using DSP

Three phase voltages and currents are inputted to RTU from CTs and PTs of substations or switchgears. These voltages and currents are instantaneous value, and the effective value was made from this instantaneous value using RMS arithmetic method at RTU. DSP(Digital Signal Processor) of RTU can calculate phase angle value by DFT(Discrete fourier transform), and apparent power, active power, reactive power, power factor and frequency by calculating with V, I, Θ . DSP can also calculate positive and negative sequence component, zero sequence component and unbalance rate using symmetrical component analysis algorithm [3].

RTU design with PQ analyzing

Old RTU have all AI(Analog input), AO(Analog output), DI(Digital input), DO(Digital output) functions, but there is no power quality monitoring function. But new RTU has the function of analyzing power quality. If there are some faults in distribution networks, RTU saves all concerned data and events, and produces the information of FI(fault indicator) in case of flowing fault current. And then, RTU transfers this information to master station using DNP3.0 (Distribution Network Protocol) directly. Of course, RTU has the following main functions [3].

- Communication between host and FRTU
- Measuring of analog data(I, V)
- Monitoring of current status
- Control execution with digital output
- Fault detection & monitoring of fault current
- Monitoring of operation counter
- Display and setting
- Function of saving historical data

For adding the function of power quality monitoring, we designed new RTU with DSP of 128 sampling calculation per a cycle. Fig. 1 is the flow diagram of RTU, and Fig. 2 shows the feature of RTU for pole mounted switchgear with the function of power quality monitoring.

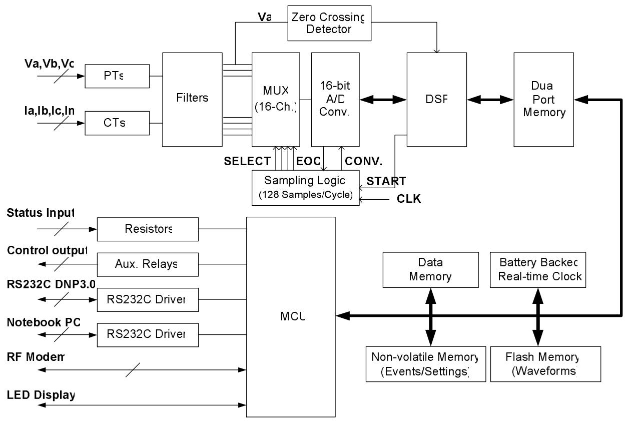

Fig. 1. Internal flow diagram of feeder RTU

RTU consists of CPU and memory, DSP, A/D converter, I/O processor, and power board. When the value of one or more items of PQ monitoring exceeds the maximum or minimum range, the event is produced, and the results are saved as data file as well as sent it to master station.

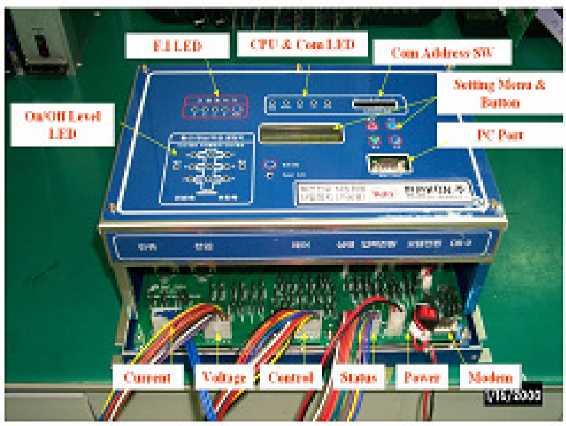

Fig. 2. Feature of RTU for pole mounted switchgear

CONFIGURATION OF PQ MONITORING

Main components for DAS(distribution automation system) include central control system(CCS), front-end processor(FEP), communication network, diverse remote terminal units(RTUs), and several kinds of automated switchgears.
CCS has the complex configuration system with dual servers with raid 5 clustering dual HDDs, historical server, web server, two or three HMIs and FEPs. This system uses Windows 2000 as operating software, MS SQL Server as DBMS, and middleware.
Main communication media of DAS is optical fiber between CCS and RTU in KEPCO because it has a characteristics of high reliability and fast transmission speed. But if utility wants only SCADA(supervisory control and data acquisition) function without file transfer, wireless or power line carrier is enough to use as a communication media. In KEPCO, TTU for monitoring pole mounted transformer uses RF(Radio frequency) and digital electronic meter(WHM) in low voltage customer for AMR uses power line carrier. Fig. 3 shows the configuration of distribution automation system with power quality monitoring [4].

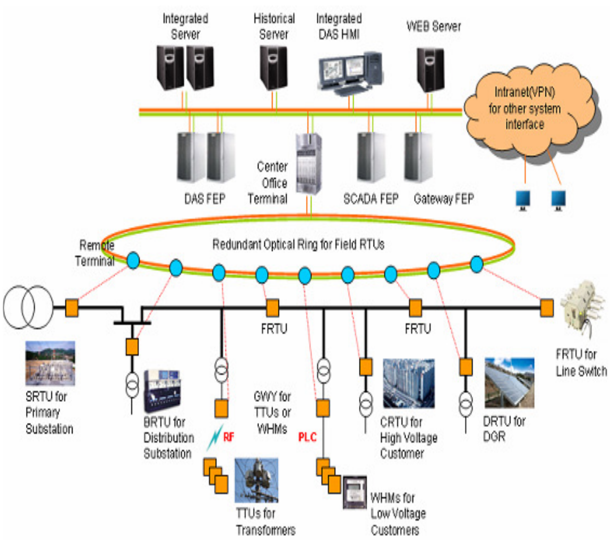

Fig. 3. Configuration of DAS for PQ monitoring

Monitoring points

Utility wants to know the condition of power quality in distribution networks using the existed DAS and its communication networks. But RTU has not enough measuring resolution, so there is some restrictions to monitor all kinds of power quality problems. Therefore we have to modify the existed RTU and determine the power quality monitoring items on economical and efficient point of view.
According to location, RTU has different measuring items. We need to monitor all kinds of items at important point such as primary substation, distribution substation, MV customer, distributed generators and MV line, but we need not to monitor full items in low voltage customer. Fig. 4 shows the positions of RTU for power quality monitoring that is connected to distribution automation system.
There are seven kinds of RTU. It is SRTU is RTU for primary substation, DRTU is RTU for distribution substation or switching station, CRTU is RTU for MV customer, FRTU is RTU for MV switchgears in networks, TTU-M is master of transformer terminal unit in secondary side of MV/LV transformer, GRTU is RTU for Distributed Generator, and WHM is digital electronic meter for AMR(automated meter reading) is installed in LV customer.

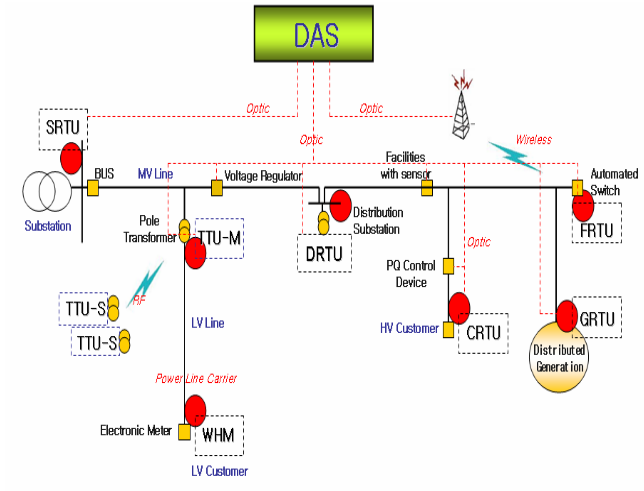

Fig. 4. Power quality monitoring points

Monitoring items of power quality problems

The items of power quality monitoring are sags (instantaneous, momentary, temporary), swells (instantaneous, momentary, temporary), interruptions (instantaneous, momentary, temporary), THD(V), THD(I), TDD, Harmonics, over voltage, under voltage, current unbalance rate and so on. We can see the power quality monitoring items of each RTU in Table 1 [5].

ANALYSIS USING PROGRAM

If there are overshoot or undershoot of preset range during monitoring the status of power quality, RTU produces the event about what time and which item happened, and sends the information to master station through communication media directly. If needed, operator commands to RTU for waveform transmission of voltage and current after the notified event is confirmed.
RTU stores the raw data of waveform automatically when power quality problem occurs, and prepares to send this data according to the command of master station by on-line or download by manual. Raw data that was transmitted from RTU was analyzed by PQ analyzing program as one of the distribution automation application software, and the result should be displayed on the MMI screen of operator.
PQ analyzing program can display the source data waveform, root mean square values, triggering time at MMI screen. Also it shows the vector diagram, positive sequence, negative sequence, zero sequence component value as symmetrical component of voltage and current.

Table 1. Monitoring items of power quality problems

Monitoring Items		IEEE std 1159		Data Storage			SR TU	DR TU	GR TU	TTU -M	FR TU	Customer	
		Magnitude	Duration(cycle)	Event	Waveform	Counter						CR TU	WH M
Sag	Instantaneous	0.1~0.9 pu	0.5~30	O	O	O	O	O	O	O	O	O	X
	Momentary	0.1~0.9 pu	30~180	O	O	O	O	O	O	O	O	O	X
	Temporary	0.1~0.9 pu	180~3600	O	O	O	O	O	O	O	O	O	X
Swell	Instantaneous	1.1~1.8 pu	0.5~30	O	O	O	O	O	O	O	O	O	X
	Momentary	1.1~1.8 pu	30~180	O	O	O	O	O	O	O	O	O	X
	Temporary	1.1~1.8 pu	180~3600	O	O	O	O	O	O	O	O	O	X
Interruption	Instantaneous	<0.1 pu	0.5~180	O	O	O	O	O	O	O	O	O	O
	Momentary	<0.1 pu	180~3600	O	X	O	O	O	O	O	O	O	O
	Temporary	0.0 pu	> 3600	O	X	O	O	O	O	O	O	O	O
Voltage	UV	0.8~0.9 pu	> 3600	X	X	O	O	O	O	O	O	O	O
	OV	1.1~1.2 pu	> 3600	X	X	O	O	O	O	O	O	O	O
Harmonics	THD(V)		Steady State		X	X	O	O	O	O	O	O	X
	THD(I)		Steady State		X	X	O	O	O	O	O	O	X
	TDD(I)		Steady State				O	O	O	O	O	O	X
	Multiple values		Steady State				O	O	O	O	O	O	X
Unbalance	Voltage	0~100 %	Steady State	O	X	O	O	O	O	O	O	O	X
	Current	0~100 %	Steady State	O	X	O	O	O	O	O	O	O	X
Frequency		45~65Hz	Steady State	O	X	O	O	O	O	O	O	O	X
PQM Waveform				O	O	O	O	O	O	O	O	O	X
Demand Waveform					O		O	O	O	O	O	O	X

This program also analyzes the harmonics and displays the magnitude of 1st to 32nd orders of harmonics, THD and TDD. Fig. 5 shows the analyzed result of harmonics. File magnitude of a phase current or voltage that sent from RTU is 128 sampling of 20 cycles.

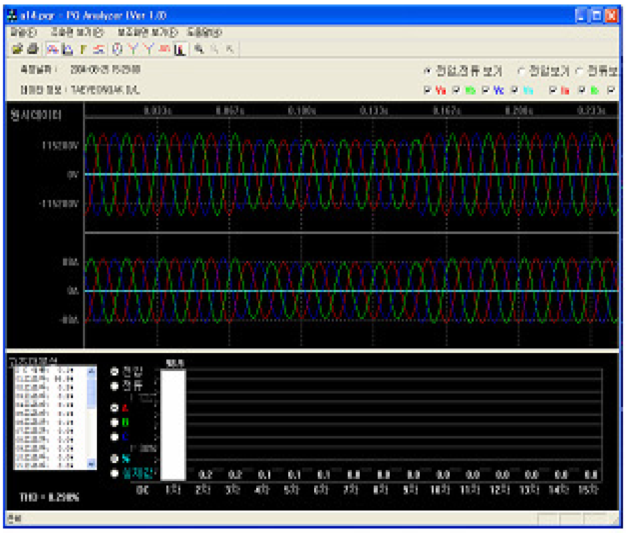

Fig. 5. MMI displays the waveforms and harmonics

CONCLUSION

Power quality can be defined from two different perspectives, depending on whether you supply or consume electricity. The definition of power quality becomes even more unclear when the roles of utility and the customer become blurred as the utility industry is restructured and deregulated.

As a utility to know the condition of real system, we are trying to monitor of power quality by using distribution automation system adding a new function in RTU. Especially, we can monitor power quality not only special point but also all distribution networks from primary sub-station through MV networks with distribution substations, automated switches, MV customers, distributed generators, and LV customers. This tryout may become very economical and efficient method to monitor the power quality on distribution networks.

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