Design and implementation of NMS using SNMP for AMI network device monitoring

Young-Il Kim, So-Jeong Park, Nam-Jun Jung, Moon-Suk Choi, and Byung-Seok Park
Smart Power Distribution Laboratory, KEPCO Research Institute, KEPCO
Daejeon, Republic of Korea
yi.kim@kepco.co.kr

***Abstract*-- KEPCO developed meter reading system based on AMI (Advanced Metering Infrastructure) over PLC (Power Line Communication) network for low-voltage customers. Currently, meter reading system of KEPCO operates 2.5 million low-voltage customers and will be 22 million until 2020. This paper introduces the AMI NMS (Network Management System) to monitor the network operating status of DCU and PLC modem for AMI network operation. AMI NMS collects property data of network device, network topology information, communication performance information, fault information, and etc. using SNMP (Simple Network Management Protocol). It analyzes collected data and controls network devices by remote access. This paper introduces main functionalities, designed context, implemented service screen and operational result.**

***Index Terms*—AMI, meter reading, network management, SNMP, PLC**

I. Introduction

Recently, an increase of fossil fuel, carbon emissions and power demand have provoked utilities to increase the use of renewable energies and the needs of integration within the existing power system. The new approach, Smart Grid requires complex two-way communication infrastructure, sustaining power flows between intelligent components, and sophisticated computing and information technologies, and business applications. The Smart Grid concept aims to achieve a sophisticated system by integrating an information and communication technology infrastructure to the existing power system. The Smart Grid has potential Applications such as AMI, DR (Demand Response), T&D Automation, OMS (Outage Management System) and etc [1].

AMI is an essential system for implementing Smart Grid and a principal means of realizing DR based on Supply-Demand mutual recognition. AMI meter reading system can improve energy efficiency and accept various distributed energy resources for the electric industry to grow constantly for the next decades solving global energy crisis [2]. Figure 1 shows the AMI system architecture of Korea. DCU (Data Concentration Unit) is installed on the concrete pole and communicated with PLC modem which collects data from smart meter by DLMS/COSEM (Device Language Message Specification / Companion Specification for Energy Metering) protocol [3][4].

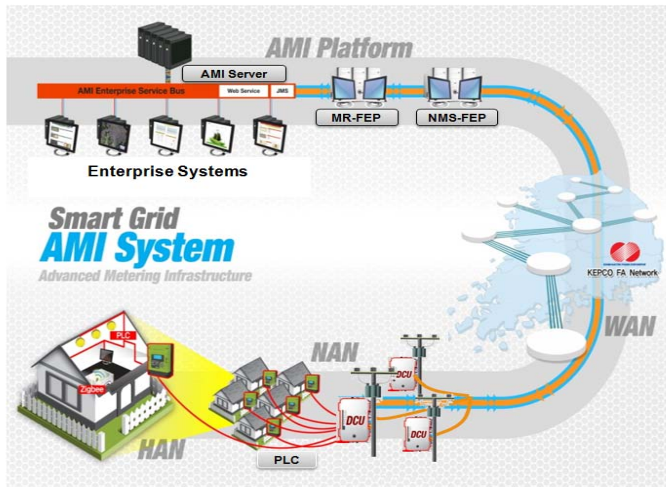

Fig. 1. AMI system architecture of KEPCO [3].

This paper is organized as follows: an introduction is shown in Section 1. In Section 2, the related works of Smart Grid and AMI are presented and in Section 3, the system design of AMI NMS, proposed in this paper is explained. Section 4 presents the system implementation and experimental result analysis. Section 5 is the conclusion.

II. Related Works

Energy utilities in 21st century have a problem to find more cost effective strategies for grid operation and intelligent power consumption of customer. The Smart Grid is a collection of next generation power delivery concepts such as ability of the grid to self healing, power supply free from sags, swells, outages and others, support for renewable energy, and asset monitoring. AMI is the deployment of a metering solution with two-way communications between utility and smart meter. It provides the ability of metering, outage reporting, DR, service connect/disconnect, on-demand reads, reconfiguration and firmware upgrade [5].

For the Smart Grid, two types of communication area are needed for information exchange. The first area, HAN (Home Area Network) is sending the data from sensor and home appliances to smart meter, the second area, NAN (Neighborhood Area Network) is between smart meters and

This work was supported by the "Development of AMI System using hybrid and composite network (No. 2014101501840)" of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea.

978-1-4673-8848-1/16/$31.00 @2016 IEEE

the utility's data centers. HAN normally uses PLC or wireless communications such as ZigBee, 6LowPAN, Z-wave, and others. NAN uses cellular technologies or the Internet. An overview of Smart Grid communication technologies are shown in Table I [6].

TABLE I.
SMART GRID COMMUNICATION TECHNOLOGIES [6]

Tech.	Specification	Appl.	Limits
GSM	Spectrum : 900□1800 MHz, Data Rate : Up to 14.4 Kbps, Coverage : 1~10km	AMI, DR, HAN	Low data rates
GPRS	Spectrum : 900 ~ 1800 MHz, Data Rate : Up to 170 Kbps, Coverage : 1~10km	AMI, DR, HAN	Low data rates
3G	Spectrum : 1.92~1.98GHz, 2.11~2.17GHz, Data Rate : 384 Kbps ~ 2Mpbs, Coverage : 1~10km	AMI, DR, HAN	Costly spectrum fees
WiMAX	Spectrum : 2.5GHz, 3.5GHz, 5.8GHz, Data Rate : Up to 75Mbps, Coverage : 10~50km(LOS), 1~5km(NLOS)	AMI, DR	Not widespread
PLC	Spectrum : 1~30MHz, Data Rate : 2~3 Mbps, Coverage : 1~3km	AMI, Fraud Detection	Harsh, noisy channel
ZigBee	Spectrum : 2.4GHz, 868~915MHz, Data Rate : 250Kbps, Coverage : 30~50m	AMI, HAN	Low data rates, short range

KEPCO use PLC technologies for NAN to communicate between smart meter and DCU. PLC technology enables utility companies to communicate with smart meter by transmitting data through an existing power line. PLC has two types: narrowband and broadband. To overcome the propagation loss and severe interference of power line channel, OFDM (Orthogonal Frequency Division Multiplexing) modulation technique is used in narrowband. Narrowband PLC has two standard protocols: PRIME-PLC and G3-PLC. A broadband PLC allows relatively higher speed data transmission than narrowband. The HomePlug specifications target broadband applications such as in-home distribution of low data rate IPTV, gaming, and Internet content. The HomePlug power line technology family includes HomePlug AV for broadband applications, HomePlug Green PHY for smart grid application and HomePlug AV2 for next generation broadband speed [7].

KEPCO developed Korean broadband standard in 2006. It has a specification of 24 Mbps MCM (Multi Carrier Modulation) method and 2.15~23.15MHz bandwidth. This standard was proposed to ISO/IEC and published as ISO/IEC 12139-1 standard in 2009. KEPCO developed AMI system and installed 50 thousand customers in 2008, 550 thousand customers in 2010, 5.5 million customers in 2015 [8][9][10]. Metering system of KEPCO uses DCU to collect metering data from smart meter and send it to AMI data server with Internet, D-TRS (Digital Trunked Radio Service), or WiBro (Wireless Broadband). In case of detached house, meter and modem are connected one to one. In case of multiplex house, several meters are connected to single modem by RS-485 serial cable. Communication protocol between meter and modem is IEC 62056 DLMS/COSEM. PLC bridge is developed to overcome the propagation loss and severe interference. A slave DCU is developed to reduce the WAN service cost. A master DCU has a static IP received from WAN service provider. A slave DCU is connected to master DCU with coaxial cable and send metering data with PLC communication.

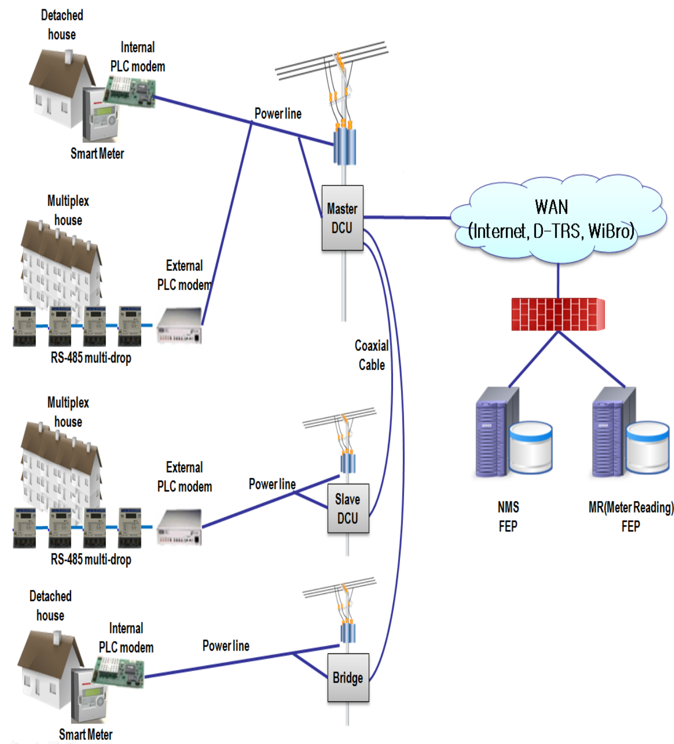

Fig 2. Communication Architecture of KEPCO AMR system.

Main systems of AMI Servers are AMR (Automatic Meter Reading) FEP (Front End Processor) and NMS FEP. AMR FEP collects metering data from DCUs every 15 minutes by FEP protocol defined by KEPCO. NMS FEP collects network status data from DCUs every 15 or 30 minutes by SNMP protocol. Polling mechanism has a system overhead concentration problem on FEP, SMCP (Smart Meter Concentration Protocol) has been researched [11].

III. SYSTEM DESIGN

AMR FEP of KEPCO collects 15 minutes' load profile from meter via PLC modem and DCU by FEP protocol defined by KEPCO. A modem communicates with DCU through power line which has a characteristics of propagation loss and severe interference. In order to operate the metering network more stably, NMS is needed to check the communication status of DCU and modem periodically.

A. Requirement Analysis

KEPCO collected the functional requirements of NMS from network operators of each KEPCO branch offices by several meetings. A use case and process diagram was defined by requirement analysis phase. Key features of NMS are as follows:

- Total dashboard represents the overall install and operational status of DCUs and modems.
- Statistics function provides the installed devices number per manufacture, firmware version, and branch codes.
- The list of communication fault devices per day, week, month, and year.
- The devices list of missed meter reading.
- Topology viewer provides the network topology diagram of PLC modem which consists ad hoc network.
- NMS collects the status and control data periodically.
- Trap event receiver and management. Automatic registration process starts when new peer notification trap arrived.
- Firmware management and upgrade.
- Batch and scheduled process support for reset or operational control.

B. System Design

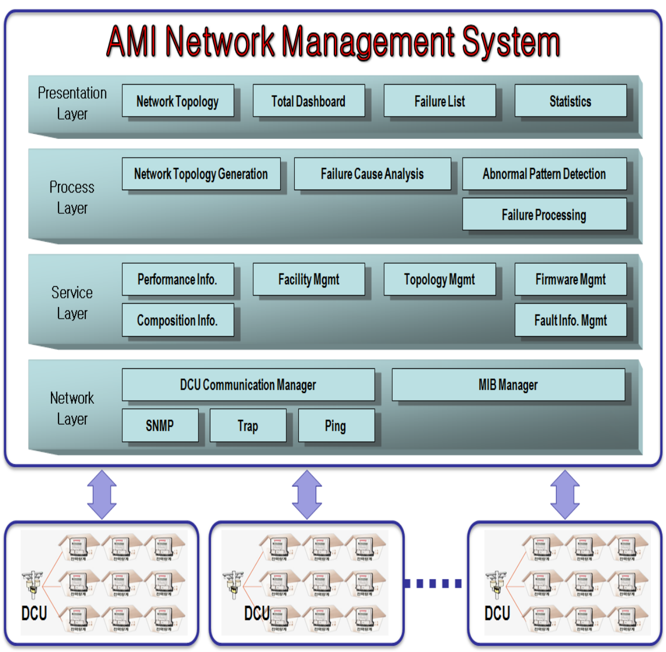

Fig. 3. Layered architecture of AMI Network Management System.

Figure 3 shows the layered architecture of NMS. The network layer provides SNMP, trap, ping modules for DCU communication. OID (Object Identifier) of DCU MIBs (Management Information Base) are defined by RFC 1150 ISO standard. A basement OID is 1.3.6.1.4.1.29408.11 (iso.org.internet.private.enterprises.kepco.integrationmib). Figure 4 shows the MIB information of DCU SNMP Agent.

A SNMP Agent of DCU sends a trap message to NMS FEP whenever it detects the trap events. CPU and memory usages are sampled by every 10 seconds, averaged by every 1 minutes. SNMP Agent sends a CPU exceed trap when 1 minutes CPU average value exceeds the CPU Threshold. Once it sends a CPU exceed trap, it waits for 10 minutes to send the next CPU exceed trap to avoid the unnecessary redundant trap.

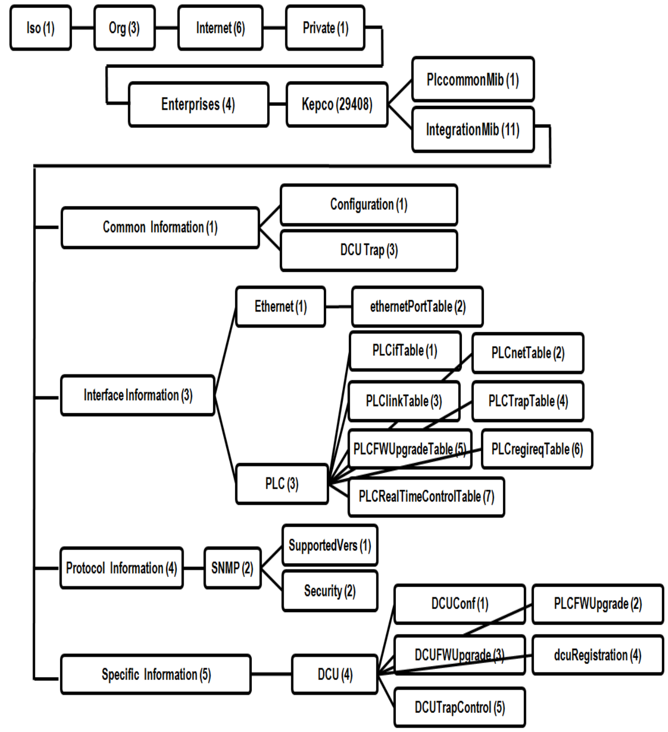

Fig. 4. OID Tree of DCU SNMP Agent MIB.

The service layer takes a role of collect of composition and performance information, and management of facility, topology, fault information and firmware. DCUs and PLC modems uses power line communication which is hard to support stable fixed network because of noisy PLC characteristics, so DCU checks the communication performance every 1 minutes and re-construct the network when they detect the worst performance. To collect the communication performance of PLC modem and PLC network topology, NMS FEP polls the DCU to get the PLC performance related information, such as the MAC address of all modems of DCU (OID=3.3.2.1.1, 3.3.2.1.2), the MAC address of parent modem (OID=3.3.2.1.3), and BPS (Bit per Symbol) value of up/down link of modem (OID=3.3.2.1.5, 3.3.2.1.6). NMS collects BPS values every 30 minutes with SNMP GET request and generates the warning message and notifies to an operator when it goes down below BPS threshold. PLCRealTimeControlEntry (OID=3.3.2.1.1, 3.3.2.1.2) provides real time inspection of PLC modem such as loopback test, MAC ping test, BPS test and real time meter reading.

Figure 5 shows the loopback test sequence diagram. NMS FEP sends PLCloopbackCmd SNMP SET request to DCU for digital loop back test of a PLC modem's serial cable connected to smart meter. DCU sends the loop back test packet to modem and calculates a round trip time and success count. DCU repeats it as much as PLCloopbackCnt. NMS

FEP sends PLCloopbackStatus SNMP GET request to check whether loop back test finished or not. NMS FEP sends PLCloopbackRtt and PLCloopbackSucessCnt SNMP GET request to make a decision whether modem serial interface or meter is broken.

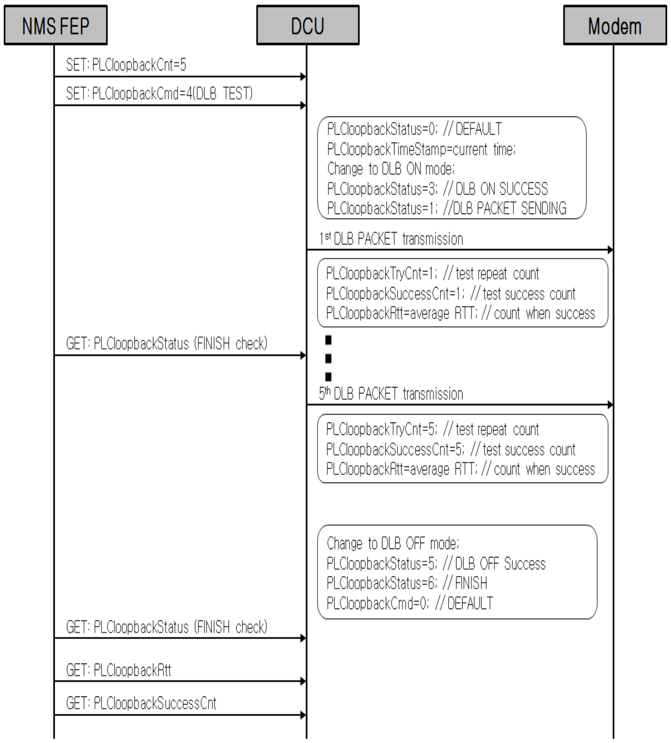

Fig. 5. Loop back test process using SNMP.

Firmware upgrade service is needed to patch the malfunction or add the new function to DCU or modem. Figure 6 shows the DCU firmware upgrade sequence diagram. NMS FEP notifies the beginning of firmware transmission to DCU by sending dcuFWUpgradeImageAck SNMP SET request, in case of modem by plcUpgradeImageAck.

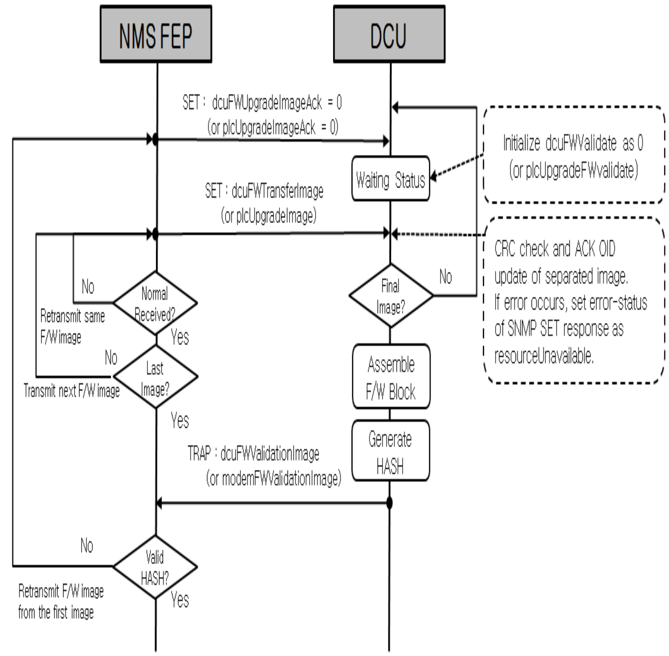

Fig. 6. DCU firmware transmission process using SNMP.

The firmware binary is separated into 60Kbyte blocks. The transfer image block consists of 1byte block number, 60Kbyte separated firmware block, 1byte option field and 2byte CRC value. DCU processes CRC test of separated firmware block and update the ACK OID after received dcuFWTransferImage SNMP SET request. NMS FEP sends remaining firmware block repeatedly. In case of last firmware block, it sets the option field of transfer image block as 9 which stands for a last block. DCU assembles transfer image blocks and generates the hash value and sends the hash value in dcuFWValidationImage SNMP TRAP. If dcuFWValidationImage SNMP TRAP is not reached to NMS FEP within 10 minutes, NMS FEP sends dcuFWValidate SNMP GET request and receives the hash value and performs a integrity check process. In case of integrity fail, NMS FEP resends dcuFWUpgradeImageAck SNMP SET request to restart the firmware upgrade process.

The process layer provides network topology generation through network analysis process using composition and performance information and failure cause analysis through abnormal pattern detection and failure processing following the analysis result. The network topology information is generated in forms of hierarchical tree using parent MAC address of each modem. A failure of modem is determined by BPS value which is below the threshold for a certain period of time or all the meters which connected to this modem are failed to read load profile. A failure of DCU is determined by ping value which is not response on ping command for a certain period of time. In case of a DCU failure, modem failure list connected with this DCU are removed to reduce the meaningless failure list.

The presentation layer provides various user screen such as network topology diagram, total dashboard, failure list and so on.

IV. Implementation and Experimental Result

AMI NMS consists of NMS FEP, database, and web server and installed on each branch office of KEPCO. NMS FEP collects the network information from DCU and receives trap information by SNMP. A collected information is stored in database server and provide to the network operator by web server. NMS FEP performs ping test of DCU every 15 minutes and collects BPS of modem every 30 minutes.

Total dashboard is provided real time operation status, regular meter reading failure, yesterday failure and etc. to network operator by analysis process of collected data. A real time operation status represents the current status of DCU and modem and is updated every 30 minutes. DCU failure column is a number of DCUs which continues ping fail more than 30 minutes. Modem failure column is a number of modems which continues BPS fail more than 12 hours. A regular meter reading failure represents the number of meters which is failed to read the load profile and its monthly regular meter reading date is today (D) or 3 days left (D-3). The main purpose of AMR system is automatic collection of monthly regular meter reading without visiting customer's house by meterman. To achieve the regular metering rate more than 99%, it is needed to intensively manage the meters which are left from three to zero days before monthly meter reading date.

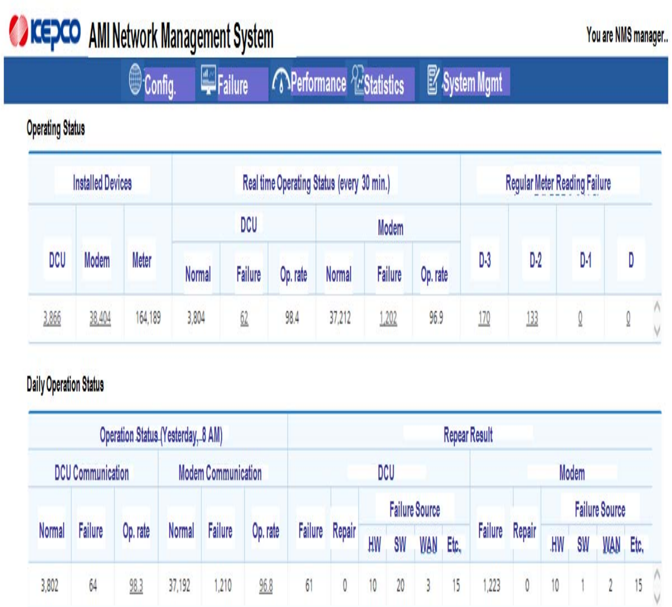

Fig. 7. Web-based total dashboard screen of AMI NMS.

Figure 8 shows the failure status of DCU and modem. DCU detail shows the DCU information such as DCU ID, IP, MAC, number of modem, failure information, occurring date, duration time, ping command, and reset command. Modem detail shows the modem information such as modem MAC, DCU ID, DCU IP, number of meter, failure information, Occurring date, duration time, parent path, MAC ping command, BPS command, and so on.

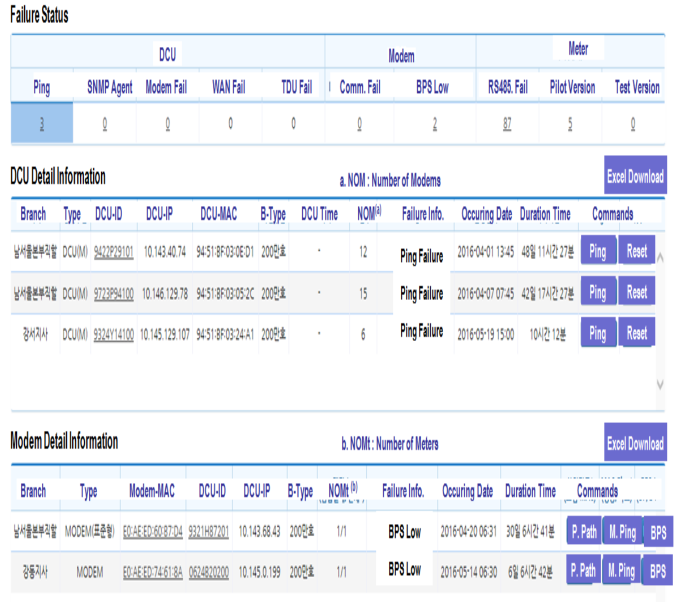

Fig. 8. Failure status and detail information screen.

Figure 9 shows the network topology of DCU and modem. Network operator occasionally need to find the candidate parent modem which is not suitably connected to PLC network. Network topology diagram screen helps the operator to analysis the network connectivity and BPS trend graph and determine whether PLC bridge is needed or not.

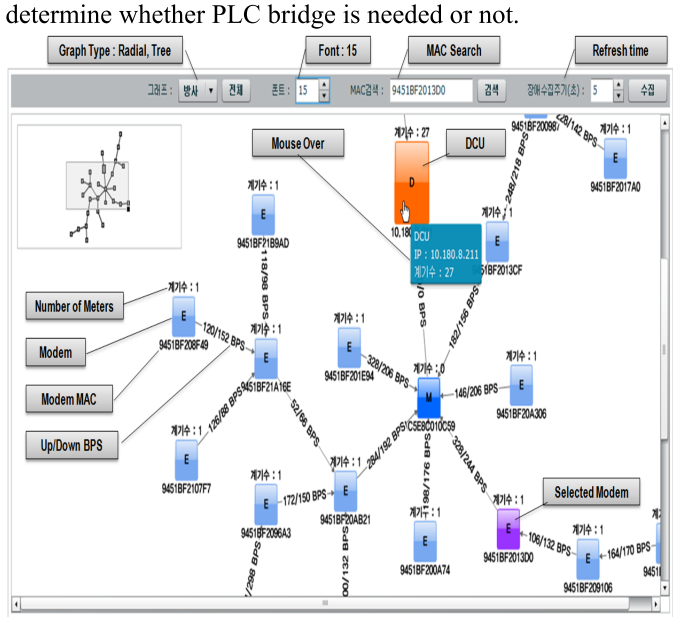

Fig. 9. Network topology of DCU and modem screen.

Developed AMI NMS is operating 40 thousand DCUs and 560 thousand PLC modems at 14 branch offices. Table II shows the number of installed DCUs and modems, and daily operation rate. A DCU connected with averagely 14 modems. Average operating rate of DCU is 99.3 percents and average operating rate of modem is 98.5 percents. Operating rate is number of normal state devices out of number of totally installed devices. The more number of modems are connected to DCU, the lower operating rate of modems are.

TABLE II.
INSALLED NUMBER OF DCU/MODEM AND OERATING RATE

Branch Office	Quantity of DCU	Quantity of Modem	Op. Rate (%) of DCU	Op. Rate(%) of Modem
Branch #1	5,175	53,048	99.6	99.5
Branch #2	3,617	41,577	99.7	99.5
Branch #3	3,804	34,342	99.5	96
Branch #4	6,045	66,464	98.7	99
Branch #5	1,362	23,200	99.8	99.6
Branch #6	4,700	62,412	99.4	98.6
Branch #7	2,861	53,723	99.1	98.3
Branch #8	2,007	28,731	99.9	94.5
Branch #9	5,475	79,167	99.5	98.7
Branch #10	2,368	43,792	99.8	98.3
Branch #11	5,884	99,362	99.7	98.4
Branch #12	1,487	27,035	99.3	97.6
Branch #13	3,829	38,344	98.6	97.7
Branch #14	2,031	35,190	98.5	96.9
Sum. & Avg.	50,645	686,387	99.4	98.0

According to our analysis, low operating rated area had a high population. A modem was connected to many meters and a DCU was connected to many modems on that area. In dense area, the more noise had occurred by various electric usage patterns of customers. The operating rate would be higher by installing the PLC bridge device on the weak point using network topology screen and analysis function of NMS.

V. CONCLUSION

This paper introduces the AMI NMS of KEPCO which manages the DCU and modem for meter reading of low-voltage customers. The AMI NMS collects the communication status information of DCUs every 15 minutes and modems every 30 minutes. Failure level has three stages and duplicated failures are removed by redundancy check module to provide the optimized failure list to the operator. An operator could manage the metering network more stably by using the NMS functions such as real time failure list, failure handling with remote control and communication tree and performance analysis with network topology diagram.

For the future work, a network consulting algorithm will be researched which recommends the area needed to install the bridge by network analysis. The SNMP MIB will be added to strengthen the network monitoring ability and research of NMS will be continued to enhance the metering rate of KEPCO's AMI system.

VI. REFERENCES

[1] V. Cagri Gungor, Dilan Sahin, Taskin Kocak, Salih Ergut, Concettina Buccella, Carlo Cecati, and Gerhard P. Hancke, "A survey on smart grid potential applications and communication requirements," IEEE Transactions on Industrial Informatics, vol.9, no.1, pp.28-42, February, 2013.

[2] V. C. Gungor, B. Lu, and G. P. Hancke, "Opportunities and challenges of wireless sensor networks in smart grid," IEEE Trans. Ind. Electron., vol. 57, no. 10, pp. 3557–3564, Oct. 2010.

[3] Young-jun Kim, Do-eun Oh, Jong-min Ko, Young-il Kim, Shin-jae Kang, and Seung-Hwan Choi, "A Remote Firmware Upgrade Method of NAN and HAN Devices to Support AMI's Energy Services," Convergence and Hybrid Information Technology, Springer Berlin Heidelberg, pp.303-310, 2011.

[4] IEC 62056-1-0, "Electricity metering data exchange – The DLMS/COSEM suite –Part 1-0: Smart metering standardisation framework", 2014.

[5] David G. Hart, "Using AMI to Realize the Smart Grid," IEEE PES, General Meeting, pp.1-2, July, 2008.

[6] Vehbi C Güngör, Dilan Sahin, Taskin Kocak, Salih Ergut, Concettina Buccella, Carlo Cecati, and Gerhard P. Hancke, "Smart grid technologies: communication technologies and standards," IEEE Transactions on Industrial informatics, vol.7, no.4, pp.529-539, November, 2011.

[7] Chaiyod Pirak, Tanayoot Sangsuwan, Sirinapa Buayairaksa, "Recent Advances in Communication Technologies for Smart Grid Application: A Review," International Electrical Engineering Congress 2014, 2014, pp.1-4.

[8] Byung-seok Park, Cheoul-shin Kang, Young-Hun Lee, and Sang-yeom Lee, "Study on Smart Meter Concentration Protocol for AMI," International Information Institute (Tokyo), vol.17, no.3, pp-1065-1070, May, 2014.

[9] Seong-Ho Ju, K. Y. Gwak, Byung-Seok Park, Tae-Young Lee, Duck-Hwa Hyun, Young-Hyun Kim, Moon-Seok Choi, "Development of the composite communication system based on PLC for distribution automation system," IEEE International Symposium on Power Line Communications and Its Applications, pp. 283-287, 2006.

[10] Byung-Seok Park, Cheoul-Shin Kang, Eun-Jeong Lim, Seong-Ho Ju, Gi-Seok Ahn, Jin-Seok Bae, "Automatic repeat protocol for distribution automation system through powerline communication," IEEE International Symposium on Power Line Communications and Its Applications, pp. 316-321, 2008.

[11] Park, Byung-Seok, Cheoul-Shin Kang, and Young-Hun Lee, "Design and Implementation of Smart Meter Concentration Protocol for AMI", Communication and Networking, Springer Berlin Heidelberg, vol.265, pp.179-187, 2011.