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Hybrid AMI Design for Smart Grid Using the Game Theory Model

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Abstract. Recently, in the Republic of Korea, there's a growing interest in the Smart Grid and IoT technologies and many companies are attempting to build the IoT-applied Smart Homes. Although a variety of related products are being introduced to the market, their effects are yet to be recognized. The major reason is that new structures need to be added to existing homes to implement the technology which requires a base platform for the communications between relevant 'Things'. In the future, it is expected that the electric charges will vary depending on each time slot and season. Thus, in this paper, we propose a 'Hybrid AMI (Advanced Metering Infrastructure) Design for Smart Grid' which utilizes the game theory model.

Keywords: Game Theory Model, AMI, Hybrid AMI, Smart Grid

1 Introduction

Due to the rising interest in the Smart Grid and IoT technologies in Republic of Korea, the major Korean companies such as Samsung, LG and KT are pushing forward with their smart home construction plans aggressively and many allied products are being introduced to the market recently.

Contrary to such efforts, their effects are still minimal in real life as there are some problems to be solved to implement the IoT technology. That is, to achieve this technology, additional structures are needed to construct a base platform on which the communications between 'things' in the household will be carried out. This platform enables wireless communications based on WiFi and Zigbee, or wire communications that use the LAN system. Although the former has an advantage of not requiring any additional cable installations, there could be a problem of communication speed decline or lower reliability due to signal interferences at the final implementation process where all the electric appliances in the smart home are being interconnected and starting to communicate. The Power Line Communication (PLC) has been developed to complement above this problem. This technology does not require additional wiring but instead, it complements demerits of LAN- and wireless-based communications by forwarding data using existing 220V household power line. To implement the technology, we transform existing power outlets into the ones that include a module which can monitor and control the household power use with the PLC modems. All the power usage patterns will be recorded and the data will be pieced together and analyzed by the home server, and then the usage patterns of the electrical appliances in the household will finally be optimized with an

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artificial intelligence (AI). The system will provide the user with daily, monthly, and real-time power use information on the web with the android application. Moreover, the system can provide the power usage analysis data obtained through comparative analysis between the actual user, other user(s) who uses similar home appliances, and actual user's past usage records. For the convenience of the user, a control function for both the AI and the user has been enabled. Ultimately, our goal is to implement a 'Smart Grid' within the households.

2 Related Research

2.1 Smart Grid (Server - Client communication)

We've chosen the PLC system as a platform for Smart Grid implementation purpose. We shall achieve Server - Client communication by installing the PLC modems on both the Home Server and the Client [Fig. 1]. The structure of the module used is shown in [Fig. 2]. The PLC modem of the Client side uses the Mamba Shield [Fig. 3], which is an Arduino PLC modem shield, and for the server side, NC-EPLC [Fig. 4] (i.e., the PLC developer unit) will be used.

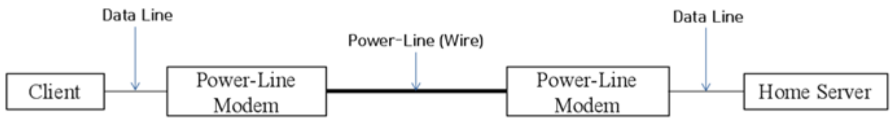

Fig. 1. PLC Home Server – Client Communication

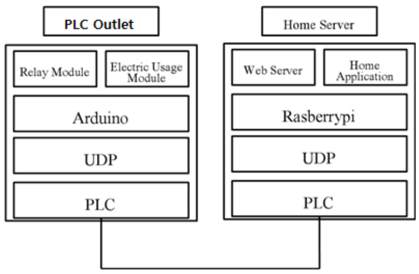

Fig. 2. Structure of Smart Outlet Communication

Fig. 3. Mamba Shield

Fig. 4. NC-EPLC

2.2 Client: Smart Outlet

The Smart Outlet achieves three kinds of functions such as power control, power use measurement and Pulse Width Modulation (PWM). These are achieved with Arduino Uno R3 and for power control, with a relay module; for power use measurement, with WCS 1600 current measuring sensor, and as the dimmer for LED illuminance control, with AC Dimmer Board ver. 1.1. Also, for power control, a 4-channel relay module [Fig. 5] was used to create 2~3 hole-type outlet (i.e., a type often used in existing households).

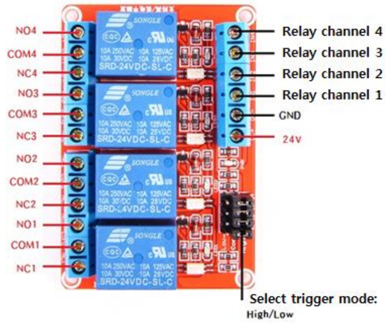

Fig. 5. Relay Module

The WCS 1600 current measuring sensor is used for the power measurement. Arduino runs with the power supply of 5V so that it needs to be converted to measure the currents typical of Korean domestic electrical appliances which normally use 220V alternating current.

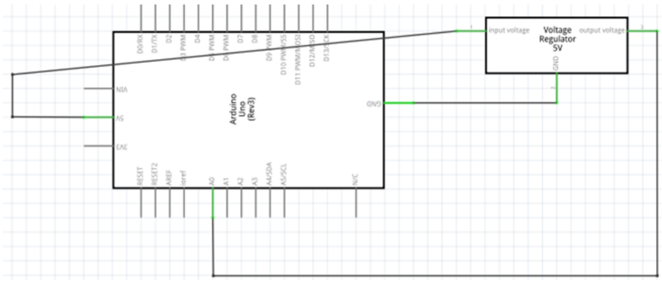

Fig. 6. Power measurement

After being measured by the sensor, the current reaches Arduino passing through Vout. When the Arduino operable at 5V is connected to the current sensor, 2.4654V will be loaded on Vout in a condition where no other current is flowing yet. As for the Arduino, since its range of analog input is 0~5V and the resolution is 10 bytes, 2.4654V is equivalent to a value of about 504.91392. Therefore, subtract this value from the return value calculated as an analog value using the analogRead() function. Also, for the reason that the current being an alternate current, we can increase the accuracy of measured value by applying the root mean square (RMS).

Finally, for the calculation of amount of electricity used, first calculate W (watt) by multiplying the used current and 220V and then record the starting and finishing times to get WH (Watt per Hour). Coding for the control of above process is shown below. The process involves initializing Ethernet and serial ports, reading result value from the sensors, transmitting the W values every 10 seconds to the server, and accumulating/storing these values as WH values at the server.

For the illuminance control, a circuit called the 'Dimmer' is required. It's a circuit that controls illuminance by adjusting the voltage internally using the variable resistor.

Brightness can be controlled remotely by connecting the dimmer and Arduino together. Here, illumination adjustment command is sent to the home server (Arduino) remotely and the corresponding value will be sent to the dimmer from the server. As a result, brightness of the light(s) in the house will be adjusted and by changing the value to a minimum voltage, the light(s) will go out so that the power consumption can be minimized.

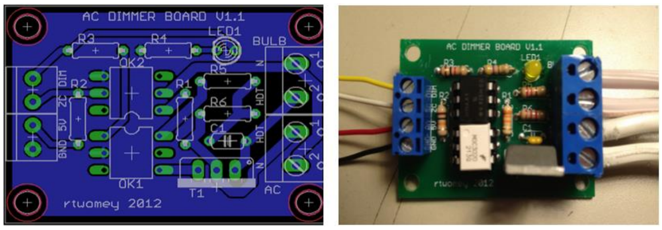

Fig.7. Illuminance control

2.3 Home Server

Home server establishes a connection with the PHP web server with android application. The home server is linked using an android application so that the user can remotely control home appliances thorough the application and also receive information concerning his/her whereabouts, pre-set remote control patterns and times. The system analyzes user's usage patterns with the application adopting the Artificial Intelligence (AI) after receiving the data transmitted from the Client to optimize household power use and to provide convenience to the user. The application was implemented using JAVA. Communication to a single outlet is enabled as described below, and by linking the lines with all the outlets, we can let all the home appliances to be connected to the home server [Fig. 8].

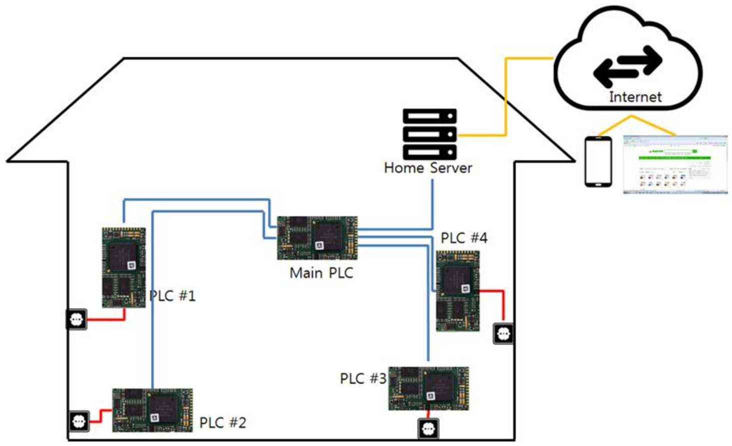

Fig. 8. Smart Home Platform

3 Hybrid AMI Design for Smart Grid Using the Game Theory

3.1 Spot price of electricity

When network loss is not considered, the spot price of electricity [1, 2] is defined as below Equation (**1**). In a deregulated market system, the power production cost is treated as confidential information. However, the spot price of electricity may be estimated by checking the minimum price offered in the market.

$$\rho = \frac{\partial C}{\partial P_i} + \sum_{\ell=1}^{N_L} \mu_\ell \frac{\partial Z_\ell}{\partial P_i} \qquad \text{for bus i in the Pool}$$

Equation (**1**)

ρ	Spot price of electricity
C	Total generation cost
P_i	Generation level in bus i
N_L	Number of lines in the system
μ_ℓ	Lagrange multiplier for maximum capacity of line ℓ
Z_ℓ	Power flow in line ℓ

3.2 Hybrid AMI design

For the hybrid AMI design proposed in this paper, the most economical electric charge for the PLC system can be calculated by estimating the spot and futures price.

Also, both the Nash's equilibrium theory and the hybrid concept are being adopted in the estimation. Examining the equation used in the proposed model, a single PLC model has a structure described by Equation (**2**). Since the proposed model has one main and four auxiliary power lines communication structure, it can be represented using Equation (**3**). The problems involved in verification and performance evaluation will be added in the extended journal paper.

$$\rho = \frac{\partial C}{\partial P_1}$$

Equation (**2**)

$$\rho = \frac{\partial C}{\partial P_1} + \frac{\partial E_1}{\partial P_1} + \frac{\partial E_2}{\partial P_2} + \frac{\partial E_3}{\partial P_3} + \frac{\partial E_4}{\partial P_4}$$

Equation (**3**)

4 Conclusion and future work

In the Republic of Korea, it is expected that the electric charges will be differentiated depending on the time slots and seasons (peak/off). Thus, we've proposed a 'Hybrid AMI Design for Smart Grid Using the Game Theory Model' which is able to efficiently save electric power by modeling spot and futures prices.

Convergence of home networking markets is continually developing with the entertainment sector at the center and it will evolve into an integrated network in the future. While 300,000 consumers comprise the entertainment-oriented market, only 20,000 prospective consumers exist for the home automation and data network markets. But total integrated demands will certainly be increased in the near future. Household power uses can be optimized by using our proposed model and the 'Smart Meters' for the home smart grid. We consider that it would have much significance even if we would save some portion of standby electricity which accounts about 520 billion Korean won worth of wasted electrical power. Also, we expect that our model will maximize the user convenience as it helps to control power through IoT between home appliances without special operations by the user. The model also has an advantage in future functional scalability because it enables communications between home appliances by connecting all the devices or equipments to a home server with the PLC technology that is probably the most appropriate method for such system. We also expect that this system will eventually become a perfect example of Smart Home in the future where each home appliance does its own thinking instead of user. The problems involved in verification and performance evaluation will be described further in our future extended journal paper.

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