RESEARCH ARTICLE OPEN ACCESS

A Step Forward to a Smart Grid by Implanting Smart Monitoring System

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Abstract:

By development of smart Grid, renewable energy such as wind generation (WG) and photovoltaic generation (PV) are getting attention in distributionsystems. Additionally, all-electric apartment houses or residence such as DC smart houses are increasing.However, due to the fluctuating power from renewable energy sources and loads, supply-demandbalancing of power system becomes problematic. Smart grid is a solution to this problem. This paperpresents a methodology for optimal operations of a smart grid, to minimize the power flow fluctuation by reduceinterconnection point and over load connection. To achieve the proposed optimal operation, we use distributed controllable loadssuch as halogen lamps and fans. By minimizing the interconnection point and over load, it is possible to reduce the electric power consumption and the cost of electricity. This system consists of battery, solar collector, and load.Energy efficient smart buildings are possible by integrating smart meter, smart sockets, domestic renewableenergy generation and energy storage systems for integrated energy management, and this integratedsystem supports demand side load management, distributed generation and distributed storageprovisions of future smart grids. Coming era of smart grids has implications for domestic DC distributionconcepts with smarts sockets.

Keywords— **DC distribution Home electronics appliances Smart buildings and systems Demand side load management Smart grid DC smart house optimal operation Interconnection point power flow and load shedding.**

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1. Introduction

Due to global warming and exhaustion of fossil fuels, we are required to reduce CO2 emissions and energy consumption.However, CO2 emissions and energy consumption are increasingrapidly due to the proliferation of all-electric houses. As countermeasuresagainst these problems, in residential sector, installationof photovoltaic (PV) system and solar collector (SC) system are proposed. On the other hand, many of the dispersed generators such as PV can be connected to Direct Current (DC) sources and DCsystems are expected to be of high efficiencies and lower cost dueto the absence of inverter and rectifier circuits. It is possible tooperate PV and SC systems in residential house with high efficiency. Therefore, this equipment can help to reduce the use of fossil fueland the emission of CO. As these research, suppress of power fluctuation by loads are proposed. However, installation of renewable energy causes frequency fluctuation anddistribution voltage fluctuation because output power fromrenewable source fluctuates due to weather condition.

In addition, electricity cost is determined by maximum electric powerconsumption for the year. Hence it is possible to reduce electricity cost by achieving load following control using power storagefacility. It is necessary to smooth power flow from distributionsystem to achieve above technical problems and reduce electricity cost. Because of the above factors, smart grid concept is developed which cooperatively balances supply-demand between powersupply side and power demand side [7,8]. By applying the smart grid concept, we can expect high efficiency power supply, energyconservation and low-carbon society. For the research of smartgrid, a method to obtain the optimal operation of thermal unit, battery and controllable loads by deciding the thermal unitcommitment is already proposed [9]. The thermal units can operate in high efficiency by operating the controllable loads in coordinatedmanner and can achieve to reduce the total cost of thermal units.However, the reference [9] mainly focus on supply side in powersystem, so it is important to considering demand side. As a countermeasureat demand side, for maintaining supply-demand balance, controllable loads can be used.

The study of supply demand balancing by power consumption control of controllableload at each demand side in small power system is already reportedin Ref. [10]. This paper presents an optimal operation method of DC smart house group with the controllable loads in the residential houses asa smart grid. The DC smart house consists of a solar collector (SC),a PV generator, a heat pump (HP), and a battery. HPand battery areused as controllable loads in this paper.

The proposed method hasbeen developed in order to achieve the interconnection pointpower flow within the acceptable range and the reduction of max-mininterconnection point power flow error as low as possible tosmooth the supply power from distribution system. Powerconsumption of controllable load is determined to optimize themax-min interconnection point power flow error based on theinformation collected from power system through communicationsystem. By applying the proposed method, we can reduce addition of over load fluctuation, and it is possible toreduce electricity cost due to the reduction of the contract fee forthe electric power company. Also, by using battery as the powerstorage facility, which can operate rapidly for charge and/ordischarge, the rapid output fluctuations of DC load and PV generatorare compensated.

2. Smart Grid System

The smart grid model is shown in Fig. 1. DC Grid The smart grid has sixsmart houses, and connected to power system and control systemthrough transmission line and communications infrastructures.

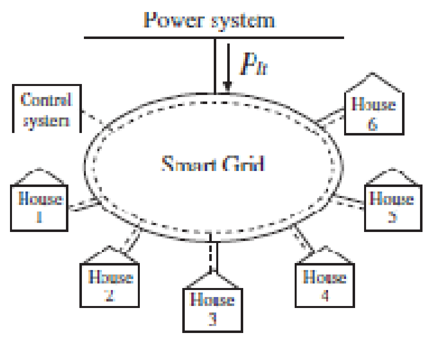

Fig. 1. Smart grid model

The control system sends required control signals to smart-housegroup which response to system conditions. Each smart housedetermines the operation of controllable loads. The interconnectionpoint power flow is the power flow from the power system to thesmart grid in Fig. 1. DC smart-house model is shown in Fig. 2, whichconsists of a DC load, a PV module and a battery. Survey on solar power[32].

3. Smart power management and DC distribution for residences

Nowadays, DC distribution has found numerous application switch different voltage levels and power ratings. DC distribution systems may have a simple structure containing two converters and a DC link, such as a high-voltage direct current system [30],or a complex structure with parallel connected converters used both for connecting to the source of energy and supplying loads as in ship power systems [31–32] and hybrid electrical vehicles[24,25]. Power converters with high-speed switching technology promotes to development of more complex DC distribution system. The converters are fundamental components of DC distribution systems so that they can adjust and stabilize voltage levels throughout the distribution networks [16].House power management systems using direct control schemes by means of home network device have been proposed in many recent works [18–20,22–24].

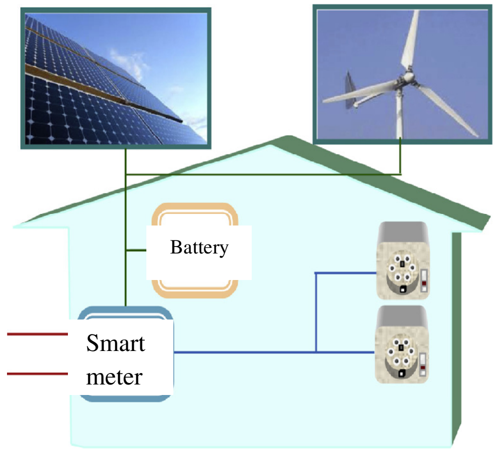

Fig. 2. DC Smart house Model

Microcontroller (MCU) basedintelligent energy management apparatus were used for control ofpower flow simply by switching on/off [31,42]. Another theoretical study presented a smart home energy system concept based onmany dispersive parts including smart meter, smart socket/switch,grid friendly appliance controller, smart interactive terminal andother smart devices [43].The current study presents a domestic DC power distributionconcept containing smart sockets. Fig. 2 shows schematic diagramof the proposed domestic DC power distribution system for smarthouses. SMs work at the core of home distribution and power managementsystems [45]. SMs are intelligent devices containingpower line communication units, controllers, measurement units,rectifiers and inverters. It can perform all control and communicationoperations concerning with domestic power managements.Hence, a SM functions as a fundamental domestic power managementdevice in smart grids.

The proposed DC/AC outlet smart socketsare controlled by the SM of the residence via power linecommunication. Today, SM and smart sockets can be implementedby using supervisory control and data acquisition (SCADA) technologiesand thus the smart sockets turn into distributed peripheralsof local-area decentralized load control schemes and become one of fundamental components for smart house energy managementsystems. This communication-control-power infrastructure allowsdevelopment of smart power application for energy efficiency,power reliability and demand elasticity.Direct load control implementing load shedding algorithm canbe performed via smart sockets and it makes possible the sheddingloads for cheap energy hours. Considerably facilitates penetration of intermittent renewable energy sources into grids [46].

The proposed sockets contain DC/ DC power conversions with desired voltage levels of HEAs and thus power conversion becomes more standardized, controlled and manageable. This elasticity in consumer demand, domestic DC distribution facilitates integration and control of domestic hybrid renewable energy systems (solar and wind) so that they can be integrated to DC distribution system, directly [47]. Hence, the DC distribution supports efficient, clean, decentralized micro generation for future smart grids [48].Fig. 3(a) shows functional block diagram of the smart socket concept. The power line communication module communicates with the SM and conveys SM commands to the microcontroller.

AC & DC input and AC & DC output				
Grid distribution voltage	Home distribution voltage	DC socket output voltage		
		Voltage	Type	Point
240 V AC 400 V AC	240 V AC 120 V DC	5 V	DC	B–A
		48	DC	D-A
		120	DC	E-A
		240V	AC	C-F-G

Table 1:Voltage points used in the DC socket according to the input voltage type of the home.

The microcontroller performs the commands of SM, measurement and control operation of power conversion module. Fig. 3(b) illustrates a smart socket design example. There is a plastic rectangular tip located on the DC plugs. The pin corresponds to a rectangular nest placed on the socket. This conjunction prevents a possible faulty connection for each DC voltage level on the plug. For the security purposes, DC neutral can be grounded in the system. Also, there is a metal side pin mounted at the down side of the socket and it provides the ground connection. To prevent faulty connection in 240 V AC voltage level, this pin corresponds to a metallic nest on the AC plug. The socket outlets labeled by {A, B, C, D, E, F, G} are connected to power conversion and switching module. A three states appliance priority bottoms p1, p2 and p3 are placed to the socket case in order to configure priority of appliance, manually.

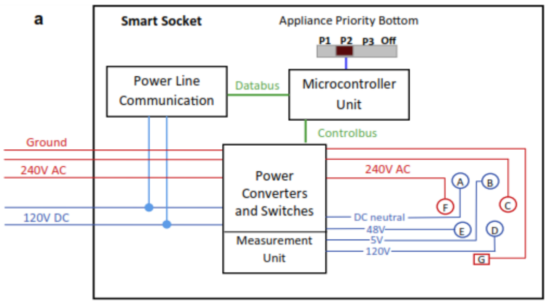

Fig. 3. Block diagram of DC distribution smart socket

Table .1, suggests a minimal voltage level diversity for DC outlets of the proposed smart socket. However, the output terminals of the DC power socket can increase in response to potential new DC volt- age level requirements in future. The 5 V outlets are reserved for low-power consumer electronics, such as phone chargers, the 48 V outlets are for mid-power home equipment such as laptops, TVs and computers, and the 120 V outlets are for high-power home appliances such as ovens, air-conditioners and washing machines. The 120 V DC also supports output standards for domestic renew- able energy systems, such as solar panel arrays, it is because that 120 V bus voltage is the order of the 12 V and 24 V generation volt- ages. These systems can be directly connected to 120 V home dis- tribution lines via parallel connection of an adequate number of solar panels.

4. Optimization method

In this section, optimal operation of smart grid is determined to minimize the interconnection point load flow fluctuations. The objective function and constraints are described below.

Set-up of objective function

From Fig. $1P_{IT}P_{LT}P_{BT}$ and P_{VT} represent the interconnection point power flow, power consumption except controllable loads, power consumption of battery and PV output powerrespectively, where:

$$P_{IT} + P_{BT} + P_{VT} = P_{LT}$$

The supply-demand balancing can maintain the equilibrium state to satisfy the above equation. In this paper, the objective function minimizes the interconnection point power flow fluctuations. Due to reduce the interconnection point power flow fluctuations, it is possible to suppress the harmful effects to power system, and it is possible to reduce electricity cost.

Objective function:

The objective function and constraints are described by the following equations:

$$min\ F = \sum_{t \in T} \{B_{Icen} - P_{It}\}^2$$

Constraints:

$$P_{Imin} < P_{It} < P_{Imax}$$

$$|P_{B_{it}}| < P_{Bmax}$$

$$C_{Bmin} < C_{B_{it}} < C_{Bmax}.$$

T: All time section
I: Smart house i group
B_{Icen}: Interconnection point power flow reference
P_{It}: Interconnection point power flow from power system to smart grid
P_{Imin}: Interconnection point power flow bandwidth minimumvalue
P_{Imax}: Interconnection point power flow bandwidth maximumvalue
P_{Bit}: Charge/discharge power of battery
P_{Bmax}: Charge/discharge power maximum value of battery
C_{Bit}: Remaining energy capacity of battery
C_{Bmin}: Battery capacity minimum value
C_{Bmax}: Battery capacity maximum value

Where, we have power flexibility by defining bandwidth for interconnection point power flow in equation we set power flexibility to _10% from power reference B given by power system in this paper. Equations (12) and (13) show battery inverter and capacity constraints, and P Bmax, Icen ¼ 4kW,C ¼ 20% and $C_{BmaxBmin}$ ¼ 80%, respectively. Furthermore, the proposed configuration of electric price as shown in Fig. 4 assumes the smart grid system in the future. If interconnection point power flow within the bandwidth (Region A), electric purchase cost is 10 Yen/kWh, and if interconnection point power flow departs from the bandwidth (Regions B and C), electric purchase cost are 20 Yen/kWh and 30 Yen/kWh, respectively. Moreover, electric selling cost to power system is 10 Yen/kWh. The bandwidth is given by power system to smart grid as power. Fig. 2, the grid can connect to house with 240 V AC or 400 V DC voltage in control of SM. Two lines with an AC voltage of 240 V and a DC voltage of 120 V supply sockets inthe house. Each socket provides 5 V, 48 V or 120 V DC and a conventional 240 V AC. Conventional power plugs can be placed in a lateral pins C–F inside the smart socket and the smart sockets becomes compatible withconventional 240V HEA standards.

Tabu Search

TS with local search methodology, which always moves neighborhood solution, are used for optimal technique in order to address the problems for determine charge/discharge power of battery and HP operation time for each smart house. In this paper, it is possible to determine heating time of HP by assuming power consumption, except controllable loads and heat load which could be forecasted. Therefore, charge/discharge power of battery and HP operation time for each smart house are calculated by using tabu search under the objective function and constraints. Of course, the proposed method can be calculated according to other optimization methods such as dynamic programming and GA. However, the searching area is not wide scale so we adopt tabu search. The details of the optimization are described as follows.

1. It is possible to forecast loads except controllable load for electrical and heat in each smart house: PV power output and amount of SC heat collection are calculated based on insolation forecasting data.

2. When hot-water temperature in storage tank is lower than 60C at 19:00, hot-water is heated to 60C by HP. HP heats the required heat by a fixed power consumption.

3. Based on the objective function and constraints, we determinecharge/discharge power of battery and HP operation time foreach smart house by using tabu search.

The AC waveform in power distribution is today's standard for domestic power distribution. In this reason, smart sockets should be compatible with conventional home appliances. Three different DC voltage levels are considered for DC power distribution for household equipment in this study. The 120 V is preferred for DC power delivery inside buildings because it is sufficient to supply home loads and this level of voltage is also low enough to prevent possible hazards. The DC outlets generate lower DC levels (48 V and 5 V) from 120 V home distribution lines via DC/DC converters in the sockets.

Table 1 suggests a minimal voltage level diversity for DC outlets of the proposed smart socket. However, the output terminals of the DC power socket can increase in response to potential new DC volt- age level requirements in future. The 5 V outlets are reserved for low-power consumer electronics, such as phone chargers, the 48 V outlets are for mid-power home equipment such as laptops, TVs and computers, and the 120 V outlets are for high-power home appliances such as ovens, air-conditioners and washing machines. The 120 V DC also supports output standards for domestic renew- able energy systems, such as solar panel arrays, it is because that 120 V bus voltage is the order of the 12 V and 24 V generation volt- ages. These systems can be directly connected to 120 V home distribution lines via parallel connection of an adequate number of solar panels. This voltage level standardization is suitable for green buildings and smart houses concepts in future smart grids.

5. Result

The output from the solar panel is 12V, given to the converter and connected to the grid. The output of battery also 12V connected to the grid through converter. The grid connected with smart meter and smart socket. Smart socket controlled by smart meter, if load get increased, then the critical load will be disconnected. By this process the system stability improved by 20% of its existing level.

6. Conclusions

This paper has determined an optimal operation and DC distribution system concept for smart houses, which consists of a battery and a HP as controllable loads that may steadily increase in the demand side in the future. As an optimization method, we have used the tabu search which determines the operation method of controllable loads, to suppress interconnection point power flow fluctuations within the bandwidth, based on information obtained by the communications infrastructures. By smoothing interconnection point power flow, it is possible to reduce electricity cost due to the reduction of the contract fee of the electric power company. Power consumption in smart grid is smoothed by achieving the proposed method, so we can suppress the impact of PV against power system. Consequently, we can expect high quality power supply and reduce the cost by cooperative control in smart grid. The concept gives a perspective for energy efficient green buildings capable of DSLM. Paper discusses a possible DC voltage level standardization according to power rates of HEAs and presents fundamental components required for smart DC power management system such as SM, domestic DC distribution systems and the smart sockets. Advantages of DC power distribution with smart sockets in residences are emphasized in term of domestic renew- able energy and storage integration and DSLM.

DC sockets make HEAs more energy efficient and secure because of reducing conversion losses by using switched mode supplying technology. In order to implement DC distribution in residences, a modern DC socket design is inevitable to meet diversity in DC consumption levels of HEAs. Smart DC sockets controlled by SMs also provide a solution for direct load control methods and implements DSLM application for smart grid applications. A dynamic energy price controlled load shedding algorithm was illustrated for plug load control application by smart sockets.

The load shedding program embedded in SMs was demonstrated to govern load shedding operations according the socket prioritization and power consumption. Although, it adjusts the total home consumption of smart house with respect to maximum electricity cost presetting of consumers, it still keeps working vital HEAs regardless of electricity price. Hence, this method allows dynamic energy price driven and operationally reliable load shedding based on direct load control methodology.

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