Intelligent Management of End Consumers Loads Including Electric Vehicles through a SCADA System

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Abstract. The large penetration of intermittent resources, such as solar and wind generation, involves the use of storage systems in order to improve power system operation. Electric Vehicles (EVs) with gridable capability (V2G) can operate as a means for storing energy. This paper proposes an algorithm to be included in a SCADA (Supervisory Control and Data Acquisition) system, which performs an intelligent management of three types of consumers: domestic, commercial and industrial, that includes the joint management of loads and the charge / discharge of EVs batteries. The proposed methodology has been implemented in a SCADA system developed by the authors of this paper – the SCADA House Intelligent Management (SHIM). Any event in the system, such as a Demand Response (DR) event, triggers the use of an optimization algorithm that performs the optimal energy resources scheduling (including loads and EVs), taking into account the priorities of each load defined by the installation users. A case study considering a specific consumer with several loads and EVs is presented in this paper.

Keywords: End consumers, demand response, intelligent management, electric vehicles, SCADA

1 Introduction

The main goal of power systems is to guarantee that the generation meets the consumers demand, including the domestic, commercial, rural and industrial types of consumers. The power system should remain in a stable state, matching generation and demand values. The consideration of consumers' behavior (participating in Demand Response events) is one of the distributed energy resources, which have been of increasing importance [1]. In certain periods of the day, mainly when the generation is lower than the demand or the marginal cost of increasing generation is high, the use of Demand Response (DR) programs is interesting for reducing the demand level as an alternative to increase the generation. The demand level reduction in a real time horizon is one of the most common events of DR. In the opposite situation (when the generation is higher than demand), it is possible to store the excess energy in a storage system by optimizing the use of energy resources. The increase of small resources use at lower voltage levels of distribution networks leads to the context of Smart Grid (SG) operation [2, 3].

In this context, the Electric Vehicles (EVs) with gridable capability (V2G) can be used as a storage unit, storing energy when there is an excess of generation and, discharging energy when the load is higher than the generation [4]. Only one V2G has no impact on the grid; however, the large integration of V2Gs can have non-negligible positive or negative impacts. The different V2Gs user profiles, which consider the daily necessities of people, will cause changes in consumption daily diagrams [5].

The optimization of load consumption and V2Gs use is able to improve the energy use efficiency, while allowing the system operator to control some loads of installation. This makes possible the increase of energy resources management flexibility [6, 7]. A consumer endowed with an intelligent energy resources management system allows the interaction with the grid operator, improving the effectiveness of the consumer‘s participation in a DR event, by receiving and sending event-related information [8, 9]. A SCADA system must support a decentralized structure to control, monitor, supervise and optimize all consumer energy resources, even in a real time horizon [10].

The paper deals with the intelligent management of a Domestic Consumer (DC) that adds two V2Gs to the system beyond the normal consumption loads. As these V2Gs are used by house users to travel to their respective workplaces, the effects of V2Gs on the intelligent management of a Commercial Consumer (CC) and an Industrial Consumer (IC) are analyzed. In this way, an optimization methodology is proposed and implemented in a SCADA system considering each type of consumer. This SCADA system considers all loads and V2Gs to perform an intelligent management.

Given the differences between the load curves for each type of consumer, it is important to analyze how the management systems will consider the V2G connection when applied to the three types of consumers at different times of the day.

After the introductory section, Section 2 presents the proposed methodology and Section 3 describes the energy resources considered by the SCADA system developed by the authors of the paper. A case study is presented in Section 4. The final section includes some conclusions.

2 Methodology applied in SCADA management

The intelligent management systems used by different consumers have the same basic structure, being some differences related to the characteristics of each consumer. Considering the context of participating in DR programs, any of the systems used aims to optimize the total consumption of the installation, keeping it lower than the established limit consumption or cutting power indicated by the system operator or by the installation user [11]. The optimization is directly affected by the users' consumption patterns and by the context of the day, which depends on several factors, such as the season, the temperature, the day of week, the time and the electricity price [12].

The SCADA House Intelligent Management (SHIM) has been described in previous works, and it was only applied to the DC [13]. In the present work, the integration of V2Gs is also considered. The same SHIM methodology is used to implement intelligent management systems for the CC and the IC. These systems include the following features, management of the power consumption in an installation, while maintaining user comfort and loads operation continuity; adaptability of the system to several daily factors that may influence the consumption; and ability to interact with DR events in the SG context.

The base algorithm, presented in [13], is able to manage the installation consumption whenever there are changes in the system operation conditions. The same algorithm has been improved in order to consider the CC and the IC. As mentioned before, this algorithm considers the consumers' loads and V2Gs, associated with a usage priority defined by the installation user. In the presence of a new event, the algorithm evaluates the current state of all installation equipment and, in accordance with the priority of each resource. It performs an optimal scheduling regarding the methodology presented in Figure 1. The Mixed Integer Non-Linear Programming (MINLP) optimization algorithm has been implemented in General Algebraic Modelling System (GAMS).

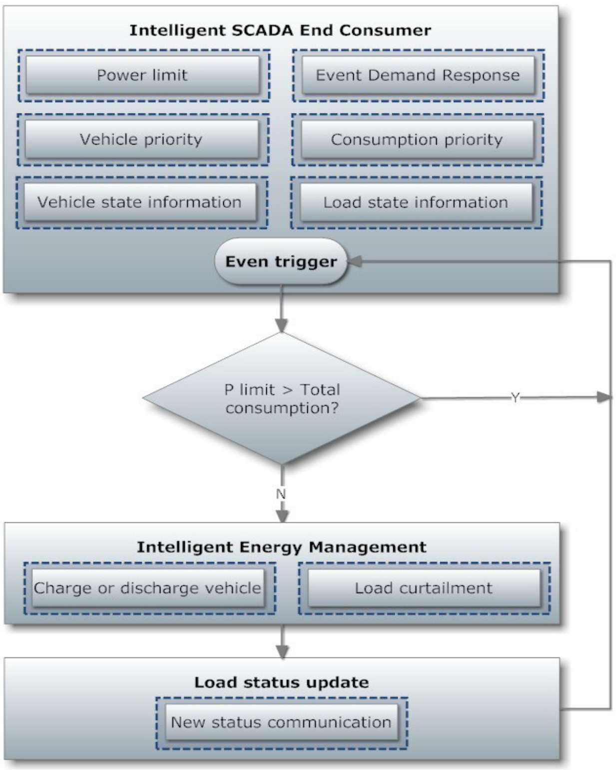

Fig. 1. SCADA End Consumer methodology

3 Energy Resources Description

3.1 End consumers with V2G

Each consumer installation has its load. Otherwise, V2Gs are common resources for the three considered installations of the SCADA system (see Figure 2), i.e., these resources have different connection points (installations) in different periods of the day as V2Gs travels between them. The current state/position of each V2G depends on the period of the day. For example, on Monday at 9 a.m. (peak consumption in the IC), the V2Gs are connected to the IC network and the charge / discharge periods could be managed by the SCADA system focusing on the IC installation resources use optimization. On the other hand, at 8 p.m. (peak consumption for DC and CC) V2Gs are connected to the housing network. The SCADA system is able to manage two V2Gs at the same period in a house (DC). In the case of the CC or the IC, it is prepared to receive one of the V2Gs that belongs to a DC. This is due to house users who give different functions to each V2G presented in Figure 2:

1. Move one user from the house to the industry (30 km) and return (30 km);
2. Move one user from the house to the commerce (15 km) and return (15 km).

The charge/discharge rate considered for both vehicles is 2.3 kW/h and a V2G battery at full charge has 16 kWh. The V2G have 160 km autonomy [14]. In this way, the V2G consumes 1500 Wh to travel 15 km (go to CC) and 3000 Wh to travel 30 km (go to IC).

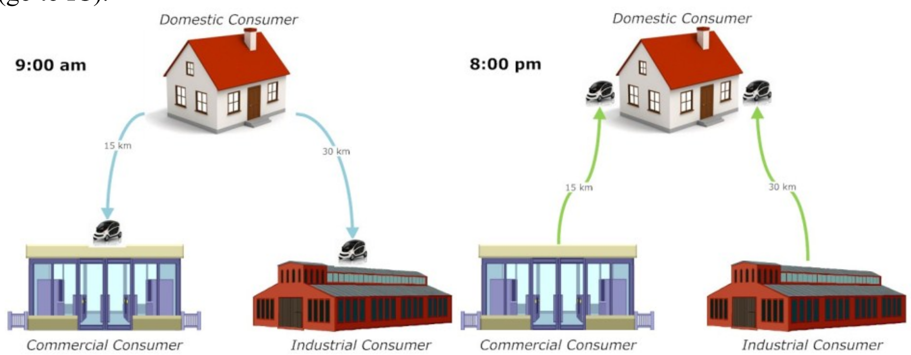

Fig. 2. End consumers with V2G at different times of the day

3.2 Description of End Consumers Loads

It has been considered different loads to perform the developed SCADA system, regarding the three consumers of different types. The GECAD's Intelligent Energy Systems Laboratory (LASIE) [11-13] loads were considered to represent the DC. The LASIE loads considered for the CC (coffee shop type) and for the IC (textile factory type) are presented in Table 1.

Table 1. Loads characteristics of end consumers

Type*	Domestic Consumer		Commercial Consumer		Industrial Consumer	
	Load	Max Power (W)	Load	Max Power (W)	Load	Max Power (W)
V_1	Induction Motor 1	90	Induction Motor 1	180	Induction Motor 1	450
V_2	Induction Motor 2	200	Induction Motor 2	400	Induction Motor 2	1 450
V_3	Induction Motor 3	300	Induction Motor 3	600	Induction Motor 3	1 700
V_4	Fluorescent Lamp	70	Fluorescent Lamp	700	Fluorescent Lamp	2 800
F_1	Incandescent Lamp 1	30	Incandescent Lamp 1	300	Incandescent Lamp 1	300
F_2	Incandescent Lamp 2	30	Incandescent Lamp 2	300	Incandescent Lamp 2	300
F_3	Heat Accumulator 1	1 600	Coffee Maker	1 500	Heat Accumulator 1	1 800
F_4	Heat Accumulator 2	1 000	Heat Accumulator 1	3 200	Heat Accumulator 2	1 800
F_5	Halogen Lamp	500	Dishwasher	1 500	Halogen Lamp	2 500
F_6	Exhauster	138	Plasma TV 1	276	Sewing Machine 1	690
F_7	Refrigerator 1	300	Desktop Computer	600	Iron 1	3 000
F_8	Washing Machine	550	Refrigerator 1	1 100	Clothes Dryer	5 500
F_9	Television 1	138	Security System	138	Sewing Machine 2	690
F_{10}	Refrigerator 2	300	Dehumidifier	600	Iron 2	1 500
F_{11}	Microwave	550	Plasma TV 2	300	Clothes Washer	2 750
F_{12}	Television 2	138	Sound System	138	Vacuum upright 1	690
F_{13}	Kettle	300	Refrigerator 2	300	Vacuum upright 2	1 500
F_{14}	Dishwasher	550	Air Conditioner	2 750	Cutting Machine	2 750
Total	**Maximum Power**	**6 784**	**Maximum Power**	**14 882**	**Maximum Power**	**32 170**

4 Case Study

In the case study, the SCADA system is applied for each type of end consumers (domestic, commercial and industrial) to perform an intelligent management of their energy resources (loads and V2Gs). The optimal energy resource scheduling is solved by the methodology presented in Section 2. Some scenarios are simulated in order to analyze the scheduling results for both consumers in different periods of the day.

All end consumers presented in this work have a database that contains a load priority, and the minimum and maximum power of each load and each V2G, depending on the context of the day. The SCADA system optimization analyzes the database and, according to the context, performs an optimal scheduling. The first development in previous work is the inclusion of two V2Gs in the optimization of the DC installation. After that, the methodology was improved in order to consider the CC and the IC, regarding the different characteristics of these consumers. The IC is the building with higher consumption. In this way, only one V2G should have low impact in the optimization process.

The present case study considers a Monday in the winter season, with an external temperature of 10ºC. At 9 a.m. and 8 p.m. the three consumers receive the simulated DR event respectively, according to the results presented in Table 2.

4.1 Timeline Results of the V2G State

In order to validate the case study, the results were analyzed. At 9 a.m. and 8 p.m. all end consumers receive the information regarding the DR event to cut or reduce loads consumption or to sell the energy stored in the V2G. The optimization of each end consumer installation depends on the availability of the V2G to be considered by the SCADA system. The timeline of the V2G state is presented in Table 2 according the DR event. The blue color means that the V2G is connected to the SCADA system respective, the red color means that the V2G is travelling and the green color represents the DR event participation at 9 a.m. (100 W to DC, 1450 W to CC and 5235 W to IC) and 8 p.m. (400 W to DC, 600 W to CC and 850 W to IC).

Table 2. V2G state and participation in a DR event

Hour	V2G	Domestic Consumer			Commercial Consumer			Industrial Consumer		
		State	Energy (Wh)	Charge/ Discharge Rate (W)	State	Energy (Wh)	Charge/ Discharge Rate (W)	State	Energy (Wh)	Charge/ Discharge Rate (W)
7 a.m.	1	Connected	16 000	0	Out	None	None	Out	None	None
	2	Connected	16 000	0	Out	None	None	Out	None	None
8 a.m.	1	Travel	None	1 500	Out	None	None	Out	None	None
	2	Travel	None	3 000	Out	None	None	Out	None	None
9 a.m.	1	Out	None	None	Connected	14 500	1 450	Out	None	None
	2	Out	None	None	Out	None	None	Connected	13 000	2 300
10 a.m.	1	Out	None	None	Connected	13 050	0	Out	None	None
	2	Out	None	None	Out	None	None	Connected	10 700	0
6 p.m.	1	Out	None	None	Travel	None	1 500	Out	None	None
	2	Out	None	None	Out	None	None	Travel	None	3 000
8 p.m.	1	Connected	11 550	400	Out	None	None	Out	None	None
	2	Connected	7 700	0	Out	None	None	Out	None	None
9 p.m.	1	Connected	11 150	0	Out	None	None	Out	None	None
	2	Connected	7 700	0	Out	None	None	Out	None	None

At 7 a.m. both V2Gs are connected to the DC SCADA system (with 16000 Wh of energy stored) but consumers do not receive any DR event. At 8 a.m., DC users begin the journey to their workplaces and at 9 a.m. a DR event is announced. At this time, $V2G_1$ is connected to the CC and $V2G_2$ is connected to the IC. This means that the DC will only be able to meet the DR event by cutting or reducing the loads consumption. Other end consumers can also use the discharge capacity of the V2G in the optimization process, according to the priority of the SCADA database.

At 9 a.m. all consumers receive the DR event order to reduce 100W, 1450W and 5235W corresponding to the DC, CC and IC respectively. The $V2G_1$ have 14500 Wh of energy due to the journey of 15 km to the CC and $V2G_2$ have 13000 Wh due to the journey of 30 km to the IC. At 10 a.m. one can verify that the $V2G_1$ storage energy is of 13050 Wh. This means that $V2G_1$ discharges 1450 W over one hour after the DR event announcement. The discharge value corresponds to the reduce power of the DR event and the loads that were being used by the CC were not changed, ensuring consumers' priorities. Regarding the $V2G_2$, the storage energy is of 10700 Wh. This means that $V2G_2$ discharges 2300W over one hour after the DR event announcement. The discharge value corresponds to a portion of the total reduce power of the DR event (5235 W). In this case, the IC SCADA system also needed to reduce the consumption in the lower loads' priority in order to fully meet the DR event requirements.

At 6 p.m. one can verify that any consumer of the SCADA system have V2Gs connected, because the V2G users begin the return journey, from the workplace to their houses, which will reduce 1500 Wh in $V2G_1$, and 3000 Wh in $V2G_2$. At 8 p.m. all consumers receive the DR event order to reduce 400W, 600W and 850W corresponding to the DC, CC and IC respectively. $V2G_1$ has 11550 Wh of energy and $V2G_2$ has 7700 Wh of energy.

At 9 p.m. one can verify that $V2G_1$ energy is of 11150 Wh. Thus, $V2G_1$ discharges 400W over one hour after the DR event announcement. The discharge value corresponds to the reduce power of DR event and the loads that were used by DC were not changed, ensuring consumers' priorities. Regarding $V2G_2$, the energy is 7700 Wh, maintaining therefore the initial energy. In this case, the CC and IC see the consumption reduced in the lower loads' priorities in order to fully meet the DR event, 600W and 850W respectively.

4.2 Energy Resources Scheduling Results

Tables 3 and 4 present the results of the optimization process to validate the methodology proposed in Section 2. Table 3 shows the priority of each load and of each V2G to charge (Ch) or discharge (Dch), when end consumers meet the first DR event at 9 a.m.. Table 4 summarizes the optimization results at 8 p.m. (second DR event). The coloured cells represent the resources which were subjected to changes.

The SCADA management system selects the loads or V2G mode (charge or discharge) according each priority. For example in first DR event to CC, the resource with low priority is 20 ($V2G_1$ discharge) and the resource with higher priority is 1 (Induction motor #2). The priorities are predefined by the installation users.

Table 3. Optimization results at 9 a.m. to end consumers

Type	Domestic Consumer			Commercial Consumer			Industrial Consumer		
	Priority	Power before (W)	Power after (W)	Priority	Power before (W)	Power after (W)	Priority	Power before (W)	Power after (W)
V_1	12	0	0	9	180	180	12	450	450
V_2	17	200	130	1	400	400	17	1 450	615
V_3	11	0	0	2	600	600	11	1 700	1 700
V_4	10	0	0	10	700	700	10	2 800	2 800
F_1	9	0	0	14	0	0	19	300	0
F_2	18	30	0	15	0	0	5	300	300
F_3	15	1 600	1 600	3	1 500	1 500	3	1 800	1 800
F_4	16	1 000	1 000	7	3 200	3 200	18	1 800	0
F_5	8	0	0	6	1 500	1 500	2	2 500	2 500
F_6	6	0	0	8	276	276	9	690	690
F_7	14	300	300	11	600	600	4	3 000	3 000
F_8	7	0	0	4	1 100	1 100	15	5 500	5 500
F_9	5	0	0	17	138	138	8	690	690
F_{10}	13	300	300	16	0	0	16	1 500	1 500
F_{11}	1	0	0	12	300	300	1	2 750	2 750
F_{12}	3	0	0	13	138	138	13	690	690
F_{13}	4	0	0	5	300	300	7	1 500	1 500
F_{14}	2	0	0	18	0	0	6	2 750	2 750
Total Power		**3 430**	**3 330**	**-**	**10 932**	**10 932**	**-**	**32 170**	**29 235**
$V2G_1$	None	None	None	Ch – 19 Dch – 20	14 500	13 050	None	None	None
$V2G_2$	None	None	None	None	None	None	Ch – 14 Dch – 20	13 000	10 700
Reduce Power		**100**		**1 450**			**5 235**		

Table 4. Optimization results at 8 p.m. to end consumers

Type	Domestic Consumer		Commercial Consumer		Industrial Consumer	
	Power Before (W)	Power After (W)	Power Before (W)	Power After (W)	Power Before (W)	Power After (W)
Loads Power	6 784	6 784	12 132	11 532	15 140	14 290
$V2G_1$	11 550	11 150	None	None	None	None
$V2G_2$	7 700	7 700	None	None	None	None
Reduce Power	**400**		**600**		**850**	

In the first DR event, at 9 a.m., the DC fulfilled the reduce power (100W) by turning off the incandescent lamp #2 and reducing the consumption of the induction motor #2 (loads with lower priority). The CC fulfilled the DR event requirement (1450W) through the $V2G_1$ discharge, keeping the same load consumption. The IC beyond the $V2G_2$ discharge, also turned off the incandescent lamp#1 and the heat accumulator #2, and reduced the consumption of the induction motor #2 to guarantee the required reduced power of DR event (5235W). In the second DR event at 8 p.m., the DC fulfilled the reduce power (400W) with $V2G_1$ discharge, keeping the same load consumption. The CC fulfilled the DR event requirement (600W) through the loads with lower priority; the same happened in the IC (850W).

5 Conclusions

This paper presents a case study considering a SCADA system to manage and optimize the consumption of all energy resources of the DC, CC and IC consumers. The case study is discussed and analyzed applying the methodology to the CC and IC in a particular context, and verifying the usefulness of V2Gs in their management systems. The results of using the proposed methodology regarding working days or weekends specificities, which require some distinct characteristics, have been addressed and will be reported in near future work.

In the present work, one can verify that V2G has direct participation and impact in the consumption optimization. The SCADA system of any consumer is provided with the priorities defined by the installation users to each load and each V2G according to the operation context. The SCADA database allows to know the user's needs in real time in order to guarantee the fulfilment of the DR event requirements.

One V2G may have more influence in the DC optimization than in the IC optimization, as the IC is a consumer with higher energy requirements. In this way, one V2G may have little impact in IC resources use optimization, but if we are dealing with a considerable number of V2Gs, this impact must be adequately analyzed. This means that the optimization decisions depend directly on the consumers' energy needs, on the number of V2Gs considered and on the type of end consumer. The benefits of using the proposed SCADA system can be summarized as follows:

- Creation of a system with its own capacity for decision in real time to support the grid operator with energy management capability;
- The methodology development can be adapted for any type of end consumer and amount of energy resources;
- Each SCADA system is able to be adapted to the current system conditions over the day with or without of V2G;
- The inclusion of V2G in the SCADA system makes possible to ensure the end consumer comfort through the V2G batteries energy discharge.

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