

Assessment of the impact of intelligent DSM methods in the Galapagos Islands toward a Smart Grid



D.X. Morales^{a,b,*}, Y. Besanger^a, S. Sami^c, C. Alvarez Bel^d

^a Univ. Grenoble Alpes, CNRS, Grenoble INP*, G2Elab, F-38000 Grenoble, France

^b Universidad Católica de Cuenca, Ecuador

^c Universidad Católica de Cuenca—CERN Research Center, Ecuador

^d Universidad Politécnica de Valencia, Spain

ARTICLE INFO

Article history:

Received 24 October 2016

Received in revised form 2 February 2017

Accepted 3 February 2017

Keywords:

Smart Grids

LV network

Electrical vehicles

Demand Response

Distributed generation

Time of use

Optimal energy management

DSM

ABSTRACT

The Galapagos Islands are a fragile ecosystem, which belongs to Ecuador country. The supply of energy is through of combined technologies such as thermal, photovoltaic and wind. The government of Ecuador is fostering the policy zero CO₂ emissions within the islands. In order to achieve this objective, some initiatives are carried out like replacing the conventional vehicles and the gas stoves by electrical ones. Taking into account this framework, it becomes vital to assess the impact of these new policies on the distribution network; for sure, this will change significantly the operation and control of Galapagos distribution grid. In addition, once determined the impact it is worth proposing smart strategies in order to deal with the load growth due to new services. Thus, this paper proposes an adapted and intelligent method for performing Demand Side Management in the Galapagos low voltage network, the proposal executes Demand Response in the presence of time of use pricing. An ingenious approach, which consists in modifying load curves by means of polynomial functions is presented; several scenarios with different strategies are analyzed, the main results show as the proposal strategy respect all the limits established by the regulator and as the rebound effect is annulated. Real field information has been used in the presented models.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

The Galapagos Islands are an archipelago of volcanic islands distributed on either side of the equator in the Pacific Ocean, 926 km west of Ecuador. The Galapagos Islands and their surrounding waters form an Ecuadorian province, a national park, and a biological marine reserve. Since 1978, they are accepted as World Heritage [1].

Due to the growth of the population, there are several social, economic and environmental problems, which endanger the environment conservation of the Islands. According to the census made on 2010 by the INEC, on the Galapagos province there are 25.274 people, of which 15.393 live at Santa Cruz, 7.475 at San Cristobal at Isabela 2.256 and 150 at Floreana [3]. The Ecuadorian government

wants to preserve its ecological heritage. Hence, with the participation of several stakeholders such as the Ministry of Energy and Renewable Energy, Galapagos Government Council, among others, released several initiatives such as replacing the conventional vehicles by electrical ones and the gas stoves by induction ones, strong integration of distributed generation, deployment of an ADMS and a future deployment of smart meters in order to improve the general services provided to the islands population. Presently, one of these initiatives is the EcoSmart Project [4], which is intended to improving the preservation of the Galapagos Islands and reducing the environmental footprint, becoming a world class reference in management of the energy and sustainability. In order to accelerate the islands through efficiency and quickly transition toward a SG some ADA functions such as self-healing [5], DSM [6], VVC [7], and NR [8] have to be implemented. Refs. [9,10], defined Smart Grid as “An electricity network that can intelligently integrate the actions of all users connected to it—generators, consumers and those that do both functions to efficiently deliver sustainable, economic and safe power supply”.

Worldwide improvements achieved in the ICT field, the implementation of Smart Grid are significant tools recommended for

* Corresponding author at: Univ. Grenoble Alpes, CNRS, Grenoble INP*, G2Elab, F-38000 Grenoble, France.

E-mail addresses: Diego.Morales-Jadan@g2elab.grenoble-inp.fr, dmoralesj@ucacue.edu.ec (D.X. Morales), Yvon.Besanger@g2elab.grenoble-inp.fr (Y. Besanger), ssamih@ucacue.edu.ec (S. Sami), calvarez@upvnet.upv.es (C. Alvarez Bel).

Nomenclature

ADMS	Advanced Distribution Management System
ADA	Advanced Distribution Automation
AMI	Advanced metering infrastructure
ARCONEL	National Agency Regulation of Ecuador
CENACE	National Center of Energy Management of Ecuador
DER	Distributed energy resources
DG	Distributed generation
DR	Demand Response
DSM	Demand Side Management
DSO	Distribution system operator
EE	Energy efficiency
EM	Electrical motorbike
EV	Electric vehicles
G	Growing of population, therefore of the load
IC	Induction cooker
ICT	Information and communication technology
INEC	National Institute of Statistics and Census of Ecuador
LV	Low voltage
MV	Medium voltage
NR	Network reconfiguration
PV	Photovoltaic panel
PQ	Load fed with active and reactive power curves
SG	Smart Grid
SR	Spinning reserve
TOU	Time of use
TOU ARCONEL	DSM with the schedule defined by ARCONEL
TOU UPV	DSM with the schedule defined by UPV
TOU Smart	DSM with a soft and intelligent function
UPV	Polytechnic University of Valence
VVC	Volt var control

use electric power systems. For example, Denmark, a pioneer in the development of Smart Grids; concludes in its report “Smart Grids in Denmark” [6] that a Smart Grid is the most effective strategy to develop the electrical system and prepare it to meet future challenges. In this context, it is important to change the distribution networks, since distribution networks are the connection point between new agents with the grid [11]. The Ecuadorian electrical sector is currently pursuing new concepts like *DG* such as micro and peak hydraulic, photovoltaic, wind and biomass, and new loads such as *EV* and induction cookers. The induction cooker represents new electrical load in Ecuador, which has been recently deployed into the *LV* grid to replace gas stoves. 80 induction cookers have already been deployed for the specific case of Galapagos Archipelago and 240 have been requested [12]. The *AMI* technology would collaborate to perform *DSM* and to improve agent’s visibility in the network [13,14]. Encourage customers for generating their own energy is a key aspect considered within the new policies to convert Galapagos to an archipelago energetically self-sustaining.

The advent of all these challenges must be evaluated and quantified their impacts on the electrical network. Once made it, must be proposed smart techniques in order to manage adverse effects and to keep the clients comfort. In Ref. [15] all the assessment of these policies is conducted in the specific case of Galapagos. Due to the demographic characteristics and the existent logistics, this paper will focus the *DSM* program implementation on the islands, which represent most of the population, i.e. Santa Cruz (61%), and San Cristobal (30%). In Ref. [16] a methodology to evaluate *DSM* in electric distribution systems, based on time of use pricing and elasticity concepts is presented, the evaluation is performed through an optimal power flow model considering linear constraints. Ref. [17] presents a time-of-use-based bottom-up model of residen-

tial electricity consumption, the model deals with the presence of multiple individuals in a household, their behavior and the related use of appliances. Ref. [18] simulates domestic energy consumption and presents an algorithm which control consumption during peak hours. The results indicate 40% reduction in peak time energy demand. In Ref. [19] two *DR* program options are analyzed for low voltage feeders, the first based on the electricity price, and the second one based on the loading of the network, the benefits of two *DR* programs are presented. In Ref. [20] the likely impacts of China’s on-going power sector reform on its *DSM* is conducted, the impacts of the new reform are determined, among them (i) grid companies may have more motivations for *DSM* investment, (ii) electricity end-users’ motivations for *DSM* may be both enhanced and dampened [21]. Affirms that the tariff programs commonly used do not achieve the desired results, hence, the article includes an assessment of using a Decentralized Active Demand Response system for activities related to the reduction of peak loads.

Ref. [22] proposes a stochastic programming approach model, which is developed with cloud computing scheme for effective *DSM* in Smart Grid. In Ref. [23] the new proposal of the tariff structure of distribution companies in Brazil, which is looking for establish a mechanism called Tariff Flags, which aims to foster a Demand Response Program in Brazil via an increase in the energy tariff is analyzed. In Ref. [24] a two-stage stochastic problem for energy resource scheduling to address the challenge brought by the demand, renewable sources, electric vehicles, and market price uncertainty is proposed. The proposed method minimize the expected operational cost of the energy aggregator. Ref. [25] develops an algorithm for automatically adjusts the power demand according to the output of the distributed renewable generation, mitigating disruptions due to variations of the *DER* output, as well as, adjusting the load demand dynamically according to the fluctuations of electricity price [26]. Proposes a detailed bottom-up response modeling methodology, as a first step toward understanding and formulating consumer response at the level of individual activities.

The literature review reveals a need for research in *DR* programs applied in presence of *TOU* pricing, mainly in *LV* networks. Most of the research is focused in independent initiatives. Thus, this paper proposes an innovative combined program *DR*+*TOU* in Galapagos Low Voltage network. This paper also analyzes in objective way the current rate model of Ecuador, as well as, the proposal made by UPV. Taking into account, client’s real information, topology network and real measurements in subtransmisión level a new rate period is suggested. By means of weighted function, all the load curves are modified in order to implement the integral *DSM* program. The proposed *DSM* program meet some goals such as (i) avoid peaks canceling the rebound effect, (ii) keep the voltage profile within acceptable limits and (iii) shift the energy during the whole day and not only after the peak period. A key element into simulations consist in simulating the appliance controller device in each household in order to manage the shifted energy that will be consumed during the whole day (Fig. 1).

2. Demand Side Management

Ref. [15], presented a detailed study about the impact of electric motorbikes (motorbikes are the most used vehicles in Galapagos), induction cookers and distributed generation, specifically *PV* panels. The main results show, for example, that the relative load of one of the *MV/LV* transformers (Table 1) reaches 142,12% as maximum, and the transformer is overloaded during almost 2 h per day (Fig. 2 in red).

The Galapagos power system has mainly single-phase at the *MV* level and pole-mounted *MV/LV* transformers distribute electric



Fig. 1. Galapagos satellite view [2].

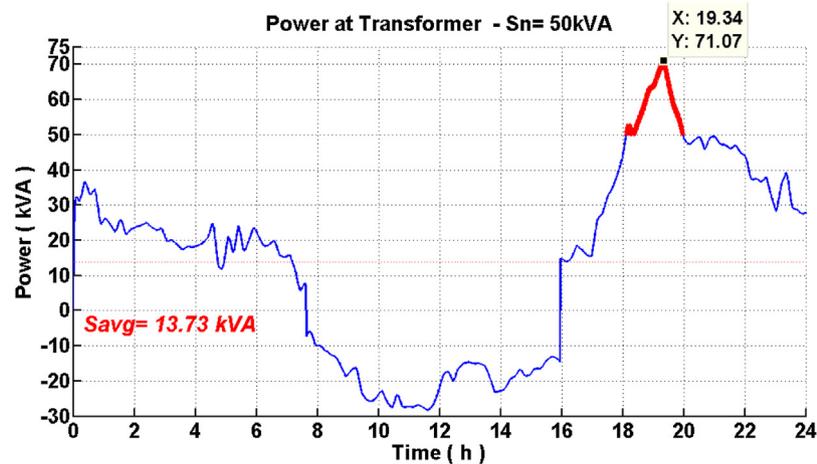


Fig. 2. Active power through a MV/LV transformer. (For interpretation of the references to color in the text, the reader is referred to the web version of this article.)

Table 1
Description of the modeled LV network.

Substation	Transformer	Power (kVA)	Customers	Nodes
Santa Cruz	TR1	50	40	15

power for distribution to end-users. On the LV side of the transformer, a single-phase three-wire supply provides electricity at 120 V and 240 V levels, as shown in Fig. 3.

The reverse flow due to the PV panels installed at households also is depicted. However, as it was expected, the main peak during the night is still present. This clearly shows the need for performing additional techniques such as DSM in order to reduce the peak at the transformer. DSM programs involve an intelligent effort to encounter the increasing electricity demand, through shifting the peak load and using energy in an effective way. According to Ref. [27], an intelligent DSM provides a good approach to optimize the management of energy use by means of (i) advanced communica-

tion device, (ii) regulation methods and (iii) appropriate economic incentives. Depending on the type of DSM, different means of technology, and especially communication, are necessary. DSM is seen in Ref. [28] as a good promoter of distributed generation: In order to avoid long-distance transport, locally generated energy could be consumed by local loads, immediately when it is available [29]. The main advantage of DSM, taking into account the economical point of view, is that it is a less expensive way to influence changes in the load than to build a bulk power plant. In Ref. [30] a multi-agent system for the coordination of active demand and plug-in EV is presented, the agents perform the optimization following the Nash's theory on games. Ref. [31] recommend an optimum use-times to consumers accepting ideal use preferences from an external load manager and computing the cost savings of these preferences, also the residential electricity cost of individual homes by shifting demand over a daily forecast price cycle is minimized. DSM can be classified as presented in (Fig. 4):

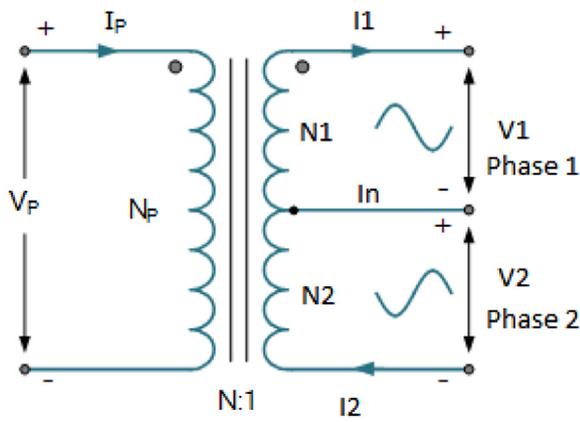


Fig. 3. Equivalent circuit for centre tapped transformer.

- a) EE
- b) TOU
- c) DR
 - Market DR
 - Physical DR
- d) SR

2.1. Energy efficiency

At the lower level of DSM, all the permanent changes on equipment or improvements on the system are considered in this category. This kind of actions results in immediate and permanent energy and emissions savings. Hence, the Ecuadorian government has launched two initiatives: the first one was to replace the conventional light bulbs by energy saving ones and the second consists in changing the inefficient refrigerator by efficient ones. Indeed, since 2012 in Galapagos, 1053 refrigerators of class D has been replaced by refrigerators of class A, reaching a saving of \$200,754.45 annuals. The goal is to change 3000 refrigerators by 2017. At the national level, the adoption of these actions made it possible to reach a reduction of 8,6% in the consumption peak. By means of 15 million of saving bulbs delivered, 85,000 refrigerators changed, 65,000 street lights replaced, 600 industrial users trained in the standard ISO 50001, 35 factories with efficient energy management systems, 8 standards of Energy Efficiency and 22 regulations of Energy Efficiency. As a consequence, 600 million of investment needed for building bulk power plants were deferred [32].

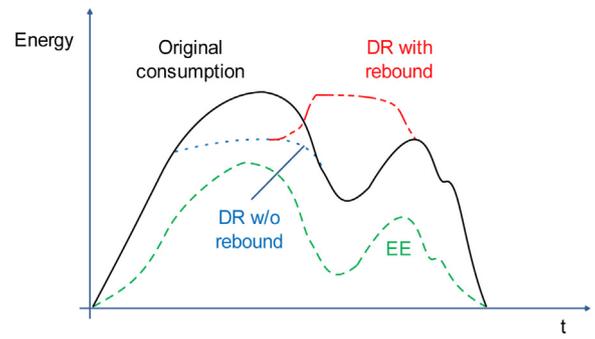


Fig. 5. DSM with and w/o rebound [28].

2.2. Time of use

The time of use is an array of static tariffs that penalize with a higher price certain periods of time, generally the peak hours, in order to motivate the customers to re-arrange their processes to minimize the energy cost. This does not mean that a consumption reduction exists in all the cases, but an expected change in the consumption patterns would be registered. In the worst scenario case, even if we have a reduction of the consumption in a first step, a period known as “rebound effect” (or payback) [33] generally appears, thus the expected energy saving is typically not carried out and maybe even a new peak is generated [28] (see Fig. 5).

Ref. [34], presented the rebound effect and the energy shifted that are taking into account through a shedding vector. The peak could be moved before or after, however it is better to move the peak before the shed time and be prepared. There are two additional options considered as time-based rates (i) critical peak pricing and (ii) real-time pricing [35].

2.3. Demand Response

In this DSM, a signal coming from the DSO is broadcasted to the clients in order to get a much quicker response than TOU. Normally, this signal contains (i) price of energy (ii) command for load shedding or shifting. To perform DR efficiently, a “controller” is required (see Fig. 6), which uses load models for taking good decisions. This can be done in an autonomous way or in a coordinated way, because is difficult to imagine a big group of autonomous distributed controllers, without communication. It is worth noting that performing load shedding at the same time because DR, can cause some issues

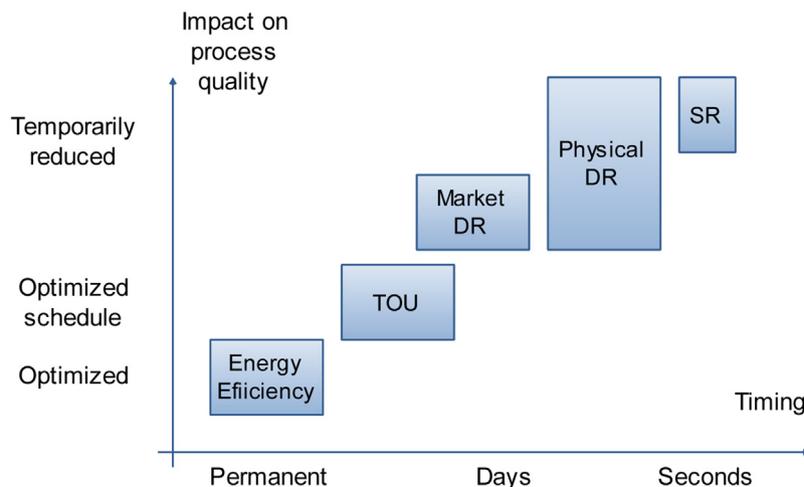


Fig. 4. DSM categories [28].

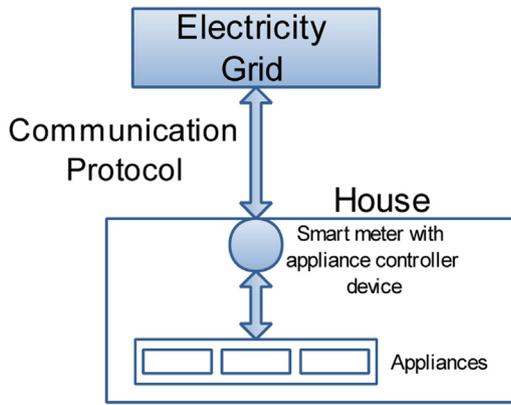


Fig. 6. DR using Appliance controller device [39].

Table 2
Tariff for EV.

Days/hour	Demand (USD/kw)	Energy (USD/kwh)	Commercialization (USD/consumer)
M–F 8 h00–18 h00	2,43	0,08	1,414
M–S 18:00–22:00	4,050	0,10	1,414
M–S 22 h00–8 h00	1,458	0,05	1,414
S*–D 8:00–18:00	1,458	0,05	1,414

M = monday, F = friday, S = sunday, S* = saturday.

3. Intelligent DSM for Galapagos Islands

In this section the current TOU in Ecuador will be explained; also a proposal developed by the UPV for Ecuador is analyzed, after an intelligent method that combines DR + TOU is presented. Nowadays, considering all the policies launched by the government the ARCONEL has updated the tariff schedule in order to include a new tariff for EV (up to 10 kw) [42]. See Table 2. The main initiative is based on fostering the EV deployment, ought their efficiency and contribution to environment. In addition, the power grid applications such as (i) voltage control, (ii) exchange reactive power for autonomous voltage support without communicating with the distribution system operator, (iii) influencing the available active power for primary transportation function [43]. Unscheduled high penetration of EVs surely have negative effects on power system performance when EVs used widely, as a result there is an exigent need to predict the EVs' consumption [44]; present a probabilistic modeling for EV charging demand, in order to avoid irreparable effects, especially for the distribution network. In Ref. [45] a time series forecasting of EV charging demand for stochastic power system is conducted.

The above table presents the tariff calculated by two variable components and by a fixed one. The variables components (i) demand, and (ii) energy, changes according the day and hour, for instance the consumption in the national peak period (18:00–22:00) is the most expensive; demand 4,05 USD/kw and energy 0,10 USD/kwh. Assuming that 15% of the loads are controllable [46] and that every household possesses at least one controllable device which participates in the load management process, a polynomial function is created in order to represent the effect of applying TOU according Table 2, and a 50% rebound is integrated into the simulation [47] (Fig. 7).

The weekly tariff (Monday to Friday) is implemented by the weighting function. The A region from 18:00 to 22:00 is shifted immediately after the most expensive period to the region B where we have the cheapest price, this mean from 22:00 to 08:00. How-

such as cold load pickup and DR dependency on voltage, and phase imbalance [36]. In addition, using DR with the loads represents virtual storage via load shifting [28,37]. In order to execute automated Demand Response, a new protocol has been presented recently by OpenADR [38].

Market DR relies on a market place where transactions are done a day ahead considering prices signals and incentives, whereas physical DR uses emergency signals and takes into account grid management.

2.4. Spinning reserve

The traditional spinning reserve is an ancillary service that correspond to generators that are in operation (spinning) with additional production capacity and can be produced (injected into the network) in an interval of 10 min for at least two hours [40]. Hence, DSM spinning reserve attempts to imitate this behavior, in other words the load must be reduced or increased when the grid frequency drops or rises. In Ref. [41] presented a comprehensive load-side frequency control mechanism that can maintain the grid within operational constraints using controllers that can rebalance supply and demand after disturbances, restore the frequency to its nominal value and preserve inter-area power flows. Based on the Smart Grid concept, the electricity consumption could vary with the changes in the price according to their requirements [27].

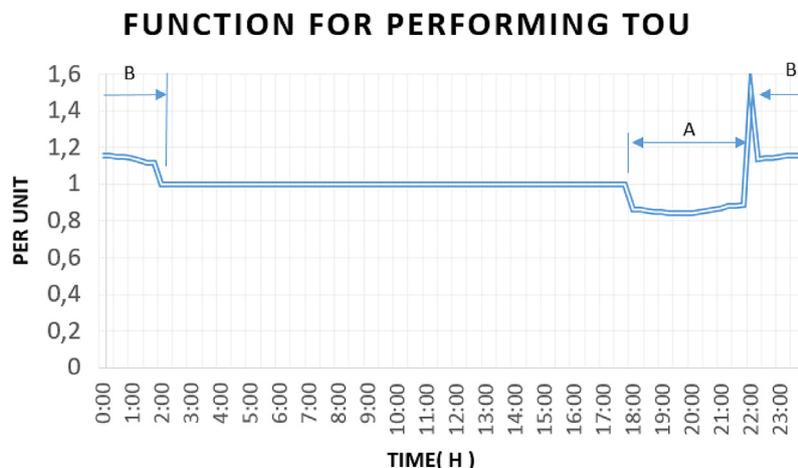


Fig. 7. Weighting function for performing TOU considering the guidelines given by ARCONEL.

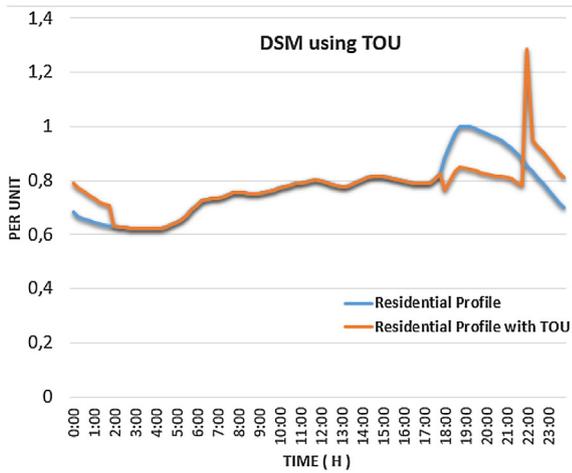


Fig. 8. Comparative curves of residential profile vs residential profile with TOU.

ever, the reader should take into account that the energy of 4 h was shifted. Thus, energy now is consumed between 22:00 and 02:00. An important premise, this kind of DSM keeps the consumption almost equal, since exits only a load shifting [48]. See Eq. (1):

$$\int_0^{24} R_{pbTOU} \approx \int_0^{24} R_{pwTOU} \quad (1)$$

where:

RpbTOU = residential profile before TOU

RpwTOU = residential profile with TOU.

Fig. 8 illustrates an example of changing caused over an average residential profile; this profile has a typical shape and was given by ElecGalapagos Utility. However, it is worth noting into simulations are used measured load curves for the 40 clients. It is possible to identify the rebound and how the load is shifted to the night hours.

A modification in the model developed by Ref. [15] was executed in order to perform DSM, basically, the changes consist in adjusting

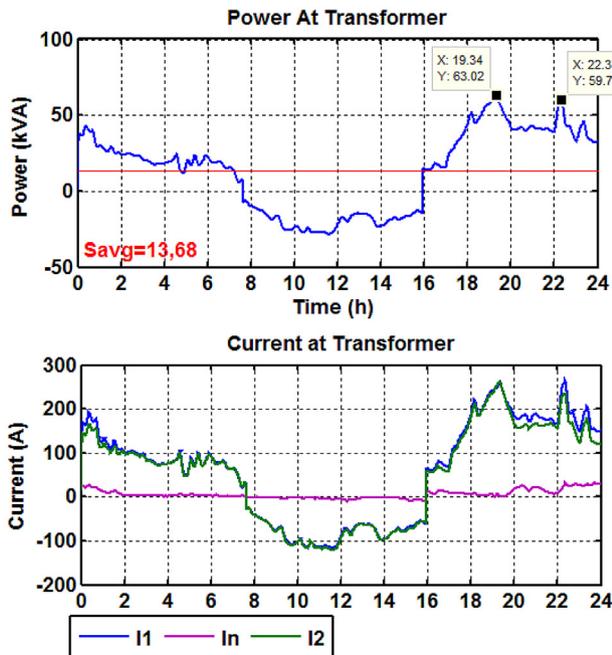


Fig. 9. Results after applying DSM using ARCONEL curve.

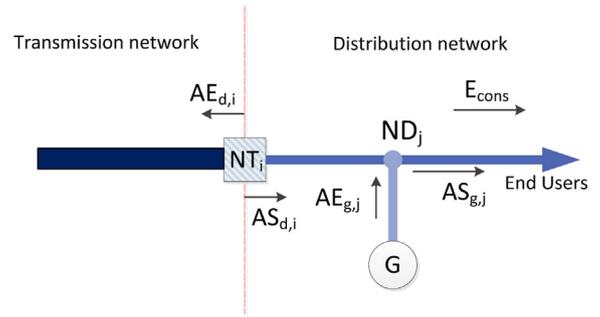


Fig. 10. Methodology for getting the power delivered to the end users.

all the residential curves (40) by means of multiply the curve by the weighting function defined using the information of Table 2.

As illustrated in Fig. 9, and comparing to Fig. 2, the power peak in the transformer at 19:18 has been decreased to 63,02 kVA, but a new peak at 22:18 is registered (59,7 kVA). The voltages are exceeding the limits required by the quality standard (minimum 114 V). Additionally, the neutral current at 22:18 is higher than the original case. In summary, the rate scheme proposed by ARCONEL is not suitable.

A first study about the feasibility of deploying Smart Grids in Ecuador [49] proposes a new TOU schedule considering different profiles in the country, since ARCONEL has been using only a national profile. This methodology is more consistent because it takes into account the real time measurements available at the interconnection points between transmission and distribution, which were taken by the CENACE. Fig. 10 depicts the methodology achieving the new profiles.

Eq. (2) defines the total power delivered to the end users.

$$E_{cons} = \left(\sum_{i=1}^n AS_{d,i} + \sum_{j=1}^m AE_{g,j} \right) - \left(\sum_{i=1}^n AE_{d,i} + \sum_{j=1}^m AS_{g,j} \right) \quad (2)$$

where,

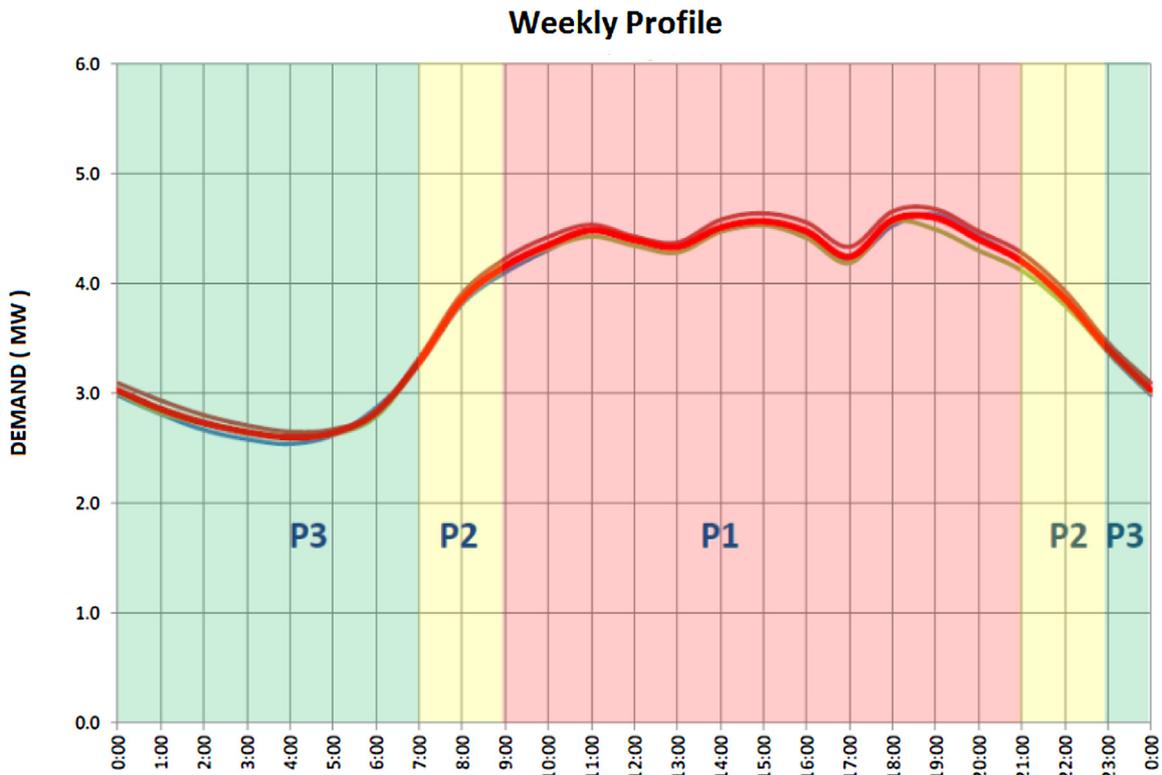


Fig. 11. TOU defined by real measurements [49].

E_{cons} = total power delivered to the end users connected at the distribution network

$AS_{d,i}$ = power delivered coming from the transmission network to the distribution network at the node NTi

$AE_{d,i}$ = power delivered coming from the distribution network to the transmission network at the node NTi

$AE_{g,j}$ = power delivered to the distribution network by the generators connected at the node NDj

$AS_{g,j}$ = demand of the elements connected at distribution network at the node NDj

n = transmission nodes

m = distribution nodes with a generator connected.

Once defined the methodology and Eq. (2), different profiles are determined for 6 regions in Ecuador, (i) Cost, (ii) Sierra, (iii) Amazon, (iv) Quito, (v) Guayaquil and (vi) Galapagos; those profiles are divided by week, weekend and holidays as well as season. For the purpose of this paper, only a typical profile will be considered (weekly profile during summer). Then, a new TOU schedule is defined. Fig. 11 depicts 3 periods within Galapagos, P1 is the on-peak, P2 semi-peak and P3 off-peak.

Ref. [49], reported that after performing an in-depth analysis on the monotonic curve, three periods are identified and the peak period (P1) is located between 09:00 and 21:00. Then, a new simulation considering the described above is performed. The main curves are depicted in the following figures (Fig. 12).

This function starts the shifting process in the region A (16:00–21:00) and shifts this reduction in the consumption to the region B (21:00–02:00). In addition, the rebound effect is taken into account. Fig. 13 illustrates the changes caused over an average residential profile given by the local utility, and it is possible to identify the rebound and how the load is shifted.

As we can see in Fig. 14, a higher peak (74,31 kVA) at 21:00 is recorded. The voltages are worst compared with the previous scenarios and the limits accepted by the quality standard are violated (minimum 111.3 V).

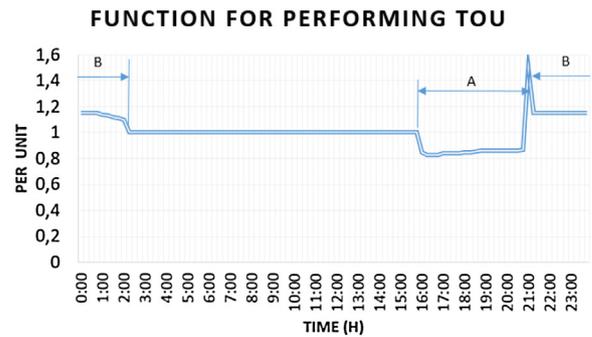


Fig. 12. Weighting function for performing TOU considering the guidelines given by the study performed to deploy Smart Grids in Ecuador -UPV-.

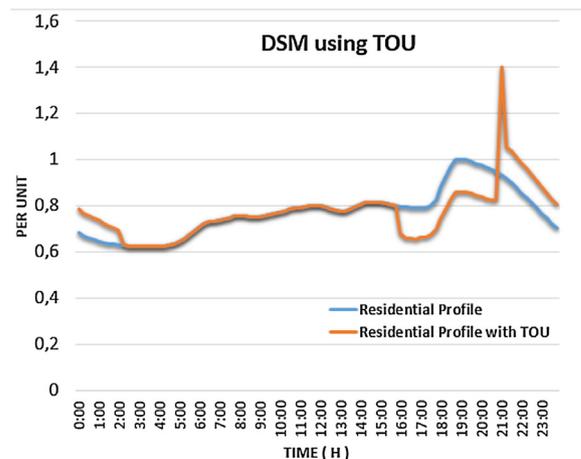


Fig. 13. Comparative curves of residential profile vs residential profile with TOU defined by regions.

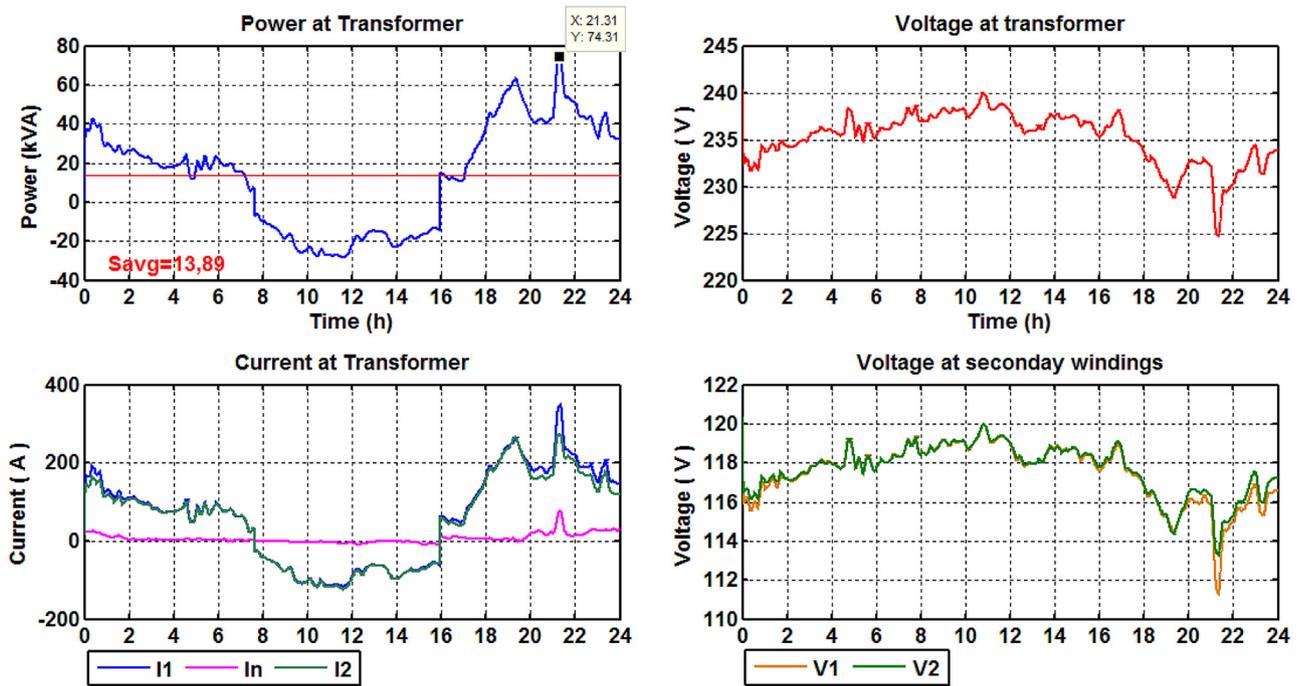


Fig. 14. Results after applying DSM using UPV curve.

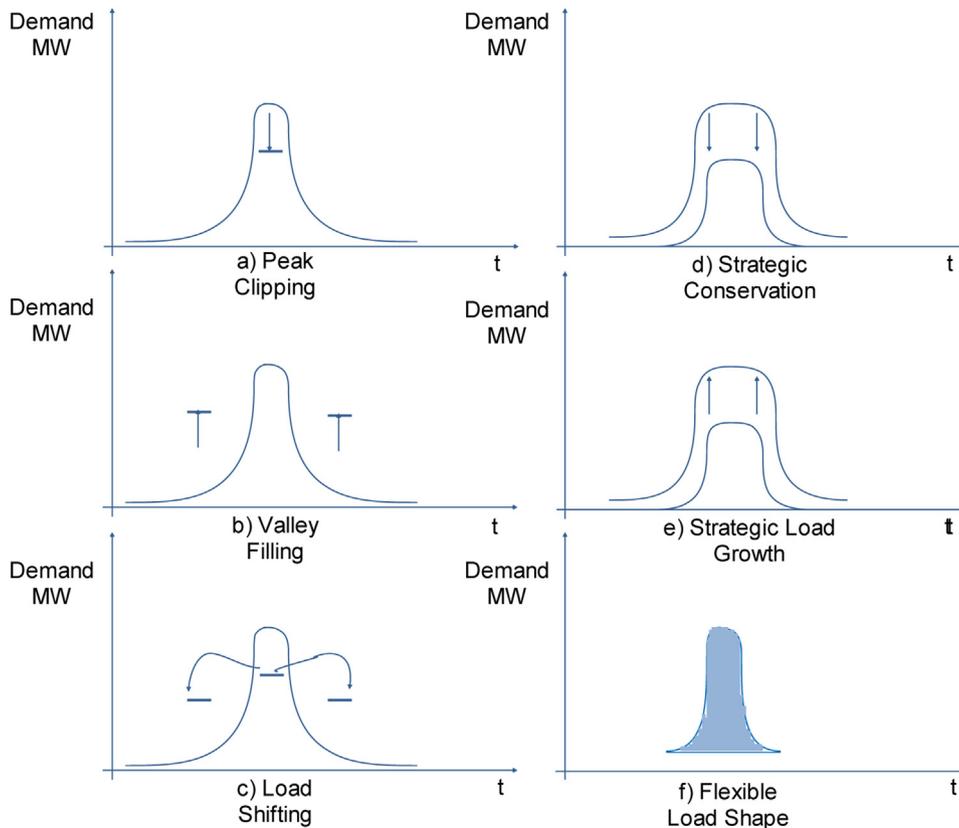


Fig. 15. Load Shapes for DSM program [50].

Obviously, the rebound added to the original power around 21:00 (higher than 22:00, see Fig. 2) cause this increase in the peak. Hence, a smart strategy must be implemented in order to avoid the peak as well as to shift the energy during the whole day and not only after the peak period. Therefore, the previous weighting func-

tion is modified until to reach a soft function, which has the same energy during the whole day with the difference that now, it will be considered an algorithm for the appliance controllers device in each household and the shifted energy will be consume during the whole day. It is worthwhile to mention there are two key technologies

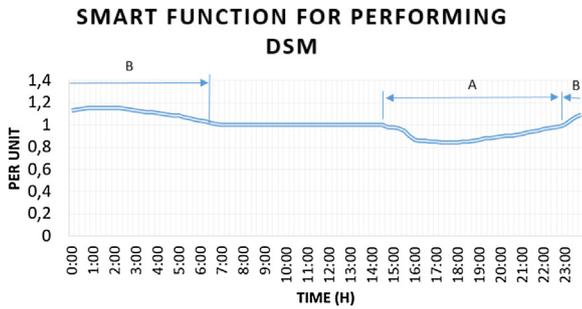


Fig. 16. Smart function for performing DSM.

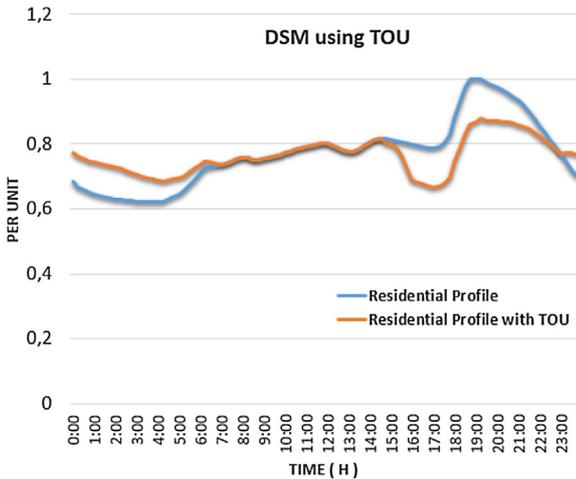


Fig. 17. Comparative curves of residential profile vs residential profile with smart function.

enabling demand side load optimization (i) building automation and (ii) smart metering + appliance controller.

Previously was defined a 15% of controllable loads, the loads normally are classified as:

- Baseline loads refers to those appliances that must be activated immediately at any time, or maintained at 'Stand by' mode. Their economic value does not allow any intelligence integration, and they are not controllable because they depend on consumer behavior and comfort [24]. Lighting, TV, and computing are some examples.
- Regular loads are those corresponding to the appliances that are operated for long time periods like fridge and water heater.
- Burst loads concern the appliances that must operate for a limited time period within deadlines. This last type can be flexible and so delayed to start operation in another moment, like washing machine, dryer dishwasher, air conditioning and EV.

The peak load problem is mainly caused by regular and burst loads combination. In addition, DSM programs could be classified as traditional or as modern ones. Fig. 15 shows the ways to perform DSM. The items *a*, *b* and *c* are considered as traditional ways and on the other hand, the items *d*, *e*, and *f* are modern techniques.

Thus, the smart strategy will consider only actions over the burst loads and will use a modern DSM program (TOU + DR), thus, no more rebound (f program). See Fig. 16.

As depicted, the consumption of the region A is shifted to the Region B. The limit of the region B is 7:00 because after this time, the price is not the cheapest. Fig. 17 illustrates the new residential profile obtained without peaks.

In order to summarize the process, a flowchart on the developed methodology, with the main steps, is presented in the Fig. 18

This flowchart depicts the whole process for performing the TOU+DR program, as input information are defined (i) 40 residential profiles, (ii) topology information (GIS) and (iii) electrical database. After, all these information is transformed in a electrical model. The program implements 3 options:

1. ARCONEL DSM, which uses the function defined in Fig. 7
2. UPV DSM, which uses the function defined in Fig. 12 and
3. SMART DSM, which consider the implementation of appliance device controllers, as well as, minimize the peaks originated by rebound effect through of shifting the consumption in the whole day and use the function of Fig. 16. The program respects Eq. (1) and creates modified profiles, which will be used for new simulations.

Using the profiles affected by the smart function, another simulation is performed.

Fig. 19 shows the main curves of active power and voltages. As we can see, the peak generated by the rebound in the previous scenarios is annulated due to the consideration of an installed controller at the households and ought to a smart technique for DSM.

In this scenario, all the limits are respected (114,3 V minimum) and the lowest peak between scenarios 7–8 is registered (64,07 kVA). The average power in the transformer is 13,13 kVA and the overload is 128%.

4. Results

4.1. Scenarios

Ref. [15], presented several scenarios that were created in order to assess the impact of different services. This paper aims to determine the impact of the DSM program; therefore, additional scenarios are created. A summary of the initial scenarios is presented. It is worth noting that simultaneous scenarios must be planned [51].

4.1.1. Scenario PQ

This scenario represents the current situation.

4.1.2. Scenario PQ+IC

An induction cooker is implemented for each residential client.

4.1.3. Scenario PQ+IC+EM

An electrical motorbike for each client is added to the previous scenario.

4.1.4. Scenario PQ+IC+EM+G

This scenario considers an annually growing of population leading to a 8,5% increase of the load [52].

4.1.5. Scenario PQ+IC+EM+G+PV

Taking advantage of the existence of solar resources, an array of PV panels [46] is connected in each client.

4.1.6. Scenario TOU ARCONEL

Upon the scenario 5, a DSM program is simulated, here the weighting function defined in Fig. 7 is considered. The 40 load curves are affected by the weighting function.

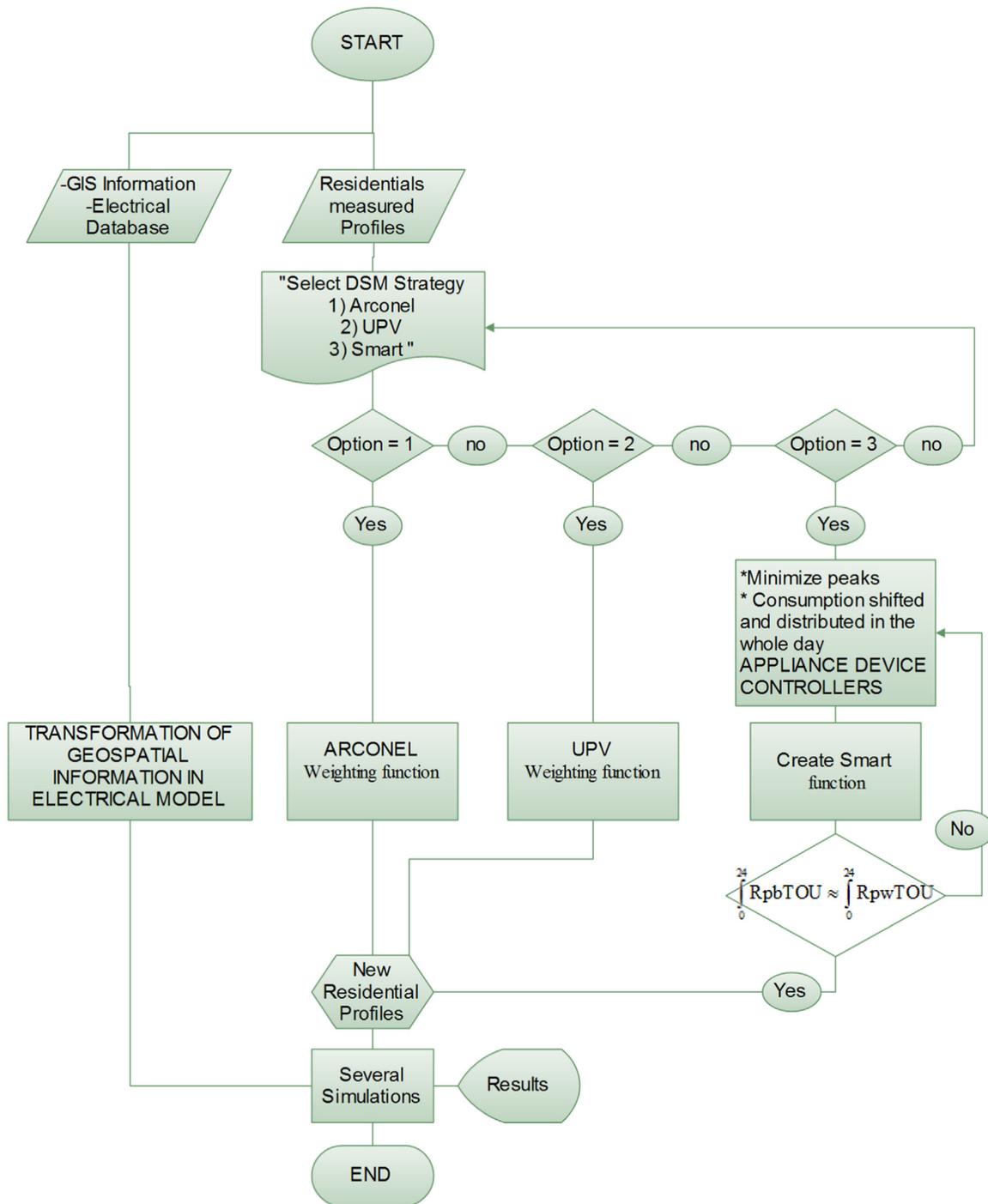


Fig. 18. Flowchart of the DSM programs executed.

4.1.7. Scenario TOU UPV

Upon the scenario 5, a DSM program is simulated, in this case the polynomial function defined in Fig. 12 is considered. Therefore, the 40 load curves feeding the model are affected by this function.

4.1.8. Scenario DSM Smart

Upon the scenario 5, a DSM program, which considers all the premises about DSM techniques and percentage of controllable load as well as the types of loads, is simulated. In this case, the smart function of Fig. 16 is considered for modifying the 40 load curves of the model.

4.2. Analysis and discussion of the results

As it was expected, until the scenario 4, the average power at the transformer grows. However, in the scenario 5, due to the installation of PV panels, this average decreases by almost 60%, but we still have the same peak during the night. Whereby, the scenario 6, which consider a DSM program, achieve a peak of 63,03 kVA (12% reduction compared with the scenario 5). The scenario 7 has a peak around 21:00 of 74,40 kVA (4% of increase compared with the scenario 5), this scenario is the worst because it reaches the highest peak and the lowest voltage. The last scenario is an intelligent DSM program, which is able to remove the peak created by the rebound

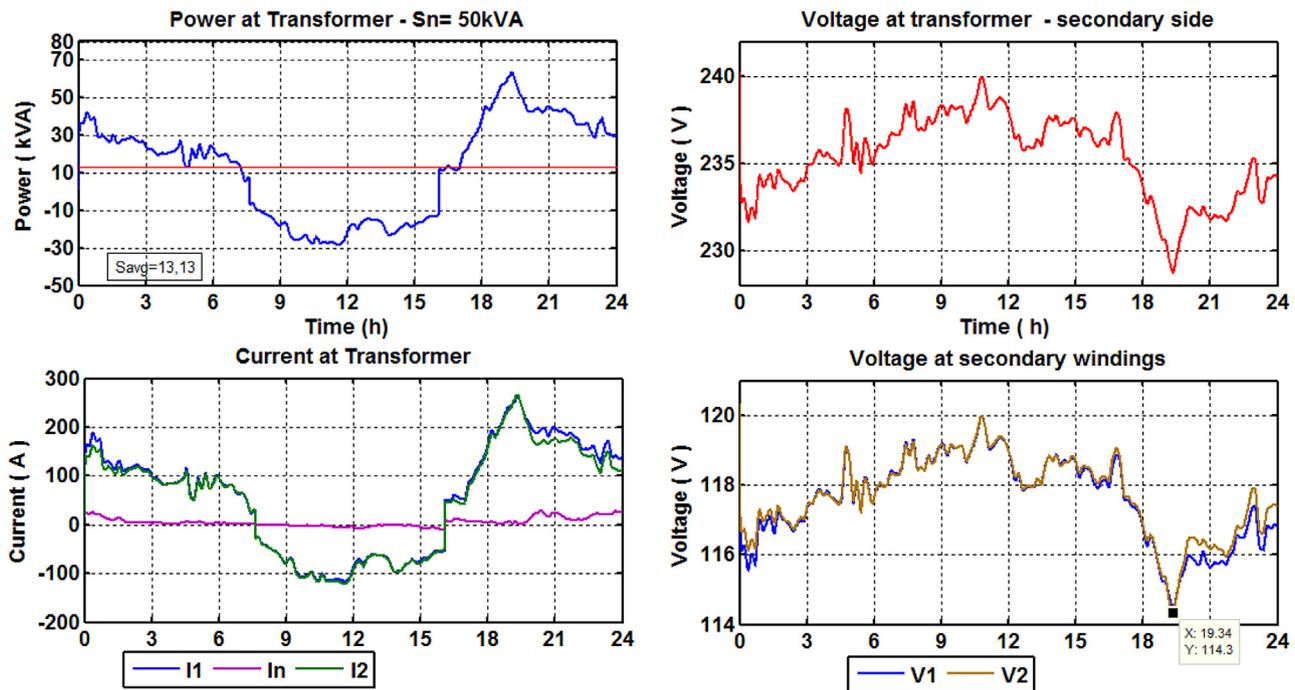


Fig. 19. Results after applying intelligent DSM.

and to shift the energy during the whole day keeping the average power at the transformer. See next figure.

In terms of overload, the best scenario between DSM scenarios (6–8) is the 6 with 126%. Nevertheless, the scenarios 6 and 7 do not comply the quality regulation, where is defined the lower limit in 114V at the secondary side. The scenario 7 is the worst. In terms of voltage levels, the scenario 8 appears to be a better one, because it respects the quality regulation all the time, the reduction of the peak is around 10% compared with the scenario 5. In addition, in terms of power overload of the transformer, it is a good solution because the value is “only” 128%. Indeed, according to Ref. [53], an acceptable value during two hours is 133%. Finally, the scenarios 5–8 inject current through the transformers due to the reverse flows originated by the PV panels.

4.3. Smart DSM results

The scenario 8 is the scenario, which takes into account the implementation of an appliance device controller in each household. By means of the option 3. (SMART) of the flowchart illustrated in Fig. 18, the residential profiles are modified in order to perform DSM program to decrease peaks through of consumption shifting of energy in expensive periods to cheapest periods along the day. The maximum overload is 128%, as we can see the voltages in the Phases L1 and L2 respect the quality regulation. The maximum power during the day is 64,07 kVA, the reverse flow generated is 28,33 kVA and the average power is 13,13 kVA. Considering all these values, it is easy to conclude that the scenario 8 is the better. The next figures show a comparative analysis between the DSM programs in reference to the active power and voltages (Fig. 20).

Fig. 21 depicts the power along a typical day, as we can see the first strategy (ARCONEL in blue) has an important peak around 22:00, the second strategy (UPV in green) reaches the higher peak around 21:00. Whereas the Smart strategy in red has the minimum peak and the shifted energy is allocated mainly in dawn hours. In addition, the peak created for the rebound effect is completely annulated.

Fig. 22 depicts the voltage profile along the day, as it was expected the minimum voltage value is reached when the load is highest. The ARCONEL strategy reached a minimum voltage of 113,58V the average voltage is 117,55V. The UPV strategy reached during the peak a minimum voltage of 111,3V and average voltage of 117,51V. Whereas, the Smart strategy shows the best profile, since there are not minimum peaks disrespecting the quality regulation.

5. Conclusions

In this paper, different strategies were evaluated; the first one is created upon the regulation given by ARCONEL, the second one is created taking into account a study developed for deploying Smart Grids within Ecuador. The results clearly show the either ARCONEL or UPV strategies are nor suitable, since in some periods the voltages limits are violated and the peaks created by rebound effect are important. Hence, a Smart DSM program composed of DR+TOU was implemented, this program uses a practical and ingenious approach in order to modify the load curves and to create new ones, and these new curves consider peak reduction and shifted energy along the whole day. In addition, the algorithm developed simulate an appliance controller in each house in order to neutralize the rebound effect and keep the load curve without new higher peaks. According to Figs. 21 and 22 the scenario 8 is the best option to perform DSM. First, due the peak reduction and second because according the voltage profiles, during the whole day is respected the limits established by the regulator. It is worthwhile mention that right application of Eq. (2) allow us to obtain the rate periods depicted in Fig. 11, this new rated model adjusted to the reality and validated by measurements must be applied in Galapagos in order to have good results with the DSM program developed.

According to Fig. 19, the peak generated by the rebound in the previous scenarios is annulated due to the consideration of an installed controller at the households and ought to a smart technique for DSM. Fig. 21 depicts as the Smart strategy has the minimum peak and the shifted energy is allocated mainly in dawn hours. Fig. 22 depicts as the Smart strategy shows the best pro-

Scenario	Name	V1			V2			Power (kVA)			Overload
		Max	min	Avg	Max	min	Avg	Max	min	Avg	
1	PQ	119,94	116,40	117,59	120,34	116,69	117,71	36,96	0,35	24,40	0,74
2	PQ + IC	119,94	114,84	117,08	120,34	114,88	117,21	56,05	0,35	30,13	1,12
3	PQ + IC + EM	119,94	114,06	116,99	120,34	113,99	117,13	66,81	0,35	31,39	1,34
4	PQ + Growing	119,94	113,58	116,71	120,34	113,48	116,87	71,06	0,35	33,77	1,42
5	PQ + PV	120,01	113,58	117,54	120,34	113,48	117,67	71,06	-28,38	13,73	1,42
6	TOU arconel	120,01	113,58	117,55	120,34	114,36	117,68	63,02	-28,38	13,68	1,26
7	TOU rebote	120,01	111,30	117,51	120,34	113,29	117,66	74,40	-28,38	13,89	1,49
8	TOU smart	120,01	114,37	117,59	120,34	114,31	117,72	64,07	-28,38	13,13	1,28

Fig. 20. Results of the different scenarios.

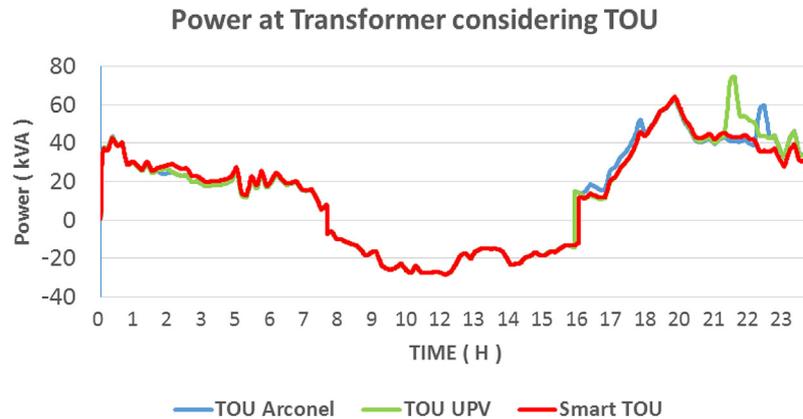


Fig. 21. Comparative analysis: power at transformer. (For interpretation of the references to color in the text, the reader is referred to the web version of this article.)

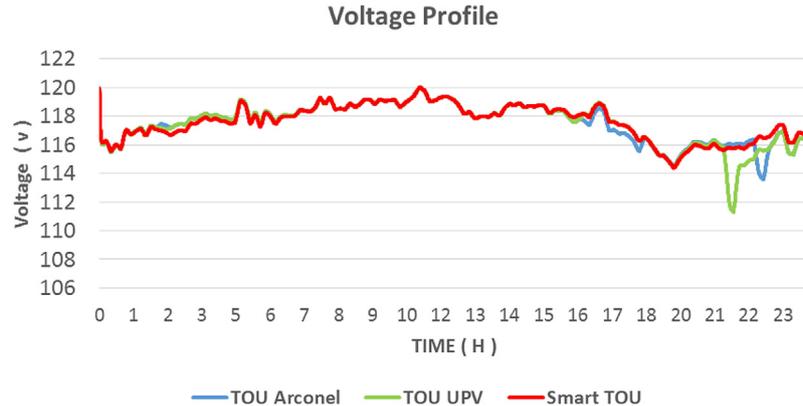


Fig. 22. Comparative analysis: voltage profile.

file, since there are not minimum peaks disrespecting the quality regulation. In the future work we will seek to build the smart architecture needed to implement the simulations in the real life as well as an innovative technique to reduce the imbalance. Finally, as suggestion, energy storage systems must be analyzed in order to get a complete Smart Grid model in low voltage. As last point, a powerful interface between GIS and Simulink has been developed to facilitate the carrying out of several analyses with different scenarios and topologies, and a Simulink library was created with new blocks for considering the Galapagos reality.

References

- [1] Ecuador_Travel, Galapagos Islands EcoTourism, 2016, Available: http://www.ecuador.us/travel/galapagos_islands/info/galapagos_islands.ecotourism/.
- [2] Google_Earth, Galapagos's Satellite View, 2016 <https://www.google.com/earth/>.
- [3] INEC, Ecuador en Cifras—Población y Demografía, 2015.
- [4] AYESA, EcoSmart Galapagos. A Sustainable City, Quito, Ecuador, 2014.
- [5] M.H. Amini, B. Nabi, M.R. Haghifam, Load management using multi-agent systems in smart distribution network, 2013 IEEE Power & Energy Society General Meeting (2013) 1–5.
- [6] F. Kamyab, M. Amini, S. Sheykhha, M. Hasanpour, M.M. Jalali, Demand response program in smart grid using supply function bidding mechanism, IEEE Trans. Smart Grid 7 (2016) 1277–1284.
- [7] L. Mokgonyana, J. Zhang, L. Zhang, X. Xia, Coordinated two-stage volt/var management in distribution networks, Electr. Power Syst. Res. 141 (December) (2016) 157–164.
- [8] P. Chittur Ramaswamy, J. Tant, J.R. Pillai, G. Deconinck, Novel methodology for optimal reconfiguration of distribution networks with distributed energy resources, Electr. Power Syst. Res. 127 (October) (2015) 165–176.
- [9] United_State.Department.of.Energy, What is the Smart Grid, 2016, Available: https://www.smartgrid.gov/the_smart_grid/.

- [10] K.G. Borojani, M.H. Amini, S.S. Iyengar, Overview of the security and privacy issues in smart grids, in: *Smart Grids: Security and Privacy Issues*, Springer International Publishing, Cham, 2017, pp. 1–16.
- [11] D.X. Morales, R.D. Medina, Y. Besanger, Proposal and requirements for a real-time hybrid simulator of the distribution network, IEEE 2015 CHILEAN Conference on Electrical, Electronics Engineering, Information and Communication Technologies (CHILECON) (2015) 591–596.
- [12] Ministerio de Electricidad y Energía Renovable, Dashboard Cocinas de Inducción, 2015, Available: <http://gis-sigde.maps.arcgis.com/apps/dashboard/index.html#/a84655ed31fc407bb9afdfc0dae968c6>.
- [13] S. Huibin, S. Ying, L. Wei-Jen, A demand side management model based on advanced metering infrastructure, 2011 4th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT) (2011) 1586–1589.
- [14] P.R. Harvey, B. Stephen, S. Galloway, Classification of AMI residential load profiles in the presence of missing data, IEEE Transactions on Smart Grid vol. 7 (2016) 1944–1945.
- [15] D.X. Morales, Y. Besanger, C. Alvarez, R.D. Medina, Impact assessment of new services in the Galapagos low voltage network, in: IEEE PES T&D Transmission and Distribution Latin America, Morelia, Mexico, 2016.
- [16] J.C. Galvis, A. Costa, Demand side management using time of use and elasticity price, IEEE Latin America Transactions vol. 14 (2016) 4267–4274.
- [17] F. Bizzozero, G. Gruosso, N. Vezzini, A time-of-use-based residential electricity demand model for smart grid applications, IEEE 16th International Conference on Environment and Electrical Engineering (E3E) (2016) 1–6.
- [18] L. Kaira, M. Nthontho, S. Chowdhury, Achieving demand side management with appliance controller devices, 49th International Universities Power Engineering Conference (UPEC) (2014) 1–6.
- [19] M. Nijhuis, M. Babar, M. Gibescu, S. Cobben, Demand response: social welfare maximization in an unbundled energy market case study for the low-voltage networks of a distribution network operator in the Netherlands, IEEE Transactions on Industry Applications vol. 53 (2017) 32–38.
- [20] S. Zhang, Y. Jiao, W. Chen, Demand-side management (DSM) in the context of China's on-going power sector reform, Energy Policy 100 (January) (2017) 1–8.
- [21] S. Werminski, M. Jarnut, G. Benysek, J. Bojarski, Demand side management using DADR automation in the peak load reduction, Renew. Sustain. Energy Rev. 67 (January) (2017) 998–1007.
- [22] S.S. Reka, V. Ramesh, Demand side management scheme in smart grid with cloud computing approach using stochastic dynamic programming, Perspect. Sci. 8 (September) (2016) 169–171.
- [23] D.A. Lima, R.C. Perez, G. Clemente, A comprehensive analysis of the Demand Response Program proposed in Brazil based on the Tariff Flags mechanism, Electr. Power Syst. Res. 144 (March) (2017) 1–12.
- [24] J. Soares, M.A. Fotouhi Ghazvini, N. Borges, Z. Vale, A stochastic model for energy resources management considering demand response in smart grids, Electr. Power Syst. Res. 143 (February) (2017) 599–610.
- [25] R. Tulabing, R. Yin, N. DeForest, Y. Li, K. Wang, T. Yong, et al., Modeling study on flexible load's demand response potentials for providing ancillary services at the substation level, Electr. Power Syst. Res. 140 (November) (2016) 240–252.
- [26] A. Chrysopoulos, C. Diou, A.L. Symeonidis, P.A. Mitkas, Response modeling of small-scale energy consumers for effective demand response applications, Electr. Power Syst. Res. 132 (March) (2016) 78–93.
- [27] X.-t. Chen, Y.-h. Zhou, W. Duan, J.-b. Tang, Y.-x. Guo, Design of intelligent Demand Side Management system respond to varieties of factors, 2010 China International Conference on Electricity Distribution (CICED) (2010) 1–5.
- [28] P. Palensky, D. Dietrich, Demand side management: demand response, intelligent energy systems, and smart loads, IEEE Transactions on Industrial Informatics vol. 7 (2011) 381–388.
- [29] K.G. Borojani, M.H. Amini, S.S. Iyengar, M. Rahmani, P.M. Pardalos, An economic dispatch algorithm for congestion management of smart power networks, Energy Syst. (2016) 1–25.
- [30] S. Mocchi, N. Natale, F. Pilo, S. Ruggeri, Demand side integration in LV smart grids with multi-agent control system, Electr. Power Syst. Res. 125 (August) (2015) 23–33.
- [31] M.H. Amini, J. Frye, M.D. Ilić, O. Karabasoglu, Smart residential energy scheduling utilizing two stage Mixed Integer Linear Programming, North American Power Symposium (NAPS) (2015) 1–6.
- [32] Ministerio de Electricidad y Energía Renovable, Rendición de Cuentas 2015, MEER, Quito, Ecuador, 2015.
- [33] V. Gouin, M.C. Alvarez-H, B. Raison, Operational vs. structural strategies for distribution grid planning in Smart Grids context, PowerTech, 2015 IEEE Eindhoven (2015) 1–6.
- [34] V. Gouin, M.C. Alvarez-H, B. Raison, Benefits of load shedding for distribution grids investments planning, IEEE Power & Energy Society General Meeting (2015) 1–5.
- [35] A.H. Mohsenian-Rad, A. Leon-Garcia, Optimal residential load control with price prediction in real-time electricity pricing environments, IEEE Transactions on Smart Grid vol. 1 (2010) 120–133.
- [36] J. Medina, N. Muller, I. Roytelman, Demand response and distribution grid operations: opportunities and challenges, IEEE Transactions on Smart Grid vol. 1 (2010) 193–198.
- [37] R. Atia, N. Yamada, Sizing and analysis of renewable energy and battery systems in residential microgrids, IEEE Transactions on Smart Grid vol. 7 (2016) 1204–1213.
- [38] M.A. Piette, Automated Demand Response to Enable the Integration of Renewable Resources, Cuenca, Ecuador, CIEELA : Colegio de Ingenieros Electricos y Electronicos del Azuay, 2015.
- [39] L. Kaira, M. Nthontho, S. Chowdhury, Achieving demand side management with appliance controller devices, Power Engineering Conference (UPEC), 2014 49th International Universities (2014) 1–6.
- [40] N. Hadjsaid, J.-C. Sabonnadière, Power System and Restructuring, vol. 1, John Wiley & Sons Inc., United States, 2009.
- [41] E. Mallada, C. Zhao, S. Low, Optimal load-side control for frequency regulation in smart grids, 2014 52nd Annual Allerton Conference on Communication, Control, and Computing (Allerton) (2014) 731–738.
- [42] ESQUEMA TARIFARIO PARA LA INTRODUCCIÓN DE VEHÍCULOS ELÉCTRICOS EN EL ECUADOR, ARCONEL, 2015.
- [43] K. Knezović, M. Marinelli, Phase-wise enhanced voltage support from electric vehicles in a Danish low-voltage distribution grid, Electr. Power Syst. Res. 140 (November) (2016) 274–283.
- [44] M.H. Amini, M.P. Moghaddam, Probabilistic modelling of electric vehicles' parking lots charging demand, 21st Iranian Conference on Electrical Engineering (ICEE) (2013) 1–4.
- [45] M.H. Amini, A. Kargarian, O. Karabasoglu, ARIMA-based decoupled time series forecasting of electric vehicle charging demand for stochastic power system operation, Electr. Power Syst. Res. 140 (November) (2016) 378–390.
- [46] UPV, ANÁLISIS PARA LA IMPLEMENTACIÓN DE REDES INTELIGENTES EN ECUADOR, Definición Cuantitativa Instituto de Ingeniería Eléctrica, Quito, Ecuador, 2015.
- [47] Greenlys.Project, Un premier retour sur expérience, 2015, Available: <http://greenlys.fr/>.
- [48] D.X. Morales, Y. Besanger, M. Toledo, R.D. Medina, Impact study of new loads and time of use schedule in the low voltage network, in: IEEE PES Innovative Smart Grid Technologies, Europe, Ljubljana, Slovenia, 2016.
- [49] UPV, Modelo Conceptual para la Implementación de Redes Inteligentes en Ecuador, Aspectos Técnicos y Económicos Instituto de Ingeniería Eléctrica, Quito, Ecuador, 2015.
- [50] E.H. Et-Tolba, M. Maaroufi, M. Ouassaid, Demand side management algorithms and modeling in smart grids: a customer's behavior based study, International Renewable and Sustainable Energy Conference (IRSEC) (2013) 531–536.
- [51] M.H. Amini, M.P. Moghaddam, O. Karabasoglu, Simultaneous allocation of electric vehicles' parking lots and distributed renewable resources in smart power distribution networks, Sustain. Cities Soc. 28 (January) (2017) 332–342.
- [52] ARCONEL, Estadísticas del Sector Eléctrico—Demanda Anual, 2015, Available: <http://www.regulacionelectrica.gob.ec/estadistica-del-sector-electrico/demanda-mensual/>.
- [53] Facilities.engineering.branch.denver.office, permissible loading of oil-immersed transformers and regulators. In: Facilities Instructions, Standards, and Techniques, vols. 1–5, Denver, Colorado, UNITED STATES DEPARTMENT OF THE INTERIOR, 2000, p. 28.