An approach to an electricity tariff for responsive demand in the Uruguay of next years with high penetration of Wind and Solar energy.

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***Abstract*--Uruguay is changing its electricity generation matrix integrating a great amount of wind power. This implies that there will exist an energy surplus that can be exported to other countries or may be used in Uruguay if a new demand appears capable of absorbing this type or surplus. Examples of this type of demands may be intensive irrigation agriculture or the fleet of electric cars. This work shows an approximation to definition of a price signal that can be used by smart controllers distributed over the grid to manage such demands. Simulation of the proposed algorithm are carried out showing that the stability of the system is achievable.**

***Index Terms*-- Responsive Demand, renewable energy, price signal, simulation, power system.**

I. Nomenclature

RD: Responsive Demand.
RTT: Real Time Tariff.
U(a, b) denotes a random variable with uniform distribution in the interval [a, b].

II. Introduction

Uruguay is changing its electricity generation matrix from one based on hydro-generation and fuel fired thermal plants to one based in hydro-generation and wind and solar plants. In the future matrix, the fuel fired thermal plants will be used only in times of draught or to cover some peaks of the demand in hours of low wind.

The Fig.1 shows the projected installed capacity for the next years. As can be verified, the wind capacity will be nearly the same as the maximum of the Demand in August of 2016 and surely in some hours of the day the wind generation will be greater than the demand. This implies that there will exist an energy surplus that can be exported to other countries, spilled or if a new demand appears capable of absorbing this type or surplus, consumed in Uruguay. This surplus is the result of an optimal investment planning optimized to minimize the future cost of the energy supply of Uruguay as shown in works [7], [8] and [9]. The projected surplus is a direct consequence of the cheap price of the wind generation and must be consider as assets of the system that can be profitable by promoting new type of demands. The Fig.2 shows that the expected value of the surplus is positive until 2024 and zero after that. This not means that there will not be surplus after 2024. Each time that strong wind, low demand and high hydro generation occur, will result in a surplus although its the expected value is zero.

Examples of this type of demands may be intensive irrigation agriculture or the fleet of electric cars and buses. In order to promote these types of demands, it is necessary to define a price signal that can be used by smart controllers distributed over the grid to manage such demands.

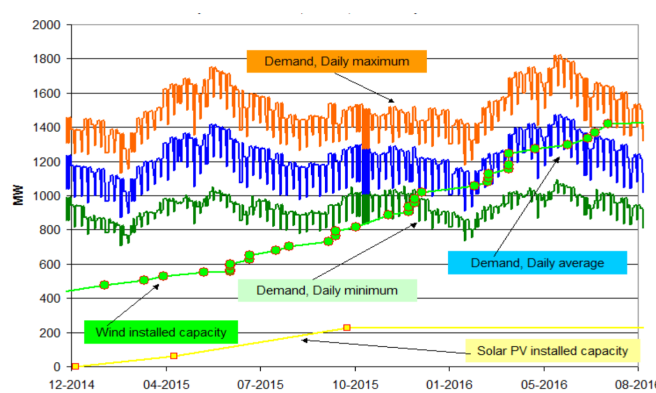

Fig. 1: Wind and Solar instaleed capacity vs. Daily Demand.

This work shows an approximation to the calculus of such signal price and simulations results using SimSEE and Vates model.

III. The approach.

There are many forms to implement a tariff or signal price for a responsive demand environment. The kinds of implementations goes from a fixed price by hour, a payment for peak saving to a real time varying price. These schemes are not mutually exclusive. The best one, in the sense of maximum global welfare is theoretically the real time pricing and the others ones can be implemented over that. Not always theoretically better is achievable, but always an effort to made it possible must be done. With this objective in mind, a scheme for calculate a Real Time Tariff (RTT) based on the Marginal Cost of Generation (MCG) plus a Cost of Network and Distribution (CND) is presented. In the group of RTT there are also some different solutions depending for example on the risk-price allocation and the interaction level between the ISO

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and the end consumers. A good description of these alternatives can be found in [10]. Depending on the available communication technologies, some solutions that few years ago looked as a fantasy, nowadays may be easy to implement. Today the communication network is not a problem, so it might think in a dynamic price based in a two ways communication between the ISO and the end users directly.

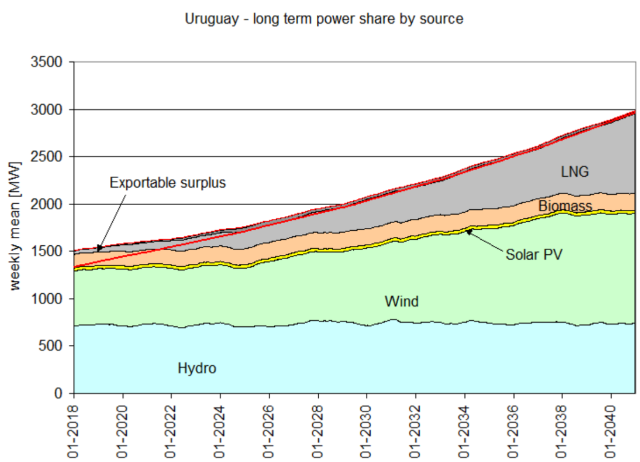

Fig. 2: Average power share by source. (long-term)

The approach proposed in this work is schematized in Fig.3. The RTT is computed in a two nested loops. In the core of the inner loop are the program VATES that takes forecasts of wind, hydro and solar generation and load and RD forecasts and use the platform SimSEE to simulate the next 72 hours of the system (100 Montecarlo chronicles was used). As a result of the simulation a forecast of the RTT is computed for the next 72 hours and filled to the "RD cloud model". Inside this model, each RD atom compute its intended consume and that information is feed to the forecasts box ready for the next iteration. If the result of the simulation is far from the previous one then a next iteration is performed with the news forecasts.

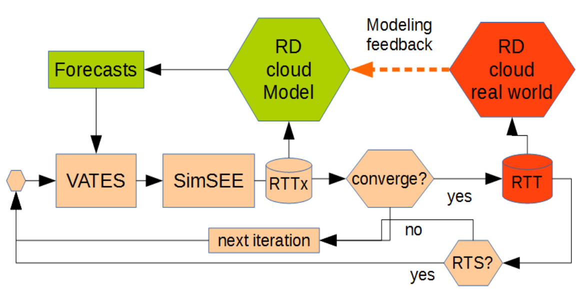

Fig. 3: Real Time Tariff flowchart.

After a few iterations the algorithm converges and a RTT is published in the real world for the real world RD cloud. After that publication, the RTS (Real Time Step) box check if the real time has advanced an hour. If it is the case then all forecasts are shifted one hour an a new iteration cycle begins. If the RTS = NO then the iteration loop continues. It is an important assumption for the stability of the system that the RTT is published several time during the same hour and that the each atom of the RD cloud take that information randomly at one time during the hour.

The first step is to model how the Responsive Demand (RD) will behave if a dynamic price is implemented. This model is developed in section V. After that hourly simulation in some scenarios of Uruguay 2018 was carried out and the result are presented in section VII. In section VIII the conclusions about the proposed model and RTT are presented.

IV. Simulation Tools.

The models created for this work where implemented in the SimSEE platform. SimSEE [1] is a Platform for Simulation of Systems of Electric Energy. Basically the SimSEE use classical stochastic dynamic programming to simulate the optimal operation of the power system. The renewable resources where represented inside SimSEE using CEGH [2] [3] modeling technique. For perform short time repeated simulations considering the wind generation forecast in real time the VATES program was used.

The methodology adopted to compare results was the consideration of two cases. One with the RD responding to the RTT and the other supposing that the RD see a fixed price instead of the RTT. In the first case the RD will optimize it consumption considering the RTT and theirs set of restrictions. In the second case, the consumption is optimized looking to reduce the loss of energy while fulfilling the set of restrictions.

V. Modeling the Responsive Demand.

Examples of responsive demand (RD) loads are water heating with heat storage capacity, electric vehicle and massive irrigation. These types of loads can be modeled defining two periodically time windows, one where the load can interchange energy with the power grid and the other where the energy is finally used by the end user without exchanging energy with the power grid. In the case of the electric vehicles the RD also can inject energy to the grid in some cases acting as a generator.

Each RD must satisfy the following restrictions:

1. It can only supply or demand energy from the grid at certain hours of the day. The rest of the time it can only consume from the stored energy.
2. Each RD must achieve a minimum amount of stored energy (E_{min}) at the hour in which is going to be used (deadline hour)
3. Power supplied or demanded to the grid can´t exceed the maximum ratings of the machine.
4. In all cases there are some kind of energy storage with a capacity limited and losses. The stored energy must be between 0 (zero) and the capacity limit.

For the simulations, each RD is modeled as an atom of a population, supposing some distribution in the specification of the time windows, power and storage capacity limits. Every hour of a day, each RD receives a vector containing the RTT forecast for the next 72 hours. Given the RTT forecast and the restrictions mentioned above, each RD decides its intended supply or demand to/from the grid for the next 72 hours to minimize its expected cost.

The eq. 1, 2 and 3 models the general behavior of the RD considered during the time window in which it can exchange energy with the power grid. The equation 1 states that energy E_k at the end of the hour k is the energy at beginning of the hours multiplied by a reduction factor ρ, plus the energy drawn from the power gird minus the energy injected to the power grid.

$$E_k = \rho E_{k-1} + \eta_{Dem} P_k^{Dem} \Delta T - \frac{P_k^{Gen}}{\eta_{Gen}} \Delta T \quad \text{eq.(1)}$$

$$\text{subject to} \quad 0 \leq E_k \leq E_{max}$$

The equations 2 and 3 represent the power limits of the RD.

$$0 \leq P_k^{Dem} \leq P_{max}^{Dem} \quad \text{eq.(2)}$$

$$0 \leq P_k^{Gen} \leq P_{max}^{Gen} \quad \text{eq.(3)}$$

Where:

E_k : Stored energy at the end of hour k

E_{k-1} : Stored energy at the beginning of hour k.

E_{max} : Storage capacity.

ρ : Energy loss factor for an hour.

η_{Dem}, η_{Gen} : Efficiency as a demand or as a generator respectively.

P_k^{Dem} : Power demanded from grid at hour k.

P_k^{Gen} : Power injected to grid at hour k.

ΔT : Time step. One hour in this example.

At each hour k in which the final user needs a minimum amount of energy E_{min} available in the storage, the eq.4 must be satisfied. The hour k can be viewed as the deadline to achieve the E_{min}. The controller of the RD must take care of that deadline.

$$E_k = \rho E_{k-1} + \eta_{Dem} P_k^{Dem} \Delta T - \frac{1}{\eta_{Gen}} P_k^{Gen} \Delta T \geq E_{min} \quad \text{eq.(4)}$$

For the simulations, in each hour after a deadline (hour $k+1$ in eq.4) a consumption of a portion E_{Cons} of stored energy is supposed to occur, and there is no possibility to demand or generate power to the grid from that hour until the next time window where exchange with the power grid is allowed. In the hour after a E_{min} deadline, the stored energy evolves following the eq.5.

$$E_{k+1} = \rho E_k - E_{cons} \quad \text{eq.(5)}$$

A. The model of household water heaters.

The implemented model for the electrical household water heater as a RD was made using eqs. 1 to 5. The factor computed as the volume of the water storage by the calorific value of water is the relationship between the stored energy and the temperature. The set of restrictions in terms of the temperature can be written as:

1. The water heater may consume energy all hours of the day, except one hour after a limit hour where the final user needs the water at least at a given temperature. (deadline hour).
2. The water temperature at the limit hour must be greater than or equal to T_{min}.
3. The hour after a deadline, it is assumed that the water heater is off and the temperature decrease several °C (T_{cons}).

B. The model of electrical vehicles.

The mains hypothesis for the Electrical Vehicles (EV) modeling where taken from [4]. The implemented model for the electrical vehicle as a RD was made using eqs. 1 to 5. The set of constraints can be expressed as:

1. The electrical vehicle can consume or supply energy from /to the power grid during some specific hours of the day.
2. The energy stored at the deadline hour must be greater or equal to E_{min}.
3. In the hour after a deadline, the consumption of energy is E_{Cons}.

The evolution of the storage energy during consumption/supply time window are modeled as specified by equations (1) to (4).

In the hour after a deadline the evolution of the stored energy is defined by equation (5).

VI. Hypothesis

The simulations considered in this paper starts at Aug-1-2018 and end at Aug-8-2018. In this week, the installed power capacity is composed by: 1400 MW of wind capacity, 225 MW of Photovoltaic (PV), 107 MW of biomass, 1541 MW of hydroelectric, 80 MW of fuel oil motors, 532 MW of combined cycle and 452 MW of aero-derivative Gas turbines. The variable cost of wind energy, PV and most amount of installed biomass capacity is considered as 0 USD/MWh.

The interconnection capacity with Argentina is 2000 MW and the energy export price is 7 USD/MWh.

The annual electricity demand of 2018 will be 11,539 GWh (source [5]) plus the electrical vehicle consumption.

Based on EIA forecast (source[6]), the considered crude oil price Brent is 80 USD/bbl.

It is assumed that RD is composed by:

1) 100,000 electrical water heaters with the following specifications:

Volume = 60 lts. P_{Max} = 1.5 kW, η_{Dem} = 0.995, ρ = 0.98 p.u. T_{Cons} = 40 ºC, T_{Max} = 70 ºC, T_{Min} = 55 ºC, Initial temperature random U(10, 30) °C, and Consumption deadline as a random U(18, 23) h.

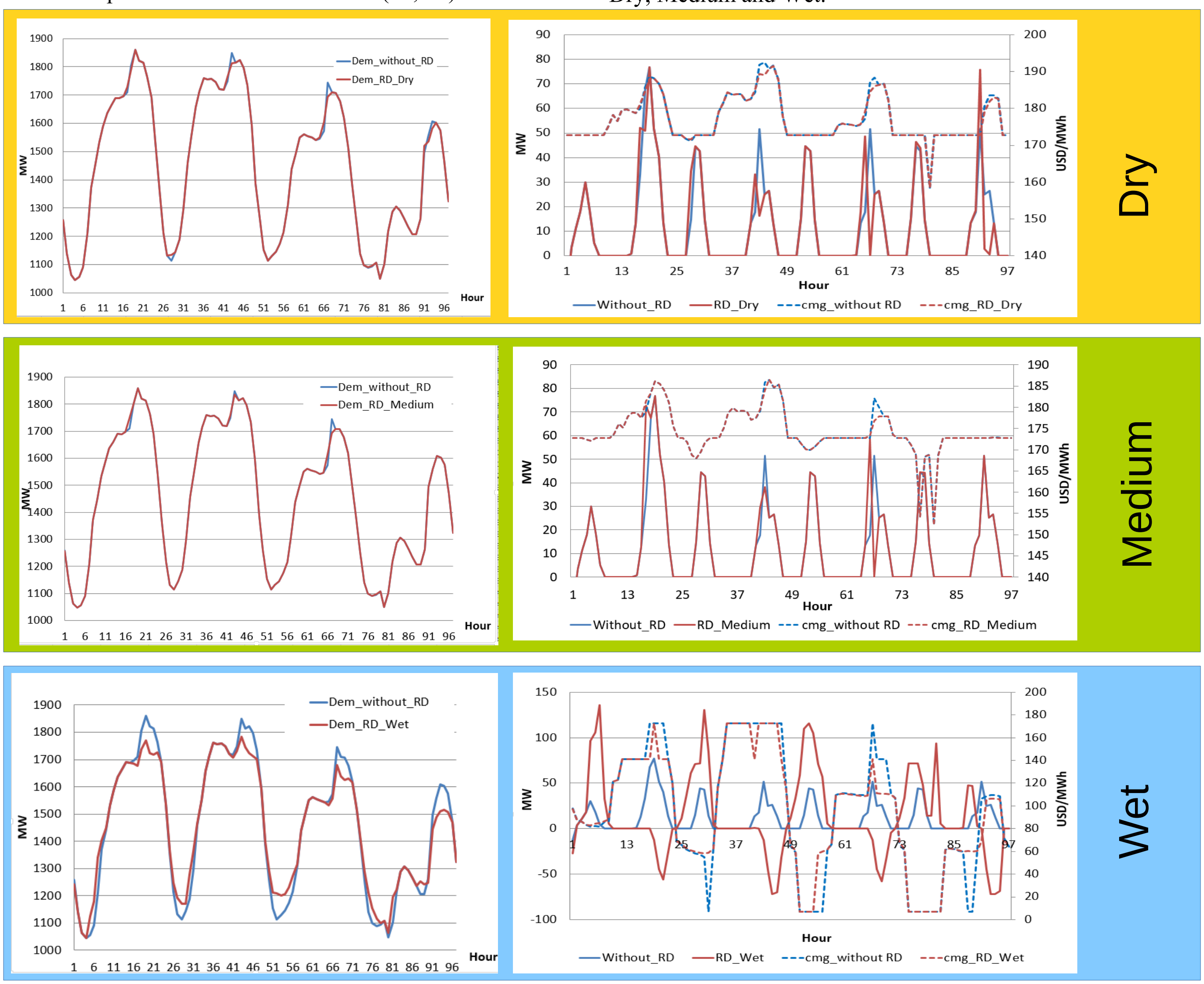

Fig. 4: Results for the three cases, with and without RTT.

2) 40,000 electrical vehicles with the following specifications:

E_{max} = 15 kWh * U(0.8, 1.2),

$P_{Dem} = P_{Gen}$ = 1.8 kW, η_{Dem} = 0.85, η_{Gen} = 0.7, ρ = 0.98,

$$E_{Cons} = 1.5\text{ kWh} + U(0, 2.5) * \frac{E_{max}}{12}$$

$$E_{min} = E_{Cons} + 2 * \frac{E_{max}}{12}$$

Initial charge $E_{ini} = E_{max} * U(0, 1)$

Consumption deadline = U(6, 8) h and can not demand or supply energy to the grid between Consumption deadline and U(19, 21) h.

VII. Results

The three scenarios considered in this paper only differ each other in their hydrological conditions and are denoted as Dry, Medium and Wet.

The left side pictures of Fig.4 shows the system demand comparison with and without RD for each of the three scenarios. The right side pictures of Fig.4 shows the comparison of electrical water heaters and electrical cars demand and the marginal cost of the system with and without RTT for the three scenarios. As can be observed in the pictures the great differences appear in the Wet scenario.

The table 1 shows the difference in the weekly operational variable energy costs between the scenarios with and without RTT consumers. Also, it is shown the average costs for RTT consumers considering the marginal cost as the energy tariff computed as shown in eq.6:

$$E(RTT)=\frac{\sum_{i=1}^{N} cmg_i \times RD_i}{\sum_{i=1}^{N} RD_i} \quad \text{eq.(6)}$$

VIII. Conclusions.

In the case of electric vehicles with no RTT, it was assumed that energy demand occur at the valley of demand, associated with low marginal costs. As a result of this, there is not a significative difference between cost operation with the consideration of responsive demand in electric vehicles. This result is only a primary one and perhaps may be more appreciable differences with more large period of simulation taking in consideration a larger number of Monte Carlo realizations for the stochastic process considered, specially the process associated with the wind power generation.

In the case of electric water heaters with no RTT, energy demand was assumed to occur at the peak, associated with high marginal costs. As a result, when considering water heaters with RTT, demand shifts from peak to valley with low marginal costs and therefore reducing operating costs. In addition to the reduction of operational costs the shift of load from the peak implies a saving in transmission and distribution infrastructure.

Table 1: Expected weekly operational cost.

Scenario	Delta Operational Cost [kUSD]	Expected value of cost of energy for RTT consumers [USD/MWh]
DRY	14	179
MEDIUM	7.8	176
WET	253	-16

In dry and medium scenarios, where marginal costs have low variations, responsive electrical vehicles does not buy to then sell energy to the grid. In the wet scenario, extra energy is stored in batteries on the valley to then sell it at peak demand with high marginal costs, obtaining a surplus for that energy and a negative average cost of -16 USD/MWh.

In all the scenarios, the operational variable energy costs are lesser when the RTT is active than when it is not active.

In the dry and medium scenarios the cost reduction were not significant, while in the wet scenario a reduction of 7% is obtained.

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X. Biographies

Lorena Di Chiara was born in Montevideo, Uruguay, on November 7, 1977. She received the Electrical Engineer degree in 2003. She worked in UTE Distribution from 2003 to 2009 and in National Energy Directorate (DNE) from 2009 to 2014. Since December 2014 she works in ADME as a staff engineer.

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Enzo Coppes was born in Paysandú Uruguay in 1969. He received the Electrical Engineer degree in 2003. He is currenty Grade 2 teacher from the Faculty of Engineering of Uruguay. He was Chief Execution of Operation on energy power company UTE in Uruguay and currently is an adviser of the president of UTE.

Gonzalo Casaravilla (S'89-M'91) received the Electrical Engineering degree and the M.Sc. degree in Electrical Engineering in 1990 and 2000, respectively, from the Universidad de la República, Montevideo, Uruguay, where he is currently pursuing the Ph.D. degree. Currently, he is Associate Professor with the Institute of Electrical Engineering, Universidad de la República, where he has been since 1986 and the President of the UTE the power utility of Uruguay.

Ruben Chaer was born in Tacuarembó, Uruguay, in 1962. He received the Electrical Engineer degree in 1990 and the Master's Degree in Electrical Engineering in 2009 from the University of the Republic of Uruguay. He is currently Professor at the Institute of Electrical Engineering and manager at the ADME the Administration of the Electrical Market of Uruguay..