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Graphical language for identification of control strategies allowing Demand Response

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Abstract

Due to new innovations in communication systems, electrical appliances are now capable of participating actively in smart grids control management.

Each appliance has already several controls incorporated. In order to determine the best way to control an appliance in a smart grid context, we present a methodology based on a graphical language, which makes possible an easy identification of the available control strategies and will be used for future developments in terms of smart controls.

The Language is divided into two different levels of complexity with different results.

First level: Based on an empirical description of the controls available to the user, a first graphical representation of the appliance operation can be produced. This will allow the identification of the electric appliance availability for demand response control strategies based on the appliance existing controllers.

Second level: This level requires detailed information and/or measurements of the appliance operation, so that more complex control strategies can be deduced. Due to the more complex operation description some of the deduced strategies, for this second level, could need adding new controls to allow their correct application. However it is up to the user of the language to choose the degree of the description complexity.

This second level allows the user to know which components are the more energy and power demanding and how they are controlled, meaning that more accurate strategies can deducted.

Manufacturers and power utilities can then identify their control strategies to be implemented in terms of demand response for electrical appliances.

Introduction

An important part of electrical equipments flexibility analysis is related to their aptitudes for possible remote control and/or operation modification. The control of electrical equipments will depend in large part where the controls or operation modification can be made.

To be able to detect and analyze the possible operation controls, it was created a graphic language which represents, in a methodical and simplified form the electrical appliances operation and it reveals the operating processes called “non-visible” (to the user) of equipment operation. Thus allow to understand the various operating processes of the equipments and their load diagram. This language enables to condense all the information of an equipment operation into graphic.

As a result, this language makes it possible to find in a simplified and precise approach, the existing control strategies but also to find possible equipment modifications, in order to make them more attractive for the intelligent control.

The existing languages were created for product development, automation of processes or equipments, software and other. In our case, we do not want to describe the appliances operation with this purpose; the goal of the language is only to highlight the control options in a simplified, fast and intuitive form.

In the following sections it will be presented and defined the suggested language specifications.

Description of the graphical language for Identification of load control availability (ILCA)

The definitions and descriptions of the various elements which constitute the language are described hereafter:

State: it defines the operating condition, like an appliance operation process with a precise objective.

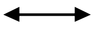

: This symbol represents an operating state of the appliance. The power demand can be static or dynamic (ex: power modulation). A state can also contain sub-states. Sub-State is an object in a stage where one or more operations can be carried out. (Example: state washing of a washing machine □Figure 3)

Transition: the transitions are the elements responsible for the passage for a state towards the other. They can be simple Boolean transitions to more complex transitions including equations or logical functions.


: This symbol represents one transition. It displays the event which must occur to have a transition from one state towards other. There are of several types transitions: a contact ON/OFF, a logical test, introduction of the value of a variable or other.

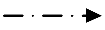
Connection: elements with one or two directions, they make the connection between states and transitions or between transitions.

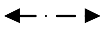

: This symbol represents a connection with the user intervention and it can occur only in one direction;


: This symbol represents a connection with the user intervention and it can occur in both directions;


: This symbol represents an automatic connection (internal control of the appliance) only in one direction;


: This symbol represents an automatic connection (internal control of the appliance) in the two directions;


: This symbol represents a connection from/with a communication network (ex: grid price signals□), where the information can be transmitted only in one direction.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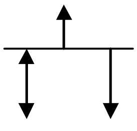
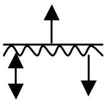

: This connection represents a logical disjunction □or□ i.e. the appliance operation is divided into two or more pathways and then the first to be activated (by a transition) will determine the next appliance pathway.

The arrows show, if the transition can be made in the two directions (marks with arrows on the left) or only in one direction (marks with arrows on the right).



: This connection allows that two or more transitions are carried out starting from a single state or transition. This connection can also be used to converge stages or transitions.

The arrows show if the transition can be made in the two directions (marks with arrows in bottom on the left) or only in one direction (marks with arrows in bottom on the right).

-----► : Connection of an external variable (example: external temperature, thermal loads of the building)

External Parameters: This object specifies the external parameters to the system in analysis, which will have a direct role in the machine operation (ex: Temperature of water, temperature of air, etc).

⬚ : This symbol represents the external or variable variables controlled by the user

Possible Control points: the objective of these elements is to indicate the parameters which have an impact on the operation of the machine in analysis, so that strategies can be identified afterwards.

➡ : indicate the places where a control can be implemented

Operating States

Several studies [1,2] have identified the principals operating states of electrical equipments. Next we present most important operating states and their definitions.

Off - The equipment remains connected to the power source but it does not produce any function and it does not transmit or receives any information. The equipment expects a physical intervention of the user (through an ON/OFF button for example).

In this mode the appliance can consume, however a modest amount of energy.

Passive Standby - In this state the equipment is put into low power mode by a certain means like switch or remote control ("sleeping mode", if remote control or internal sensor or timer). The principal function of the appliance is not carried out in this state.

"*Passive Standby*" can normally understand the following functions:

- Reactivation by remote control ("remote control", it should not be confused with *Network Standby*[1])
- Continuous functions:
    - Information or screens with the description of the state of the equipment or clock
    - Sensor of safety
    - Internal Sensor or programmer

Delay Start - the appliance can be programmed to begin functioning at a later time; in some cases up to 24 hours later.

Activate Standby - When the appliance is "ON" but it does not exert his main function (example: when a thermostat stops the electric resistance). This state is normally presented during one of the following cases:

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[1] -Network Standby : In this mode the appliance provides one of the following additional functions (not a main function):

- Reactivation via network command
- Network integrity communication
-

- When a mechanical function is not active (DVD *drive* or engine) but the circuit is energized.
- When the appliance has a battery and it is charging
- When the appliance is in a quiet state (example: amplifier is ON but no audio sound

ON - the appliance executes its principal function

Application method of the ILCA language

The language can be divided into two analysis levels: *User Level* and *Manufacture Level.* Even so, the degree of detail for each of the presented analysis levels is left to the user, who applies this language, according to his objectives.

Level user - the first level is based on the instruction manuals of the equipment and on the empirical experiment of the regulation/control of the equipment.

This level aims to establish appliance control opportunities without the need of additional equipment and/or modifications on the equipment components.

In this case the language describes the operation of the equipment based on the available controls to the user or based on existing external connections.

Level manufacturer - *the* objective of this level is to identify advanced control strategies.

This level of description is directed towards the manufacturers because the new identified strategies, in this level, normally need the addition of the additional regulators, or the appliance components modification.

The manufacturer level is based on technical documents and/or measurements in order to understand the operating/regulation rules of the equipment in analysis, and taking into account the designers expertise. The appliance graphical representation is created by taking into account all its operating conditions and the rules of order intervening in the transition processes between the various states.

Application of the ILCA language to a washing machine

In this chapter we exemplify the application of language ILCA for the case of a washing machine.

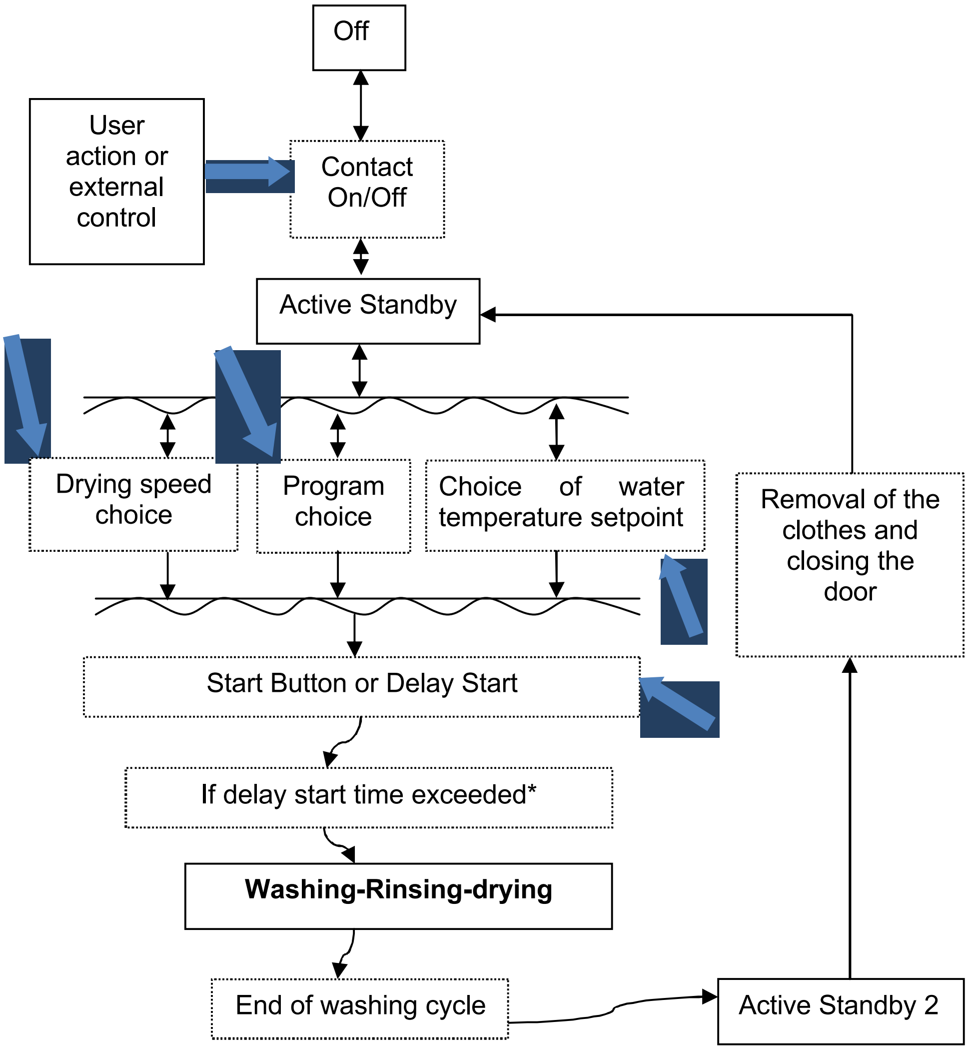
User level analysis of a washing machine

In this analysis we will try to determine the operating states, taking into account the controls available to the user without considering the internal operation cycle of the washing machine.

Table 1 - Operating states of a washing machine - user analysis level

Operating States
Off - the appliance is turned off but it can still be connection to the mains (Possible energy consumption)
Activate Standby - the appliance is ON but it does not perform his principal function. He expects an action of the user to start the washing cycle.
Washing-Rinsing-drying includes several stages: washing, rinsing and drying
Activate Standby 2 - State where the appliance expects an action of the user to empty the machine. In this mode some blink lights and an audio signal can be activated.

The graphic of a washing machine user level is shown in Figure 1.



*-if Delay start available

Figure 1-Graphic of the user level

From the user level analysis, the following control strategies can be deduced:

- *Direct action on the contact ON/OFF* Washing machine power outage due to high electricity price or due to a direct load program.
- *Choose a different temperature* Choose a lower washing temperature, which will result in lower energy consumption.
- *Choose a different program* program with consumes less energy (depends on the appliance model)
- *Delay start* - User information about TOU tariffs (Time Of Use) or other tariffs can be a motor to deferrer the machine operation.
- *To start the machine at low price hours manually* Same as for delay start, however more difficult to apply since it needs a greater effort by the user

The delay start option has a great value since it allows the user to reschedule his machine operation in a simple and easy way. If we compare the average number of machines with Delay start in Europe (32%) and in France (42%), a difference of 10% can be found [3]. This difference can be explained by the massive diffusion of TOU *(Time of uses)* electricity tariffs in France. This means that electric tariffs diffusion can have an impact over the washing machines preinstalled components, thus allowing their shifting operation.

The mentioned control strategies can be used within the framework of demand side management programs. Programs like ECOWATT Bretagne or ECOWATT Provence-Azur [4,5], which advice consumers shift their electric appliances to off-peak hours, can take the mentioned control strategies as examples.

Nonetheless these strategies can also serve as models to implement controllers enabling the detection of high electric tariffs (smart appliances) and thus changing the machine operation.

Manufacturer level analysis of a washing machine

To be able to carry out the manufacturer analysis, it is necessary to examine technical documents and if possible power measurements to be able to identify the operation cycles.

According to project GEA 1995 and to the EuP 14 [6,3] washing machine operation is based on three stages:

The operation of these appliances is made in a first part by the entry of water and the detergent to humidify the clothes together with a slow drum rotation (during approximately 15 minutes). Then, water is heated by a resistance. The warming-up time will depend on the heater power of the machine (Resistance) and on the chosen temperature by the user. The power of water heater (Resistance) can vary between 1800 W and 2500 W.

When the desired temperature is reached the resistance is turned off and washing remains still a certain time. The “Washing” consists in the detergent action and consecutive rinsings always coupled with the rotary movement of the drum. Sometimes after a certain time the water temperature reaches the below limit fixed by the thermostat (this limit depends on the type of thermostat used) and the water is reheated. Normally the low range and standard machines are equipped with mechanical thermostats ON/OFF with a precision from approximately 5 to 6 °C and the more efficient machines are, normally, equipped with electronic thermostats (PID) which allow a precision of 1°C.

At the end of the washing, the clothes pass through several (3 or 4 generally) rinsings with cool water, where normally at the end of each rinsing the clothes pass for a small drying (rapid rotary movement of the drum). During the last rinsing the softener is applied.

Finished the rinsing phase the clothes pass for a drying phase, where the drum will turn at high speed (400 - 1600 tr/min) and will thus withdraw the water of the clothes.

All this process can be controlled either by an electronic controller or by a mechanical *timer* and it can take between 15 minutes and three hours.

Measurements were carried out to determine if these various states could be identified and to determine the load diagram of a washing machine during a washing program.

According to figure 2, we can distinguish the various operation states of a washing program.

During the phase of washing the resistance will be turned on and once the temperature arrives at the temperature setpoint (Chosen temperature by the user), the resistance is disconnected and thus the power demand is strongly reduced. After washing 4 cycles of rinsing are made, followed by drying.

The nominal power given by the manufacturer was 2000 W, but during a washing program with 30°C temperature setpoint, the 2000 W peak lasted only for approximately 4 minutes. During the rest of the washing program the power remained around 250 W and very different by 2000 W.

The energy used during all the program cycle is due mainly to the water heating, according to the study carried out by Group for Efficient Appliances [6] and by ours measurements, this energy accounts for approximately 80% of the total energy consumed (for a traditional cycle with 60°C). However this percentage is calculated by washing cycle and not by appliance life analysis.

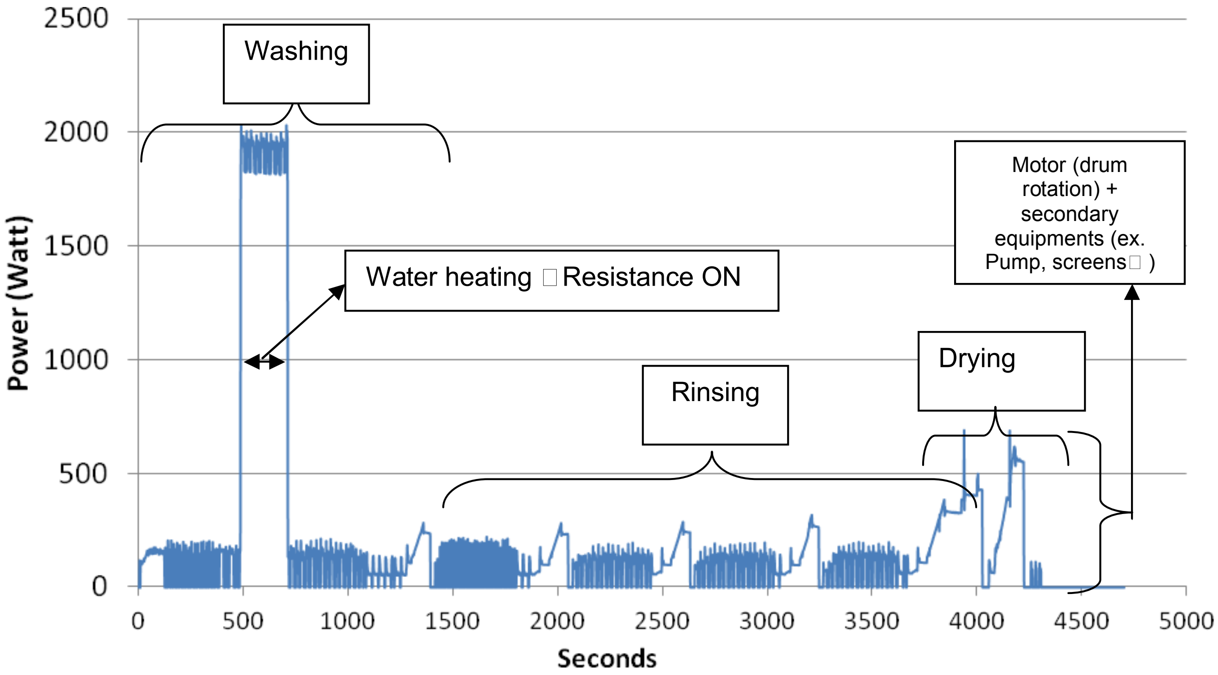


Figure 2- load diagram of a washing machine (cycle with 30°C setpoint)

In order to verify the influence of the low power modes (Off, Active Standby, Delay Start□) when a control is applied, measurements were carried out in shops, in the frame of the SELINA project [2], throughout Europe. The results are present in the Table 2.

Table 2 □Low power modes measurements

Mode	Number of measurements	Average power (Watt)
Off	329	0.34
Delay Start	181	3.14
Active Standby	268	2.31

The single demand power due to low power modes is quite low, less than 0.16 % of the nominal machine nominal power. Therefore the low power modes will have a small influence in load reduction.

Next it is presented the main operating states of a traditional washing cycle for a washing machine.

Table 3 □Operating states of a washing machine - manufacturer analysis level

Operating States
Off - the appliance is turned off but it can still be connected to the mains(Possible energy consumption).
Activate Standby - the appliance is ON but it does not perform his principal function. He expects an action of the user to start the washing cycle.
Delay start □ the appliance is On and waiting the signal from the timer to start the washing program.
Washing - continuous rotation of the drum; introduction of the detergent and after approximately 15 minutes (activation of the enzymes), water is heated until water temperature setpoint is reached.
Rinsing - cool water introduction together with the rotary movement of the drum followed by a small drying.
Drying - water draining of the drum followed by a fast rotation (Speed programmed).
Activate Standby 2 - state where the appliance expects an action of the user to empty the machine. In this mode some blink lights and an audio signal can be activated.

The graphic of a washing machine manufacturer level is shown in Figure 3.

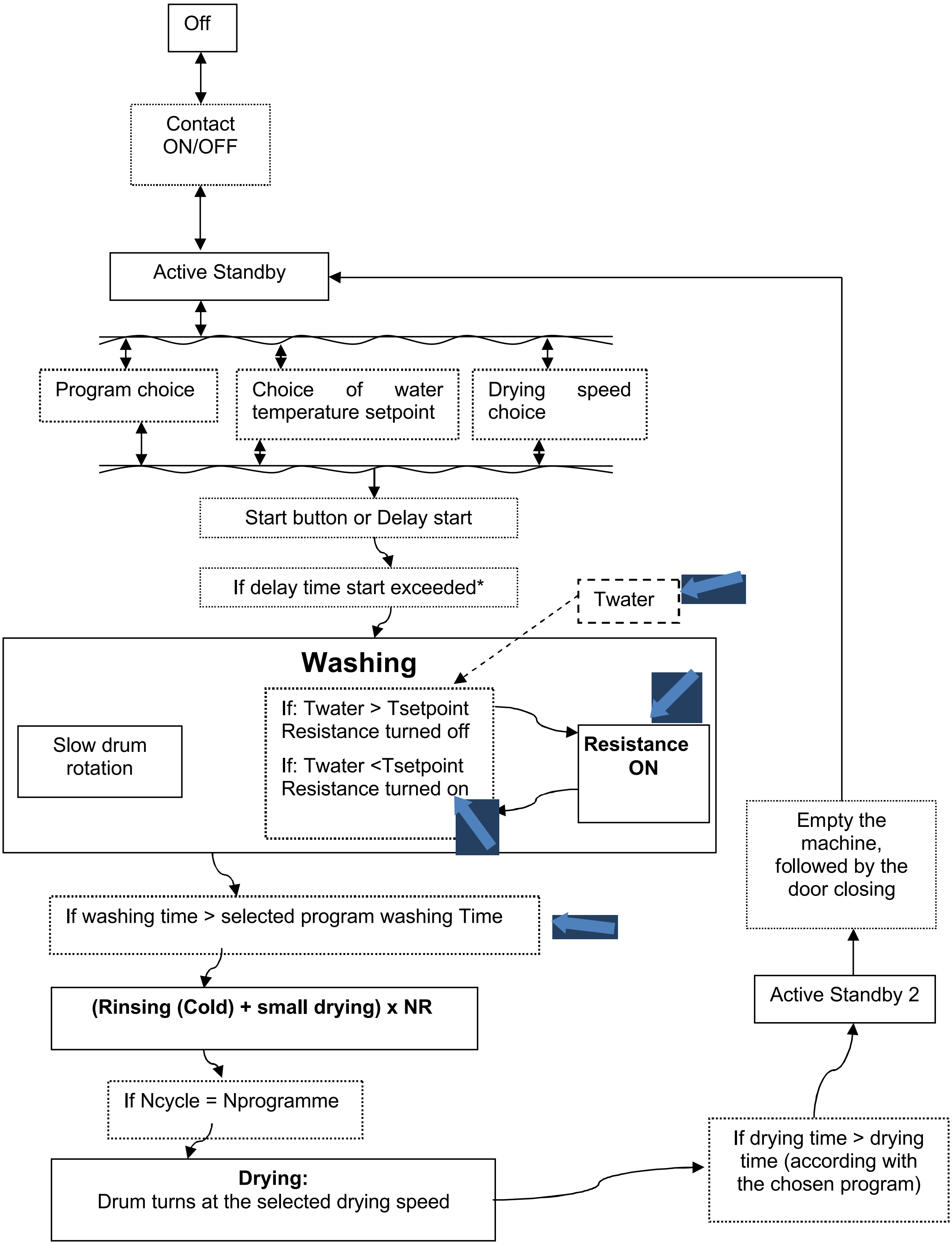


Figure 3 - Graphic of the manufacturer level

Where, Twater, Tsetpoint and NR are the water temperature, water temperature setpoint and the number of rinsing cycles for the selected program

One major power of the ILCA language is that all the gathered information about the appliance operation was condensed into a graphic that is intuitively understandable and easy to interpret.

Detailed description of washing machine operation:

The machine is turned on with contact “ON/OFF”. Then the user selects the temperature, the program and the drying speed. Next the user starts the machine by pressing the Start button.

Once started, the machine will introduce water and the detergent and the drum start to turn slowly. Then resistance is turned on, to heat the water until the water temperature reaches the setpoint. The resistance is responsible by the peak demand, once it is an instantaneous electric water heating system with power ranging between 1800 and 2500 W (see figure 2).

Then when the washing time is exceeded, the rinsing starts. This state consists into drum cool water introduction coupled with the rotary movement of the drum. At the end of each rinsing the clothes pass through a small drying. The number of rinsings will depend on the machine and/or the selected program.

When the rinsing state cycles are finished, the machine passes to the drying state, where the drum will turn at a chosen speed defined by the user (normally ranging between 800 and 1600 rpm).

Finished the drying, the machine passes into a state normally called “Active Standby 2” where the machine expects the that the user unloads the machine and then the user either switch it off or it begins a new washing.

Manufacturers analysis deduced strategies and their discussion

In the ILCA representation all the transitions have a control potential. Though, as it was seen before the responsible element for the major electricity demand is the electric resistance (water heater). The other elements represent a small part of the machine power. The rinsing state does not provide almost any potential since its cycles are necessary to provide a quality washing cycle.

Next we present and discuss the revealed control strategies for the manufactures analysis:

The element with the largest potential in terms of power demand reduction is the electric resistance. So if we just turn the resistance off and let the cycle continue as normal, the washing quality will not be the same. Nevertheless if we coupled the washing state time with the resistance control two control strategies can be deduced:

- Switch off the water heater (resistance) and washing timer

The goal of this strategy is to switch off only the electric resistance and let the drum continuing its rotary movement. However to maintain the washing quality, the washing state timer should be stopped when the resistance is switch off. So that at the end of the washing cycle, the linen spend the programmed washing time at the temperature chosen by the user enabling a quality washing.

- Reduce temperature setpoint and increase washing time

This strategy is based on the reduction of the temperature setpoint and to avoid washing quality deterioration the washing time could be increased.

A study carried out by the Group for Efficient Appliances [6] shows that there is correlation between the water temperature and the washing time in order to have the same washing quality (with some limits).

Another possible strategy could be implemented taking into account the external variable of the water temperature at the entry.

- To Introduce preheated water by another element (ex: boiler with gas, solar panels,…) with a different energy source.

The introduction of a different heat source would eliminate the need to use electricity when the electricity prices are high. However a connection with the other heating device would require, first the existence of this devices and secondly the additional controls are required to connect the water.

As we can see the manufacturer level allowed to deduce control strategies, which were "invisible for the analysis consumer level", however these strategies of control will be more difficult to set up because it would be necessary to make modifications on the appliance and/or to introduce additional equipments.

On the other hand these control strategies show the path of how to transform a common appliance into a smart appliance, capable of shifting or modify its operation in a response to electricity prices or to a direct load control.

Conclusion

The language ILCA allows by a simple and intuitive method to determine the possible control strategies of electric appliances that can be applied by demand response programs.

The example of a washing machine showed that based in the equipment manuals and empiric experience the user level analysis allowed determining control strategies that can be directly applied by the users. These control strategies can then be used by demand response programs either as practical consumer actions (to indicate how to shift or reduce equipments electric demand from peak hours) or as inbuilt control devices to shift or reduce the equipment load from peak hours.

On the other hand the manufacturer's level demanded a more detailed work. Some studies and measurements made available the detailed description of the washing machine by the ILCA language, allowing that advanced control strategies could be revealed. This language showed how advanced control strategies can be applied to new equipments in order to take full benefits of the equipment operation flexibility.

The language allowed compressing all the information about the washing machine operation into a simple graphic easy to understand.

Perspectives

Once the control strategies determined two questions can be raised.

First, which type of communication can be applied to each one of the determined control strategies without damaging or affecting greatly the machine operation?

Secondly, what are the impacts in terms of power relief and energy demand of these control strategies?

A part from these questions an evaluation of the applicability and technical application of the determined controls by the ILCA language should also be made.

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