Analyzing loads for balancing: potential for the Belgian case

Bert P. Vande Meerssche, *Student Member, IEEE*, Geert Van Ham, Geert Deconinck, *Senior Member, IEEE*

Abstract-- Applying DSM for balancing renewable energy sources (RES), makes it possible to increase energy production of RES without the need for expensive (spinning) reserve on fossil power plants. The potential of DSM has already been demonstrated for peak shaving, but to use DSM to balance RES, more knowledge of controllable loads is needed. This paper describes different controllable loads and their individual potential for balancing. The global potential for the Belgian case obtained by the considered loads is given for the year 2011 and projections for the years 2020 and 2050 are made.

Index Terms-- active demand side management, dynamic load, balancing, Smart Grid.

I. INTRODUCTION

MOST of the renewable energy sources (RES) are intermittent in nature what makes balancing of generation and load more difficult. Balancing generation and load can be done:

- by using flexible generation,
- by using storage or buffer capacity (typically batteries or pumped hydro power, which comes at a cost) or
- by Demand Side Management (DSM), exploiting controllable loads.

While flexible generation is the traditional approach, the advent of Smart Grids has put the latter two options forward as techno-economic alternatives. The potential of buffer capacity is clear. A certain power is available during a certain time which can be used when necessary. Rudimentary algorithms are already used today to manage these buffer capacities (e.g. pumped hydro). The potential for DSM is harder to determine. To that end load profiles of controllable loads are needed: how much energy is buffered in a controllable load at a given time, over what time interval can the load be shifted, etc. Also secondary effects such as rebound effects have to be taken into account. When for example air conditioners are switched off, there will be a rebound effect immediately after the switch-off period because more appliances will have to cool. DSM is already used in a rudimentary way for peak shaving [1], [2], [3], [4], but more sophisticated ways are necessary to use

DSM for balancing locally and to limit rebound effects. In this paper the flexible load profiles will be used to investigate the potential of DSM for local balancing purposes, aiming at minimizing the power injected into or retrieved from the distribution grid.

II. CURRENT SITUATION

Some distribution grid operators (DGO's) foresee load shedding for dwellings by means of a centrally controlled switchable contact on the smart meter to switch off some loads immediately when total load is too high. When the DGO sends this signal, the devices connected to it are immediately switched off. In Hungary this is already applied in the form of ripple control, other countries apply for example a two tariff structure [4] or direct load control (e.g. cycling control on air conditioners). These solutions are centrally controlled. With a smart meter this principle could be applied on a more continuous scale also for other loads than the currently used heating appliances. Pump appliances (e.g. ponds) are well suited for this, while no big changes have to be made to these appliances. For other appliances (described in the next section) such a direct control is less acceptable. Most past projects have controlled the load directly for peak shaving from a central point (direct load control), which demonstrated a large potential for load control.

In [5], simulations show that voltage rise can be kept within statutory limits and that export can be limited. Because the simulations work with basic, simple load simulations, further research on the potential of real applications has to be done to understand the full potential of DSM, limiting the rebound effect of switching off loads.

III. POTENTIAL FOR DSM PER APPLIANCE

For industry, the application of DSM should be considered per company because most companies have company-specific constraints and industry will consider DSM from the moment that market mechanisms (e.g. real time pricing) are available. For households and SME's on the other hand, appliances permit a more generic approach. Because households and SME's represent up to 50% of total electricity consumption [2] and (centrally or price) controlled DSM and load shedding are not yet implemented, the potential is worthwhile to investigate.

The Smart-a project (IEE) [6] has investigated the potential of ten household appliances. The considered load profiles however are rather simple and the assumptions conservative,

This work was supported in part by IWT (agency for Innovation by Science and Technology) under Grant 090182.

B. P. Vande Meerssche and G. Van Ham are with KHKempen, Kleinhoefstraat 4, Geel, Belgium (e-mail: bert.vande.meerssche@khk.be).
G. Deconinck is with Electrical Engineering, Faculty of Engineering, K.U.Leuven, Kasteelpark Arenberg 10, 3001 Heverlee, Belgium (e-mail: Geert.Deconinck@esat.kuleuven.be).

but nevertheless the potential of the investigated appliances was significant. The project mentions that “*the feasibility of individual appliance types for smart operation has to be further assessed taking individual technical possibilities better into account*”[7]. This section discusses the potential of a number of appliances validated by measurements on these appliances and compares the results, where possible, with the results of Smart-a. Short time variations (seconds) are not considered to be compensated by the loads. The potential for balancing is considered on a 15 minute basis. Short-time variations are partly compensated by the inertia of the system and for the rest could be compensated by fast energy storage such as supercaps or batteries. Furthermore, using loads for very rapid changes might lead to excessive wear and tear for some of these loads.

A. Freezer

A typical duty cycle of a freezer is approximately 1/3 [6] [8]. So statistically, [6] assumes that in normal operation only one third of the freezers is cooling and on a longer time scale the power consumption is constantly one third of the total installed power. The possible energy storage effect by cooling to a lower temperature is not taken into account in that reference. Therefore the potential for DSM determined in the Smart-a project is limited to a starting delay of only 15 minutes. In [8], the dynamic characteristic of a freezer has been measured by monitoring temperature and energy consumption in an acclimatized room to determine the full capacity for DSM. The results show that a full freezer can postpone its energy consumption up to 30 hours, if it has cooled down to -28°C^1 (e.g. with cheap energy). The potential of a freezer is thus significantly larger than a 15 minute delay. Simulations [8] show that shifting the consumption of a full freezer completely to night tariff is possible while consumption rises with (only) 20%. In Belgium, the financial profit in this case varies between 7.5 and 16% depending on the supplier.

Figure 1 shows a possible power variation per unit of all freezers if a national load shedding signal would be sent. The flat line illustrates the power consumption without DSM. Power consumption remains constant at 0.33 p.u. The dotted line represents the power consumption for freezers with the potential determined by Smart-a [6]. For simplicity, freezers are divided into three groups, each group operating during 20 minutes². At 0h20’ the signal is sent. Only the freezers that normally cool for the next 20 minutes can postpone their start for 15 minutes. The other freezers normally would not cool, so the total consumption drops to zero. At 0h35’, the freezers which postponed their start, start cooling. Because the warming period is extended with 15 minutes (37.5% longer warming time) in comparison to their normal cycle, these freezers will also cool longer. Assuming that the total energy

consumption does not change³, the freezer will cool longer for also 37.5%, bringing the cooling period at 27.5 minutes. The freezers stop cooling at 1h02’30’’.

At 0h40’ the second group of freezers should have started, but if the load shedding signal is still active, these freezers also postpone their start for 15 minutes and start cooling at 0h55’.

Between 0h55’ and 1h02’30’’ the number of freezers that are cooling has doubled. Even though the load shedding signal could still be active, the power consumption (0.67 p.u.) is twice the consumption without the signal. There is a certain rebound effect and this would even be worse when the second group does not postpone its start. The increased power consumption would last 20 minutes (between 0h40 and 1h00) and it would repeat itself every hour (but also the drop to zero would repeat itself every hour). In the figure also the third group of freezers delay their start with 15 minutes which gives a similar profile. Assuming that the freezers react only once on the signal unless it is reactivated, the consumption retakes its normal profile at 1h22’30’’ (with at 1h42’30’’ the switch between group 3 and 1). Another possibility would be to repeat the action. In that case the period between 0h20 and 1h42’30’’ repeats itself until the load shedding signal is stopped.

The above reasoning is of course only valid when the duration for the required DSM operation is sufficiently long and no new generation can be started in the meantime.

The potential of DSM when the full buffer capacity of freezers is used, is visualized with the dashed line. In the figure it is assumed that the period prior to the load shedding signal, is characterized with plenty of cheap energy and all freezers are cooling to create a significant cold buffer. At 0h20, the load shedding signal stops all freezers since they all have a sufficient buffer. The freezers only start cooling if they reach their critical temperature (-18°C) or if the signal is stopped. To avoid any power spikes, the start of the freezers should either be randomized or better, controlled by price signals ensuring that the freezers with the highest temperatures start first.

Figure 1 Power variations per unit of all freezers as a reaction on a national signal at 0h20

The use of the buffer capacity however leads to an increased energy consumption (up to 165% keeping a freezer constantly at -28°C instead of -18°C) [8]. Extra cooling should therefore be limited to strictly necessary levels. Predictions of

¹ Not harmful for the products stored in the freezer

² In practice not all freezers operate during 20 minutes

³ In practice, the average temperature rises due to the delayed start which diminishes energy consumption. This can be neglected because the delay is only 15 minutes.

production and demand will thus be very useful to determine the minimum necessary buffer capacity, minimizing extra energy consumption. One can note that if freezers consume more energy to create a buffer capacity, this is not a sustainable solution. On the other hand, exploiting this buffer capacity can facilitate more RES without the need for more installed balancing power (spinning reserve, peak plants, storage), making it sustainable and affordable.

B. Refrigerator

In Smart-a the potential is taken similar to that of a freezer. It is assumed that a refrigerator can postpone its consumption up to 15 minutes. For freezers the potential is much larger, but for refrigerators the potential of 15 minutes is realistic due to the limited allowed temperature variation. Attention has to be paid on the rebound effect illustrated in **Figure 1**.

C. Air conditioner

The Smart-a project also mentions a great potential for air conditioners. A modest assumption for a time shift of maximally one hour is believed to be achievable for 10% of the room air conditioners. These air conditioners have an average power of 4.6kW and operate on average for 500 hours per year at full load.

The IEA DSM program [4] mentions a lot of projects for peak shaving (direct load control) specifically focusing on air conditioners. The hardware varied from basic ‘Direct Load Controllers’ up to ‘Smart Thermostats’. The control is limited to reducing the consumption during typical peak periods. The reduction is achieved by either cycling control (e.g. obliged 15’ off every 30’ between 2 pm and 6 pm) or by modifying temperature set point (e.g. by 4°F). Using this basic control, the potential for peak shaving is already considerable. Temporally peak load reductions of up to 50% have been reached. Approximately 1kW per appliance⁴ could be shed without the need for a two-way communication system and without complaints from end users. These results indicate a much larger potential than assumed in Smart-a. The projects described in [4], maintain the possibility for the end users to overrule the DSM control. Without this possibility the user acceptance would have been much lower, which could explain the modest assumptions taken in Smart-a.

Although the original peak load could be limited in [4], the problem is not solved. When all air conditioners start cooling at maximum power after the load shedding period, there is another (even higher) peak load. Therefore a more intelligent control is necessary. Similar to freezers, air conditioners can cool a room in advance of the peak load and the cooling can be matched to the locally produced energy. A lot of parameters (like internal heat production of people and equipment, solar irradiance, ventilation, thermal insulation of the building) influence the room temperature, making it difficult to make general assumptions for the buffer capacity of a building. Therefore, buffer capacity has to be determined case by case.

Nevertheless, the time shift of one hour assumed in [6] is a good starting point. For example **Figure 2** and **Figure 3** give the temperature variation of a room with measurement equipment. In this setup the air conditioner needs 1h35’ to cool the room from 25°C to 20°C after which the room does not need cooling during 2 hours keeping temperature below 25°C.

Figure 2 Cooling a room with measurement equipment

Figure 3 Warming up of a room with measurement equipment

Besides the buffer capacity of the building, the chiller itself can also have some storage capacity by storing cold water or even ice in advance so that the buffer capacity further increases. When absorption cooling is used, the necessary heat can be stored.

Another possibility offered by air conditioners is that users can define different comfort levels. Depending on the electricity price, users are prepared to hand in a little bit of comfort.

D. Boiler

[6] confirms the large potential of domestic hot water boilers (DHW) for DSM. In practice, about 29% of all installed boilers are electrically heated. For Belgium this means around 1.2 million electric boilers with a power between 2 and 6kW, representing a fully controllable load of 2,4 to 7,2GW. Hot water usage varies between 40l and 70l a day. But consumption profiles are hard to determine. Energy consumption for 50l a day with a temperature rise of 50°C (from 10°C to 60°C) amounts to 2.9kWh of controllable energy per day. A boiler with an electric power of 2kW will thus only need to operate during about 1.5 hours, mostly during the night. For no-load losses, [6] mentions 1.8 to 2.6kWh a day for large storage tanks. Including no load losses, operating hours increase to about 3 hours a day (or night) for a 2kW boiler.

Hot water boilers are already used in a rudimentary form of DSM (two tariff Time of Use (ToU)). [6] also notes that

⁴ on an average capacity of 3.84kW for residential air-conditioning units, while the average capacity of small commercial units was 6.38kW.

electricity is not the best way to produce heat in view of primary energy use. [6] suggests to use thermal solar panels for hot water instead of electricity from PV-panels because of efficiency, but these systems always include a second way to produce heat, for periods of low sunshine. To achieve the 2050 goals (80% reduction of greenhouse gases (GHG)), electricity becomes a very interesting second way to produce heat when there is no sunshine. For example when there is a large amount of wind to produce electricity, this electricity can be used to produce DHW. To enlarge the buffer capacity, the water temperature can be increased from the normal 60°C up to 80°C to 90°C. The operating hours for a 2 kW boiler then increase from 3 hours up to 6.5 hours. A 200l boiler needs 8 hours to heat water from 10°C up to 80°C. If electric power increases (e.g. 4kW) operating hours per boiler decrease, but on a national scale the buffer capacity (total kWh) remains the same having the possibility to switch only a part of the boilers on.

The potential of electric heat for DSM is comparable with smart battery charging. A certain amount of kWh (chemical or thermal) can be stored, practically at a random time. But capital expenses are lower because the installation is necessary anyway, which is not the case for batteries. Together with a large installed capacity and possible long operating times, electric heat (in general) can be a viable option for DSM. Because the consumption profile of hot water is hard to predict, the buffer capacity should always be sufficiently large. As with the freezer, the extra buffer should be limited to limit the extra no-load losses.

E. Electric heater

Like boilers, heat accumulation stores energy during off peak periods. With real time pricing (RTP) or time of use (ToU) and RES, these appliances can be used at periods of cheap (renewable) energy. [6] mentions that electricity for room heating has a large potential, but is not the best way in view of primary energy use. But making use of heat pumps (not considered in [6]), even with a limited coefficient of performance (COP) of 2 [9], [10] and electricity produced from e.g. a combined cycle power plant, electric heating is more energy efficient than heating with fossil fuels. Again, taking into account the 2050 goals, electric heating is a very good solution, providing a large buffer capacity which is needed to facilitate large amounts of intermittent RES, while limiting capital expenses.

Results of a low energy dwelling demonstrated that the energy consumption of a heat pump with a hot water tank of only 200l as buffer, could be fully shifted to the night while the room temperature could be kept above 19.6°C. Clearly, buffer capacity depends on building parameters and can further be increased by buffer tanks. Therefore, buffer capacity has to be determined case by case.

F. Ventilation

Only recently, ventilation has become more important in dwellings, specifically in new ones. Ventilation as such is not often considered for DSM. The rated power for ventilation of

dwellings can vary between 15 and 170W, depending on the system and the air capacity [11]. But penetration rates are still low. For larger buildings, ventilation is more common and the installed power is significantly larger. Values of 25 up to 40 W/person are commonly used.

The potential buffer capacity mainly depends on the occupancy of a room. This makes simulations very difficult. Therefore the potential has to be determined for each individual case. Results on classrooms show a possible delay of 40 minutes before CO₂-concentration becomes too high. Also in the agricultural sector, ventilation is a large consumer and a time shift may be possible but also has to be determined case by case.

G. Laptop

Laptops can be looked at as mobile batteries for DSM. A typical load curve shows the ‘constant current – constant voltage’ charging. Figure 4 shows power consumption for charging the laptop’s battery from zero percent to completely charged while the measured laptop remains switched off. When the considered laptop is active, its maximum power consumption is 100W. This is a typical value for laptops.

Figure 4 charging of a laptop battery

The total charging time is three hours of which the constant current charging takes 1.4 hours (5000s). During the constant current charging the battery charges up to 80%. Using the laptop does not change the charging curve of the battery, the extra power consumption is directly drawn from the grid. The influence of the different energy modes of the measured laptop becomes most visible when the battery is being discharged. In “high performance mode” a completely charged battery is empty after 3 hours and 21 minutes in standby while in the “energy saving mode” discharging takes 6 hours and 20 minutes.

Power consumption of a laptop varies between zero (working on battery) and 100W (charging and using the laptop in “high performance” setting). Although a lot of people have a laptop, the potential for DSM is rather small. Assuming that every household has one laptop, the total potential amounts to 450MW for Belgium. This power is not always available and depends on the state of charge (SOC) of the battery and the connectivity. Assuming that all laptops are fully charged and connected to the grid, the load represents 150MW (consumption of the laptop in test setup was 33W) which could be disconnected up to 3 hours. Attention has to be paid to the rebound effect. After this load shedding of three hours,

all batteries will be empty and will start charging representing a total load of 450MW (100W per laptop; charging and using the laptop in “high performance” setting). Economic gains for the end user will be marginal because of the limited total energy use.

H. Electric vehicles

Electric vehicles for DSM behave the same as laptops, they can be regarded as mobile batteries. Whereas the potential of laptops is rather small, the potential of plug-in hybrid electric vehicles (PH)EV's can be even larger than that of electric heat. An average EV would practically double the electric energy consumption of a household [12]. When also vehicle to grid (V2G) power flows are possible, the potential for DSM becomes even more interesting. Assuming that 20% of future households owns a (PH)EV with a charging power of 3kW (typical 16A outlet on 230V), for Belgium this would amount to approximately 3GW controllable load which is most of the time available⁵, until the batteries are full (around 8 hours for 150km autonomy). Charging electric vehicles shows the same profile as charging laptops. Practically half of the total charging time is necessary to charge up to 80% at constant current.

In case of fast charging, the controllable load would be even larger, but the accepted time delay to start charging would be very limited because fast charging is typically applied when the owner wants his car to be charged as soon as possible. Battery life and efficiency during frequent cycling remains a major issue with current technologies.

I. Water pump

Some applications with water pumps can have a buffer capacity thanks to a physical buffer (pressure, volume) or a buffer of the process like with ponds, pools and water treatment plants. Depending on the process, pumps can be switched off for 30 minutes up to several hours. [4] mentions a project in India where direct load control on agricultural pumps was implemented by establishing schedules specifying the times during the day when each agricultural feeder would be energized.

Total available power on national scale is difficult to determine. Pumps for ponds usually consume around 60W, a small pool pump can consume 300W. If 10% of all households have a pond and 5% own a pool, for Belgium this would result in 30MW controllable load for ponds and 75MW for private pools. The potential power is rather small but there is no rebound effect and flexibility is large. These pumps can be started and stopped at best periods for DSM. In agricultural applications installed powers are much larger. [13] also mentions the possibility of DSM for water utilities. Instead of always having full storage containers, the basins will only be filled during off-peak time. But are water utilities willing to

take the risk of reducing their buffer?

J. Dish washer

A dish washer (and washing machine, dryer, but also conveyor belts and some other industrial processes) does not have a buffer capacity but can have a delayed start. According to [6], dish washers have the largest potential for DSM (apart from electric heating) because they are characterized by a large power (± 2 kW) and can delay their start up to 19 hours. Also user acceptability for DSM is high. Unlike with washing machines and dryers, users do not mind keeping the dish washer on during nighttime. Yet, [6] assumes that only 20% of the owners are willing to accept DSM on their dish washer. The authors believe that this is a large underestimate. Automation of the system makes that only minimal user input is needed to implement DSM. Moreover applying DSM lowers the electricity bill for the user. To our opinion almost all users are willing to apply DSM on their dish washer. Therefore in section IV, it is assumed that all dishwashers are available for DSM.

Currently dish washers are mostly being used in the late afternoon and early evening, so shifting the operating moment can significantly decrease peak loads on the distribution grid. Approximately 40% of the households have a dish washer and use it on average 4 times per week. Although it has a large delayed start potential, the flexibility is limited because once the process is started, it is better not interrupted and the total on time is limited to 1 up to 2 hours per cycle or 4 to 8 hours per week.

Figure 5 shows power consumption of the tested dish washer. It was started at 9:25 and ended its cycle at 10:34. The dish washer does not consume 2kW during the whole cycle. It only needs the maximum power to heat the water and dry the dishes. During the washing process the tested dish washer only consumed around 40W. To choose an optimal starting point, the whole load profile of Figure 5 should be taken into account.

Figure 5 power consumption of a dishwasher

K. Lighting

[4] mentions a peak load reduction of 15% only by implementing compact fluorescent lamps (CFL's) instead of incandescent lamps. The potential for balancing is rather limited. Although lighting is considered as non-controllable load, [14] mentions a relative high elasticity for lighting (and also other non-controllable loads such as brown demand like television, radio,...). Simulations show a reduction of 1.5GW for lighting at peak prices in the UK. If electricity prices become sufficiently high, users are willing to switch some

⁵ Vehicles are only available when connected to the grid. It is assumed that a technical solution makes it easy to plug the vehicle (automatically) onto the grid. In this case it is reasonable to assume that vehicles are grid connected when they are not used.

(ambient) lights off. This delay represents energy savings during the delayed time period because lighting does not have a rebound effect.

Similar as with air conditioning, the user can be given the possibility to define different comfort levels. DSM cannot switch lighting off automatically for security reasons, but switching to a lower comfort level could be possible in case of energy shortage. This has an additional advantage that people are immediately visually informed of energy shortage and can possibly switch off other non-controllable loads.

IV. DSM COMPARISON

Table 1 lists a typical value of the nominal power of each type of the considered controllable appliances. For building-related appliances an office space for 15 persons has been considered. For each person a surface of 11 m² has been taken, with the total surface approximately equal to the surface of a 3 bedroom-dwelling in Belgium. The power of the heat pump can thus be the same of that of an average dwelling. The ventilation has to provide 54 m³/h per person (to guarantee IDA class 2 [15]) and consumes approximately 0.7W per m³/h. This leads to 550W for SME's. For dwellings the ventilation is calculated for fewer persons resulting in approximately 100W. The air conditioner consumes approximately 50W/m² and for lighting the guidance value of 2.5W/m²/100 lux leads to the 2000W for 500 lux.

TABLE 1 POTENTIAL FOR DSM OF CONTROLLABLE LOADS

Appliance	Nominal power (W)	Off time (hours)	On time (hours)	Installed estimated power (MW) for 4,5 million dwellings in Belgium			Normal operating hours
				2011	2020	2050	
Freezer	100	30	20	450	450	450	1/3
Refrigerator	100	0,25	0,25	450	450	450	1/3
Air conditioning	8000	1	1	250	2500	2500	500/summer
Electric boiler	2000	24	8	2400	3600	8000	3/night
Heat pump	4000	16	8	40	400	16000	1000/winter
Ventilation	100	1	cont.	10	100	450	24/day
Laptop	100	6	3	450	450	450	4/day
EV	3000	24	8	0,13	300	12000	4/day
Water pump	60 – ...	24	24	30	60	120	1...24/day
Dish washer	2000	19	2	3600	5400	7200	170 cycles/year
Lighting	2000	reduced comfort	cont.	9000	9000	9000	domestic 1/day SME 10/day

The table summarizes per appliance the earlier described possible 'off-' and 'on-times' available for DSM. The table further gives estimated installed power for these appliances for the 4.5 million households in Belgium for 2011, 2020 and 2050. These values indicate the most promising loads for DSM.

Practically every household already owns a freezer and a refrigerator resulting in 450MW total installed power each for the three considered years. Demographic growth for all appliances is considered zero in order to compare the figures with the 2010 peak load. For the nominal power of an air conditioner, 8kW is taken (50W/m² for an office of 15 persons). To calculate the total installed power for all households in Belgium, only 1% of all households is considered to have an air conditioner limited to 5kW in 2011.

This is estimated to further increase (with increasing comfort requirements), up to 10% of all households in 2020 and stabilizing (rational energy use and passive houses) to 2050. In 2011 almost 1.2 million households have an electric boiler of an estimated average nominal power of 2000W. This results in 2.4GW for all households. It is estimated that in 2020 1.8 million households will have an electric boiler, but half of these boilers only as a secondary boiler to the thermal solar panels (limiting the potential for DSM). This further increases up to 4 million in 2050, with all of these boilers only as secondary system. For heat pumps it is assumed that 10% of the new dwellings over the last two years (10.000) have a heat pump of 4kW electric power installed. This results in 40MW for all households in 2011. For 2020 the total number of households with a heat pump is assumed to increase with 20% of all new houses over this period. In 2050 practically every dwelling has to be heated electrically (heat pump or other techniques) to become CO₂-lean.

New buildings have the obligation to implement ventilation. For 2011 it is assumed that over the last two years every new building (100.000 over the last two years) has implemented mechanical ventilation of 100W resulting in 10MW total installed power. In 2020 this can increase up to 100MW taking into account the new buildings and renovation, leading to 450MW in 2050 when every dwelling will have mechanical ventilation. Assuming that, on average, every household has one laptop, the total installed power for 2011 comes at 450MW. For the values for 2020 and 2050 the number of active laptops is believed to stay stable.

The number of EV's is limited in 2011 to 43 [16] leading to 129kW 'installed' power (3kW each). The number of (PH)EV's will increase exponentially, so it is believed that the number of vehicles that can be electrically charged will increase up to 100.000 in 2020 and further up to 4 million in 2050.

Water pumps are difficult to estimate. Therefore only 500.000 pond pumps are considered for 2011. The figure is doubled for 2020 and 2050, estimating an increase in ponds, but also taking pools into account at some extent.

40% of households has a dishwasher in 2011 [6] resulting in 3.6GW total installed power in 2011. It is assumed that the number of households having a dishwasher will rise up to 60% in 2020 and 80% in 2050.

The normal operating hours of the appliances are necessary to determine the global (on national scale) potential for DSM in Table 2. For example freezers and refrigerators have typical duty cycles of 1/3. Freezers however have large 'on' and 'off' times whereas refrigerators are limited in buffer capacity. Freezers are thus practically always available for DSM, while refrigerators are practically not suited for DSM and are not included in the calculated available (peak) power for DSM. Air conditioners are only available during hot summer days and thus perfectly suitable to match PV power. Heat pumps (or other types of electric heating) on the contrary are only available (approximately 1000 hours) during winter days and are not available during summer.

Electric boilers are available during the whole year (3 up to 8 hours per day) but will only be used when no sun is available for the solar boiler in 2050 (winter and cloudy day in summer in 2050). Instead of a separate boiler also the heat pump can be used to heat the domestic hot water, but this is not taken into account. For 2011 electric boilers are always included because solar boilers are not yet installed in dwellings with electric boilers. In 2020 it is assumed that half of the electric boilers also have a solar boiler as primary system. So on 'summer sunny days' only the other half of the boilers is taken into account. In the simulations for 2050 it is assumed that if an electric boiler is available, also a solar boiler is available.

Ventilation, laptops, electric vehicles, water pumps, dish washer (and washing machine, dryer), are available during the whole year. Washing machines and dryers are not taken into account, but the nominal power of dish washers is fully taken into account. Given the limited operating times of these appliances, it is reasonable to assume that on average one of these appliances (washing machine, dryer, dish washer) is 'ready to operate' and thus the calculated available power is not exaggerated. The possible peak power for DSM can even be much larger when all these appliances operate at the same time.

For laptops and electric vehicles the normal operating hours are limited to approximately four hours a day. Once a laptop has been charged it can operate for the next 4 hours (depending on the battery) without extra energy. For (PH)EV's a charging time of also four hours a day has been considered. 80% of the Europeans travel less than 60 km a day [17] [18]. The necessary energy for this route can be delivered by a normal 230V outlet within four hours. This is the typical charging time to charge the battery up to 80%. Nevertheless, in case of extra available energy, the battery can further be charged up to 100%, totaling the possible charging time up to eight hours.

TABLE 2 POTENTIAL FOR DSM FOR 4.5 MILLION DWELLINGS IN BELGIUM

		2011	2020	2050	
Available peak power (MW) for DSM		7840,13	11660	45570	Winter
		8050,13	13760	32070	Summer cloudy day
		7150,13	11060	23170	Summer sunny day
Peak load Belgium 2010	14200 MW				
Available power (MW) for DSM (>= 8hours)		3830,13	5810	37920	Winter
		3790,13	5410	21920	Summer cloudy day
		2890,13	2710	13020	Summer sunny day

Lighting is not fully taken into account. The end consumer normally wants to keep the end control of his lighting comfort. Nevertheless, it is reasonable to take 10% of installed power into account for 'summer cloudy days' and 'winter days'. Despite the large value in 2011, the installed power is

estimated to be constant in time. Average lighting efficiency will increase, but the demand for light is assumed to increase.

The available power for DSM in summer is in fact underestimated because it is assumed that only 10% of the households have air conditioning. If heat pumps are actually as much installed as assumed in the table, people will use these heat pumps also for cooling. Nevertheless, the possible (peak) power for DSM originating from households is significant, certainly compared to the national peak demand of 2010 [19]. But possible operating hours are often limited. If only the appliances with possible operating hours larger than eight hours are considered, the values are significantly lower, dominated by electric vehicles and freezers.

Table 2 only gives values for the 4.5 million households in Belgium. [20] gives the evolution of total yearly energy consumption for households and 'equally treated' (among others SME's) on the one hand and for the industrial sector on the other hand. The figures show that total electricity consumption of households together with the equally treated is practically the same as that of industry (for Belgium). Also for the rest of Europe [21] this is true.

[20] further shows that households consume practically as much as the equally treated. If the SME's are also taken into account, the possible effect (larger power, but especially enlarging buffer times because normal operating hours are largely complementary) could be doubled because possible loads for DSM are similar to that of households and SME's typically have more air conditioners and ventilation installed, which are more interesting than washing machines and dryers in view of DSM.

Electrification of the transport sector will result in a significant increase in electricity consumption. According to [20], the yearly energy consumption of transportation is 1.3 times total electricity demand. This does not mean that electricity demand will double, because electric vehicles (EV's) will be more energy efficient than conventional vehicles with internal combustion engines. The impact on peak load could be reduced when EV's are intelligently charged [12], but still it is difficult to estimate future peak loads, therefore only the peak load of 2010 is given in Table 1.

V. CONCLUSIONS

To use DSM for balancing, detailed load profiles are necessary. This paper has presented different controllable loads in view of DSM. The potential of the different controllable loads and their profiles have been discussed, with specific attention paid to the potential for Belgium. Table 1 lists the maximum on- and off-time per load and lists the possible available power for DSM in 2011, 2020 and 2050. For loads where the buffer capacity can easily be extended (e.g. larger hot water tank with heat pump), the figures represent an assumed acceptable average installation.

Buffer capacities depend in general on use and scale of the appliances. But even with moderate assumptions, the potential for DSM of the considered appliances is significant. The available peak power for DSM in 2050 becomes even up to 3

times higher (depending on season) than the 2010 peak demand. DSM power which is available for more than eight hours increases from approximately 3GW today up to 13GW in summer and 38GW in winter in 2050. Because the available controllable power in winter is significantly larger, not only PV should be installed, but other renewables like wind have to be considered in Belgium.

VI. FUTURE WORK

To calculate the possible increase in renewable sources facilitated solely by DSM, simulations considering the effect on a whole year are necessary. With the loads described in Table 1 a practical test infrastructure is being built at KHKempen to investigate the total potential of DSM for balancing PV power. The control strategy will take into account the parameters of Table 1.

VII. REFERENCES

- [1] IEA DSM (2008); "The Role of Advanced Metering and Load Control in Supporting Electricity Networks. Research Report No 5 of Task XV of the International Energy Agency Demand Side Management Programme"; October 2008. Hornsby Heights, Australia
- [2] IEA DSM (2009); "Implementing Agreement on Demand-Side Management Technologies and Programmes, 2009 annual report", task XIX: Micro Demand Response and Energy, January 2010, Stockholm
- [3] IEA DSM (2008); "Assessment and Development of Network-driven Demand-side Management Measures. Research Report No 2 of Task XV of the International Energy Agency Demand Side Management Programme", Second Edition, Revised, October 2008. Hornsby Heights, Australia
- [4] IEA DSM (2008); "Worldwide Survey of Network-driven Demand-side Management Projects", Second Edition, Revised, 10 October 2008, Hornsby Heights, Australia
- [5] Lim, Y. S.; White, S.; Nicholson, G.; Taylor, P.; "Additional applications of demand side management techniques in power systems integrated with distributed generation", CIREN 2005 18th International Conference on Electricity Distribution
- [6] Timpe, C.; smart-a (IEE), "Smart Domestic Appliances Supporting the System Integration of Renewable Energy", November 2009, <http://www.smart-a.org/> accessed on August 2010.
- [7] Seebach, D.; Timpe, C.; Bauknecht, D.; "Costs and Benefits of Smart Appliances in Europe"; Final Report – September 2009, www.smart-a.org/W_P_7_D_7_2_Costs_and_Benefits.pdf, accessed July 2011
- [8] Vande Meerssche, B.; Van Ham; G.; Deconinck, G.; "Capacity of a freezer for active demand side management", 2nd International Conference on Innovation for Sustainable Production 2010, Bruges, April 2010
- [9] Baetens, R., De Coninck R., Helsen, L., Saelens, D.; "The impact of domestic load profiles on the grid-interaction of building integrated photovoltaic (BIPV) systems in extremely low-energy dwellings", Zero Emission Buildings pages:3-14, Jun 2010
- [10] <http://www.liveheatpump.be/>
- [11] Renzon system C+ Eco and D+ <http://www.renson.be/fb111mvye1163guhc1smhc248.aspx>
- [12] Clement, K.; "Impact of plug-in hybrid electric vehicles on the electricity system"; Dissertation K.U.Leuven, October 2010 (p. 36)
- [13] Kadar, P.; "Multi Objective Optimisation of Smart Grid Structure"; 15th International Conference on Intelligent System Applications to Power Systems, 2009. ISAP '09., Page(s): 1 – 5
- [14] Roscoe, A.J.; Ault, G.; "Supporting high penetrations of renewable generation via implementation of real-time electricity pricing and demand response", Renewable Power Generation, IET 2010 Volume: 4, Page(s): 369 – 382

- [15] EN 13779 Ventilation systems in non residential buildings
- [16] 40 laadpunten voor elektrische wagens in Antwerpse Parking Quellin; <http://www.elektrischrijden.be/2011/05/40-laadpunten-voor-elektrische-wagens-in-antwerpse-parking-quellin/> in Dutch, accessed July 2011
- [17] Gemiddeld aantal afgelegde kilometer per persoon per dag; <http://www.mobielvlaanderen.be/pdf/ovg03/ovg03-analyse-b3.pdf>, in Dutch, accessed July 2011
- [18] Opel Ampera productiewagen – e-mobiliteit binnen het bereik van de bestuurders; http://www.opel.be/Media/news/pdfs/04_08feb11_geneva%20motor%20show_opel%20teaser_ne.pdf in Dutch, accessed July 2011
- [19] Synergrid "Elektriciteitsstromen in België"; <http://www.synergrid.be/index.cfm?PageID=18213#>, in Dutch, accessed July 2011
- [20] FOD economie, energie (Belgian government); <http://statbel.fgov.be/nl/statistieken/cijfers/energie/statistieken/index.jsp> in Dutch, accessed July 2011
- [21] Kok, K.; Warmer, C.J.; Karnouskos, S.; Nestle, D.; Dimeas, A.; Weidlich, A.; Strauss, P.; Buchholz, B.; Drenkard, S.; Hatzigiorgiou, N.; Lioliou, V.; "Smart houses for a smart grid", CIREN, 20th International Conference on Electricity Distribution, Prague, 8-11 June 2009 <http://www.ecn.nl/docs/library/report/2009/m09110.pdf>

VIII. BIOGRAPHIES

Bert Vande Meerssche received his M.Sc. in Electrical Engineering from the K.U.Leuven (Belgium) in 2003. After working for the Belgium transmission system operator (elias), he started a Ph.D. research project at the K.H.Kempen University College of the K.U.Leuven (Geel, Belgium). He leads projects in the field of SmartGrids and DSM. He teaches topics related to production and distribution of energy and lighting. He is a student member of IEEE and can be reached at bert.vande.meerssche@khk.be.

His research interests are smart grids, active demand side management and rational energy use. He can be reached at geert.van.ham@khk.be.

Geert Deconinck is full professor (gewoon hoogleraar) at the Department of Electrical Engineering (ESAT) of the K.U.Leuven (Belgium). He performs research on the design of dependable system architectures for industrial control and smart grids. He teaches topics related to industrial automation and hardware, lighting, and measurement techniques. He received his M.Sc. in Electrical Engineering and his Ph.D. in Engineering from the K.U.Leuven, Belgium in 1991 and 1996 respectively. He is member of the IEEE SMC TC on Infrastructure Systems and Services and chairman of the TI society BIRA on industrial automation. He is a member of the Royal Flemish Engineering Society, the Institute of Engineering and Technology (IET), a senior member of the IEEE and can be reached at Geert.Deconinck@esat.kuleuven.be.