An Efficient energy management system for smart homes with solar panels

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Abstract - A chance to accomplish their energy expenditure is given to the residents by introducing smart grid that exhibits the upcoming phase of electrical power systems. With respect to minimize the overall energy cost, the optimal and grid operation of a smart home is supported and a Smart Homes Energy Management System (SHEMS) is presented by this paper. Intended for the past few centuries, consumption of electricity has been increasing progressively in households. Certain complications are presented by these changes for services, for customers and for the atmosphere. While the adequate real-time data are provisioned on the consumption, the micro generation and the energy storing (mainly, in electric vehicles), the present evaluating systems ensure major drawbacks. In a dynamic pricing perspective, they are moreover unprepared for handling the charges that depends on the generation combination. The Smart Grid, which is the electric grid of the future must go afar from home meters and must focus on readings of the consumption of individual appliance. Primarily, in order to reduce the energy consumption, customers (who may also be "prosumers" – i.e., producers and consumers at the same time) doesn't have information about their appliances, the actions they must implement and also the information of the actual financial effect of the energy consumed, produced or stored at every instant. Moreover, since the output of many renewable energy sources that are frequently irregular resources cannot be predicted accurately and the consumption of the customers cannot be influenced individually, the transmission or distribution system operators are facing problems in their grids regularly. Thus, the lack of efficiency rises in the usage of resources.

I. INTRODUCTION

A life sustaining commodity is Energy. A fundamental requirement for society and a vital thing for socio-economic expansion is electrical energy based on the entire energy requirements. Even though it is unnoticed every time, it has turned out to be a universal requirement of human life for the last century and is one of the enabling technologies. The necessity and dependence on this commodity has never shown signs to recede and it is still expected to increase in the future. In most part of the world, access to electricity is the right of every citizen but has to be paid for according to the market rules. The power industry has been under a constant but slow evolution. Power grids arose because local demand could not be met by local generation. With generators and their natural fuel sources often situated far from consumers, networks were set up to transmit power from generators to consumers. The development of the power system was, and still is, governed by the ultimate goal of providing consumers with quality and reliable power supply at minimum cost. Nowadays, electricity is generated from multiple sources such as hydro, nuclear and fossil fuel power plants, giving it the greatest degree of energy resilience. As our society becomes more sustainable through awareness of future shortages and environmental consequences of fossil fuels, an effective way of ensuring fossil fuel independency is a transition towards alternative energy sources (such as wind and photovoltaic), and a more efficient use of electricity. Residential loads are changing in power, complexity and quantity. Serving the residential electricity demand is the main goal of the power grid with constant monitoring and control to provide a safe, reliable and efficient electricity supply. With increasing share of distributed generation in the home environment, there is a new challenge to operate the power grid in an efficient, safe and reliable manner. The existing electricity distribution system must be transformed to a more robust, reliable, and efficient one with more control functions to enable bidirectional flow of energy and information between households and the power system. The Smart Grid technology is envisioned as an intelligent way to effectively accommodate the changes in the power system.

Modern house

Figure 1: Evolutions in residential loads and comfort levels.

II. FORMULATION OF OPTIMIZATION PROBLEM

In this paper we consider four kinds of home energy assets such as energy storage system, electric vehicle, smart appliances and a set of photovoltaic power panels installed on the roof. Here we are assuming that all the appliances are must run and considered them as base load demand. The smart home environment considered in this paper is depicted as in Fig. 1. It can be observed in Fig.1 each assets possess technical capabilities such as PV-to-grid (PV2G), PV to-home (PV2H), vehicle-to-grid (V2G), vehicle-to-home (V2H), ESS-to-grid (ESS2G) and ESS-to-home (ESS2H). It is assumed that the consumers are considered to be under an hourly-varying pricing tariff scheme. The smart meter is used to communicate with the utility.

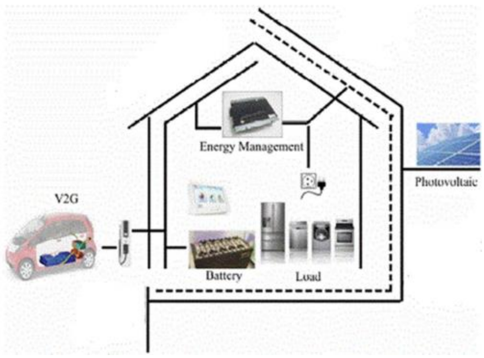

Fig. 2. The schematic diagram of a smart home with assets

III. LITERATURES

Ke Meng et al [1] proposed that a challenge to organize several groups of aggregate air-conditioners for delivery system load managing. This projected method aim to present a challenge to synchronize compound group of Virtual Power Storage Space Scheme (VPSSS) to deal with complex load. A circulated manage system is future to distribute the essential dynamic control reduction among the aggregators during limited announcement to switch in order with nearby aggregators and an balance position can be met between complicated aggregators. In a distributed manage approach; the essential dynamic energy restriction can be collective amongst the participate aggregators.

Mario Collotta et al [2] has proposed system present an Artificial Neural Network (ANN) as maintain for a Home Energy Management (HEM) arrangement base on Bluetooth low energy, called BluHEMS. The objective of infrastructure technology is to realize an extensive energy savings, in order to cut greenhouse gas emissions and to reach effectual ecological security in more than a few contexts, counting infrastructure, developed, transport, buildings, electricity generation and delivery. A smart grid is conceptualized as a grouping of underlay electrical network and superimposes communication system. In this proposed system a profound examination for the pattern of the ANN in arrange to get the one that achieve the best presentation. This system supply widespread simulative assessment, perform all the way through the Network Simulator Version-2 (NS-2), in conditions of energy utilization, demand profit, delay practiced by consumers for the planned HEM solution and in conditions of package delivery relation, delay, and jitter for the wireless networks.

Siyun Chen et al [3] gives a human-centric Smart Home Energy Management System (SHEM) with the intention of mechanism at the “butler” plane. Based on this structure, our SHE system provide smart military to make happy the supplies of user as a butler aim not just to keep the electrical energy cost or decrease the max out load, but in addition to forecast user’s stress and supervision “servants.” Smart grid strategies are incorporated keen on smart home systems; it willpower be more hard and complex for user to control all strategy wisely. In this proposed system a human-centric smart home construction by the combination of considerate the behaviours of person being, infer the user’s weight and utilization preference and optimally running the energy plans in smart home. The SHE system can be comprehensive for respond to a variety of require response signal and contribution expensive maintain for programming and result make at all levels of usefulness based on the people-centric framework.

S. L. Arun et al [4] has deals with an Intelligent Residential Energy Management System (IREMS) for producer of neat housing buildings are planned. The most important purpose of IREMS is decrease in electrical energy bills whereas maintain the power require less than the maximum demand limit subjected to the variety of constraints principal the procedure of household demand and Renewable Energy Resource (RER). Through demand manage and Real Time Pricing (RTP) is two ordinary techniques in Demand Side Management (DSM) projected by special energy suppliers. A mixed-integer linear programming based preparation algorithm whereas considers the purpose as decrease in energy consumption bill for residential energy consumers. Price profit analysis for showcasing the investments and least Cash Payback Period (CPP) predictable from the propose techniques. The resources are optimally sized with Genetic Algorithm (GA).

Daniel Minoli et al [5] has residential the representation of energy larger than Ethernet, as measurement of an Internet of Things (IoT) -base solution, offer disrupting chance in transform the in-building connectivity of a huge swath of policy. A Building management System (BMS) is a complete platform that is working to observe and organize a building’s automatic and electrical apparatus. The technical junction is as it service of IP-based end tip strategy below the power of IoT. The convergence of IoT, PoE, IP (IPv4 as well as IPv6) is predictable to improve the functionality, capability, power efficiency, and price-effectiveness of building, affecting them up the computerization range to a “smart building” position. The expansion of cloud-based high-class analytics will facilitate international optimization and apposite data pulling out, trending, and forecasting.

Bharatkumar et al [6] has presented to expand the Neural Network (NN) base tidy demand estimator, practical data from a real power hub managing system is use for supervise preparation. The perception of central energy management system for micro grids, base on Unit Commitment (UC) and Optimal Power Flow (OPF) model, contain been report. The optimization difficulty is solve at separate time steps taking into account reorganized forecasted input with a progressing time p ossibility, with obtain most constructive decision being single suitable for the next instant step. A NN based Housing Convenient Demand Profile Estimator (HCDPE) is accessible, which is urbanized by deliberate and imitation data as of a real Energy Hub Management System (EHMS).

H. S. V. S. Kumar Nunna et al [7] has presented two power management strategies near efficiently makes use of V2G possible of Plug-in Electric Vehicles (PEVs) in supervision power imbalance in grid associated micro grids. The proposed scheme V2G combination strategies are implemented with a multi-agent arrangement developed in Java Agent progress structure and practical to a micro grid case study arrangement. The proposed cost system for fitting the PEV charge cost less than both grid connected and islanded method of process of the micro grid. The proposed approach is implementing with a Multi- Agent System (MAS) developed in Java Agent Development (JADE) structure. The projected approach is sensible to a micro grid case study scheme with two sets of information.

Neeraj Kumar et al [8] has presented a smart, energy-efficient system in smart grid Cyber-Physical Systems (CPSs) by means of coalition-based game theory. Mobile Cloud Networking (MCN) is a rising tools in which mobile policy are linked to a cloud server with Access Points (APs). Game is formulated connecting the smart strategy (players) and the service provider (clouds) in which together players and service providers aspire to exploit their proceeds through admiration to the accessible resources. The manage algorithms are execute in the cloud atmosphere, which is measured because the cyber plane. The proposed resolution can be implement in a real-world smart city situation for solve issue connected to demand management, frequency and voltage fluctuations at the grid.

Xin Wang et al [9] proposed with active energy management for smart-grid power-driven Coordinated Multi Point (CoMP) transmission. An infinite-horizon optimization difficulty is formulated to attain the most favourable downlink hand on grin formers that are robust to control reservations. Leveraging the stochastic dual-sub gradient method, expand a virtual queue base online control algorithm. Relying lying on the supposed Lyapunov optimization method as well as the exposed distinctiveness of the optimal schedules, properly launch that the proposed algorithm yields a feasible and asymptotically most favourable supply management approach for the innovative difficulty

Ganesh Kumar Venayagamoorthy et al [10] proposed the expansion of an Intelligent Dynamic Energy Management System (I-DEMS) meant for a smart micro grid. An evolutionary adaptive dynamic programming and support learning structure is introduced for developing the I-DEMS online. To develop adaptive I-DEMS by means of an Action-Dependent Heuristic Dynamic Programming (ADHDP) approach. ADHDP is base on joint concept of adaptive dynamic programming and reinforcement culture concept. The ADHDP structure employs two neural networks. I-DEMS, even as fulfilling the main goal of assembly 100% of the serious load exact requirements, still manage to advance the power dispatch to convenient loads. These resources that micro grids of the potential can be manage brightly to be self-sustainable, consistent, and ecological responsive.

Ayan Mondal et al [11] proposed the spread Home Energy Management System with storage (HoMeS) in a combination, which consists of compound micro grids and multiple customers, is calculated by means of the multiple-leader–multiple-follower Stackelberg game theoretic model—a multistage and multilevel game. The HoMeS model for instantaneous energy utilization of consumers in the attendance of storage space conveniences and more than a few micro grids in a combination. The first algorithm is used in the Initialization Phase (IP) for the micro grids to conclude the smallest amount of power to be generated. By the proposed advance, the distributed energy management scheme in the attendance of storage can be complete with the most favourable value of the power request by the clientele, while consider the in general energy demand in the system.

Kun Wang et al [12] has proposed a power system through together Distributed Generators (DGs) and consumers and proposition a Distributed Location Marginal Pricing (DLMP)-based Unified Energy Management System (UEMS) representation. This projected system contains two parts: a game theory-based Loss Reduction Allocation (LRA); and a Load Feedback Control (LFC) with price elasticity. To developed an iterative loss decrease method by means of DLMP to compensate DGs for their contribution in energy loss reduction. This proposed system uses DLMP as a financial signal to manage and control Distribution Power Systems (DPSs). In cooperation LRA and LFC are well incorporated with a DLMP indication for the DPS.

IV. RESIDENTIAL ENERGY SYSTEMS

Energy consumption in the residential sector

On account of global population growth and increase in economic activities (especially in China, Brazil and India), the consumptions of global energy keep growing every year. For around 80% of the ultimate energy demand in the domestic zone, space heating and cooling and domestic hot water are expected to account in Europe for 2010. However, due to regulatory requirements and guidelines for the residential sector, the residential energy demand is proposed in order to preserve after 2015 that drives significant energy effective savings. Better insulation of new buildings, retrofitting of existing ones, and the implementation of intelligent technologies are measures towards energy savings. In the Netherlands three main energy sources are entering houses and buildings, namely, electricity, natural gas, and heat.

Electricity consumption

Electricity is one of the most efficient and convenient energy carriers. Hence increase in the electricity consumption is not a negative scenario if it contributes to the reduction in the total energy consumption. The EU report on Energy Trends to 2030 describes a growing electrical energy use resulting from the rising demand for increased comfort in households, and a decreased dependency on natural gas for heating and cooking purposes. The expected rates of increase for the future are 1.2% and 0.7% per annum in the periods 2010 - 2020 and 2020 - 2030 respectively, excluding the possible scenarios of increased penetration of special loads, such as electrical vehicles and heat pumps. In the Netherlands, the residential sector takes a sizeable portion of the total electric power consumption. Mainly due to increasing use of household appliances such as freezers, dishwashers and cloth dryers. Households accounted for 24% of the national electricity consumption in 2010 with an average of 3500 kWh per household. Cold appliances, laundry appliances, consumer electronics, and lighting are the top electricity consuming devices in the residential sector on a yearly basis. With the emerging of low-energy residential lighting technologies, such as light-emitting-diode (LED) and compact fluorescent (CFL) lamps, electricity consumption due to residential lighting can be reduced by 60% compared to their conventional counterparts.

Distributed generation

Distributed generation (DG) technologies are electricity production units that are not centrally planned, or dispatched, often located close to the load centre, and connected to the distribution electricity network. They are primarily not involved in system balancing, systems reserves or auxiliary services. The maximum rating that can be connected to a distribution system depends on the capacity of the distribution system, which is correlated to the voltage level within the distribution system. DGs offer the possibility of introducing renewable energy resources, like wind, solar and biomass into the electrical power system. This provides significant environmental benefits, such as local use of generated energy, reduction in CO2 emissions, and furthermore, fuel diversification, energy autonomy, and eventually improvement on power quality and reliability of the local electricity network. However, integration of (non-dispatchable) DG technologies into power systems is technically challenging due to their less controllability. The penetration of large amount of DGs without strict requirements is a concern for network operators as they have to balance out generation and demand, and to provide for secure network operation. This section summarizes the development and operation of three most common DG systems in the residential sector: photovoltaic systems, micro combined heat and power units, and micro wind turbines.

Photovoltaic system

Photovoltaic system installations has grown (and continues to grow) at a remarkable rate over the past decade. The growth is attributed to reduced capital cost of the PV system, improved generation efficiency of PV modules, increased utility electricity costs, and incentives offered by national governments - enhanced feed-in tariff, capital subsidies, and income tax credits. From figure.3, it can be noticed that the technology grew globally from 24 GW installed capacity in the world at the end of 2009 to 138.9 GW by end of 2013 with Europe as the world's leading region in terms of cumulative installed capacity. In the Netherlands, the total installed capacity PV systems by 2010 was 88 MW. However, in year 2012 alone, a total capacity of 220 MW of PV systems was installed, resulting in an increase of 152% in capacity compared to the level of the previous year. By the end of 2013, the total cumulative installed PV power for the Netherlands has reached 722 MW (Figure.3).

Figure.4 gives a representation of a single-phase two-stage PV system converter for a household. In general, PV systems are operated to maximize the production (tracking the maximum power point) to serve part of or the entire domestic load. However, high PV penetration creates reverse power flows (flow from LV into MV distribution network and possibly even into the HV network), voltage fluctuations, and frequency deviations. Therefore, the integration of PV systems into the electricity

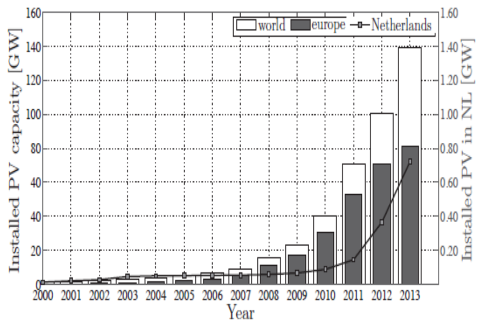

Figure 3: Cumulative installed PV capacity for the Netherlands, Europe and the world

Grid will require flexible operation of the inverter control circuitry to meet the expectations of owners and to support the grid. Multi-purpose control strategies which combines maximum power point tracking, specified real power injection, voltage/var control, frequency support and off-grid operations, will make PV system to have more adaptability. The switch between different operation modes must be automatic and seamless to provide means to deliver control commands to coordinate multiple PV.

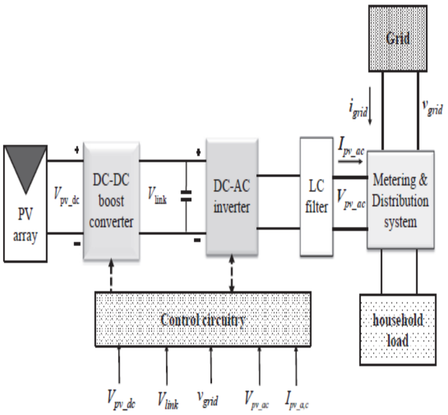

Figure 4: Schematic diagram of a single-phase two-stage PV system converter.

V. RESULTS

Fig.5 shows the simple single smart home, which includes solar panel, home equipment, Home BESS, a SHEMS and utility grid. The home battery management system is communicating with SHEMS, home appliances, battery management system (BMS), solar panels and the PEV BMS. The home battery system is designed in such a way to allow a bidirectional power flow meanwhile PEV battery is allowing bidirectional and unidirectional power flow.

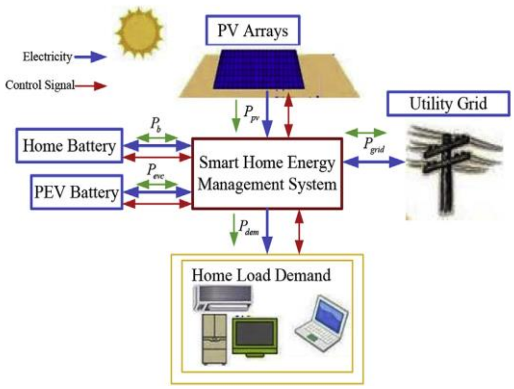

Figure.5. Structure of smart home Nano grid with a PEV and PV arrays

System parameters

This section analyses the properties of the proposed CP approach. The key parameters of the smart home are listed in Table 1. All the simulations were run on a PC with a 2.50 GHz Intel Core i5-2450 M CPU and 4 GB of internal memory. Thanks to the mentioned advantages of the proposed method, the CP computational time is less than 30 s using CVX tool in the Matlab environment when optimizing component size and control strategy simultaneously. And the CP computational time is less than 1 s when only optimizing the HEM control strategy with a 24 h look ahead horizon. The hourly home load data and PV power supply data on each day and average from a single family home in California, US are shown in Fig. 6-(a) and (b). The collected data corresponds to date range from 2014-01-01 to 2014-12-31. The hourly home load demand varies from 0.25 kW to 4.58 kW. The peak loads always happen from 7:00e15:00 and 18:00e1:00. The hourly PV power supply varies from 0 to 2.81 kW. It is easily observed that the PV power supply is centralized from 9:00 to 15:00 and sometimes more than the instantaneous home load demand. Referring to Pacific Gas and Electric Company's (PG&E) special EV rate plans for residential customers, they are non-tiered, time-of-use plans as shown in Fig. 6-(c) [41]. The electric price is lowest (10 cents/kWh) from 23:00 to 7:00 when the demand is lowest. Electricity is more expensive during Peak (43 cents/kWh, 14:00e21:00) and Partial- Peak (22 cents/kWh, 7:00e14:00 and 21:00 to 23:00) periods. Fig. 6-(d) plots the state of the PEV. The PEV plugs-out from 7:00 to 20:00 (not at home) and plugs-in from 20:00 to 7:00 (at home). It is obvious that the house sells electric energy to the grid with Partial- Peak electric price and buys it with peak electric price. If there is a home BESS, users can not only store the redundant PV power, but also buy electric energy with low price for the use of high price time. The home BESS can not only reduce household electric energy costs, but also supply back-up electric energy to the house during

Table 1
Key parameters.

Parameter Description	Symbol	Value	Unit
Step time	Δt	1	hour
Maximum PEV battery SOC	SOC_{ev}^{max}	0.90	–
Minimum PEV battery SOC	SOC_{ev}^{min}	0.20	–
Maximum home battery SOC	SOC_{b}^{max}	0.90	–
Minimum home battery SOC	SOC_{b}^{min}	0.20	–
PEV plugging-out time	t_d	7:00 a.m.	–
PEV plugging-in time	t_a	8:00 p.m.	–
Lost efficiency	η_{evc}/η_b	0.10	
Maximum power from grid	P_{grid}^{max}	10	kW

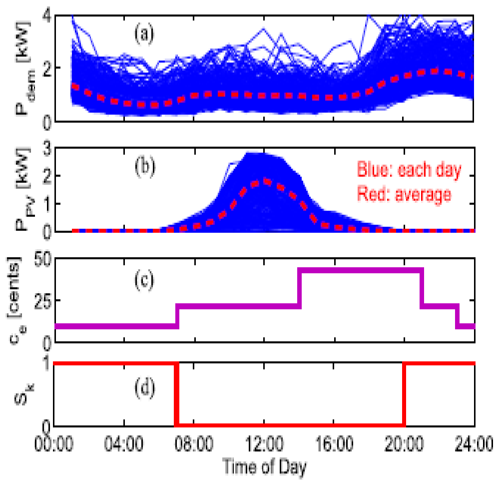

Figure.6. Real-world data of home power demand, PV generation, electric price, and state of vehicle.

Based on the historical home load demands and PV power generation data, as well as the hourly time – varying electric price and state of PEV, the optical parameters of home BESS and energy management strategy can be procured via CP. In light of the report of Avicenne Energy, the worldwide battery price might vary from 60 ₹/kWh to 203 ₹/kWh in 2020. Considering different time horizons of optimization, home BESS prices, different control modes of PEV, the parameters of home BESS can be explored, as well as the total cost. First, we consider that the owner has a Nissan Leaf with 24 kWh battery that cannot discharge power to the home. Independently of the time horizon of optimization (1e10), battery price (60 ₹/kWh to 203 ₹/kWh), and charger price (1000 ₹/kW), the maximum power Pmax b maintains constant, equals to 2.26 kW. The reason for this result may be due to the constraint, not permitting power supply to the grid. The optimal values of battery energy capacity Qb;eap are shown in Fig. 7-(a). The battery energy capacity is augmented as the optimization time horizon increases. The total electric costs with/without home BESS

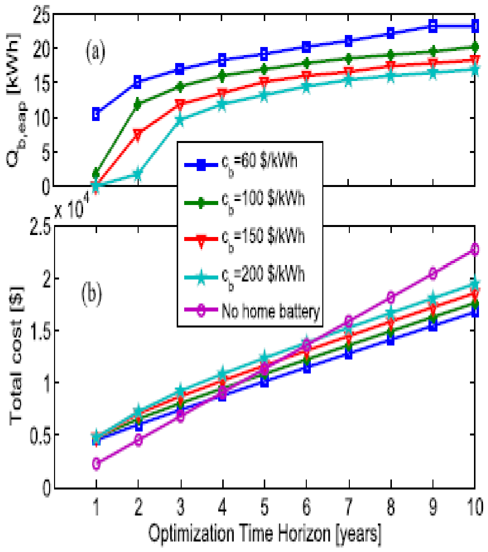

Figure.7. Battery energy capacity and total electric cost, given different time horizons and battery prices.

For different time horizons of optimization are also shown in Fig. 7- (b). Given the battery price and charger price of 100 ₹/kWh and 1000 ₹/kW, as well as different time horizons, the optimal values of home battery energy capacity Qb;eap, and electric cost are shown in Table 2, where Fe, F, F no B, and F diff are the electric cost for one year with home BESS, the total cost with BESS in n years, the electric cost without BESS, and the cost difference between the cases with and without BESS in n years, respectively. The home battery energy capacity increases as the time horizon becomes larger. The total cost F of the house with home BESS is larger than that in the case of the house without home BESS, when the time horizon is less than 5 years. However, when the time horizon is 5 years, the house with home BESS, for instance, can save 487 ₹. The cost savings become more significant with increased time horizons. If we assume a home battery life to be 5 years, the optimal value of home battery energy capacity that we consider is 17 kWh, and the cost of home BESS is 3960 ₹. With home BESS, the electric energy cost in one year is 1382 ₹, whereas without the BESS, the counterpart is 2271.3 ₹. The associated reduction reaches up to around 39.2%.

VI. CONCLUSION

In the housing sector, the consumption of Energy is going on increasing. However in Europe, due to the energy efficiency measures implementation, the consumption of residential energy is expected to stabilize. A significant growth in consumption of residential electricity and a fall in consumption of gas and heat are caused by the mobility electrification in addition to heating systems, the use of more domestic electrical appliances as well as the demand for more luxury by residential customers. For the implementing efficient guidelines and energy efficiency methods, this chapter presents the basic factors of the consumption of residential energy that are essential. The relationship between gas and electricity consumptions and the physical characteristics of residential buildings (the type and the vintage), and the household demographic composition were investigated. Housing units built after year 2000 use about 60 - 70% less gas compared with similar buildings constructed before 1905. The variation among housing types and the year of construction are less pronounced with regards to electricity consumption. Families with children living in detached houses have the highest annual electricity consumption. The elderly households have the highest annual gas demand because they live in relatively old houses and need for more thermal comfort. Additionally, residential loads are changing in capacity and complexity. Shiftable loads (washing machines, dishwashers and tumble dryers) represent a huge cost saving potential because of the ability to shift their operation cycle to favourable time periods. New technologies such as heat pumps, electric vehicles, PV systems and μCHPs will contribute significantly to the total residential energy consumption. The penetration of these technologies depends on societal acceptance and national or regional government policies. Residential energy storage systems may not be economically beneficial for individual customers at the moment however, aggregation and of storage units and implementation of control and coordination techniques will provide collective benefits to the customers, energy suppliers and the network operators.

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