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**Autonomous Integration of Distributed Energy Sources and Home Appliances Coordination Scheme in Future Smart Grid Networks**

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**Abstract**

Currently world is trying to sweep over new challenges in energy market, such as climate change, demand response, energy conservation, etc. These issues cannot be overcome with the conventional power system. It needs to promote the existing power system to improve the efficiency, sustainability at lower cost. The next era of power system, known as Smart Grid(SG) is a combination of Information, Technology and Computer (ITC) with the conventional power system. New ideas and emerging technologies are already being used such as IED (Intelligent Electronics Device), SCADA (Supervisory Control and Data Acquisition) and AML(Automatic Metering Infrastructure). But these methods fail to integrate renewable energy sources with grid. In this work Autonomous Integration of Distributed Energy Sources (AIDES) method along with new Home Appliance Coordination Scheme (HACS) for scheduling of domestic appliance is proposed. This method minimizes the load on live grid and increase the participation of renewable energy sources in our daily energy consumption. Appropriate use of this scheme provides the solutions for energy management issues in smart grids as confirmed by simulation results.

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**Keywords:** Smart Grid(SG), Power supply, Renewable resources, Distributed energy Sources(DES), carbon foot print, integration.

1. Introduction

Our current electric grid was conceived more than 100 years ago when electricity need were humble, power generation was limited to a small area and built around communities because they have small energy demands. Generally the grids were design for utilities to deliver electricity to consumer’s home and bill them once a month. This limited one-way interaction makes it difficult for grid to response for ever changing and rise in demand of
21st century. The SG provides a two way dialogue where electricity and information can be exchange between the utility and its customer. It’s developing network of communication, control, computer, automation, new technologies and tools working together to make the grid more efficient, reliable, secure and greener. The SG enable renewable energy resources to be integrate such as wind, solar, geo-thermal etc. The SG will replace the aging infrastructure of today’s grid and utilities can have better communication with us, which help to manage and monitor our electricity needs. The smart home communicate with grid and enable consumers to manage their electricity usage by measuring home’s electricity consumption more frequently by a smart meter. The utilities can provide their customer with much better information to manage their electricity bill.

We use energy, lots of energy but there is going to be big changes in the way we use energy. The world is running out of oil, coal and natural gas. Therefore, we need to find alternative and eco-friendly energy source. In future we will live in intelligent houses which control our energy consumption easily, conveniently and intelligently without us really knowing. The consumer could simply use an ordinary mobile phone to automatically start and stop the appliances depending on the per unit price of electricity. Human behaviour is contagious, actions are often guided by how people around us and behaving. It has been understood that adjustment to the way we utilize energy as a part of demand side couldn’t just save money but also reduce the load proposed by M. Jun Hong B.Eng (2009)[1].

Fuchs, et al., (2014) [2] describes the difficulties in the field of integration of distributed energy resources and also stress the need of emerging technologies, power electronics and business studies for the implementation of smart grid technology in integration of Distributed Energy Resources (DER). Hoffmann et al. [3] provides an important features on which the integration of DER depends. The properties of electrical grid, voltage, frequency, phase and grid impedance changes with time. There are several two way communication technologies available to manage, monitor and control the grid integration. The communication system used in a real renewable energy project such as Bear Mountain wind farm in British Columbia, Canada and Photovoltaic power systems. It also show the challenges and limitation for the integration of Renewable Energy Sources (RES) and also show the possible solutions respectively [4]. World’s population and energy demand increases exponentially. Anees. A.S, [5] demonstrate us a broad outline about the RES in India. As on march, 2012 the power generated by renewable sources was 24914MW i.e. approximately 12.1% of total power generation. Furthermore the Government of India is planning to achieve 20000MW power from solar and 38500MW from wind by 2022.

The Power Grid Corporation of India limited initiate a project on large scale development of desert power and it’s grid integration by the name of Desert power India-2050 [6].The new strategy of appliances control using a Home Energy Management(HEM) system is demonstrated. The appliances communicate with each other through Energy Management Unit(EMU) to operate appliances at reduced mode of power consumption with minimum inconvenience[7]. Cyber security and consumer’s data privacy is most vital requirement of a system. Customers information should be guarded from theft, data loss and hacking. EMU is a basic entity for data collection and energy management at both power generation side and at demand side. Ye Yan et al.,(2011) [8] provide a secure network for data aggregation and dispatch to keep confidentiality for power usage information of smart home device to the smart meter and for the reverse control message distribution procedure. A.Mahamood et. al (2014),[9] demonstrates a home energy management scheme based upon coordination and communication among appliances through a Wireless Sensor Home Area Network(WSHAN). It uses ZigBee protocol for communicate through messages among appliances, smart meter and central controlling unit.

This paper is composed of as follows: Section-2 elaborates the brief introduction of smart grid and Section-3 explains the power system model,Section-4 contains proposed work and algorithm. Finally, simulation results and conclusion of this paper is presented in Section-5.

2. Smart Grid

Electrical grid mainly consists of four major parts: electricity generation, transmission, distribution and utilization. Smart Grid generally refers to a class of technology people are using to bring utility electricity delivery system into the 21st century using computer based remote control and automation. To move forward we need a new kind of electric grid that can automate and manage the increasing complexity and needs of electricity in 21st century. These systems are made possible by two way communication technology and computer processing. For a century, utility companies have had to send workers out to gather much of the data needed to provide electricity. The workers
read meters, search for broken equipment and take readings. Much in the way that a Smart phone these days means a phone with a computer in it, SG means computerizing and automates the electric utility grid. It includes adding bidirectional digital communication technology to devices associated with the grid. Each device or the network can be embedded with sensors to gather data, two way digital communication between the device in the field and the network operation center. The pivotal aspect of the SG is automation technology that lets the utility adjust and control each individual device or millions of devices from a central location. Benefits include augment cyber security, handling renewable sources of electricity like wind and solar power and even integrating electric vehicles onto the grid.

2.1. What makes a Grid “Smart”?:

In simple way, the advance technology that makes two way communications possible between utility and consumers, and the sensors along the transmission lines and at home is what makes the SG. Some people compare this SG technology with the internet revolution of 90’s. Smart grid consists of computer, control, automation and new technologies and equipment working together with the electrical grid to respond digitally to our quickly changing energy demand. Real time monitoring and control will become possible in future SG by integration of advances Information and communication Technologies (ITCs). New advancement are being created by scientists for real time understanding of grid and make it smart including: Advance Metering Infrastructure (AMI), Home Area Network (HAN), Energy Management Unit (EMU), and Distribution Automation(DA) etc. Home appliances equipped with sensors along with AMI makes the real time energy monitoring possible which help in reducing carbon footprint, and smoothen the load curve of grid [9].

2.2. What does Smart Grid do?:

The Smart grid gives us new opportunity to reincarnate our existing power system and move to 21st century of reliability, availability, and efficiency that will contribute to our economic and environmental health. The benefits associated with the Smart grid includes:

- More efficient use of electricity.
- Self-healing and self-learning from power breakdown events.
- Enabling active participation by consumer in demand response.
- Accommodate all options of generation and storage capacity.
- Quicker recovery of electricity after power disturbances.
- Enable new products and services and markets.
- Optimize and operate efficiently.
- Reduced operations and management cost for utilities and ultimately low power costs for consumers.
- Reduced peak demand to lower electricity bill.
- Increased participation of large scale renewable energy in power systems.
- Better integration of consumer owner power generation system, including renewable energy system, improve security.

Today, an electricity disruption such as breakdown can be results into series of failures. A SG will add resiliency to our electric power system and make it prepared to address exigencies. Because of its two way bilateral capacity, the SG will allow for automatic rerouting when equipment fails or outages occur. SG technologies will spot and isolate the outages, resolve them before they became large scale blackouts. The new technologies will also help ensure that electricity recovery resumes quickly and strategically after emergency routing electricity to emergency services first. In addition, the SG will take greater advantages of consumer-owned power generators to produce power when it is not available from utilities.
2.3. Giving Consumers control:

The smart grid is not just the utilities and technologies; it is about giving consumer the information and tools needs to make choice about energy use. A smart grid will enable an unprecedented level of consumer participation. For example: A user will no longer have to wait for his monthly statement to know how much electricity he has used because he would have a clear and timely picture of energy consumption by using a smart meter. Smart meter is a device to collect measurement of heterogeneous type, analyze data and report reading in real time. Smart meter is usually an electronic device which allows us to know how much electricity we consume at which time and also tells us about the real time pricing of electricity. Combined with real time pricing, this will allow the consumer to save money by using less power when electricity is most expensive. While the potential asset of smart grid are usually deliberate in terms of finance, national security and renewable energy sources. The smart grid has the unique feature to help the consumers to save money by helping them to manage their electricity use and choose the best time to purchase electricity and by generating their own power.

2.4. The Smart Home (Smart Appliances and Home Automation):

Now a days emerging SG technologies are available to save energy, search out the minimal rates and contributes to the smooth and efficient functioning of our electric grid. A key element that allows all of the emerging smart grid technologies to function together is the interactive relationship between the grid operators, utilities and the consumer. Computerized controls in home and appliances can be set up to respond to signals from the energy provider to minimize their energy use at times when the power grid is under stress from high demand or even to shift some of their power use to times when power is available at a lower cost.

2.5. Smart meter and Home management system:

Smart meter provide the smart grid interface between consumer and energy provider. Instead of the conventional energy meter, these meters operates digitally, and allow for automated and complex transfer of information between consumer and energy provider. Smart meter deliver signals from energy provider that can help the consumer to cut energy costs. This energy information coming to and from a home through a smart meter can be run through a HEM system which will allow the consumer to view it in an easy to understand format on his computer or hand held device. A HEM system allows the consumer to track the energy use in detail to better save energy [9]. A consumer can save the energy impact of various appliances and electronic product simply by monitoring the Home Energy Management System (HEMS) while turn the device ON and OFF. An HEMS also allows user to monitor real time information and price signals from utility and create setting to automatically use power when prices are lowest. Consumer can also choose settings that allow specific appliance and equipment to turn off automatically when a large demand threaten to cause an outages avoiding peak demand rates, helping to balance the energy load in his area and preventing blackouts. The utility may provide financial incentives for doing so.

3. Power System Model

In the power system model of this paper we consider a single user. A consumer obtains electricity from different power supplies, mainly live grid, solar and local energy storage capacity (e.g.UPS). In this power system model a consumer can turn on any appliance at any instant of time. Then an optimal scheduling of DES and home appliances is done in order to minimize peak demand and total energy cost.

Relation of energy consumption of an appliance over a period is given as:

\[ E_a = \sum_{h=1}^{H} Z_a^h \]  
(1)
Here,

\[ E_a \] - energy consumption of appliance 'a'.

\[ Z_a^h \] - energy consumption of appliance ‘a’ over 1 hour.

We consider peak hours between 6 PM to 11PM.

\[ 18 \leq T_p \leq 23, \ 1 \leq T_{op} \leq 17, \ 23 \leq T_{op} \leq 24. \]

The electricity bill gives us the record to know how much electricity we consume at what cost. It depend on at which time how much power is consumed. Therefore the cost function depends on time of use of electricity. Total energy consumption of appliance ‘a’ is the sum of energy consumption in on-peak hour and off-peak hour.

\[ E_a = E_{a,p}^t + E_{a,op}^t \]  \hspace{1cm} (2)

Similarly, energy consumption of all the appliances over a period of 24 hour is given as:

\[ E = \sum_{a=1}^{A} E_a \]  \hspace{1cm} (3)

The cost function is the product of energy consumption and per unit price of energy. Due to Time of Use(ToU) pricing scheme electricity rate is more at on-peak hour and less at off-peak hour.

\[ C_t = \left\{ \begin{array}{l}
\sum_{a=1}^{A} \sum_{t=1}^{T_p} E_{a,p}^t R_p \quad \text{.... peak} \\
\sum_{a=1}^{A} \sum_{t=1}^{T_{op}} E_{a,op}^t R_{op} \quad \text{.... off – peak}
\end{array} \right\} \]  \hspace{1cm} (4)

\[ R_p \] - per unit electricity prices in on-peak hour

\[ R_{op} \] - per unit electricity price in off-peak hour

The total cost function of 24 hour will be the sum of on-peak hour and off-peak hour. It depends on two things: the energy consumed and per unit price of electricity. To minimize the cost function these two entities can be adjust. Therefore, we need to implement the optimization technique to minimize the cost function.

\[ \text{minimize} \left[ \sum_{t=1}^{T} C_t \right] \]  \hspace{1cm} (5)

The optimization can be achieved by schedule the operation of appliances from on-peak hour to off-peak hour. It results in minimize the peak load in on-peak hour and reduce the energy consumption cost.

4. Proposed Work

In this section, we propose an autonomous and distributed energy consumption scheduling scheme to meet home energy demand. This scheme is a combination of two algorithms first is Autonomous Integration of Distributed Energy Sources(AIDES) and second is Home Appliance Coordination Scheme(HACS). The functionality of the
whole system can be understood by figure 1. In this system the HEM system is combination of two individual functional blocks. It provides real time monitoring, managing and controlling of household appliances and DES to achieve minimum electricity consumption and reduce peak load.

![Diagram](image)

Figure 1: Functioning block of proposed scheme.

This scheme is based on communication between smart appliances, smart meter and distributed energy sources through a smart energy management unit. Here the Energy Management Unit is the central processing unit which acts as a decision making centre. Conceptually integration of the distributed power sources (live grid, solar and batteries or UPS in our case) is done by prioritizing the sources on the basis of available power. Here loads are divide into two categories, shiftable and non-shiftable loads. The shiftable loads are those whose operation can be shifted form on-peak hour to off-peak hour without making any inconvenience to the user e.g. dryer, washer, washing machine etc. On the other hand non-shiftable loads are those whose operation cannot be delayed e.g. medical equipment, water purifier, lighting, refrigerator etc. Figure 2 shows communication between different entities of the proposed scheme briefly.

![Diagram](image)

Figure 2 Interaction among major entities of proposed scheme.

The aim of this scheme is to decrease the electricity bill of the consumer by increasing the use of solar power available and to minimize the peak load by schedule the shiftable loads from on-peak hours to off-peak hours. The consumer may turn on any appliance at any moment of time irrespective of the on-peak hour concern.

4.1. Message Flow of Proposed Scheme:

When turn the appliance on, a start request \( R_{st} \) packet is sent by the appliance to EMU. Upon receiving the start request \( R_{st} \) packet, EMU corresponds with the distributed energy sources individually to inquire about the available energy and check for on-peak hour by sending available request \( R_{av} \) packet. EMU communicated with the distributed energy sources individually, checks the available energy according to the proposed scheme. EMU
also communicates with the smart meter to know about the updated prices of electricity by sending a price update request \( (R_{price}) \) packet. The distributed energy sources sends an available reply \( (A_{price}) \) packet in reply, containing the information about the amount of available energy at each source and which source is better to use at that time by comparing the available energy with the energy rating of the appliance. Smart meter send an acknowledgment of updated price \( (S_{price}) \) packet. When EMU receives the start request \( (R_{st}) \) packet, it schedules the distributed energy sources and shift the appliance on the basis of proposed scheme and notifies the consumer by sending a start appliance \( (S_{app}) \) packet. The consumer at this stage may be willing to negotiate with EMU, through the notification packet. The message flow of proposed scheme is shown in figure 3.

Proposed Algorithm:

In this section, we proposed an algorithm to enable integration of distributed energy sources and scheduling of home appliances in future smart grid. We consider a single user equipped with smart meter, smart appliances and have EMU are used for optimal scheduling of distributed energy sources and home appliances. These entities are in interaction with each other through EMU to exchange information with each other and user. The prime objective of this scheme is to decrease the electricity bill of consumer by scheduling the energy source, electronic gadgets and increase the use of renewable energy in domestic use. The EMU keep the record of power rating of appliances \( (P_{app}) \), starting time of \( i^{th} \) appliance \( (S_i) \), maximum available power through UPS \( (P_{ups}) \), maximum available power through solar panel \( (P_{solar}) \), currently available power through UPS \( (P_{pups}) \), currently available power through solar panel \( (P_{psolar}) \), power rating of live grid \( (P_{grid}) \). In our simulation we have set the value of various appliances used.

Proposed work can be divide into two separate algorithm which is demonstrate as follows:

1.) Autonomous Integration of Distributed Energy Sources (AIDES).
2.) Home Appliance Coordination (HAC) Scheme.

AIDES algorithm consists of seven steps which are shown graphically in Fig.4 and are elaborated as follows:

In addition, energy sources are also being prioritized on the basis of demand response.

**Step-1:** In first step of proposed algorithm, the consumer turns on the appliance which generate and sends a start request packet to EMU. In simulation we generates these packets randomly. The appliance is not switched on immediately, in fact the request is sent to EMU.

**Step-2:** When EMU receives the request, it checks the current available power and on-peak hour condition. If on-peak hour condition not satisfied then move to step-3 immediately, otherwise EMU check all the standby appliances and switch off all because standby state of appliances are responsible for significant amount of energy wastage. The EMU communicate with the smart meter to know about the time of use (ToU) prices. The ToU price scheme informs the EMU about the corresponding energy consumption prices at that particular moment.

**Step-3:** Now EMU check appliance power rating \( (P_{app}) \) w.r.t. current available solar power \( (P_{p,solar}) \). If
If \( P_{app} < P_{p,solar} \), then immediately switch on the appliance through solar power, otherwise algorithm moves to next step.

**Step-4:** Now the EMU checks the appliance power w.r.t. live grid power. If \( P_{app} < P_{p,grid} \), then immediately switch on the appliance through live grid, otherwise the algorithm moves to next step.

**Step-5:** At the last, if all of the above power sources are not available then finally the system moves to operate on UPS or batteries. The finally available current power is termed as \( P_{thr} \).

**Step-6:** The remaining energy (i.e. \( P_{p,solar} - P_{app} \) or \( P_{grid} - P_{app} \)) should always be used for UPS charging.

**Step-7:** If all the above conditions are not satisfied then the EMU shows a message to the user that sufficient energy is not available and suggest to use the appliance later.

**Step-7:** At this point the consumer may be willing to negotiate with the EMU. The consumer may deny or accept the schedule provided by EMU. The EMU updates the local database and inform the smart meter about the consumer’s decision. If an appliance’s rating is higher than the available energy, its operation cycle is shifted to off-peak period.

Similarly HACS algorithm consists of seven steps which are shown graphically in Fig.5 and are elaborated as follows:

In this algorithm the EMU runs a distributed algorithm to minimize the peak load by schedule the shiftable loads from on-peak hours to off-peak hours.
Step-1: A user can start the appliance randomly, which generate and sends a start request packet to EMU.
Step-2: When EMU receives the request, it checks the starting time of appliance \( (S_{st}) \), EMU check for on-peak hour and calculate the ToU price.
Step-3: If \( S_{st} \) lies outside the peak hour then appliance starts immediately otherwise algorithm moves to next step.
Step-4: If \( S_{st} \) lies in on-peak hour then EMU check all the standby appliances and turn off all. Here it checks the appliance is shiftable or not. If yes then shift the appliance to off-peak hour otherwise algorithm moves to next step.
Step-5: EMU check the power rating of \( i^{th} \) appliance and maximum available power through grid or solar \( (P_{thr}) \).
Step-6: If \( P_i > P_{thr} \) then switch ON the appliance through local energy storage(UPS) capacity, otherwise switch it ON through non-storage supply(live grid, solar).
Step-7: EMU update local database and check for on-peak hour again.

Figure 5: Flowchart of HAC scheme.
5. Simulation Result

For simulation purpose, we have used a scenario of six loads: a tube light, a ceiling fan, a fridge, a TV, an AC an a washing machine with energy consumption ratings of 0.036kWh, 0.040kWh, 0.400kWh, 0.080kWh, 1.400kWh, 0.230kWh respectively. In our scheme we schedule the appliances from 12:00AM to 12:00PM. We consider on-peak hour between 6:00PM to 10:00PM. We use the time of prices scheme in our model where the utilities charges the consumer differently depending on the time of use of electricity. Per unity electricity charge is different in peak hours and off peak hours. In our scheme we consider electricity price in peak hours is Rs. 8/kWh and electricity price in off peak hours is Rs. 6/kWh. We consider peak hours between 6 PM to 11PM.

The simulation result is quite efficient in terms of reducing peak load demand, charges of electricity consumption, with consumer’s comfortable level being increased. The prime objective of this scheme is to minimize the load on live grid and increase the participation of renewable energy sources in our daily energy consumption by scheduling of appliances. This scheme also refers to the problem of minimizing electricity wastage by standby appliances. Literature[10] provide an introduction about standby appliances. Standby power of an appliance is the power consumed by the appliance when it is not functioning or when switched off. Standby appliance has been reported to be contributing to energy wastage and it consumes 10% of electricity. Furthermore our proposed scheme contributes more to comfortability level of the consumer, if the appliance cycle is shifted to off peak hours and the delay goes beyond the limit the cycle is retained and the appliance is switched on immediately.

5.1. Peak load reduction:

In Fig. 6, the energy consumption result of proposed scheme and the case when no energy management is employed in 24 hours is shown. It is clearly shown that the load is evenly distributed over the entire day. The proposed work provides us the liberty to integrate the renewable energy sources with live grid and shift the domestic appliances from on-peak hour to off-peak hour. A typical solar panel produce around 200 watt of power. Our array has 10 solar panels and each is rated by the manufacturer as outputting 200 watts. That means, the theoretical maximum power that our array can produce in a day is 200x10=2000 watts or 2kW. The simulation results show the average energy consumption of a house is 18.902kWh per day. This total consumption is made by live grid without proposed scheme. After proposed scheme this total consumption is divided between different available energy sources. The solar energy fulfils 10.58% of total energy requirement. In our scheme, EMU schedule the sources more efficiently to reduce the use of live grid and increase the use of solar energy and reduce the total load over the time period of day by 40.92% and load in on-peak hour by 22.31% as shown in figure 8.

![Fig. 6: Energy Consumption With and Without Scheduling](image-url)
5.2. Monetary cost reduction:

We also minimize the monetary cost by applying our efficient scheme. We have simulated the electricity consumption cost of a single home when no energy management is applied and compared the result with the case study of proposed work. Energy consumption cost with and without scheduling is shown in fig. 7 consequently energy cost reduces by 38.35%.

![Energy Consumption Cost With and Without Scheduling](image1)

![User's percentage load in peak hours](image2)

**Conclusion**

In this paper we proposed an autonomous and distributed energy consumption scheduling scheme in order to minimize the load on live grid and increase the participation of renewable energy resources in our daily life. This paper focuses on algorithm for HEM to reduce the cost of energy consumption and minimize the peak hour demand. Zigbee protocol can be used as HAN to collect the information about the appliances at regular intervals. This scheme evenly distribute consumer’s load over the entire day and balance the residential load among different energy sources those are connected to a single home energy bank. Simulation results confirms that the proposed scheme efficiently reduces load at live grid, peak hour demand and energy cost. In future, this scheme can be extended to optimize the use of available power sources at user’s premises to obtain better results.
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