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Comparative study of AC and DC Smart Residential Complex Advantages, Disadvantages and Applications

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Abstract

In this paper, energy management in a smart residential complex is investigated in both AC and DC modes. The contribution rate of solar and wind generators and the charging and discharging planning of the energy storage system is calculated to supply the load of the residential complex. To analyze the proposed method, a planning problem using three-price electricity tariff is used to show the efficiency of the energy storage system. Voltage converters in AC residential complex are more than DC residential complex. The greater number of converters makes the AC residential complex more complex. A large number of voltage converters and a decrease in efficiency in voltage converters cause more energy losses and higher operating costs. In the simulation part, the amount of required production power and the costs of power production in both AC and DC modes have been calculated. The results presented in this article show that with proper energy management, the DC smart residential complex will have lower operating costs than the AC smart residential complex.

Keywords: smart residential complex, operating costs, energy management, voltage converters

1. Introduction

Smart residential complex (SRC) is a technologically modern urban area, which uses advanced technologies such as the Internet of Things, smart home systems, smart security, smart energy management and other smart systems to make the lives of residents more convenient. In addition to providing welfare and entertainment services for residents, these types of complexes also make smart decisions for managing available resources and energy. These complexes are able to automatically optimize decisions such as energy consumption control, parking lot management, security monitoring and access control, waste and water management, traffic management and public transportation and other urban services [1]. Also, these complexes have smart architecture, among their features are the use of sustainable building materials, smart lighting systems, smart air and heat management, use of renewable energy, etc. [2]. In this way, SRC improves the quality of life of citizens, increases security and reduces energy and resource consumption.

The idea of smart homes has a long history and dates back to the early 20th century. However, it wasn't until the late 1990s and early 2000s that the first truly smart housing complexes were built. The first true home automation system was invented in 1966, named ECHO IV, by Westinghouse engineer Jim Sutherland [3]. The system could control temperature and appliances, as well as allow entry and retrieval of shopping lists, recipes and other family notes. The X10 system was introduced in 1975 and was used to control appliances and lighting through power lines. X10 paved the way for the development of other home automation systems [4]. In the 1980s, home networks were developed. In this decade, new technologies such as LonWorks and BACnet made it possible to connect different devices in a house or building [5]. In the late 1990s, the term "smart home" became popular, and various companies began offering home automation systems to consumers. The advent of the Internet of Things in the late 2000s revolutionized home automation. With IoT, devices could be connected over the Internet and controlled by mobile or web applications. In this decade, with the advancement of technology, the price of home automation systems decreased and these systems became available to a wider range of consumers [6]. In the 2010s, artificial intelligence was increasingly used in home automation systems. This allowed systems to learn resident habits and automatically adjust settings to optimize comfort and efficiency.

In the 2020s, Augmented Reality (AR) [7] and Mixed Reality [8] (MR) technologies are emerging and have the potential to change the way residents interact with their smart homes. Today, smart residential complexes are built around the world using new technologies to provide a higher standard of living, more security and efficiency, and reduce energy consumption. As technology continues to evolve, we can expect smart housing complexes to have more features and capabilities in the future.

Currently, there are smart residential complexes in different parts of the world that use new technologies to improve the living standards of residents, increase security and efficiency, as well as reduce energy consumption. Some examples of the most prominent smart residential complexes in the world include CIBSE Case Study This building was built in London, England and is the first building in the world with a BREEAM Outstanding energy certificate. Smart systems are used to manage the consumption of water, light and heating of the building. The luxury residential tower The Parker Condominiums in Chicago, USA has apartments with integrated smart systems that allow residents to control lighting, temperature, music and more using voice commands or a mobile app. Parker Condominiums Chicago, Illinois, United States, this high-rise residential tower uses solar panels, rainwater harvesting systems and vertical gardens to reduce its carbon footprint. It also has a mobile app for residents that can be used to book facilities, request services and communicate with management. Sky Habitat in Bishan, Singapore This high-rise residential complex with more than 500 apartments has the largest vertical garden in the world. It also uses smart systems to manage energy consumption, rainwater collection and wastewater treatment.

In Iran, we also see the growth of smart residential complexes, Lexon Tower in Chitgar area of Tehran, Mahsan Villa 5 in Tehran, including fire alarm and extinguishing system, energy control system (EMS), green space irrigation and smart parking, Bianco Villa Town in Mazandaran, it is located and equipped with equipment such as smart lighting, smart parking, smart music system. Chenaran Tower of Tehran Residence Park is known as one of the most luxurious and expensive buildings in Iran. This smart building is built on 13 floors and hosts 26 residential units. Smart security system, smart parking, smart kitchen appliances, smart lighting system, smart door and smart cooling and heating system are among the features of this smart building. It should be noted that smart home technology is constantly evolving and it can be expected that smart residential complexes will have more features and capabilities in the future.

In this article, energy management in an SRC in two AC and DC modes is investigated. The number of converters in both AC and DC networks is checked. The modeling of AC and DC residential complex connected to the distribution network has been done. Simulation required for the amount of production power of energy generators including wind turbine (WT), photovoltaic system (PV) and distribution network (Grid) and energy exchange and storage in energy storage devices (ESS) including batteries and electric vehicles (EV) and operating costs have been carried out. The results presented in this article show that SRC DC will have lower operating costs than SRC AC.

2. The Importance of Developing Smart Residential Complexes

Smart residential complexes are designed as a new generation of apartments and houses, using new technologies to increase the efficiency, comfort and security of residents. These complexes offer numerous benefits to residents, owners and the environment. Smart residential complexes can help residents save time and energy by automating tasks such as lighting, air conditioning, home appliances, and security systems. These complexes can provide a comfortable and pleasant environment by automatically adjusting the temperature, light and humidity according to the residents' preferences. Smart security systems can increase the security of the complex by monitoring the premises, detecting intrusions and warning residents. Residents can access various services such as booking amenities, paying rent and requesting repair services through mobile applications. Some smart housing complexes use internal communication platforms to facilitate interaction between residents. Automation of tasks and intelligent energy management systems can help reduce complex operating costs. Smart residential complexes increase property value due to the many benefits they provide. There are several reasons that the use of smart residential complexes has a great impact on preserving the environment and keeping it healthy. Smart energy management systems can help reduce electricity, water and gas consumption, thereby using less non-renewable energy sources. Also, smart recycling systems and the use of energy-efficient household appliances can help reduce waste. In smart residential complexes, wind generators, solar panels and other renewable energy sources are used to supply electricity. All in all, the development of smart residential complexes can bring significant benefits to residents, owners and the environment. As technology advances and the demand for smart living increases, these types of complexes are expected to become more popular in the coming years.

3. AC and DC Smart Residential Complexes

While the term "Smart residential complex" generally refers to apartments and houses that use modern technologies to increase the efficiency, comfort and security of residents, these types of complexes can be divided into two general categories, AC and DC.

In AC smart residential complexes, alternating current (AC) is used as the main power source. Connecting the electrical network of the residential complex to the national electricity distribution network is done easily and at a low cost. AC power infrastructure is also widely available and compatible with existing home appliances and electrical equipment. Motorized devices such as refrigerators, washing machines, elevators need AC voltage to work. But some electronic devices need DC voltage. But converting AC power to DC for the use of some electronic devices can lead to energy losses. The lighting system equipped with LED requires DC voltage. Also, the production of electricity by renewable solar, wind and energy storage generators is in the form of DC voltage, and converting them to AC voltage and injecting it into the power grid of the residential complex, in addition to being expensive, has significant energy losses.In DC smart residential complexes, direct current (DC) is used as the main power source. DC power can be directly used by many modern electronic devices, LED lighting systems, which can lead to increased efficiency and reduced energy loss. DC power systems can be simpler than AC systems, especially when they include energy storage components such as batteries. DC systems can be easily integrated with renewable energy sources such as solar panels and wind turbines, and there is no need for energy conversion. It should be noted that although the power output of wind turbines is in alternating form, but to connect to the grid, the generated power of wind turbines is converted to DC form in the first stage due to their asynchronous voltage and then connected to AC grids with DC to AC converters convert to synchronous AC form. Therefore, in general, the output of wind generators can be considered DC. Electric vehicles use DC motors to move. Electric vehicle batteries, like energy storage batteries, are DC and there is no need to convert energy to connect to the DC network. Therefore, sometimes, if needed, the battery of electric cars with the lowest energy loss can be used to power the network.

Currently, AC system components are widely available and inexpensive, and relatively simple to install and maintain. Therefore, most smart residential complexes use AC power systems. However, with the increasing popularity of renewable energy sources and the advancement of DC technologies, DC smart housing complexes are expected to become more popular in the coming years.

4. Line Losses in AC and DC Network

The general relationship for calculating line losses is:

$$P_{loss} = R.I^2 + X.I^2 \qquad (1)$$

P_{loss}: Power loss (watts), I current (amperes), R resistance (ohms), X reactance (ohms).

Line losses in DC systems are generally lower than in AC systems. The main reasons for this are:

- **Ohmic losses**

The ohmic loss caused by the resistance of the wires is proportional to the square of the current. In AC systems, the current alternates in different directions, resulting in higher ohmic losses. On the other hand, the current in DC systems is constant, which means less ohmic losses.

In AC systems, RMS (root mean square) current is used to calculate ohmic losses because the current alternates in different directions. In addition, the skin effect of the conductor (energy distribution lines) is greater in alternating current. Therefore, the tendency of alternating current to move on the outer edges of the conductor. This increases the electrical resistance of the conductor and consequently increases the ohmic losses. But in DC systems, the current is uniformly distributed over the entire surface of the conductor, so there is no skin effect.

- **Inductive losses**

Considering that, induction losses are caused by variable magnetic fields. Therefore, these losses in AC systems are significant due to the continuous change of current direction. But in DC systems, the magnetic field is constant and there is no induction loss.

- **Capacitive losses**

Capacitive losses are caused by alternating current in capacitors. These losses are significant in AC systems due to the constant charging and discharging of capacitors. In DC systems, although there is capacitance in the lines, but the charging and discharging of the capacitors is negligible due to the change, so there is no appreciable capacitive loss.

Considering that in DC systems, the value of X=0. Therefore, line losses in DC systems are:

$$P_{loss} = R.I^2 \qquad (2)$$

Due to the mentioned reasons, line losses in DC systems are generally lower than AC systems due to the absence of induction losses, capacitive losses and skin effect.

5. Output and Input Power of Generators and Consumers in Residential Complex

5.1. AC residential complex

Electric Vehicles: The input and output voltage of the micro-electric is DC in both consumption and power injection modes. Therefore, an AC to DC converter is needed during consumption and a DC to AC converter is needed when injecting power to the complex.

PV and WT: The output voltage of PV and WT is DC. It should be mentioned that the WT production power is normally used, although it is AC, but because it is asynchronous, it is stored in batteries and for AC networks, it is again converted into synchronous AC form by converters. Therefore, it can be said that the output of wind turbines is DC after initial conversion and storage in batteries.

Energy storage: They are similar to electric vehicles. Therefore, an AC to DC converter is needed during consumption and a DC to AC converter is needed when injecting power to the complex.

Distribution network: The output voltage of Grid is AC. And they can be directly connected to the residential complex.

5.2. DC residential complex

Electric Vehicles: The input and output voltage of the micro-electric is DC in both consumption and power injection modes. The micro-electric can be directly connected to the DC residential complex. Therefore, no converter is needed when consuming and injecting power to the complex.

PV and WT: The output voltage of PV and WT (explained in part A) is DC. Therefore, no converter is needed when injecting power into the DC residential complex.

Energy storage: can be directly connected to the DC housing complex.

Distribution network: The voltage of the Grid is AC. AC to DC converters should be used to inject power into the DC residential complex.

Figures 1 and 2 show AC and DC smart residential complexes and their converters.

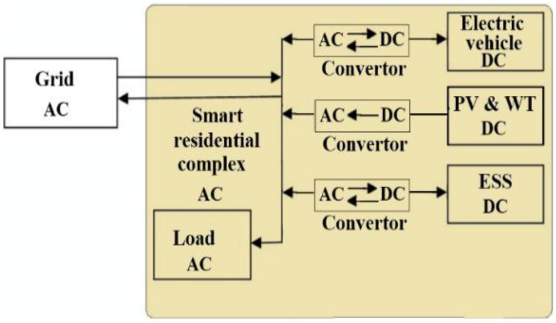

Fig. 1. AC smart residential complex and its converters

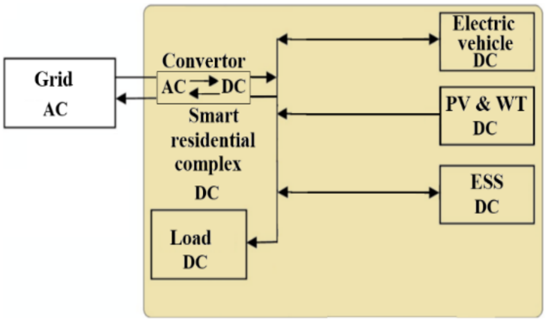

Fig. 2. DC smart residential complex and its converters

The objective function investigated in the article is the operation cost function of the residential complex. In terms of energy utilization, the main difference between AC residential complex and DC residential complex is in the number of converters and their efficiency. As can be seen in Figures 1 and 2, in the DC residential complex system, the converter is used only at the point of connection of the complex to the distribution network.

6. Simulation Results

In this paper, a 128-unit residential complex is investigated as a SRC connected to the distribution network.

The residential complex has 4 battery banks with dc to ac and ac to dc converters, a PV system on part of the roof and the yard area of the complex, a WT in the complex area, a 20 kV to 380 V transformer at the entrance of the complex (connected to the distribution network and network integrated electricity), electric vehicle sockets for every consumer connected to smart meters.

It should be noted that the power stored in electric vehicle batteries is similar to the integrated battery bank. Therefore, in the presented tables, which are the results of simulations, the total power stored in the batteries of electric vehicles with the battery bank is shown as battery power.

In this article, the triple electricity tariff of the state of Toronto, Canada is used [9]. Table 1 shows the electricity tariff used in this article.

Table 1. The triple electricity price tariff used in this article

-	Low Load	Mid load	Full Load
Price per tariff (₵)	7.7	11.4	14
Tariff hours	1 to 7 & 20 to 24	8 to 11 & 18 to 19	12 to 17

In the performed simulations, there is an energy exchange between the network and SRC. Power can be transferred both from the distribution network to the SRC and from the SRC to the distribution network. Therefore, the excess power of the network can be injected into the network.

This analysis has been done for a program during the day and night. In the studied residential complex, energy sources are divided into three categories. Non-renewable energy sources (diesel generators, distribution network generators), renewable energy sources (wind, solar) and energy storage devices (battery bank and electric vehicles of the residents of the complex), including electricity from the distribution network, a WT, a set of PV systems, there are 4 battery banks and electric vehicles. The WT installed in the system is 500 kW. The standard deviation of the predicted errors of wind speed and load demand are 5% and 18%, respectively [10]. Energy storage devices with an efficiency of 86% in energy storage and an efficiency of 86% in the discharge phase are considered. Therefore, the total efficiency of batteries (battery banks and electric vehicle batteries) in two stages of charging and discharging is 73.9%.

6.1. AC SRC simulation results

Table 2. Shows the economic distribution results of SRC AC load. In this table, the load and power values of all energy sources are shown in kilowatts during the day and night. The last columns of the tables show the power and energy of the battery in the studied modes. The battery bank and electric vehicles deliver power to the network during peak hours, similar to an electric energy generator, and act as a consumer during low-load hours, taking power from the network and storing it. Figure 3 is the load power curve of consumers and the production power of all SRC generator components and shows the result of the economic distribution of the load in the form of a curve. Another result of the problem of economic distribution of the peak shift load, which can be seen in Figure 3.

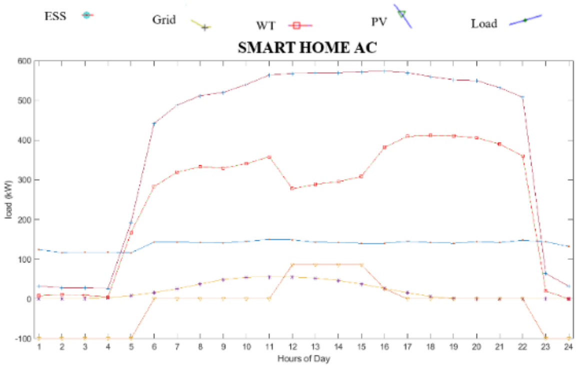

Fig. 3. Load demand curves and production power of all AC SRC generator components

Batteries and wind and solar generators play an important role in changing the peak during peak times. It should be noted that the power stored in electric vehicle batteries is similar to the integrated battery bank. Therefore, in the presented tables, which are the results of simulations, the total power stored in the batteries of electric vehicles with the battery bank is shown as battery power.

Table 2. Economic dispatch of AC residential complex

hours	Demand (KW)	Grid power (KW)	PV power (KW)	WT power (KW)	ESS power (KW)	ESS Energy (KWh)
1	32	8	0	124	-100	0
2	28	11	0	117	-100	86
3	28	9	0.5	118	-100	172
4	26	5	3	118	-100	258
5	192	167.5	8.5	116	0	430
6	442	283	16	143	0	430
7	488	332	25.5	143	0	430
8	512	332.5	37.5	142	100	430
9	520	330	49	141	100	430
10	540	340.5	54.5	145	100	430
11	564	358.5	55.5	150	100	430
12	568	277.5	55.5	149	86	430
13	570	288.5	52.5	143	86	330
14	570	295.5	46.5	142	86	330
15	572	308.5	37.5	140	86	130
16	574	381.5	26.5	140	26	30
17	570	409.5	15.5	145	0	0
18	560	412	4	142	0	0
19	552	411	1	140	0	0
20	550	406	0	144	0	0
21	532	390	0	142	0	0
22	508	360	0	148	0	0
23	64	20	0	144	-100	0
24	32	0	0	132	-100	86

The electricity cost of the AC residential complex during the day and night is shown in table 3.

The total energy cost of the residential complex is the power purchased from the distribution network.

6.2. DC SRC simulation results

Table 4 shows the economic distribution results of DC SRC load. In this table, the load and power values of all energy sources are shown in kilowatts during the day and night. Figure 4 is the load power curve of the consumers and the production power of all components of the DC SRC generator and shows the result of the economic distribution of the load in the form of a curve.

Table 3. AC residential complex electricity cost during the day ahead

hours	Demand (KW)	Total cost (₡)	hours	Demand (KW)	Total cost (₡)
1	32	69.60	13	570	4943.40
2	28	95.60	14	570	5193.00
3	28	82.65	15	572	5319.00
4	26	43.50	16	574	5553.00
5	192	1457.25	17	570	6870.60
6	442	2462.10	18	560	7371.00
7	488	2779.65	19	552	5438.40
8	512	4389.00	20	550	3532.20
9	520	4356.00	21	532	3393.00
10	540	4494.60	22	508	3132.00
11	564	4732.20	23	64	174.00
12	568	4995.00	24	32	0.00

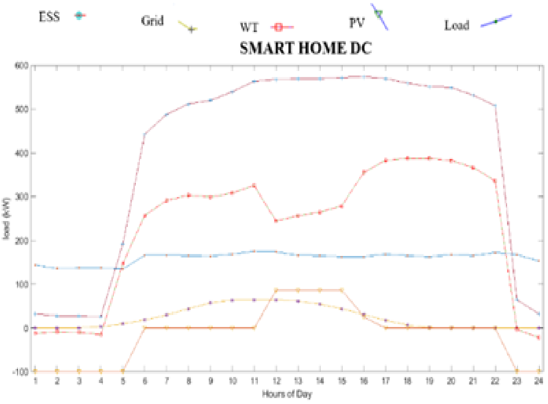

Fig. 4. Load demand curves and production power of all DC SRC generator components

Table 4. DC residential complex electricity cost during the day ahead

hours	Demand (KW)	Grid power (KW)	PV power (KW)	WT power (KW)	ESS power (KW)	ESS Energy (KWh)
1	32	-12.2	0	144	-100	0
2	28	-8.0	0	136	-100	86
3	28	-9.8	0.6	137	-100	172
4	26	-14.7	3.5	137	-100	258
5	192	147.1	9.9	135	0	430
6	442	257.1	18.6	166	0	430
7	488	292.1	29.7	166	0	430
8	512	303.3	43.6	165	100	430
9	520	299.1	57.0	164	100	430
10	540	308.0	63.4	169	100	430
11	564	325.0	64.5	174	100	430
12	568	244.2	64.5	173	86	430
13	570	256.7	61.0	166	86	330
14	570	264.8	54.1	165	86	330
15	572	279.6	43.6	163	86	130
16	574	354.6	30.8	163	26	30
17	570	383.4	18.0	169	0	0
18	560	387.9	7.0	165	0	0
19	552	388.0	1.2	163	0	0
20	550	382.6	0	167	0	0
21	532	366.9	0	165	0	0
22	508	335.9	0	172	0	0
23	64	-3.4	0	167	-100	0
24	32	0	0	153	-100	86

6.3. Comparison of the results in the two cases of AC and DC residential complex

By comparing Tables 2 and 4, it can be seen that in both operating modes of AC and DC residential complex, in limited hours which are low load hours of the network, the production power of renewable resources is sufficient to supply the required power of SRC. Also, the battery charging time is almost the same in two working modes and it is SRC during low load. The battery discharge hours in both modes are during peak hours, which is completely logical, in these hours’ part of the load is supplied by the batteries to put less pressure on non-renewable resources and buy less power from the distribution network and Operating costs are reduced.

Table 5. Economic dispatch of DC residential complex

hours	Demand (KW)	Grid power (KW)	PV power (KW)	WT power (KW)	ESS power (KW)	ESS Energy (KWh)
1	32	-12.2	0	144	-100	0
2	28	-8.0	0	136	-100	86
3	28	-9.8	0.6	137	-100	172
4	26	-14.7	3.5	137	-100	258
5	192	147.1	9.9	135	0	430
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13	570	256.7	61.0	166	86	330
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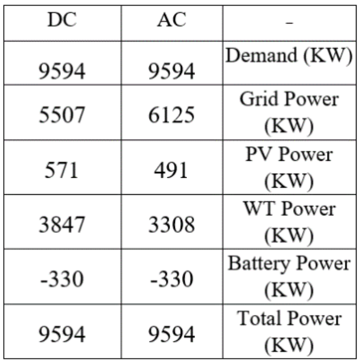
18	560	387.9	7.0	165	0	0
19	552	388.0	1.2	163	0	0
20	550	382.6	0	167	0	0
21	532	366.9	0	165	0	0
22	508	335.9	0	172	0	0
23	64	-3.4	0	167	-100	0
24	32	0	0	153	-100	86

Table 6 is the distribution of the total power supplied in 24 hours by energy sources in kilowatts, in both SRC AC and DC modes.

Table 7 shows the operating cost of SRC in both AC and DC modes.

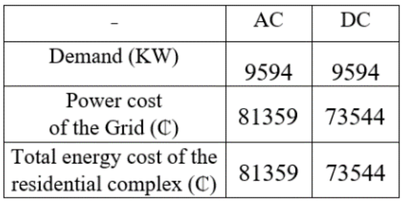
According to Table 7, the operating cost of SRC in both AC and DC modes shows that SRC has a higher operating cost of about 11% in AC mode than in DC mode. This difference in operating cost is due to the use of voltage converters in AC operating mode.

Table 6. Economic dispatch in day ahead



DC	AC	-
9594	9594	Demand (KW)
5507	6125	Grid Power (KW)
571	491	PV Power (KW)
3847	3308	WT Power (KW)
-330	-330	Battery Power (KW)
9594	9594	Total Power (KW)

Table 7. Operating cost of SRC in both AC and DC modes



-	AC	DC
Demand (KW)	9594	9594
Power cost of the Grid (ℂ)	81359	73544
Total energy cost of the residential complex (ℂ)	81359	73544

7. Conclusion

In this article, energy management in both AC and DC modes was investigated. The amount of participation from solar generators and the charging and discharging planning of the energy storage system to supply the load of the residential complex was calculated. To analyze the proposed method, a planning problem was analyzed using a three-price electricity tariff to show the efficiency of the energy storage system. The results presented in this article show that with proper energy management in a DC SRC, it has more favorable operating costs than an AC SRC. The reason for this is the large number of voltage converters in the residential complex with AC power supply network compared to the residential complex with voltage. Reduction of efficiency in voltage converters causes more energy losses and higher operating costs. In addition, converters can be expensive. Eliminating converters can significantly reduce the overall cost of the power system and reduce the complexity of the system.

References

[1] A. H. M. Mehbub Anwar, and Abu Toasin Oakil, “Smart Transportation Systems in Smart Cities: Practices, Challenges, and Opportunities for Saudi Cities,” Studies in Energy, Resource and Environmental Economics (SEREE), Springer, Pages 315–337, 01 October 2023.

[2] S. Bibri, J. Krogstie, A. Kaboli, and A. Alahi, “Smarter eco-cities and their leading-edge artificial intelligence of things solutions for environmental sustainability: A comprehensive

systematic review," Journal of Environmental Science and Eco technology, Vol. 19, May 2024.

[3] E. Tomayko, "Anecdotes: Electronic Computer for Home Operation (ECHO): The First Home Computer" IEEE Annals of the History of Computing. Vol. 16, No 3, Pages 59–61, 1994.

[4] Rye, Dave, "My Life at X10". AV and Automation Industry eMagazine. Archived from the original on 2016-10-15. Retrieved October 10, 2019.

[5] S. Makhadmeh, A. Khader, M. Al-Betar, S. Naim, A. Abasi, and Z. Alyasseri, "Optimization methods for power scheduling problems in smart home: Survey," Journal of Renewable and Sustainable Energy Reviews, Vol 115, Pages 1-15, 2019.

[6] Yinqiu Liu;Kun Wang;Kai Qian;Miao Du;Song Guo, " Tornado: Enabling Blockchain in Heterogeneous Internet of Things Through a Space-Structured Approach," IEEE Internet of Things Journal, Vol 7, No 2, Pages 1-15, 2022.

[7] S. R. Zehra, J. Mu, B. V. Syiem, A. N. Burkitt, and D. B. Grayden, " Evaluation of Optimal Stimuli for SSVEP-Based Augmented Reality Brain-Computer Interfaces," IEEE Access Journal, Vol 11, Pages 87305 – 87315, July 2023.

[8] L. Ko, C. Stevenson, W. Chang, K. Yu, K. Chi, Y. Chen, and C. Chen, "Integrated Gait Triggered Mixed Reality and Neurophysiological Monitoring as a Framework for Next Generation Ambulatory Stroke Rehabilitation," IEEE Transactions on Neural Systems and Rehabilitation Engineering, Vol 29, Pages 2435 - 2444, November 2021.

[9] http://www.ontario-hydro.com/ index. php? Page = current_rates.

[10] C. A. Hans, P. Sopasakis, J. Raisch, C. Reincke-Collon, and P. Patrinos, "Risk-Averse Model Predictive Operation Control of Islanded Microgrids" IEEE Trans. Autom. Control, vol. 28, no. 6, pp. 2136 - 2151, 08 August 2019.