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Advanced energy management system with the incorporation of novel security features

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ABSTRACT

Nowadays, energy management is a subject of great importance and complexity. Pakistan, being in a state of developing country, generates electrical power mainly by using non-renewable sources of energy. Non-renewable entities are fossil fuels such as furnace oil, natural gas, coal, and nuclear power. Pakistan has been facing a severe shortage of production in energy sector for last two decades. This shortfall is affecting the industrial development as well as economic growth. With the growing population, the load demand is rapidly increasing and there must be a need to expand the existing ones or to build new power systems. In this paper, an autonomous management system has been proposed to enhance quality, reliability and confidence of utilization of energy between end consumers and suppliers. Such objectives can only be fulfilled by making the power supply secure for end consumers. Distributed and centralized control systems are involved for maintaining a balance between renewable energy resources and base power, so that end consumers demand can be fulfilled when required. A reliable Two-way communication system between suppliers and end consumers has been proposed by using Message Digest algorithm which ensures that there would be no energy theft. Simulations have been done in MATLAB/Simulink environment and results have been presented to show the effectiveness of proposed model.

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1. INTRODUCTION

Role of electrical power is an essential part towards enhanced industrial growth and to raise living standard of general public. According to water and power development authority (WAPDA), government has to spend about billions of US dollars per year to import oil to meet requirements of an electricity supply companies in Pakistan. Energy crises need a prompt action and it should be addressed within next decades. To do this, one must switch towards renewable energy sources and to minimize usage of non-renewable sources.

A lot of research has been conducted to increase practical impact of renewable energy sources. Wind energy conversion system (WECS) is developed in optimal power flow (OPF) model [1]. Weibull distribution is utilized to determine optimal wind speed for generation and distribution of power in a stochastic way [2-4]. For storing excess energy, a battery is added which can be retrieved at night or when sunlight is obstructed. For battery protection from overcharging, a charge controller is used [5].

With introduction of renewable energy technology at consumer end, geography of power system is totally changed. Consumers have ability to produce energy for utilization. Concept of two-way flow of power is matured. Therefore, there is an immediate need to devise improvements in energy management system (EMS). A highly secured and enabled communication between end consumer and supplier is established. Encryption

and decryption of information is done for enhancing the security [6, 7]. An autonomous management system is made in the researches to enhance the quality of utilization of energy between consumers and suppliers [8-12].

Theft detection is done by measuring power on both sides; load and distribution transformer. Imposters use different techniques to steal. Therefore, different techniques for theft detection must be developed to overcome such events of energy theft. [7, 13]. Blowfish, advanced encryption standard (AES), data encryption standard (DES) and Triple Data Encryption Standard (3DES) are common symmetric algorithms. It is found from literature that Blowfish is the best in terms of encryption time, decryption time, memory usage, power consumption, latency, and jitter and security level. On the other hand, rivest shamir adleman (RSA), elliptic curve cryptography (ECC) and Ellamae are the common asymmetric algorithms. It is found from literature that ECC is best in almost all parameters except in signature verification time. Secure hashing algorithm (SHA1) and (SHA256) are also found in research but because of its increase encryption time on large input size and more power consumption, it is impractical to implement [14, 15]. In this research, message digest (MD5) algorithm is implemented for securing communication between supplier and consumer because of its less encryption time and power consumption [12, 14-18].

It is possible to maintain power production system with carbon dioxide emission reaching to zero with help of incorporation of renewable energy resources. Reduction in CO_2 emission is being considered in all other developed countries like India, Romania, Germany, UK and Denmark; Germany and Denmark. That's why it should be considered by developing countries like Pakistan as well. Wind power generation is found to be the best renewable energy source for energy generation in India so that India is focusing on wind power generation and is successful in easily elimination of effects of global warming [19, 20]. Renewable energy sources can be integrated with the conventional grids through high voltage direct current transmission (HVDC) via maximum efficiency and transferability [21-25].

In this research, renewable energy sources-based EMS is developed and further, security features are incorporated to cease cyber-attacks and energy theft. Hardware prototype is developed for EMS. Simulations are carried out in MATLAB/Simulink. Rest of paper is designed in following sections. Comprehensive details about message digest algorithm for security is covered in section 2. Section 3 contains the details about proposed methodology of this research. Section 4 covers hardware model. Results and simulations has been presented in section 5. Scope of commercialization of the proposed idea is given in section 6. Sections 7 and 8 consist of possible future directions that can be incorporated in this research and conclusion of this research work respectively.

2. SECURITY ALGORITHM FOR ENERGY MANAGEMENT SYSTEM (EMS)

2.1. Message digest algorithm

Message digest (MD), also known as Hash algorithm, generates a sole digested message for any message. Hash function is a kernel of MD algorithm which abridges a string of any length to string for a fixed length. Hash password encryption (HPE) is an approach of encryption used for MD5. MD5 algorithm has irreversible and non-counterfeit feature. Therefore, MD5 algorithm is more superior in its anti-tamper capability. This research implements a data integrity checking system based on MD5 algorithm as shown in Figure 1.

2.1.1. Steps to implement MD5 algorithm

Message-digest algorithm (MD5) flowchart is described in the following steps:

a. First check the length of number of bits of the original message.
b. To bring about the input message multiple of 512-64 (the add bits: 1 0 0 .....0), add the number of bits to input message.
c. Now, add the 64-bits that indicates the length of input message to result of the 2ndpoint, final result will be denoted by "M" (Multiple of 512-bits).
d. "M" is divided to the blocks (B), in which each of them is of 512 bits.
e. "B" is further divided into 16 blocks (X), in which each one includes 32-bits.
f. This algorithm consists of 4 rounds, each round contains 16 steps. So, by this there are total 64 steps.
g. There are four 32-bit shift registers, all shift registers have some initial values (Hex.) as given in the following:

$$\text{Register A} = [6\ 7\ 4\ 5\ 2\ 3\ 0\ 1]\ 32-\text{bits};\ [A] = [D]'$$

$$\text{Register B} = [e\ f\ c\ d\ a\ b\ 8\ 9]\ 32-\text{bits};\ [B] = [C]'$$

$$\text{Register C} = [9\ 8\ b\ a\ d\ c\ f\ e]\ 32-\text{bits};\ [C] = [B]'$$

$$\text{Register D} = [1\ 0\ 3\ 2\ 5\ 4\ 7\ 6]\ 32-\text{bits};\ [D] = [A]$$

h. The values of A, B, C and D are temporarily stored in AA, BB, CC, and DD respectively.
i. This is core of algorithm which has 4 rounds of processing. Every round involves 16 steps and every single step is using a "table" T of 64 elements [0....63], for T[i], where "i" is the index. Thus, the four rounds have the correspondent structure, but each uses mismatched functions name as F, G, H and I.

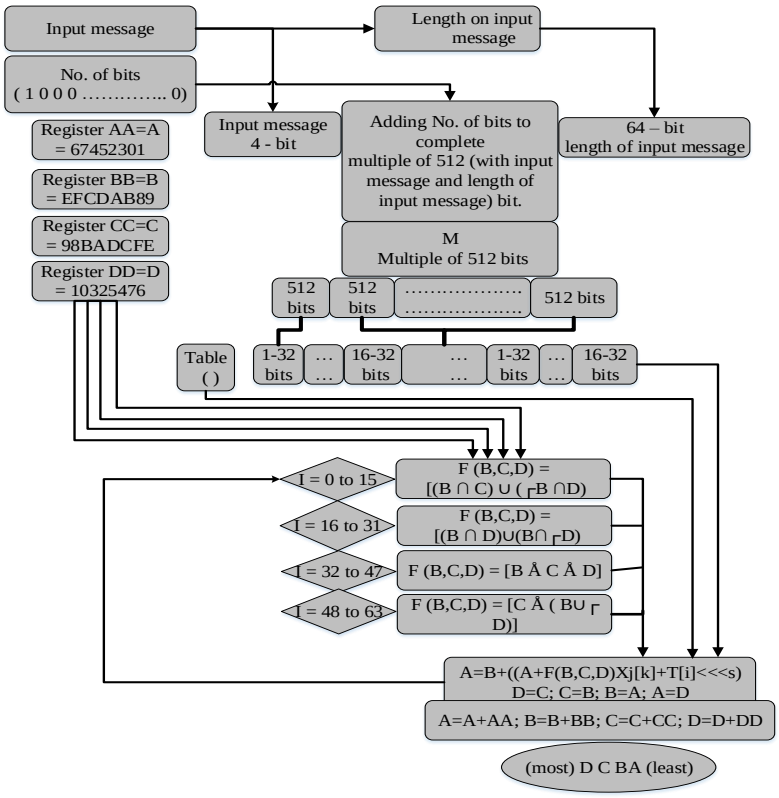


Figure 1. Message digest-5 algorithm flow chart

$$F(B, C, D) = [(B \wedge C) \vee (\neg B \wedge D)], T[0-15], \text{includes 16 steps}$$

$$G(B, C, D) = [(B \wedge D) \vee (B \wedge \neg D)], T[16-31], \text{includes16 steps}$$

$$H(B, C, D) = [B \oplus C \oplus D], T[32-47], \text{includes 16 steps}$$

$$I(B, C, D) = [C \oplus (B \vee \neg D)], T[48-63], \text{includes 16 steps}$$

where the symbols $\vee$ represents logical OR, $\wedge$ represents logical AND, $\neg$ represents logical NOT and $\oplus$ represents logical XOR. The operation in single step involves the functions:

$$A = B + ((A + F(B, C, D) + X_j[k] + T[i]) <<< s)$$

$$D = C; C = B; B = A; A = D$$

where $X_j[k] - k^{th}X$ (divided of B) and J[th] number of blocks (B-512 bits) and <<<s-circular shift left by s-bits. After four rounds, the output is added to input of the first round.

$$A = A + AA; B = B + BB; C = C + CC; D = D + DD$$

j. Then, the output is of 128-bits and will be ordered as follows:

$$(most)\boldsymbol{D} --> C --> B --> A\ (least)$$

3. METHODOLOGY

In this project, a clear energy generation is promoted by incorporation of renewable energy technologies. Proposed block diagram of this research project is shown in Figure 2(a). Data transferable security features are also introduced in this project by converting data in hash form with help of MD5 algorithm as shown in Figure 2(b).

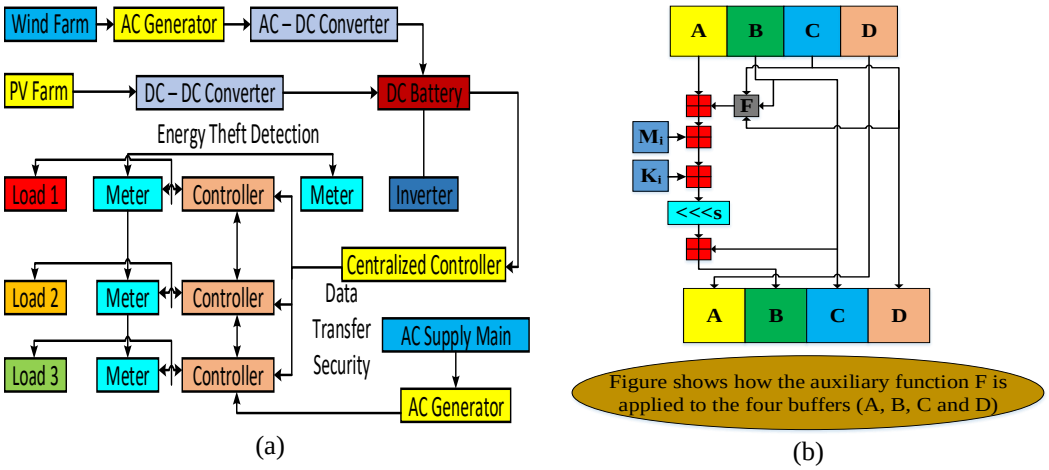


Figure 1. (a) Proposed model of energy management system, and (b) proposed encryption technique for data transfer security between consumer and supplier

4. HARDWARE DEVELOPMENT OF PROTOTYPE MODEL

Hardware prototype model is developed as shown in Figure 3 to increase the practicality and realization of proposed research.

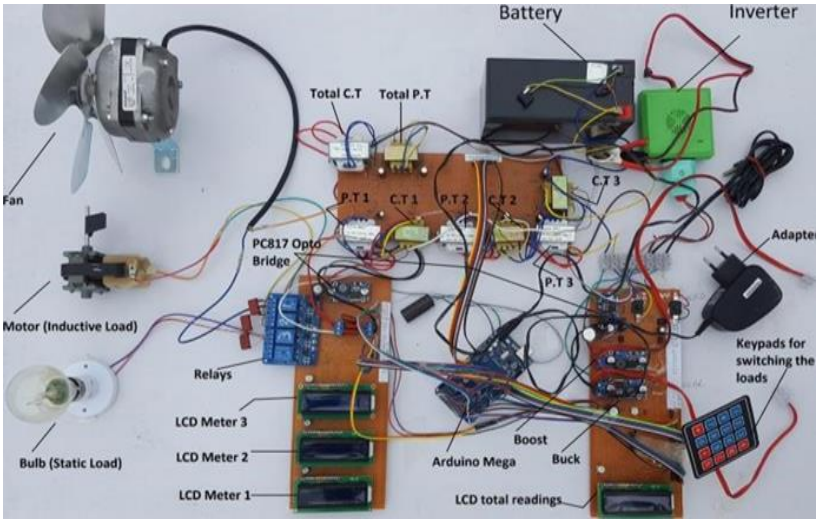


Figure 3. Hardware development of prototype/test model for validation of advanced energy management system and security features

5. SIMULATION RESULTS AND ANALYSIS

Proposed model is simulated on Matlab/Simulink and apparent power is analyzed as shown in Figure 4. This analysis helps in determining the operation of energy management system within prescribed limits for genrration and demand. Load demands with respect to generation from different sources are listed in Table 1.

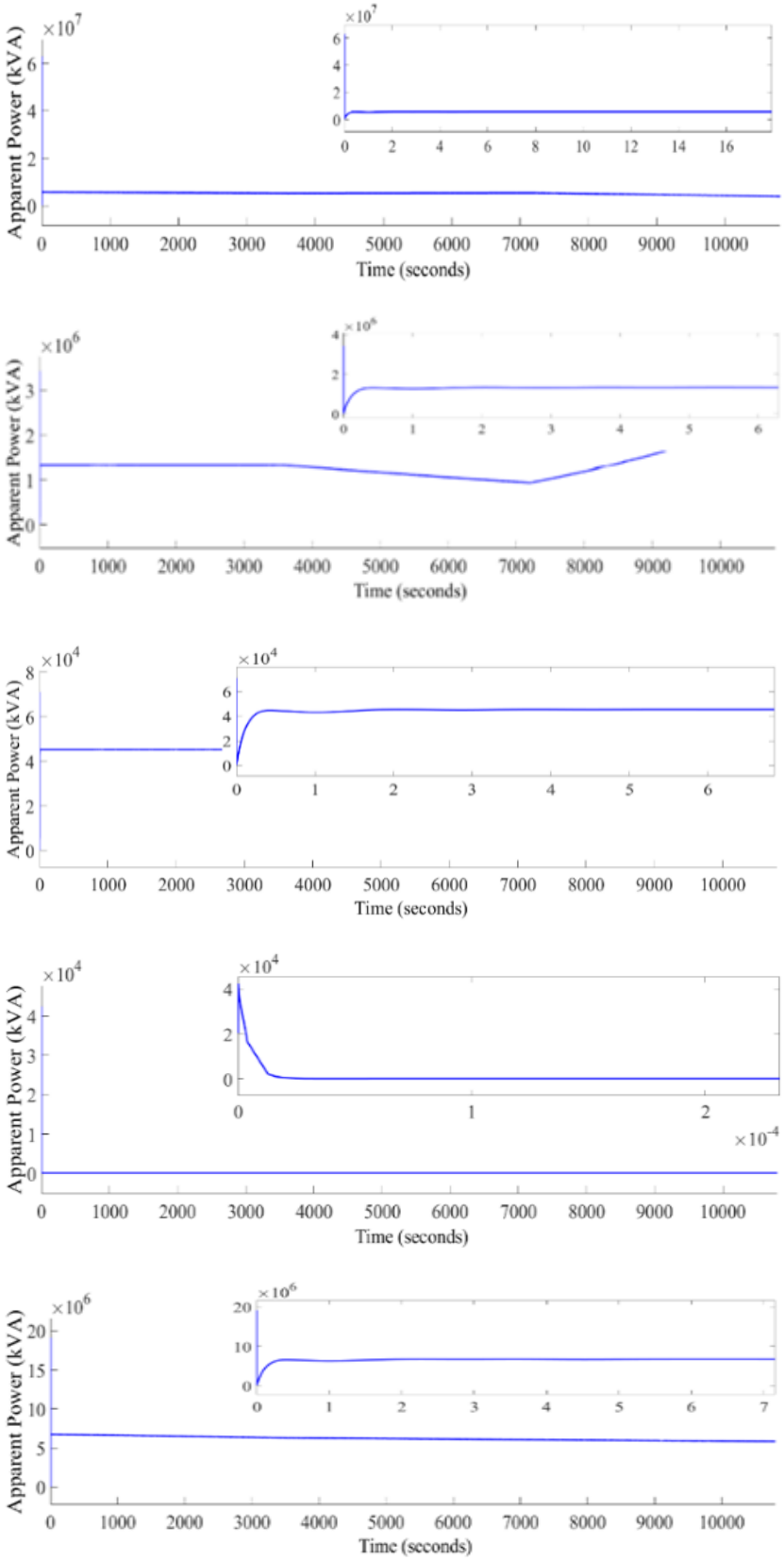


Figure 2. Characteristics of apparent power for analyzing operation of, (a) thermal generation, (b) wind power generation, (c) PV based generation, (d) industrial load, and (e) residential load

Table 1. Data of generation and demand

Parameters	Generation			Demand	
	Diesel Engine	PV Farm	Wind Farm	Industrial Load	Residential Load
V (V)	8353	188.4	8349	8348	8349
I (A)	480.3	4848	3.784	0.008351	561.7
S(kVA)	6.018e6	1.37e6	4.739e4	104.6	7.035e6
P (kW)	6.017e6	1.23e6	2.527e4	-104.6	-6.941e6
Q (kVAR)	8.692e4	-7.846e6	-4.009e4	-0.007682	1.146e6

5.1. Message digest algrithm results

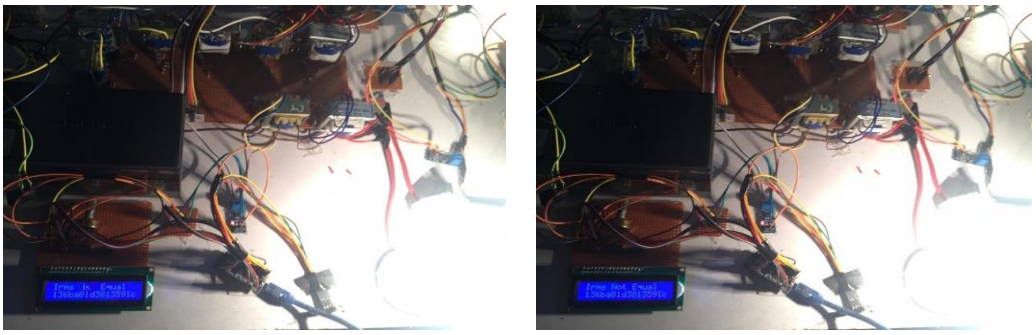
Message digest algorithm is implemented to secure the energy management system. Information about consumer parameters can be encrypted and then transferred to supply company to compare sending and receiving information. This will help against any cyber-attacks on the power networks and will also help in theft detection. For proposed model, currents I_{rms} both on the load as well as on the supply side are shown along with their hashed value. When there is no theft, the hashes are same on both sides and during theft, the hashes are seen to be different on both the sides as shown in Table 2 and Table 3 and in Figures 5 and 6.

Table 2. Hashed texts on load and supply side during no theft

Parameters	Currents	Hashed Texts
Supply	0.65 A	136ba81d3813591cdcc15fcb924b9437
Load	0.65 A	136ba81d3813591cdcc15fcb924b9437

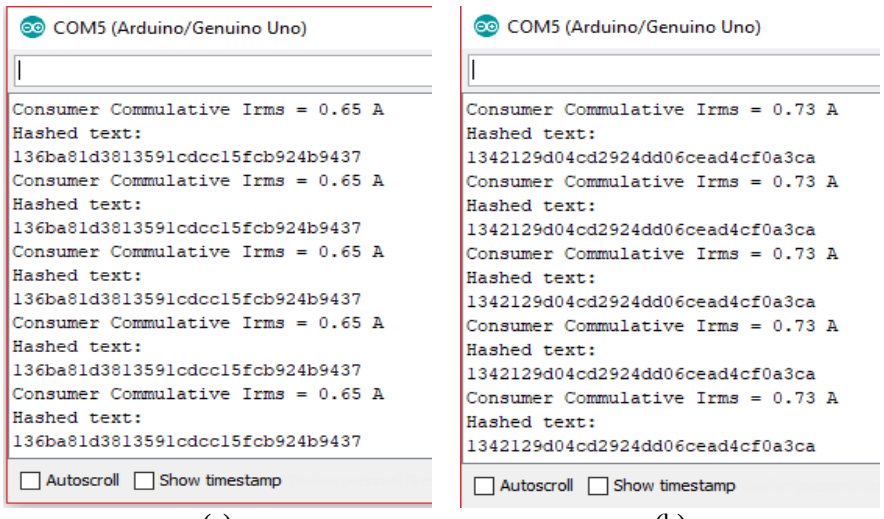
Table 3. Hashed texts on load and supply side during theft

Parameters	Currents	Hashed Texts
Supply	0.65 A	136ba81d3813591cdcc15fcb924b9437
Load	0.73 A	1342129d04cd2924dd06cead4cf0a3ca



(a) (b)

Figure 5. LCD screen during, (a) no theft, (b) theft



(a) (b)

Figure 6. (a) Similarity, and (b) difference of hashes of supply and consumer end

6. BUSINESS PLAN FOR COMMERCIALIZATION

6.1. Scope of commercialization

The proposed model highlights the importance of secured energy management with the incorporation of renewable energy technology. World is moving and discovering ways of generation of clean electricity. Supply companies are making consumers autonomous by allowing them to generate electricity by their own and sale as and when excess energy production is available. In this project, a prototype is prepared to demonstrate the importance of using renewable energy sources and secure communication between consumers and suppliers to avoid energy theft.

This project hits the small and medium sized production and manufacturing industries. Home based industries are also considered. Further, supply companies like faisalabad electric supply company (FESCO), lahore electric supply company (LESCO) etc., and consumers involved in the generation by renewable energy sources will be the most convincing customers of this idea. The companies which are serious about health safety and environment and are interested to obtain ISO certifications, can take interest in this prototype of idea. This project is successful providing a door to reduce CO_2 emissions.

Research and development involved in IOT can take interest to provide funds to commercialize the prototype with the facilities that are beyond limitations involved because of distance between consumer and appliances without any fear of cyber intruder. This project secures the wireless communication between consumer and supplier by considering the encryption through message digest algorithms and decryption via brute force attack. Therefore, this project is basically hitting the markets and investors involved and interested in interdisciplinary research and fields of ICT and Power sector.

6.2. Financial viability

Financial viability of this idea for small and medium scale industries and consumer sides at residential and commercial areas is very high. A little investment results in making systems intelligent and autonomous by securing communication with this idea. Further, reduction in CO_2 emission involves HSE and ISO certifications. Therefore, with the idea of moving towards generation via renewable resources, we cannot deny the energy management importance with the incorporation of renewable energy sources. Importance of energy management is also increased because of inflation and reduction in the capacity of acquiring capital because of decrease in the worth of rupee in Pakistan. Further, cost/benefit ratio is within acceptable limit for this idea. Rates of energy are very much independent of supply companies' tariffs with this idea.

6.3. Ease of development

Since a prototype is prepared in this project to analyze the performance of innovation, direct deployment is not possible. Changes are required with respect to the consumer's specifications. However, module required for encrypting and decrypting information transferred via wireless link can be deployed easily with a slight modification. Further, energy theft detection can be implemented without any alteration.

6.4. Scalability

As prototype is prepared, this project requires a scalability with respect to customer's properties. Further, quantitative vs qualitative evaluation is required to enhance the outcomes of this research project.

7. POSSIBLE FUTURE DIRECTIONS

Some of the ideas for future development is mentioned below:

a. Latest ways of encryption and decryption like Advanced Encryption Standard, Triple Data Encryption Standard, Twofish etc., will secure the communication between consumer and producers. This will help the consumer to act as prosumer. Prosumer is a category in which consumer has the ability to sale electricity to supply companies when excess generation is available at its side. Latest techniques of encryption and decryption will make consumer more autonomous without any fear of cyber-attack.
b. Features of smart meters can be added to introduce the concept of peak hours and off peak hours pricing. This will give birth to the concept of smart billing system for power facilities.
c. Calculation of thermal aging of components of power system will enable the supplier to intelligently handle the power transferring in the time of peak hours to avoid long term shut down in case of any cable or components failure. Temperature sensing and x-rays imaging will add fuel to this project for prolonging life.
d. Concept of two-way flow of power can be introduced and theft detection system can be upgraded according to this idea. Not only magnitude of current but also direction of flow of current can be used for theft detection.

e. IoT based configurations can be introduced in this project. Data of the current configuration of the system will be thrown over the cloud and can be accessed throughout the world with the private key. This will make the distance free app for automating energy management.

Intelligent robots can be integrated with this system to access to the points where automation is failed. These robots can be equipped with drones for landing to the faulty points or can be made travelled over the power lines like an electric cable car to the points of failures. This would help in activating timely remedial actions for manual operation of tripping faulty sections from the system.

8. CONCLUSION

Energy crises can be resolved in next decades using this advanced energy management system. This system provokes the maximum utilization of renewable energy sources along with a little reliance on conventional sources. Therefore, promotion of green energy and energy mix model is the main motivation existing behind this approach. Energy management system is simulated. Further, prototype of energy management system is developed to validate the idea of energy management with the incorporation of renewable energy sources and advanced security features. It is noticed from the recent trends of power generation that world is moving towards renewable energy sources for power production. It is because of many reasons. Some of the remarkable reasons are decrease in the fossil fuel energy reservoirs, global warming and excess CO_2 emissions. Therefore, world is looking for other sources of generation. It is found from the recent articles of energy that developed countries like England, Germany will move their entire system of power generation to renewable energy sources by the end of 2030.

Therefore, this research provides a brief introduction of energy management system with the ability of addition of renewable energy sources for power generation. Further, intelligent way of theft detection is introduced so that there could be no compromise over any energy theft. Based on the comparison of current values of supplier and consumer, power system is made secure.

In addition to this, enhanced security features for communication between suppliers and consumers in introduced for first time in power system. This will not only increase reliability of service to essential loads but also increased overall efficiency of usage of energy and capitals. Message digest algorithm based security for wireless communication between supplier and consumer make both supplier and consumer more autonomous and intelligent. Power system information cannot be altered by cyber intruder because of this type of security.

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