Smart Electrification of Rural Bangladesh through Smart Grids

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Abstract. A smart grid is a new technology that integrates power systems with communication systems. It is an intelligent and efficient management system that has self-healing capabilities. The smart grid can be applied to manage networks that integrate different types of renewable resources for power generation. Bangladesh is currently experiencing severe power deficiency. Renewable energy sources such as solar power and biogas can play an important role in this scenario, especially in rural areas where electricity is even scarcer. By applying prototype concepts of smart grid, power generation from renewable resources and efficient load management can be achieved by a centralized control center. This will control the on-off sequence of the load and maintain the system stability. In this paper, different aspects of implementing a prototype of the smart grid in the rural areas of Bangladesh are discussed.

Keywords: smart grid, rural area, power demand, renewable energy.

1 Introduction

Capability in electrical power generation is a major driving force towards socio-economic development of a country. For a developing country like Bangladesh, the electricity capacity of power generation is far less than the demand [1][2]. Therefore, to cope with the rapidly escalating demand for electricity, rigorous attention needs to be provided to generate electrical energy from renewable energy sources [3]. Rural areas of Bangladesh have limited access to the electrical power supply from the

national grid compared to the urban areas [4]. People living in rural areas which do having electricity encounter frequent power shortages [4]. Solar photovoltaic (PV) systems are widely implemented in these areas [4]. To provide electricity in rural areas with renewable resources, a prototype of the 'smart grid' concept can be considered. This approach can lead to cost-effective deployment, efficient operation and good maintenance of the deployed system [3]. Some aspects of the smart grid systems can be implemented in this type of approach. This paper provides a discussion on how a basic framework of a smart grid system can be used to achieve control strategies and well-organized operation of a prototype system that incorporates renewable resources in rural areas of Bangladesh. The existing power system situation is discussed first as well as the current state of renewable resources of Bangladesh. A brief overview of the framework of a smart system is provided afterwards. Challenges of integrating renewable resources are highlighted. Finally, the different aspects of implementing the prototype using smart grids concept are discussed.

2 Existing Power Scenario of Bangladesh

Bangladesh, a low-income developing country [5], is highly vulnerable to setbacks arising from the ongoing electricity crisis. Natural gas, the main source of fuel for energy generation, is responsible for around 72% of the total commercial electricity consumption and around 81.72% of the total electricity generated [6][7]. But, studies show indicate that the gas demand will increase up to 4,567 mmcfd by 2019-2020 [8] resulting in a shortfall of around 1,714 million cubic feet per day (mmcfd) [8]. Even if a slow growth rate of GDP is considered as 5.5% till 2025, Bangladesh will need about 19,000MW of additional power each year [8].

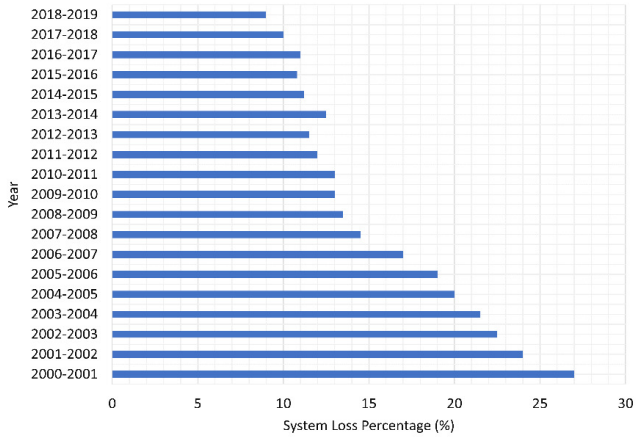

Fig. 1. System loss percentage in Bangladesh from 2000-2019 [2].

Solving the ongoing electricity crisis was one of the major issues in the election manifesto of the current government [8]. The government focused on Quick Rental Power Plants which run on diesel fuel. Initially, it was able to reduce the gap of generation and demand for electricity, but the fuel cost made the cost of electricity considerably higher [9]. Due to the latest rise in oil prices in the international market, government subsidies for petroleum-based power plants went up. As a result, the price of electricity per unit was increased three times within just four months. Cost per KW-hr of electricity rose from TK 4.16 (USD 0.051) to TK 4.72 (USD 0.058) on December 1, 2011, then to TK 5.02 (USD 0.061) on February 1, 2012 and finally to TK 5.32 (USD 0.065) on March 1, 2012 [10][11]. The average production cost of a unit of electricity is Tk 5.70 (USD 0.070), according to the Bangladesh Power Development Board (BPDB) [9].

As a developing country, it is not surprising that Bangladesh depends quite heavily on coal to produce electricity [1]. In the short term road map to meet energy demand by 2015, the Bangladesh government had contracted almost 2600MW of coal fire power plants in Chittagong and Khulna [1]. A study of carbon emission shows that carbon dioxide emission rate (Metric tons per capita) increased very rapidly from 0.2 in 2005 to 0.3 in 2008 [3]. These developments current developments in power generating plants will make Bangladesh more vulnerable to high carbon emission.

System loss is another major problem for power systems in Bangladesh. This consists of the line loss, heat loss, unaccounted energy usage and electricity theft. System loss affecting public utilities is a persistent problem in Bangladesh's infrastructure. According to BPDB, the overall system loss calculated in 2008-2009 was 6.58% of net generation [1]. The monthly system loss for various months of the year of 2011 in Dhaka, based on information provided by Dhaka Electricity Supply Company Limited (DESCO) [2] is shown in Fig. 1.

The inefficiency of the overall transmission and distribution system, shortage of gas, unavailability of some power plants from time to time due to maintenance, rehabilitation and overhauling, degenerated capacity due to aging of power plants are also some other problematic issues for the power system in Bangladesh [1].

The dependency on natural gas, oil and coal as well as abovementioned issues have changed the focus to renewable energy resources. Biomass, Biogas, Solar, Hydropower and Wind are the potential sustainable sources of energies. Energy security, as well as a cost-efficient and effective power supply to the off-grid rural areas of Bangladesh, can be provided if electricity can be harnessed from these renewable resources [3]. It is therefore imperative to study the renewable energy scenario of Bangladesh.

3 Renewable Energy Scenario in Bangladesh

To meet the existing deficit in power generation, renewable resources are becoming more attractive alternatives in Bangladesh. As a result, a policy for the effective utilization of renewable energy resources has been adopted by the Government of Bangladesh (GOB) [3]. The focus of this policy is to shift the considerable dependency on conventional fossil fuel-based thermal power plants. Global depletion of fossil fuels, increasing cost of purchasing and importing as well as a desire to move towards clean energy are the main driving forces behind it. So, the

necessity of harnessing energy from renewable resources is essential. Among different types of available renewable resources in Bangladesh, the most potential ones which be explored rigorously by Bangladesh are discussed below.

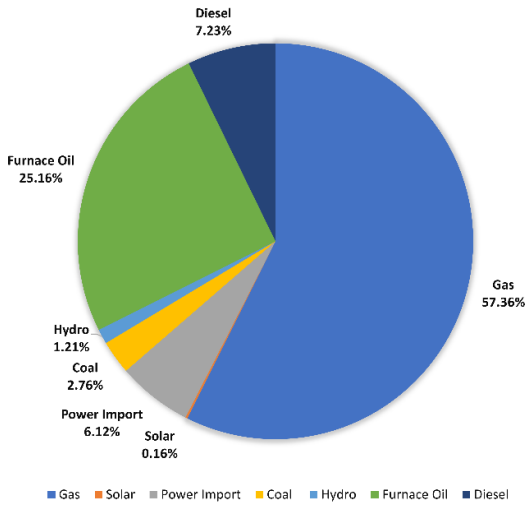

Fig. 2. Contribution of Different Implemented Renewable Energy Technologies in Bangladesh in the year 2019 [2].

3.1 Solar Energy

The abundance of solar radiation (daily 4.0- 6.5 kWh/m^2) [12] has enabled the potential growth of solar-based energy resources in Bangladesh. The months of March to April and the months of December to January provide maximum and minimum solar radiation respectively [13]. Photovoltaic (PV) solar systems and Concentrating Solar Power (CSP) systems are the most common technologies. PV solar systems have been implemented extensively throughout the country, mostly in rural areas [3]. 801,358 Solar Home System (SHS), having a capacity of 36.5 MW, had been installed by January 2011[3].

3.2 Biomass Energy

Bangladesh is an agricultural country. So, biomass is the most notable energy source in Bangladesh as biomass covers all types of organic matters which are available from a different type of crops. Biogas plants also use animal wastes from dairy and poultry farms. 70% of total final energy consumption is produced by biomass in Bangladesh [14].

3.3 Wind Energy

Wind energy generation has some prospects in the coastal areas of Bangladesh. The average wind speed available in coastal areas is 6.5 m/s and the density of wind power varies from 100 to 250 Watt/m^2 [15].

3.4 Hydro Energy

Bangladesh is a land of rivers. Approximately 1.4 trillion cubic meters of water per year flowing through different rivers. Even though the land is fairly plane, high current flows through major rivers for six months of the year which provides some locations with the prospect of 10KW to 5MW power generation capacity [3].

Based on a study by Kaiser et. al [16], the relative contributions in terms of installed capacity in MWp for five renewable resources in Bangladesh are shown in Fig. 2. From the chart, it can easily be interpreted that solar and biogas are playing the most significant role. So it can be concluded that for rural areas, the solar power can be the obvious choice for the main power generation source of a prototype grid where some technologies of smart grid concept are implemented. For successful implementation of this type of approach, the basic elements of the smart grid need to be reviewed.

4 Framework of Smart Grid

A smart grid is an intelligent network that uses digital and other modern technologies to observe and supervise the transportation of electricity from different generation resources to meet the dynamic electricity demands of the customers. Smart grid manages the requirements and capacities of all parts of the system including generators, grids, and customers as efficiently as possible. As a result, it minimizes costs and environmental impacts and maximizes system stability, reliability and resilience [17].

Smart grid helps to operate and proficiently manage the existing grid. The integration of a bi-directional communication system integrated with the power system is the most unique feature of the smart grid. Perhaps the most important feature of a smart grid is the ability to dynamically integrate the variable renewable resources which helps to reduce carbon emission and assists to meet the future power demand [18].To maintain the balance of supply and demand, it also includes a storage system. It is equipped with a real-time metering system that allows customer interaction facility, dynamic tariff system and demand-side management. Self-healing feature is an important characteristic of a smart grid. To maintain the stability of the system, the operators can manage the distributed resources to provide reactive power, voltage support and other ancillary services using the two-way communication infrastructure of the smart grid [19].

The technological improvements in the areas of communication, control and sensor technology are enabling the gradual implementation of a smart grid all over the world.

The existing grids need to be updated with modern technological advancements for the transformation towards a smart grid. A standardized bi-directional communication system is the first area that needs to be updated. Integration of improved power electronics and measurement devices are also an integral part of a smart grid. An appropriate control method needs to be developed and implemented for the successful application of smart grids [20]. The proposed prototype system borrows these features of smart grid technology along in addition to some other elements.

5 Smart Grid Prototype for Rural Areas of Bangladesh

Solar power is the most prominent source of renewable energy in Bangladesh [16]. For rural areas of Bangladesh, the Solar PV systems are most widely used. The goal of this smart grid prototype system is to provide electricity to a group of rural households of Bangladesh with the Solar PV system.

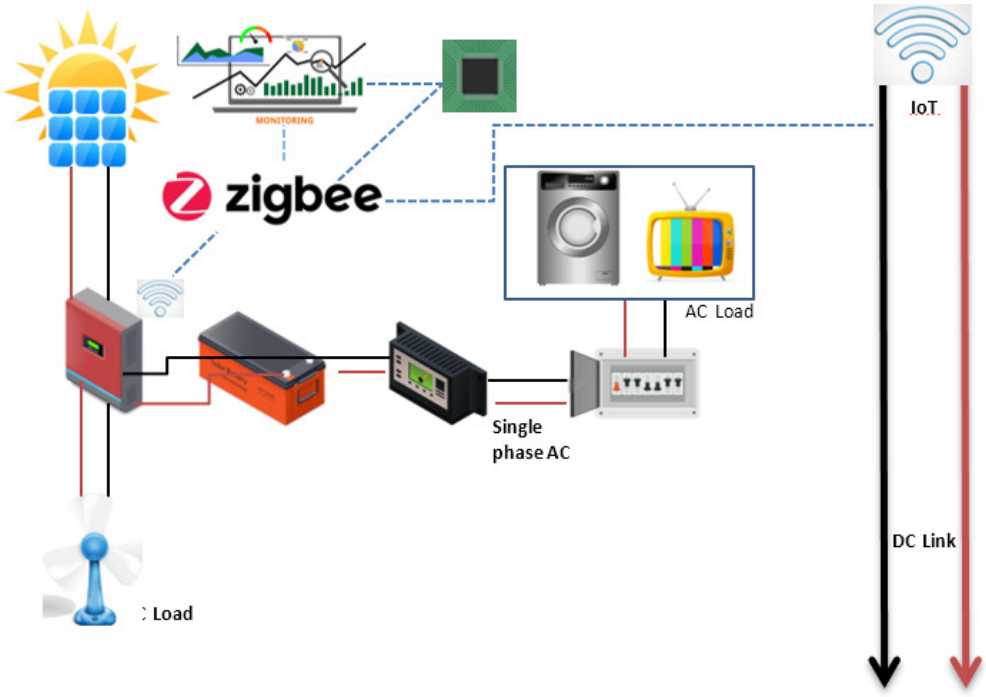

Fig. 3. Overview of a smart-grid prototype for rural Bangladesh.

5.1 Structure of Smart Grid Prototype

A stand-alone solar PV system consists of a solar panel, a charge controller circuit and a battery [23]. As our existing system is an AC grid, the electricity obtained from the solar PV system is fed to the inverter before reaching to the load [23]. In case of a DC grid, the electricity can be directly provided to load.

Renewable source of energy, that is the solar PV system, will be connected to the grid through a charge controller circuit. Depending on demand and generation, the charge controller circuit will control the charge flow to the energy storage device and the load. During high demand, available electricity will be directed to the load. During excess generation, the controller circuit will charge the battery so that this energy can be used later. Also, the controller circuit will charge the battery if the charge level falls below the threshold value of the battery. When there is a generation greater than the rated value, the controller circuit can trip to protect the devices as well [24]. The electricity produced is connected to the distribution system. A Central Control Unit (CCU) controls the total system. It includes communication devices, monitoring devices and decision-taking system.

The communication with other devices can be maintained with a wired or wireless connection. Wireless communication systems can include Zigbee and IEEE 802 based standards for short-range and moderate range applications respectively [25]. Power Line Communication (PLC) system can be implemented for the wired system. These components will have a built-in modem. All the components will be communicating with the CCU using the modems. Communication is one of the most important parts of this system. So, it needs to be ensured that the communication links among the modems have minimal channel errors and thus high reliability.

The monitoring system will be composed of different measuring devices. These devices will measure different parameters such as voltage level, current, energy usage, generation, demand etc. Since the loads are not sensitive, the measurements will be taken and transmitted to CCU periodically. This will result in a less complex system.

The decision-taking system of CCU will analyze these data. Based on it, it will take decisions which will be transmitted to respective components through modems. So, necessary actions will be taken corresponding to current parameters for efficient operation and management. For successful operation of the prototype, several other applications are also required.

5.2 Prototype of DC grid

Since a solar PV system is applied, hence DC power will be generated. So, a prototype of the DC grid is required. The solar panel will be connected to a charge controller circuit which will be then connected to a DC grid through an energy storage device like a battery. The DC grid will be connected to loads through inverters which will convert the DC power to AC. All the inverters will be connected with CCU. Fig. 4 shows the setup of the prototype DC grid. DC transmission system is preferred over AC transmission due to its higher efficiency. Only loss got is at the conversion of DC-

AC. This is about 5-10% of the generated power. As micro inverters are used the loss will be towards the lower side of the band.

5.3 Synchronization of voltage, frequency and phase

Synchronization of voltage, frequency and phase is an imperative aspect of this system. The inverters need to be synchronized before connecting them to the grid. A load and its associated inverter will be taken as reference node by the CCU. All other inverters will be synchronized corresponding to this inverter by CCU. The CCU will measure the voltage level. There are multiple inverters in this system each one connected to DC link. Each inverter is driving different load in the network. CCU controls the on-off sequence of these inverters according to the demand. Multiple inverter system has been proposed for this system to increase the reliability of the system. A central big inverter can go down even if one solar panel does not function properly whereas micro inverter diminishes this problem.

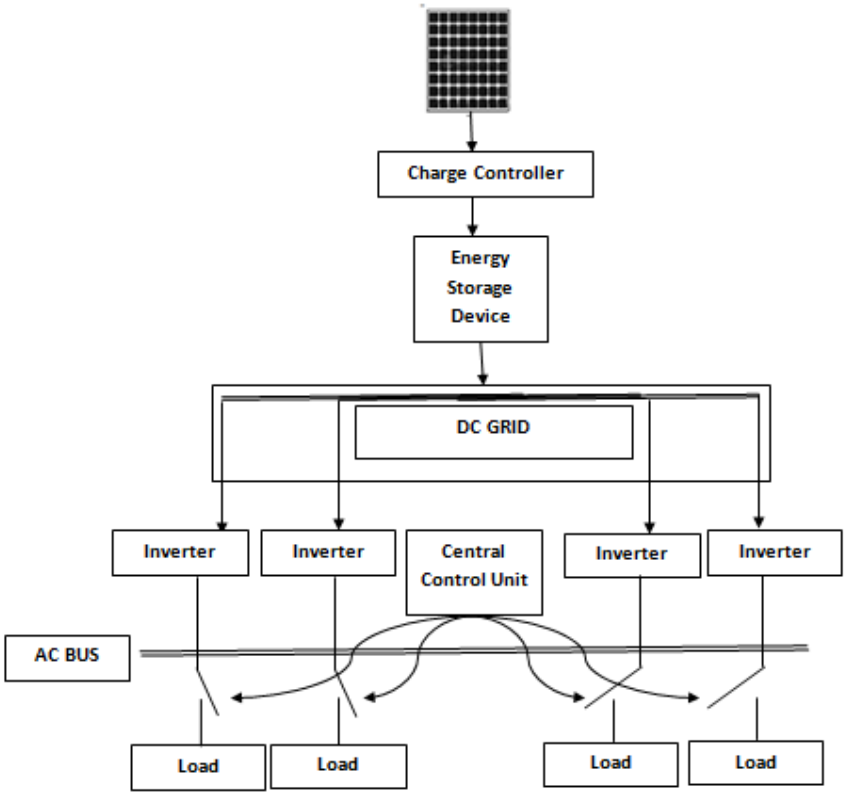

Fig. 4. Prototype of DC grid.

The control algorithm can be expressed as below.

- Initialize the reference inverter out of 'N' inverters and assign its index i=0. Turn off all the switches at other loads.
- Measure the voltage (v), frequency (f) and phase (Ø) of each inverter and transmit to the CCU:
  $\{F\}_i = \{v, f, Ø\}_i$ where i = 1, 2 ,3 ... ... (N-1)
- while $\{F\}_{ref} \neq \{F\}_i$ do
  if $\{F\}_{ref} < \{F\}_i$ then $\{F\}_i = \{F\}_i - \Delta\{F\}_i$
  where $\Delta\{F\}_i$ = step size
  elseif $\{F\}_{ref} > \{F\}_i$ then $\{F\}_i = \{F\}_i + \Delta\{F\}_i$

  else turn on the switch.
  end while
- Transmit the decisions to the sensors at each load.

This control algorithm can also be applied if an inverter goes out of synchronization due to a major disturbance.

voltage, frequency and phase of an incoming node and compare it with the reference node. Then CCU, using a control algorithm, will instruct the new incoming node to match its measured parameters till synchronization is achieved. This process is similar to the concept of micro-grids [26].

5.4 Control of Harmonics

The inverters can produce harmonics. To mitigate its effect, the CCU will periodically measure the voltages from the measuring devices connected at each inverter. Based on this, the CCU will perform a harmonic analysis and take appropriate measures to control the harmonics within an acceptable level [27].

5.5 Managing the prototype with hybrid energy sources

Diesel generators are the cheapest and the most easily available generators in Bangladesh [4]. It is widely used in rural areas for irrigation as well as supplying electricity during load shedding [4]. Since there is a lot of power shortage in rural areas, the people in these areas use diesel generators as back up source of electricity if they can afford it [4]. The prototype can have hybrid energy sources by including a diesel generator with renewable energy resources. This diesel generator can be used as a backup unit to provide electricity to the system when the load demand is higher than the capacity of solar PV source. It can also be used to charge the battery when the battery voltage becomes low and there is no solar power available to charge the battery. Since a diesel generator is an AC source, it cannot be connected to the DC grid directly. So, a rectifier needs to be placed in between the DC grid and diesel generator. Traditionally, the diesel generator is turned on manually when it is required. But this can be done automatically as well by using a smart controller circuit. The smart controller can measure the voltage level of the solar PV system and load demand and based on that the smart controller can take decisions by itself whether the diesel generator should be turned on or not. Sensors placed on the battery

will transmit the voltage level of the battery to the controller. The controller will compare this value with a threshold value. If the measured voltage of the battery is less than the threshold value, a smart controller will turn on the diesel generator. If the operating load goes beyond the rated value of the solar PV system, the measured value will be transmitted to the CCU which will switch off the loads. When there is low demand, like after midnight and when the charge level of the battery is also low, the diesel generator can be turned on to charge the battery. Since Biogas is also largely available as a renewable resource in rural areas [16], it can also be incorporated with the solar PV system in future

5.6 Synchronization for AC grid

The synchronization process for the prototype of the DC grid has been discussed previously. The similar approach can be followed to synchronize the inverters of multiple solar PV systems. These inverters need to be synchronized prior to their connection to the grid. Different operating parameters of these inverters will be transmitted to the CCU. The CCU will then compare these values with the reference node values and synchronize the inverters by instructing them to match the parameters.

5.7 Incorporating irrigation pumps

Bangladesh is an agricultural country. So, there is a lot of demand for irrigation pumps. This demand even gets even higher during the dry summer seasons. As a result, a lot of power outage takes place during the dry season when load demand in city areas, as well as rural areas, increase altogether. The irrigation pumps are mostly induction motor-based pumps [4]. As have known, the characteristic of the induction motor is to draw a large starting current. Solar PV systems are sometimes used to power these irrigation pumps [4]. So, the large starting current of the induction irrigation pumps can exceed the rated current values of solar PV systems [4]. The prototype system can accommodate this scenario. When the pumps are turned on, the sensors will transmit the signal to CCU. The CCU can monitor the current level and manage other operating parameters to accommodate the large staring current. It can also switch off other loads and turn on the diesel generator if required.

5.8 Protective mechanism

Self-healing characteristic is an important aspect of smart grid systems. The prototype system can incorporate this idea. Since the prototype system has sensors all over which communicates with the CCU, the prototype system can sense the irregular operating conditions and take required remedial actions. The prototype system will be capable of detecting over-voltage or under-voltage conditions of the sources. When the demand gets too high, the CCU can manage this situation by adding more sources on the generation side. It can also manage the system by switching off some loads, which is also known as load side management. The prototype system will be equipped

with the ability to provide reactive power support to the grid. To increase the protection of the total system, a coordinated protective relay system will be implemented as well. Frequency droop regulation technique should be implemented in the system to provide the real load (KW) sharing [28].

5.9 Load-energy economy

Demand-side management is an integral part of the prototype system. This helps to maintain the balance of generation and demand. Public awareness has to be created to ensure the efficient use of electricity. The people need to be educated and informed about when to use what type of devices. Users should be encouraged to change their habits to reduce the wastage of electricity. Sometimes, people keep electrical devices turned on even if they are not required. By creating public awareness, these types of behaviours can be changed. Also, users should be aware of peak demand periods. They should be encouraged to use less electronic devices during peak hours if possible. This will reduce and shift the peak demand and hence accommodate low generation during high demand [29].

5.10 Local energy economy

The local-energy economy will help the users under the prototype system to manage their load. When generation balances the demand, the price of electricity will be low [30]. But when demand is higher than a generation, power has to be bought from the grid or it has to be generated using the diesel generator. This is most likely to be at a higher price [30]. Also, excess generation from solar PV can be sold to the grid or used to charge the battery for later use. The difference in the price of generating power between the solar PV system and grid & diesel generator will encourage the more responsible application of demand-side management by the users [30].

6 Smart Grid and the Internet of Things (IoT)

The Internet of Things (IoT) is a breakthrough technology using which surrounding objects are connected through wired or wireless networks without any user intervention. The objects then become capable of communicating and exchanging information among themselves as well as to any servers that are available through local networks or public infrastructure such as the Internet. The information that is collected and analysed through multifarious IoT devices can offer advanced intelligent services to users [32].

In any Smart Grid setup, as shown in Fig. 5, application of IoT is vital, as it integrates almost in every sub-part of a Smart Grid, from power generation to distribution. Even at the users' end, various aspects of power consumption can be

effectively quantified and enhanced, bringing a range of benefits to not only the power distributors but also to the user base.

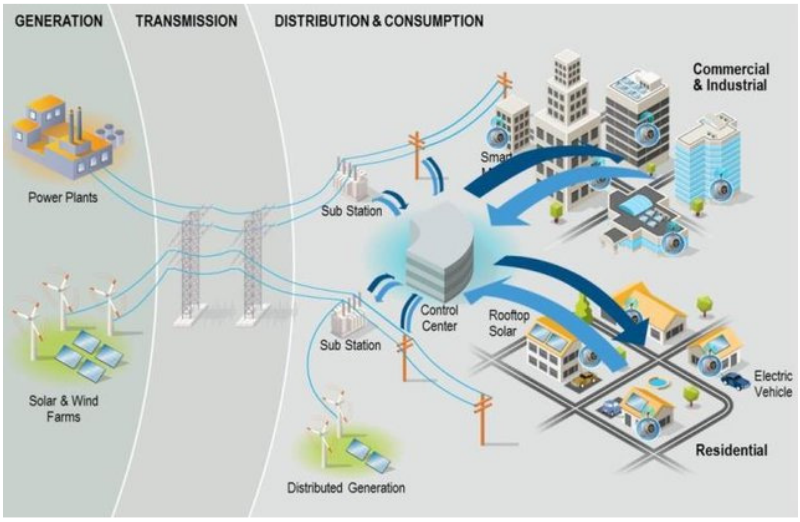

Fig. 5. IoT based Smart Grid [33]

Transformers are a key component in electricity distribution and transmission for recalibrating the source voltage for customer use. IoT enabled sensors can be installed internally to gauge operating parameters such as temperature, current, oil level fluctuation and even real-time environmental humidity and unit vibration [34]. All parameters values can be transmitted to monitoring stations through GPRS in real-time. This instantly alerts the monitoring stations in case of any emergency occurrences.

Further, sensor-enabled IoT based Power Meters, placed in any household that has basic home network-enabled, can collect many parameters from different devices in the household that uses electricity. This data can then be put to use for analysing electricity usage, calculate billing information, make real-time decisions on load distribution, recognize detect unwanted malfunctions and even risks of probable outages. In addition, the power wastages can also be separately calculated, which can have a strong positive effect in reducing the overall monthly bill [35].

There were just a few of the examples of how IoT empowers a Smart Grid setup. IoT devices can further be placed into almost at any point of a Smart Grid and can amass a massive range of critical operating information. Such large datasets of information can also be processed using state of the art machine learning algorithms [36] to generate prediction patterns. Such advanced analytics can not only bring considerable improvement in service and cost savings but also can enable automatic fault-tolerant processes within various internal equipment [37].

7 Conclusion

The increasing price of electricity, rising power demand, and significant generation deficit is driving Bangladesh to move towards renewable resources. Different types of renewable resources are now being explored and implemented as an alternative source of energy, especially in rural areas. Instead of managing these systems centrally, it will be more effective to manage these resources in a small scale. A prototype of a smart grid as discussed in this paper can ensure the intelligent and autonomous management of supplying power from renewable resources to a few households in rural areas. It can also control the load side more efficiently and thus contribute to the solution of the energy crisis in Bangladesh.

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