Overview of Integrated Energy System with Power to Gas Technology

Shah Faisal*
*(School of Electrical Engineering, Southeast University, Nanjing, China
Email: sfaisal@seu.edu.cn)

ABSTRACT
Integrated Energy System (IES) is a vision of evolution of connecting different sources of multi energy grids through information internet and physically connected devices with each other. The increasing demand of electricity and discarding the excess energy lead the idea of Power to Gas (P2G) because gas can stored economically, while electricity cannot. The process of converting electrical energy into gas and its planning for different purposes in integrated energy system is important for promoting the technology. Overview of integrated energy system with power to gas system is discuss in this paper, which includes different analysis planning of IES with P2G system. The future technologies and challenges which power to gas will face in energy systems are analyzed. Modelling and optimization techniques to enhance the performance of energy system, balance the energy system and to offer better facilities to consumer, storage, installation and energy scheduling are important and discussed in this paper of integrating energy system with power to gas system.

Keywords - Electricity, Electrical Energy, Energy System, Integrated Energy System, Power to Gas

I. INTRODUCTION
Electricity is an important aspect of human being in daily life and the advanced technology connects many things with electricity. As, the consumers are increasing so the demand also increasing. Due to the high demand of a consumer, the generation of electricity is available in different forms. To fulfil this demand of consumers, the electricity can be generated from Hydro Power, Solar Energy, Wind Energy, Fossil fuels, Biomass, Thermal, Coal and Nuclear, etc. So there are more forms of Electricity generation and consumers can get it from different sources. Therefore, more sources can generate excess electricity and due to less demand we are wasting this energy because we cannot store high voltage which is very risky. To use this excess energy the researchers started work to change the electricity to another form and take advantages of it in the future, so Power to Gas technology was introduced. Which can convert excess electrical energy to gas and can be store. The characteristic of gas is that it can be stored and can use whenever in need.

Due to the climate change the energy sector is very active for developing the Energy market, electricity market price elasticity, decrease the cost, lessen waste of energy and improve the efficiency [1][2]. Switching from conventional to renewable energy sources which produce free and zero emission energy is the long term success plan to minimize the emissions from fossil fuels [3][4]. Power energy cannot be stored at large amount and production of renewable energy is hard to describe a possible future event and may cause fluctuations of energy in the grid. Even though there is existence of problems, but they are believed to be the energy sources of the future [5][3]. When the supply surpasses the demand the problem of energy storage can be solved and consuming it when the demand is higher than the supply. Renewable energy is playing a significant role to accomplish the energy demand and the new target for renewable energy will be at least 27% by 2030. Different forms are available to store energy but the suitable choice depends on different factors such as location, performance (efficiency, energy density, etc.) and costs [3][6–10].

Integrated energy System is a revelation of development of linking different sources of multi energy grids through information internet and physically connected devices with each other through proper management. It is feasible option for the climate and energy supply. It is a setup of different renewable energies with concentrated energy acting as a central point of the system. It is
environmental friendly and carbon free system and expecting to gain the lowest energy cost in future. According to consumer requirements it can be an add-on to the existing energy system [11]. The integrated energy system includes design, analysis and long term utilization of an electrical system at all levels [12]. To keep and aware the challenges of future, Integrated energy system model the energy infrastructures and its integration with conversion technologies (for example Power-to-Gas, Power-to-Heat, Gas to Heat and Electricity) and energy storage settlement [13]. Integrated Energy System is encouraged by the idea of smart and intelligent energy sharing and management coordination and economic saving [14]. Greenhouse influence climate changes in the universe which is serious problem for society. IPCC (Intergovernmental Panel on Climate Change) are using different strategies to moderate the environment[15]. In integrated energy system multiple energy can be managed and coordinated. The converted electricity is the core of transformation of multiple energy carrier and advanced economic performance can be attain with optimization of management and coordination[16].

The integrated energy system requires a strong transmission grid for better energy flow without fluctuations. Integrated energy system is an effective approach across electricity, heating, cooling, gas, transportation and water, to increase the energy system and balance the fluctuations in a better way. For achieving the realization of the system advanced technology is necessary to get the best system. Advance Communication technology is the important aspect for information exchange. In the performance of Integrated Energy System Energy router plays a significant role. Energy router perform work as a core of energy storage, generation and energy distribution [17]. In the universe carbon emissions and Energy crises are two issues to deal with, and for minimizing these issues IES was introduced. IES is an evolution of smart grid into Integrated Energy system with power generation developing vision. The Future Renewable Electric Energy Delivery and Management System (FREEDM) is a representative IES architecture. It integrate Power System with distributed and alternative generating sources and storage devices [18]. Smart grid is one way communication whereas IES is multi-way energy sharing and information exchange. FREEDM, Distributed Renewable Energy Resources (DRERs), Smart Metering, Monitoring and Control are the key technologies to enhance the performance of IES [19].

Energy crises and carbon emissions are problems for society which needs to be solved by appropriate and feasible way, so the solution for this is integrated energy system. Integrated energy system is the advanced image for smart grid [20]. This paper is A Review Planning Approach of the Integrated Energy System with Power to Gas Technology. Electricity is generating from many sources such as Solar, Hydel, Wind, Biomass, Nuclear, Coal, Thermal and Tidal etc. Renewable Energy is the natural source which exist easily for generation of electricity. The excess power generation from renewable sources get wasted, so to get use this wasted energy in use, the power to gas technology is introduced. Power to Gas technology convert excess amount of energy to gas through electrolysis and the produced gas is then stored in tanks. The remaining sections of this paper are organized as following. Section 2 contains the modelling, structural design, fundamentals and conversion technologies. Section 3 demonstrated Planning models, Features, Challenges and site selection and installation. Section 4 contains Feasibility, applications and storage and capacity. Section 5 contains Optimization, Energy Scheduling, Economic Analysis and problems of IES with P2G. The last section is the conclusion of the paper.

II. MODELLING OF IES WITH POWER TO GAS

2.1 STRUCTURAL DESIGN OF ELECTRIC POWER AND NATURAL GAS NETWORK

The integration of Electric Power and Natural Gas is the new research work and is important for utilizing excess energy. The modelling and architecture need vast area for performing the actual work. This include many aspects of energy that is Power Energy and its conversion to Gas, Gas storage and its use. Many researchers are focusing in this research area as its spreading a new trend in the world. According to the research study gas system can minimize the cost and give better reliability to the electricity system [21]. Multi-energy
arrangements can cooperate in demand to share the prevailing capacities for improving economics, sustainability, safety, resilience and reliability in the integrated systems such as Power to Gas. Natural disasters affected power systems and interrupted the power outages. The study conducted the planning of integrated electricity and natural gas for improving the power grid flexibility in severe disrupted conditions [22]. Study shows an architecture for a future electric power distribution system that is well-organized power grid integrating distributed and effective generating sources and storage with present power systems to promote a healthy and ecological energy based environment, moderate energy crises and lessen the effect of carbon emissions. Various energy transporters with enough topological facts are established and energy conversion links between electrical and gas system. The task is to economize the system which function is to reduce the investment and operation cost of integrated system [23][24].

2.2 FUNDAMENTALS AND MAIN COMPONENTS OF IES WITH P2G

P2G is the combination of power and gas system converting surplus energy into gas, which can be easily stored in tanks and can be utilize later for different purposes. So the fundamentals are consists of three parts i.e. Power system, Electrolyzer and Gas System. The power system comprises all its process from generation to transmission and distribution. During the whole process of P2G, the generation of power is the first step that is involved in the process, power generation from renewable sources is the best option because during peak generation we can convert excess energy to gas through electrolyzer. The second step is electrolysis, which will convert surplus electrical energy to gas through water electrolysis. And the last step is gas production which we can get from electrical energy conversion through water electrolysis process, and the gas can be stored in tanks for later utilization or for regeneration of electricity. According to a research study the P2G system can achieve 41.7% decrease of energy intake and reduce annual running cost of about 1.77 million dollars, associated with the separation production system [25].

2.3 POWER TO GAS CONVERSION TECHNOLOGIES

Electric power can be converted in to gas through water electrolysis. There are different types of electrolysis process e.g. alkaline water electrolysis, Proton exchange membrane (PEM) electrolysis and high temperature water electrolysis. International Energy Association research study shows that in the year 2030, 35% electricity will be generated from natural gas. Supplying electric power to electrodes the water splits into gaseous form. Electrolysis take place in electrolyzer which is composed of electrolyte and is proficient of conducting ions and a diaphragm which is electric isolator and keeps the gas isolated to evade a combustible mixture [7][8][26]. There are three arrangements of P2G installations deliberated at three particular sets of localities i.e. congested electrical nodes, congested gas nodes and gas terminals. In electrolysis process water is divided into hydrogen and oxygen (2H2O→2H2+O2). The technology can be any electrolysis process but mostly PEM is auspicious technology for P2G process. Methanation process requires H2 from electrolysis beside carbon dioxide (CO2+4H2→CH4+4H2O) which involve Sabatier reaction [27][28][8]. Renewable Energy Sources (RES), conversion into gases (H2 etc.) efficiency is 54-77% [3]. The characteristics of electrolyseres are shown in the table 1.
Table 1. Characteristics of Alkaline, PEM and High Temperature Electrolyzer [3]

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>Alkaline Electrolyzer</th>
<th>PEM Electrolyzer</th>
<th>High Temperature Electrolyzer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolyte</td>
<td>Aqueous Alkaline</td>
<td>Solid Polymer</td>
<td>Yttria-stabilized zirconium oxide</td>
</tr>
<tr>
<td>Operation Temperature</td>
<td>60-80°C</td>
<td>50-80°C</td>
<td>700-1000°C</td>
</tr>
<tr>
<td>Operation Pressure</td>
<td>&lt;30 bar</td>
<td>&lt;30 bar</td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td>65-75%</td>
<td>50-70%</td>
<td>70%</td>
</tr>
<tr>
<td>Part Load Range</td>
<td>20-40%</td>
<td>0-10%</td>
<td></td>
</tr>
<tr>
<td>Advantages</td>
<td>Most mature technology</td>
<td>Ability to operate in part load and over load conditions</td>
<td>Can be used with high temperature heat sources like nuclear or geothermal power</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>Relatively low current density</td>
<td>Need of Constant operation</td>
<td></td>
</tr>
</tbody>
</table>

The system design model is On-grid P2G and Off-grid P2G. On-grid system is associated to a large or national grid while Off-grid P2G is design where linking with large or national grid is incredible [3]. Figure 1 is the basic model of Power to Gas system which consists of four kinds of loads that is Electrical Load (E Load), Hydrogen Load (H Load), Heat Load (Ht Load) and Natural Gas Load (G Load). Due to electrolysis the water (H2O) molecules split into gases (Hydrogen and Oxygen) and Hydrogen is stored in tank. From tank Hydrogen is injected to Fuel cell, Hydrogen boiler and for methanation process. The mathematical modelling of IES with P2G is as below.

\[
\Delta H_{298}^{\circ} = 247.8 \text{kJ/mole}
\]

The conversion of power to gas is through electrolysis and the equations is:

\[
\text{H}_2\text{O}(l) \rightarrow \text{H}_2(g) + \frac{1}{2} \text{O}_2(g) \tag{1}
\]
The idea of Power to Gas gives an additional alternative option to the researchers for economically reliable system. To take this system in real life implementation, planning of IES with P2G is the first step. China, Germany and many other countries are trying their best to take P2G in operation and give environmental friendly system to the world. Researchers conducted the optimal planning approach of IES and addresses the challenges of future renewable energy sources dominated energy systems, the system model is compared with traditional energy setups and the integration of Power to Gas etc. using conversion technologies [13]. Another research planning shows an active integrated development strategies for electricity and natural gas systems, considering the ambiguity outcome of demand progress and hydrology level. This shows that integrated study tolerate for well determination of the nominal and economic welfares that are generated by installed components in system [21]. For improving the power grid flexibility in severe circumstances an integrated electricity and natural gas conveyance system planning algorithm was presented. A variable ambiguity set is established to designate the relations among power grid development conditions and extreme occasions and the effective method to increase the power grid flexibility[22]. Due to economic and ecological compensations of natural gas related to fossil fuels, its integration with power system is taken important place. The study shows that a mixed-integer linear multistage optimization problem reduces the expenses of expenditure and operation [30][31]. In [32], the study shows new nodal generation supplies, new transmission lines and natural gas pipelines are instantaneously gained in a multi-period planning prospect, which has solved the large scale mixed integer non-linear problem. Figure 2 and 3 shows the case studied and its result.
3.2 FEATURES OF IES WITH P2G EXPANSION

The Integrated energy system is playing a vital role in the energy sector. As the use of renewable energy is increasing the energy sector is progressively changing for better efficiency in the system. The IES with P2G is the successful research work which is very important for reducing emission and improve the technologies to lower the costs and welfare the society. We know that electricity cannot be stored so the idea of Power to Gas was proposed, to convert surplus electrical energy to gas because gas can be stored economically and can be use anytime. The production of gas from electrical energy is through electrolysis process and the produced gas can be use in homes for heating and cooking, as a fuel for transportation system and also can regenerate electricity. From water electrolysis, we can get hydrogen and oxygen, hydrogen can be used for different purposes as its using now a days in generation and transportation system and oxygen can release to the environment, or give it to hospital for storing and using for patients when in need. The features of IES with P2G Expansion give us many opportunities in one system. All these discussed above was before different and taking from different sources but now all these available in one system that is IES with P2G. The P2G is a favourable choice for long lasting storing system of generating electricity from renewable energy sources. The P2G system can improve system flexibility and can integrate electrical system with other energy systems [39]. The Power to gas system could play an important role in the development of high efficiency and flexibility of energy systems. It can rapidly transform energy system towards sustainability and the produced gas (hydrogen) can enhance the development of fuel cell vehicles market [3]. Figure 4 shows sources, conversion, transmission/distribution and functions of IES with P2G system.

In [33][31], study provides a modelling methodology for combined coordination and incredulity in electricity and natural gas demand evolution. The uncertainties comprise short run uncertainties such as inconstant supply accessibility from renewable generators or long run uncertainties such as strategy or skill variations. The study conducted which shows a model decreases the investment budget of gas-fired generators, natural gas ducts and the operation budget of the natural gas-fired supply generators over a long-term planning prospect [34]. The planning model of electricity and natural gas networks shows that demand ambiguity delivers an accurate method, particularly for utilities that need to consider diverse extension strategies in diverse economic situations that influence power and natural gas consumption. Results shows that a low price result can be attained that is capable to supply different situations of power and natural gas consumption [35][36][33][37][38].
3.3 CHALLENGES OF IES WITH P2G PLANNING

IES with P2G is not a coupling of single system, it is the combination and linking of Power and Gas system together to make one system. This is not easy work and is very challenging. There are many challenges which IES with P2G system have, first of all when there is planning of IES with P2G the optimal location and energy demand challenges should be analysed. How much energy is required to link both system and which renewable source is feasible to couple Power and Gas system? Coupling both system, the system efficiency will be good or not and this is a big challenge. The gas sector challenges are capacity and flexibility and in electricity sector decreasing pressure on the energy costs are the challenges, storage and conversion challenges are quantified [31][40][27].

3.4 SITE SELECTION AND INSTALLATION OF IES WITH P2G SYSTEM

For installation of any system whether it is generating plant or storage tank, it needs proper location so Power to Gas also need proper location for installation. As Power to Gas is the conversion of Electrical Energy to Gas from renewable energy sources so Hydro, Solar and wind are best options. The availability of Renewable Carbon dioxide (CO₂) Gas Network and Renewable Energy Sources are different criteria for the selection of installation and best optimal location for Power to Gas. The installation of P2G technology is a technically safe, reliable and efficient in the selected region. The chosen region is best option for power to gas installation and the system’s cost reduction for installation and operation, minimizing the losses of power to gas system are the considered aims of the technology to profit the country [41][42][43][44].

IV. ANALYSIS OF IES WITH P2G PLANNING

4.1 FEASIBILITY ANALYSIS OF IES WITH P2G

Research study on integrated energy system with power to gas system recently is at rise and many countries focus their research towards this area. In [45], a model of the gases (hydrogen or methane) production with photovoltaic (PV) excess electricity and electricity from the power grid is gained. To assess, the economic feasibility price and rate of energy and electricity are reflected and for classifying the limitations which have high influence on electricity price sensitivity analysis is conducted. In [46], the research study shows that integrated energy system increases the reliability and reduces the dependency on single source. So compared with single approach of generation a struggle is made to increase the performance of the system. Figure 5 shows the modelling approach of input, modelling and output results for the feasibility analysis of IES with P2G.

![Figure 5. Modelling approach with input, models and output results [45]](image-url)

A research study conducted, in which upgradation of a biogas system and integration of anaerobic digester with P2G system for having CO₂ linking Sabatier reaction to enterprise technoeconomic study of P2G development. The outcomes indicates that for methane production in the Sabatier reaction 1000 kW_el, 10kmol/h are required, 4.6 kmol/h and 22 kmol/h are the flow rate of CO₂ and H₂ [47]. A surveyed study shows in Nordic countries by using TIMES-VVT model during year 2010-2050 by achieving 100% renewable energy sources by investigating the viability of P2G technology.
Industrial segments and supply of synthetic gas carriage are key drivers for P2G consumption, auxiliary to energy storage for surplus renewable electricity. In synthetic gas production power to gas has to contest with biomass gasification [48][49].

4.2 APPLICATION OF IES WITH P2G

Global warming is a big issue recently and environmental changes occurs because of it. The idea of P2G is environmental friendly which will play a key role in improving the clean environment. There are many applications of integrated energy system with power to gas system as this is a coupled system of electricity and gas system. The applications of electricity focuses on power generation, transmission, distribution and utilization and the applications of gas side are generation, transmission, distribution, storage and utilization. IES with P2G is very applicable system for the betterment of economy. Integrated management and ideal operation of electricity and gas transmission setups is the best application of IES with P2G. P2G tolerates other energy systems to couple with electrical system and provide flexibility to electrical system [39]. According to the research study the application of high level energy storage systems are economically best and can decrease the cost in the electrical system. In some circumstances, the applications of storage resulted in a rise of the fuel use and the emissions [50].

4.3 STORAGE AND INSTALLED CAPACITY OF THE SYSTEM

Power to gas technology achieved a very high attention recently as the surplus power generation is used to produce gas. This gas is stored in tanks for further utilization that can be used in industries and in homes. A study shows natural gas Company buying excess renewable energy from distant wind farms and implements a power to gas unit, from storage tanks through gas pipelines transporting synthetic natural gas to the demand centers [25]. In [51]. The basic elements used in the installation of power to gas to power i.e. fuel cell and hydrogen generator and the storage of energy in the form of hydrogen gas are discussed. As the load is variable so the efficiency of load as a function was improved for determination and the system is integrated with renewable energy sources. With the increasing load the efficiency decreased in the process (conversion, electrolyzer and fuel cell stack) of analysed power range (30% to 100%). Cost ratio of sale and purchase of electrical energy was analysed and improved which is economically feasible and efficient. Figure 6 shows the scheme of Power to Gas to Power installation.

![Figure 6. Scheme of Power to Gas to Power Installation](image)

According to the study Power to Gas system can increase the use of electricity generation from Renewable energy sources and can store excess energy. Methane gas stored in the tank obtained from Power to Gas system can be used for commercial industrial used and for electricity generation [40][52]. Power to Gas system solving the challenged issues of CO2 and storage of energy and the researchers predicts the data for 2025 energy storage. The data for demo-plants projects has the average budgets of around one million euro per year[6][53].

V. OPTIMAL TECHNIQUES OF IES WITH P2G

5.1 OPTIMIZATION TECHNIQUES OF IES WITH P2G SYSTEM

In [54], recently the development of P2G and growing capacities of generation are strengthened with the integration of electrical power and natural gas system. Expansion planning challenges are introduced to these energy systems. Reducing the costs of integrated energy system including reliability, operation and investment costs a linearized model of an IES and optimal expansion planning model with natural gas supply stations (NGSS), natural gas-fired generation plants (NGFP), gas pipelines, natural gas and transmission lines are presented. The scheme for optimal investment in a collaborative expansion planning model of integrated energy system with the constraints are...
determined from an economic point of view to minimize the costs. The equations are as below.

\[
\min \sum_{t=1}^{T} \left( c_{in} (t) + c_{op} (t) + c_{ens} (t) \right) / (1 + \lambda)^{t-1}
\]  

(9)

Equation (9) represents investment, operation and reliability costs. Where \( T \) represents planning horizon, \( t \) for year \( c_{in} \) total investment cost, \( c_{op} \) total operation cost, \( c_{ens} \) total reliability cost and \( \lambda \) for discount factor.

\[
c_{in} (t) = \sum_{i \in \Omega_l} \sum_{j \in \Omega_l} \sigma_{if,i} U_{ij,i} + \sum_{p \in \Omega_g} \sum_{f \in \Omega_{pf}} \sigma_{pf,f} U_{pf,f} + \sum_{i \in \Omega_p} \sum_{j \in \Omega_p} \sigma_{if,i} U_{ij,i} + \sum_{g \in \Omega_g} \sum_{f \in \Omega_{gf}} \sigma_{gf,f} U_{gf,f}
\]

(10)

Equations (10) represents installation and expansion cost. Where \( \sigma \) represents binary decision variable, \( l \) transmission line, \( j \) electrical nodes, \( f \) type, \( U \) investment cost, \( p \) new gas pipeline, \( \Omega_l \) set of transmission lines, \( \Omega_{pf} \) set of transmission lines, \( \Omega_p \) set of natural gas pipelines, \( \Omega_{gf} \) type set of natural gas pipelines, \( m \) and \( n \) gas nodes, \( s \) new NGSS, \( \Omega_s \) set of NGSSs, \( \Omega_{gf} \) type set of NGSSs, \( g \) new NGFP, \( \Omega_g \) set of NGFPs and \( \Omega_{gf} \) type set of NGFPs.

\[
c_{op} (t) = \sum_{i \in \Omega_s} \sum_{j \in \Omega_s} \sigma_{if,i} l_{ij,i} U_{ij,i}^{fix} + \sum_{i \in \Omega_s} \sum_{j \in \Omega_s} U_{ij,i}^{fix} S_{ij} (t) + \sum_{i \in \Omega_s} U_{ij,i}^{fix} P_{ij} (t)
\]

(11)

Equation (11) represents operation cost of NGFPs, purchasing cost of natural gas and electric power. Where \( T \) is for hour, \( E_t \) set of the existing NGFPs in the initial year, \( f \) fixed operating cost, \( v \) variable operating cost, \( E_s \) set of existing NGSSs in the initial year, \( e \) external grid, \( E_E \) set of connecting points with the external grid in the initial year and \( P \) is power output.

\[
c_{ens} (t) = \sum_{i \in \Omega_E} \sum_{\tau=1}^{8760} \tilde{P}_{L,i,j} (\tau) VOLL_i
\]

(12)

Equation (12) represents the reliability cost, where \( E_n \) is set of electrical nodes, \( \tilde{P}_{L,i,j} \) is electrical load shedding and \( VOLL_i \) is value of lost electrical load at node \( i \). A study conducted the optimal planning approach of IES and addresses the challenges of future renewable energy sources dominated energy systems, the system model is compared with traditional energy setups and the integration of Power to Gas etc. using conversion technologies [13]. Converting surplus electrical energy to gas, the general perception of the system and different sections which took part in the system and the optimal scheduling of energy system as power to gas system are introduced [29]. In [32] [38]. For large scale systems for Transmission Expansion Planning (TEP), Natural Gas Grid Expansion Planning (NGGEP) and Generation Expansion Planning (GEP) a multi-period integrated approach is discussed. The cost equations are as below:

\[
\text{Cost}_{gsp} = \sum T \left( U_i \right) + M \left( X_i \right) + O \left( X_i \right) - S \left( U_i \right)
\]

(13)

In equation (13) \( \left( U_i \right) \) is new units investment cost at time \( t \), \( M \left( X_i \right) \) is maintenance cost of existing unit, \( O \left( X_i \right) \) is outage cost and \( S \left( U_i \right) \) is salvage value of new units. The optimized evaluated step is as:

\[
\text{TEP Evaluation Function = Cost}_{gsp} + a(\text{Constraints Violations}) + b(\text{Islanding Conditions})
\]

(14)

Equation (14) is the investment and losses cost \( a \) and \( b \) are very large numbers, \( b \gg a \). The total cost minimization is as below:

\[
\text{Cost}_{total} = \text{Cost}_{TEP} + \text{Cost}_{NGGEP} + \text{Cost}_{GEP}
\]

(15)

In Europe 2% hydrogen concentration is permissible to be mixed with natural gas and then...
injected to pipeline (natural gas). According to the predictive analysis for 2020 the surplus electrical energy generated from renewable sources will reach to 40 MW and 45 GW h per year and that is the most favorable to develop power to gas capacity [55].

5.2 OPTIMAL ENERGY SCHEDULING

The energy scheduling of system is very important for proper scheduling of power conversion and gas production and storage. In [56], the study shows integrated forecast model on daily base to deal with generation and load hourly and to handle renewable energy system variability and organize flexible providing. The examples shows that cost of power system operation, flexible ramp arrangements, hourly load forecast can influence the distribution of real-time natural gas. The equation for stochastic day-ahead schedule is as:

$$
\min \left\{ \sum_{i=1}^{N_L} \sum_{t=1}^{T} \left[ F_i^c \left( P_i^0 \right) \cdot P_i^0 + SU_{i,t} + SD_{i,t} \right] + \left( \sum_{j=1}^{N_B} \sum_{s=1}^{N_B} C_{b}^{FRU} \cdot FRU_{b,s,t} + C_{b}^{FRD} \cdot FRD_{b,s,t} \right) \right\}
$$

$$
+ \sum_{i=1}^{N_L} \sum_{j=1}^{N_B} \left( \Delta F_i^c \cdot \Delta P_{i,j}^0 + C_{b}^{FRU} \cdot \Delta F RU_{b,s,t}^i + C_{b}^{FRD} \cdot \Delta F RD_{b,s,t}^i \right)
$$

In equation (16), $N_L$ is number of time periods, $N_B$ number of thermal units, $F_i^c$ cost function of generating unit $i$, $P_{i,t}$ dispatch of thermal unit $i$ at time $t$, $I_{i,t}$ status indicator of generating unit $i$ at time $t$, $SU_{i,t}$, $SD_{i,t}$ start up/shut down cost of unit $i$ at time $t$, $C_{b}^{FRU}$ / $C_{b}^{FRD}$ bidding price of flexible ramp up/down of thermal unit $i$ at time $t$ in $$/MWh, $FRU_{i,t}$ / $FRD_{i,t}$ flexible ramp up/down awards of unit $i$ at time $t$ in $$/MWh, $N_B$ number of buses, $F_i^c$ cost function of demand response $b$, $DR_{b,t}$ scheduled demand response (DR) $b$ at time $t$ in MW, $C_{b,t}^{FRU}$ / $C_{b,t}^{FRD}$ bidding price of flexible ramp up/down of DR $b$ at time $t$ in $$/MWh, $N_B$ number of scenarios, $\Delta P_{i,t}^s$ adjusted dispatch of a thermal unit $i$ at time $t$ and scenario $s$ in MW, $\Delta F RU_{i,t}^s$ / $\Delta F RD_{i,t}^s$ adjusted flexible ramp up/down awards of unit $i$ at time $t$ and scenario $s$ in MW, $\Delta F RU_{b,s,t}^i$ / $\Delta F RD_{b,s,t}^i$ adjusted flexible ramp up/down awards of DR $b$ at time $t$ and scenario $s$ in MW.

The conducted study shows that P2G technology is able to decrease the operation cost of integrated energy system and can develop the renewable power generation. The mathematical equation is as below [57].

$$
\text{Min } \sum_{i=1}^{N_{PG}} \left[ \sum_{t=1}^{T} \left( a_i + b_i + c_i P_{i,t}^i \right) + k_j P_{j,t}^i \right]
$$

In equation (17), $N_{PG}$ is bus set in power system of non-gas generators, $a_i$, $b_i$ and $c_i$ are generator’s cost coefficients at bus $i$, $P_{i,t}^i$ generator’s output power at bus $i$ at time $t$, $N_G$ node set in natural gas system, $k_j$ natural gas supply’s cost coefficient at node $j$, $P_{j,t}^i$ gas output power at node $j$ at time $t$.

Power flow and gas flow are integrated to achieve the different time constants. The coordinated scheme for energy conversion of P2G and gas system are bi-directional and the model is single optimization model. The objective is cost minimization of power and gas system and the equation is as below [58].

$$
\sum_{i=1}^{T} \left( \sum_{s \in S} c_{s} M_{s,t} + C_{i,s}^p \right)
$$
In equation (18), $c_{ui}$ is gas system constant price, $C_{i}^{PS}$ power system operation cost. The study conducted to manage and store gas load to schedule optimize operation of P2G in day ahead market (electricity and gas) and to reduce the cost [59].

### 5.3 ECONOMIC ANALYSIS OF IES WITH P2G PLANNING

The energy market play a role of a network which integrates different sectors e.g. heating, transportation and electricity with each other in P2G system. The analysis of hydrogen and methane use comparison in transportation sector and the reconversion to power are investigated [7]. P2G can contribute to reduce the ambiguity of dispatch plants and can play a key role in balancing the power grid. Different research studies are economically investigated for the optimal size of the system approximated generation, forecasting issues and load conditions are used. Economically hybrid system is best choice in performance and balancing technologies [10][60]. Macroeconomic analysis research predictive data P2G economic operation is not possible until 2030. The economic operation is expected in 2040 with full load hours in future energy system [4]. Integrated Energy System is economically beneficial for micro grid design, consumer, energy sources, education and national grid infrastructure. The research study conducted to analyse alternative generation improvement and the strategy analysed economically to evaluate the effects of PV uncertainties, renewable energy targets, gas prices, carbon prices and load growth [12][61][62][63]. In [37], a study shows an arbitrary generation expansion planning technique which improves investment verdicts under risky environment to provide secure system. In [64], in the year 2050 80% of electricity demand will be gained from renewable energy sources which need large scale energy storage and P2G is best option to achieve this target. In [65], natural gas tariffs replicates transport cost of natural gas flow direction economically which is not efficient. The integrated operation of Natural Gas and electrical system optimization are influenced by the parameters used. The dispatch of natural gas and electricity system coupling and decoupling results are compared and analysed. In [66], a methodology Dual Decomposition, Langrangian Relaxation and Dynamic programming is used to reduce the operation cost of integrated gas-electricity system.

#### 5.4 PROBLEMS RELATED TO IES WITH P2G

Designing and constructing a system is not an easy task likewise P2G is not so easy to complete, there are many problems which needs to be solved for designing of the system. In [48], Power variations cannot be avoided, as energy storage is troublesome with robust model in the study of P2G technology. There are many problems which occur in transmission, distribution and storage of gases which needs to be solved for reliable system. In [54], Integrated energy system (electrical and natural gas) issues related to collaborative expansion planning are investigated and the solution for achieving the best result is based on Gurobi solver. Long term future planning problem is discussed and formulated as a MILP and the solution approach is by CPLEX solver [13]. In [29], Problem optimized scheduling are analysed with P2G unit for multiple energy system to reduce the operation price of the system. Large scale systems issues for multi-period integrated energy system is investigated related to expansion planning of transmission, generation and natural gas grid [32] [38]. In [59], the problem of outages in the gas grid are formulated to handle the P2G storage and cost reduction of gas load.

### VI. CONCLUSION

Integrated Energy System is a setup of different renewable energies with concentrated energy acting as a central point of the system. Connecting different sources of multi energy grids through information internet and physically connected devices with each other. The increasing demand of electricity and discarding the excess energy lead the idea of power to gas because gas can be stored economically, while electricity cannot. The process of converting electrical energy into gas in integrated energy system is important for promoting the technology. Water electrolysis is a process which converts electrical power into gas and this gas is then transmitted through pipelines and can be store in tanks. This paper is the overview of integrated energy system with power to gas, which include
different studies of IES with P2G. The technologies and challenges which power to gas face in energy systems are planned. Power to Gas is economically efficient as compare to single system and play a vital role in healthy environment because due to global warming the environment is getting hot and power to gas is environmental friendly. The challenges of future, modelling, structure design, fundamentals, features, feasibility, applications, problems, energy scheduling, storage and installation capacity, economic analysis and optimal location of integrated energy system with power to gas technology are discussed in this review paper.

REFERENCES


[27] Stephen Clegg, Pierluigi Mancarella.


