VOL. 3. NO. 2
ISSN 2581-5849
INDEXED WITH J-GATE

PDPU JOURNAL OF ENERGY AND MANAGEMENT

PERFORMANCE ANALYSIS AND OPTIMIZATION OF PLATE TYPE HEAT EXCHANGER IN DAIRY INDUSTRIES
Niyant P. Thakkar, Mithilesh Kumar

STUDY OF PLATE HEAT EXCHANGER PERFORMANCE WORKING WITH THREE TYPES OF REFRIGERANTS EXPOSED TO HOT AIR FLOW
Mustafa Ahmed Abdulhussain

HELIOSTAT DESIGN FOR LOW WIND TERRAIN
Rakesh Singhai, Dr. Nitin Banker, and Dr. Harender

ENERGY SECURITY & SUSTAINABILITY: ROLE OF NATURAL GAS IN INDIAN CONTEXT
Sambhaji Kadam, and Sanjay Kumar Kar

EFFECT ON PROTECTION SCHEME BY DG IN ETAP
Preyansh Sharma, Kashyap Mehta, and R. Venkata Rama Raju

PANDIT DEENDAYAL PETROLEUM UNIVERSITY • A RESERVOIR OF KNOWLEDGE •
PDPU
PANDIT DEENDAYAL PETROLEUM UNIVERSITY
Gandhinagar, Gujarat, India

PDPU JOURNAL OF ENERGY AND MANAGEMENT

UGC APPROVED JOURNAL: NO. 63922

PDPU Journal of Energy and Management (JEM) is an International referred peer-reviewed journal. PDPU Journal of Energy and Management welcomes original papers from both academicians and practitioners on experimental energy science and technology (conventional and non-conventional), energy sector related management, business, and organizational issues related to energy and research. Papers, based on theoretical or empirical research or experience, should illustrate the practical applicability and/or policy implications of work described.

The bi-annual journal carries many features including perspectives, conceptual research, empirical research, colloquium, management case, and book reviews. Authors are invited to submit their contribution under any feature.

AIM AND SCOPE

The proposed research journal shall report and focus on identifying new opportunities, challenges, best practices and strategies for global economy on various complementing issues like business & techno-managerial Issues, regulatory & policy matters, marketing issues, financial & accounting issues, operational excellence & management, social & human resource management and capacity building in general and energy sector in specific.

PDPU JEM is a peer reviewed journal and follows a 'double blind' review process. All the papers submitted to PDPU JEM go through a preliminary review at the editorial desk and those considered appropriate are sent to an Editor representing a specialized domain. On recommendation of the concerned Editor, the Article may be rejected or assigned to two reviewers.

PUBLICATION INFORMATION

PDPU JEM shall be published biannually.
All editorial correspondence should be addressed to the Chief Editor, C. Gopalkrishnan, School of Petroleum Management, Pandit Deendayal Petroleum University, Gandhinagar, Gujarat - 382007 or sent by mail to *jem.pdpu@pdpu.ac.in* or *jem.pdpu@gmail.com.*

CONTACT DETAILS:
Dr. Ashutosh Muduli, Managing Editor

School of Petroleum Management,
Pandit Deendayal Petroleum University
Gandhinagar, Gujarat - 382007, India.

E-mail: jem.pdpu@pdpu.ac.in
jem.pdpu@gmail.com

PUBLISHER'S DETAILS:
Pandit Deendayal Petroleum University,
Gandhinagar, Gujarat - 382007, India.

Telephone: +91 79-23275101

E-mail: jem.pdpu@pdpu.ac.in
jem.pdpu@gmail.com

Website: https://www.pdpu.ac.in

PDPU JOURNAL OF

ENERGY AND MANAGEMENT

VOL. 3. NO. 2

INDEXED WITH J-GATE

CONTENT

EDITORIAL **9**
Professor C. Gopalkrishnan, Chief Editor

1. PERFORMANCE ANALYSIS AND OPTIMIZATION OF PLATE TYPE HEAT EXCHANGER IN DAIRY INDUSTRIES **11**
Niyant P. Thakkar, Mithilesh Kumar

2. STUDY OF PLATE HEAT EXCHANGER PERFORMANCE WORKING WITH THREE TYPES OF REFRIGERANTS EXPOSED TO HOT AIR FLOW **23**
Mustafa Ahmed Abdulhussain

3. HELIOSTAT DESIGN FOR LOW WIND TERRAIN **29**
Rakesh Singhai, Dr. Nitin Banker, and Dr. Harender

4. ENERGY SECURITY & SUSTAINABILITY: ROLE OF NATURAL GAS IN INDIAN CONTEXT **37**
Sambhaji Kadam, and Sanjay Kumar Kar

5. EFFECT ON PROTECTION SCHEME BY DG IN ETAP **51**
Preyansh Sharma, Kashyap Mehta, and R. Venkata Rama Raju

EDITORIAL

We are pleased to present to you the VIth edition of PDPU Journal of Energy and Management. The following are the highlights of the papers presented in the journal.

The first paper on 'Performance Analysis and Optimization of Plate Type Heat Exchanger in Dairy Industries' by Niyant P. Thakkar and Mithilesh Kumar is an experimental studies performed on a corrugated plate heat exchanger for single phase flow (water-to-water) configurations in an institute laboratory to determine the performance of plate type heat exchanger, i.e., overall heat transfer coefficient, heat transfer rate, effectiveness, cold side efficiency, and hot side efficiency. The temperatures of the heat exchanger at the inlet and outlet ports, the volumetric flow rates of the hot and cold fluids, and the pressure drops between the inlet and outlet ports are measured during the experiments. The research found that the complex corrugated surface design flow is highly turbulent which makes the design of plate heat exchanger to deviate from actual. Sometimes the flow medium cannot distribute uniformly which affects the performance of plate heat exchanger. The result of the study can be used to find the optimized condition to operate heat exchanger in dairy industries.

In the second paper, Mustafa Ahmed Abdulhussain studied the thermal effectiveness of plate heat exchanger exposing to uniform hot air flow by working with three Refrigerants (R134a, R290 and R513a). The three refrigerants are heat exchanged with cold water assuming constant flow rate, calculated via the AUTODESK CFD 2019 package using the standard K-ε turbulence model. The result shows that the PHE effectiveness decreased by (14%) for the R513a and by (17%) and (19%) for R134a and R290, respectively.

The third paper on 'Heliostat design for Low Wind Terrain' by Rakesh Singhai, Nitin Banker, and Harender studied the potential for generating electricity on a large scale for places with high DNI in concentrated solar thermal power tower plants. The researcher found that as this is capital intensive specifically on account of heliostats. As heliostats constitute 45-50% of the total cost of a PT plant, hence their design is highly influenced by wind loads. The analysis shows that significant cost reduction is possible by sizing and suitably redesigning the heliostats.

The fourth article on 'Energy Security & Sustainability: Role of Natural Gas in Indian Context' by Sambhaji Kadam and Sanjay Kumar Kar analysed the role of natural gas in energy security, sustainability & economic growth of country. In this paper, authors have developed a framework of energy security based on literature review and classroom discussion in Ph.D. course-work and added acceptability and sustainability to above mentioned aspects of energy security. In the proposed framework sustainability occupies the central position and acceptability has been added as a desirable dimension to energy security. The authors applied the proposed framework to assess the role of natural gas in sustainability and energy security of India. Further, authors analysed role of government in infrastructure development, policy reforms & recommend actionable measures to improve availability, accessibility, affordability and acceptability of natural gas to achieve energy security & sustainability goal.

Finally, the paper on 'Effect on Protection Scheme' by DG in ETAP by Preyansh Sharma, Kashyap Mehta, R. Venkata Rama Raju discusses about the analysis and coordination of protection equipment's in a power system when distributed generations are incorporated in it. The study has been conducted on IEEE 30 bus test system in Electrical Transient Analyzer Program (ETAP) simulation software. An IEEE 30 bus test system without any DG source is considered, and its protection analysis is carried out with Over-Current (OC), and Directional Over-Current (DOC) relays. Further, the DGs are then incorporated and the changes, as well as problems faced by the protection system are studied and the respective solution presented.

We wish you all the best.

C. Gopalkrishnan, Director General
Chief Editor

1

PERFORMANCE ANALYSIS AND OPTIMIZATION OF PLATE TYPE HEAT EXCHANGER IN DAIRY INDUSTRIES

Niyant P. Thakkar, Mithilesh Kumar

Uka Tarsadia University, Department of Mechanical Engineering, Surat, India

ABSTRACT: The corrugated Plate type heat exchanger is widely used in various processes of industries. The present experimental studies were performed on a corrugated plate heat exchanger for single phase flow (water-to-water) configurations in an institute laboratory to determine the performance of plate type heat exchanger, i.e., overall heat transfer coefficient, heat transfer rate, effectiveness, cold side efficiency, and hot side efficiency. The temperatures of the heat exchanger at the inlet and outlet ports, the volumetric flow rates of the hot and cold fluids, and the pressure drops between the inlet and outlet ports are measured during the experiments. Due to the complex corrugated surface design flow is highly turbulent. This makes the design of plate heat exchanger using empirical correlations to deviate from actual. Sometimes the flow medium cannot distribute uniformly which affects the performance of plate heat exchanger. The findings from this work enhanced the current knowledge in plate heat exchangers. This script is focused on the study of one corrugated type of gasketed-plate heat exchanger which is used in local dairy industry. These experimental data were used to find the optimized condition to operate heat exchanger in dairy industries.

KEYWORDS

Plate Heat Exchanger, Design parameters, Optimization, Dairy processes

Introduction

Typical applications involve heating or cooling of a fluid stream of concern and evaporation or condensation of single or multi component fluid streams [1]. In other applications, the objective may be to recover or reject heat, or sterilize, pasteurize, fractionate, distill, concentrate, crystallize, or control a process fluid. In a few heat exchangers, the fluids exchanging heat are in direct contact by the arrangement of Heat Exchanger. In most heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of a wall in a transient manner. In several heat exchangers, the fluids are separated by a heat transfer surface, and ideally, they do not mix or leak. Such exchangers are referred to as direct transfer type, or simply recuperators. In contrast, exchangers in which there is intermittent heat exchange between the hot and cold fluids via thermal energy storage and release through the exchanger surface or matrix are referred to as indirect transfer type, or simply regenerators. Such exchangers usually have fluid leakage from one fluid stream to the other, due to pressure differences and matrix rotation/ valve switching [2]. Common examples of heat exchangers are shell-and tube exchangers, automobile radiators, condensers, evaporators, air preheaters, and cooling towers. There could be internal thermal energy sources in the heat exchangers, such as in electric heaters and nuclear fuel elements. Combustion and the chemical reaction may take place within the heat exchanger, such as in boilers, fired heaters, and fluidized-bed exchangers,etc. Some mechanical devices may also be used in some exchangers such as in scraped surface exchangers, agitated vessels, and stirred tank reactors [14].

Dairy industries consumed energy for milk pasteurization process. For this process, it used Heat exchangers, Boilers, compressors and various other energy consuming devices. Energy saving can be performed at the dairy for stated devices. Heat Exchanger is a device that is used to transfer thermal energy between two or more fluids, between a solid surface and a fluid, or between solid particulate and a fluid, at different temperature and at thermal contact. Plate type Heat Exchanger is a compact device used to transfer heat in Dairy industries. The plate heat exchanger can be used to improve the performance of energy usage.

Content

In the literature review, the results of extensive literature research in the field of heat transfer enhancement in dairy industries are presented. The literature review includes numerical as well as the experimental work undertaken from time to time along with the development of the plate type heat exchanger for enhancing the heat transfer rate. The experiment and detailed study on these Heat exchangers is also included in this chapter:

Literature Review

Gajanan et al. (2016) carried out the experiments on corrugated plate heat exchanger (PHE) for water as both hot and cold fluids. The experiments were conducted for 30° corrugation angle with 15 mm channel spacing hot fluid and 5 mm spacing of cold fluid. The thermal analysis and pressure drop calculation were done for different cold channel spacing's of 2.5 mm, 5 mm, 7.5 mm, 10 mm, 12.5 mm and 15 mm with fixed corrugation angle 30°. It was found that the heat transfer rate and pressure drop decreases as channel spacing increases, also heat transfer rate and pressure drop increases as the corrugation angle increases.

Fatih Akturk et al. (2015) designed and constructed a gasketed-plate heat exchanger (GPHE) test set-up to perform experimental measurements for thermal and hydrodynamic performance analyses of plate heat exchangers. This study showed that every plate design needs its specific correlations for heat transfer and pressure drop calculations.

Vishal et al. (2013). analyzed experimental heat transfer data for single phase flow configurations in a corrugated plate heat exchanger for different chevron angle plates. The effect of variation of chevron angles with other geometric parameter on the heat transfer coefficient will be studied. Reynolds number ranging from 50 to 10000 and Prandtl number ranging from 3 to 75 will be taken for a given experiment. Based on the experimental data, a correlation will estimate for Nusselt number as a function of Reynolds number, Prandtl number and chevron angle. Experiments were performed to measure the temperature and mass flow rates at all port with varying flow condition.

Dardour et al. (2009). presented a theoretical analysis of a concurrent plate heat exchanger and the results of its numerical simulation. Knowing the hot and the cold fluid streams inlet temperatures, the respective heat capacities and the value of the overall heat transfer coefficient, a 1-D mathematical model based on the steady flow energy balance for a differential length of the device is developed resulting in a set of N first order differential equations with boundary conditions where N is the number of channels. For specific heat exchanger geometry and operational parameters, the problem is numerically solved using the shooting method.

O Rielly et al. (2017) analyzed energy usage across dairy processing co-operatives around Ireland. The comparative analysis for several dairies has been performed. Its aims to support the dairy co-operatives dealing with a new horizon of energy consumption in various departments of dairy by benchmarking the present day energy usages of seven large processing co-operatives unit. It is achieved by gathering, compiling and assessing the energy and production data. This process identified and compared the high energy consumed sections of Dairy.

Jamal, & Syahputra, (2016) presented a model of the heat exchanger temperature control using an artificial intelligence approach. Artificial intelligence based controllers used in this study is a fuzzy logic controller. The heat exchanger is a device used to perform the process of mixing a fluid having a different temperature. The temperature control becomes very important. Fuzzy logic control is applied to the heat exchanger so that the mixed fluid having a constant temperature. Model of fuzzy logic control in this study combined with neural network techniques. The results show that the control of the fuzzy logic controller capable of stabilizing the temperature of the heat exchangers well.

Soufiyan et al. (2009) undertakes a detailed exergy analysis of an industrial-scale yogurt drink production plant using actual operational data. Exergy efficiency and exergy destruction rate of each subcomponent of four main subsystems of the plant. The analysis was performed to quantify thermodynamic inefficiencies of all subcomponents of the plant in order to identify the breakthrough points for further energy savings. This survey of the plant can be an important step for future improvements of dairy processing plants from the sustainability and productivity viewpoints. This study clearly showed the effectiveness of exergy analysis for determining irreversibilities and losses occurring in dairy processing plants in order to improve their thermodynamic performances.

Taghizadeh-Tabari, Heris, Moradi, & Kahani, (2016) studied a Plate Heat Exchanger to increase its efficiency by using Nanofuilds, as it is a very important thermal component used in Dairy Industries. The Test rig for investigation of thermal parameters is used. In order to evaluate the positive and negative aspects of the nanofluid applications in the PHE simultaneously, a parameter of performance index was introduced, and the results confirmed the potential of this type of nanofluid in PHE, by looking at the ratio of convective heat transfer enhancement to the pressure drop.

Conclusions derived from Literature Review

It was observed from the literature that for the heat exchanger analysis, researchers have considered various options for the augmentation of thermal performance. The present computational fluid dynamics research work was undertaken to explore the effect on heat exchanger performance.

Literature shows fluid flow arrangements and designs in PHE for the analysis are studied: The aim of the analysis /is to compare the effect of the different arrangements in Plate Heat Exchanger to know the performance of it in various conditions.

The performance of PHE can be improved by analyzing it, so it is scope to find energy conservation in PHE. So, this analysis can be used in dairy industries to reduce energy consumption by energy conservation.

Aim

The following aims should be fulfilled by the present study:

1. To identify, understand, evaluate, interpret & report on energy usage by milk section of local dairy.
2. To study the experimental analysis of Plate type heat exchanger in dairy.
3. To study on the sizing & rating of in milk section of Plate type heat exchanger.
4. To conserve the energy use by the plate heat exchanger.

Material and Method

Experiment on Heat exchanger:

To understand the sizing process of the plate heat exchanger (PHE), an experiment has been done at University.

Description of Apparatus:

The apparatus consists of Plate type exchanger with two control valves. The arrangement is provided to run one exchanger at one time. Valves are provided to control the flow rate of hot and cold water. For flow measurement, Rota meter are provided at the inlet of cold water and outlet of the hot water line. A magnetic drive pump is given to circulate the hot water from a recycled type water tank, which is fitted with a heater and digital temperature controller.

Utilities required for the Experiment:

- Electricity supply: Single phase, 220 V AC, 50 Hz, 32 Amp MCB with earth Connection.
- Water supply: Continuous @ 5 LPM at 1 Bar.
- Floor drain required.
- Floor area required: 1.5 m x 1.0 m.

Experimental procedure:

1. *Starting Procedure:*
    - Close all the valves.
    - Open the lid of the hot water tank, fill the tank with water and put the lid back to its position.
    - Ensure that switches given on the panel are at OFF position.
    - Connect electric supply to the set up.
    - Set the desired water temperature in the DTC by operating the increment or decrement and set button of DTC.
    - Open by pass valve and switch ON the pump.
    - Switch ON the heater and wait till the desired temperature achieves.
2. *Procedure for plate type exchanger:*
    - Connect cooling water supply to the set up.
    - Connect the outlet of cooling water from the heat exchanger to drain.
    - Connect cold water pipe line at cold water inlet of the exchanger.

- Open the cold water inlet valve for circulation of cold water and adjust the Flow rate.
- Connect the hot water pipe line at hot water inlet of the exchanger.
- Allow hot water to flow through the heat exchanger and adjust the flow rate by the Control valve & by-pass valve.
- At steady state (constant temperature) record the temperatures & flow rate of hot and cold water.
- Repeat the experiment for a different flow rate of hot & cold water.
- Repeat the experiment for the different temperature of hot water.

The following readings of observation table have been taken by using an experimental procedure stated above:

Sr. No.	Hot Water Side			Cold Water Side		
	Flow rate, F_H (LPH)	Inlet Temperature T1 (°C)	Outlet Temperature T2 (°C)	Flow rate, F_C (LPH)	Inlet Temperature T3 (°C)	Outlet Temperature T4 (°C)
1.						

TABLE 1. Observation table for an experiment on Plate type Heat Exchanger at University

By using details of table Heat transfer rate, LMTD and overall heat transfer coefficient can be calculated from the following equations:

$T_H = (T_1+T_2)/2$, (°C)

$T_C = (T_3+T_4)/2$, (°C)

The properties of both fluids like specific heats and densities at temperature T_H and at temperature T_C from data book.

Area of plates (A_p) = Numbers of Plates (N) × Length of the plate (L) × Width of Plate (B), (m^2)

$\Delta T_i = T_1 - T_3$, (°C)

$\Delta T_O = T_2 - T_4$, (°C)

$Q = M \times C_p\,(T_o - T_i)$

$$\Delta T_m = \frac{\Delta T_o - \Delta T_i}{\ln \frac{\Delta T_o}{\Delta T_i}}$$

$$U = \frac{Q}{A\Delta T_m}$$

By performing the various practical parameters of hot and cold fluid and the overall heat transfer coefficient can be found. The value of log means temperature difference can also be found. The same procedure was performed at the dairy to find an overall heat transfer coefficient of the chiller.

Analysis of Chiller at Dairy

The design of gasketed-plate heat exchangers is highly specialized in nature considering the variety of designs available for the plates and arrangements that may possibly suit various duties. Unlike tubular heat exchangers for which design data and methods are easily available, a gasketed-plate heat exchanger design continues to be proprietary in nature. Manufacturers have developed their own computerized design procedures applicable to the exchangers that they market.

The chiller at dairy has two inlets and two outlets of the milk and water .The pasteurized milk cooled by the cold water which is as shown in figure 2. The pasteurized milk cooled by the cold water which is as shown in the figure in the SCADA system, which is utilized to control the performance of Plate type Heat Exchanger[8].

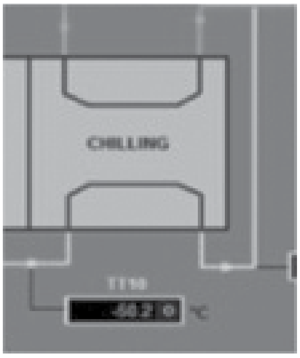


FIGURE 1. Chiller at Dairy

Supervisory Control and Data Acquisition is a control system architecture which uses the computers, networked data communications and graphical user interfaces for high-level process supervisory management, but uses other peripheral devices such as a programmable logic controller and discrete PID controllers to interface with the process plant or machinery.

The milk inlet temperature T_1 and milk outlet temperature T_2 are found from raw milk temperature. The heat transfer and effectiveness is also calculated by the following procedure for each and every reading.

For every reading,

- Temp of milk entering the cooling section,

  $T_1 = t_p - (t_p - t_r)\,\eta_r$
- Temp of milk leaving the cooling section, T_2

  Heat transfer, $Q_1 = m_h \times C_{ph} \times (T_1 - T_2)$
- Temp of water entering the chiller, T_3
- Temp of water leaving the chiller, T_4
- Hot side heat transfer, $Q_2 = m_h \times C_{ph} \times (T_4 - T_3)$
- Heat transfer area of the plate, A

  $\Delta T_1 = T_1 - T_4$

  $\Delta T_2 = T_2 - T_3$
- Logarithmic mean temperature difference,

$$LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)}$$

The heat transfer of chevron gasketed-plate heat exchanger is evaluated. The heat transfer enhancement will strongly depend on the chevron inclination angle ß, relative to the flow direction. Heat transfer and the friction factor increase with ß.

- Total heat transfer,

$$Q = \frac{Q_1 + Q_2}{2}, \text{ w}$$

- Overall heat transfer coefficient,

$$U = \frac{Q}{(A \times LMTD)}, \text{ w/m}^2\text{°C}$$

- Number of Transfer Unit,

$$NTU = \frac{U \times A}{m_h \times C_{ph}}$$

- Capacity ratio,

$$C = \frac{m \times C_h}{m \times C_c}$$

- Effectiveness,

$$E = \frac{1 - e^{(1-C)} \times NTU}{(1 - C \times e^{(1-C)} \times NTU)}$$

The performance of a chevron plate heat exchanger depends upon the surface enlargement factor corrugation profile, channel aspect ratio, $2b/P_C$, gab b, the temperature dependent physical prop¬erties and especially the variable viscosity effects.

Attempts have been made to develop heat transfer and pressure-drop correlations for use with given plate heat exchangers. In this exchanger, the fluids are much closer to countercurrent flow. The construction and geometry of plate used in the heat exchanger at the dairy are illustrated by the following figures. Total 109 numbers of identical plates are used in pasteurizer. These plates are closely spaced and are made up of SS316 material.

The rating of given Heat exchanger evaluated by following formulas [2]:

1. Effective number of the plate (N_e)

$N_e = N_t - 2 = 109 - 2$

N_t = Number of total plate

= 107

2. Effective flow length (L_{eff})
3. Plate pitch (p) p = b + t
4. One channel flow area (A_{ch}), $A_{ch} = b \times L_w$
5. Single plate heat transfer area (A_p)

$$A_p = \frac{\text{whole plate area}}{\text{No. of plate}}$$

= Projected area

6. The corrugations increase the surface area of the plate as compared to the original flat area of the plate. To determine the increase of the developed length in relation to projected length, a surface enlargement factor Ø, is then defined as the ratio of the developed length to the flat or projected length.

Enlargement factor (Ø)

$$Ø = \frac{\text{DEVELOPED LENGTH}}{\text{PROJECTED LENGTH}}$$

7. The hydraulic diameter of the channel D_h is defined as

$$D_h = \frac{4 \times \text{channelflowarea}}{\text{wettedperimeter}} = \frac{4A_C}{P_w}$$

$$D_h = \frac{4\,(b)(L_w)}{2\,(b + L_w)} \approx \frac{2b}{Ø}$$

8. Number of channel per pass (N_p)

$$N_{cp} = \frac{N_t - 1}{2N_p}$$

The Pressure drop, mass velocity, and other non-dimensional numbers can be found for hot and cold fluid. From that data, some important conclusions have been derived.

9. Mass velocity (G_{ch})

$$G_c = \frac{m}{b \times L_w}$$

10. Reynolds number (R_e)

$$R_{ec} = \frac{G_c D_h}{\mu}$$

11. Nusselt number (N_u)

$$Nu = \frac{hD_h}{k} = C_h \left[\frac{D_h G_c}{\mu}\right]^n \left[\frac{C_p \mu}{k}\right]^{1/3}$$

12. Heat transfer co-efficient (h)

$$h_c = \frac{Nu_c k}{D_h}$$

13. Pressure drop analysis

The total pressure drop is composed of the frictional channel pressure drop Δp_c and the port pressure drop Δp_c. The friction factor f f is defined by the following equation for the frictional pressure drop Δp_c.

$$\Delta p_c = 4\,f\,\frac{L_{eff} N_p}{D_h}\,\frac{G_c^2}{2\rho}\left(\frac{\mu_b}{\mu_w}\right)^{-0.17}$$

Where L_{eff} is the effective length of the fluid flow path between inlet and outlet ports and must take into account the corrugation enlargement factor Ø this effect is included in the definition of friction factor. Therefore, $L_{eff} = L_V$ which is the vertical part distance, the friction factor is given by,

$$f = \frac{K_p}{Re^m}$$

14. Port pressure drop

The pressure drop in the port ducts

$$\Delta p_p = 1.4 N_p \frac{G_p^2}{2\rho}$$

Where,

$$G_p = \frac{m}{\frac{\pi D_p^2}{4}}$$

Where m is the total flow rate in the port opening and D_P is the port diameter.

15. The total frictional pressure drop

$$(\Delta p_t) = (\Delta p_c)_h + (\Delta p_p)_h$$

$$(\Delta p_t) = (\Delta p_c)_c + (\Delta p_p)_c$$

16. Overall heat transfer without fouling

$$\frac{1}{U_c} = \frac{1}{h_h} + \frac{1}{h_c} + \frac{t}{k_w}$$

17. Overall heat transfer with fouling

$$\frac{1}{U_c} = \frac{1}{h_h} + \frac{1}{h_c} + \frac{t}{k_w} + R_{fh} + R_{fc}$$

FIGURE 3. Plate construction of Heat Exchanger

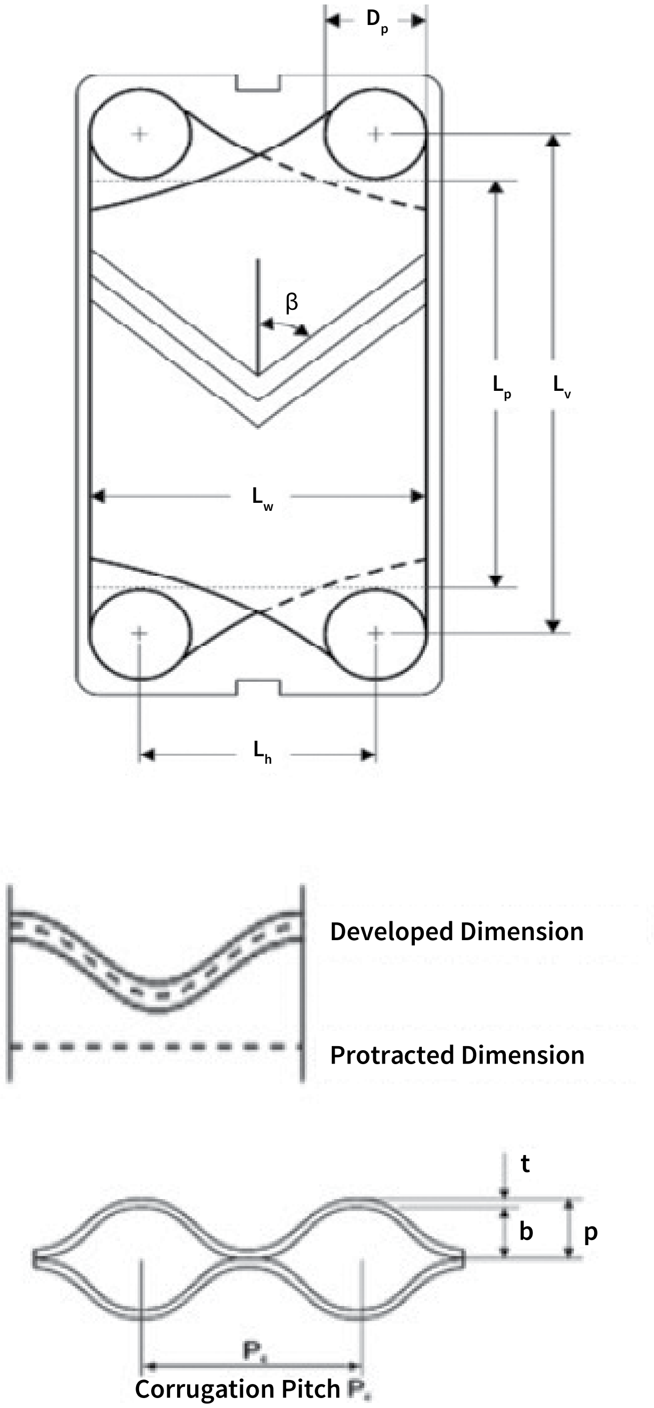


FIGURE 2. Plate Geometry

From the above stated formulas sizing and rating of Plate heat exchanger has been found [2]. The overall heat transfer coefficient, Pressure drop, Thermal properties and various other parameters for heat exchanger were measured. To analyze the performance of heat exchanger numbers of readings of temperatures and mass flow rates are measured over a period of time [11].

This study shows the detailed analysis of plate Heat Exchanger and the optimization technique used in this study would be future work. The optimization technique used to optimize the overall heat transfer coefficient.

Result and Discussion

By taking readings at the dairy the following graphs are generated, which is used to derive the conclusions.

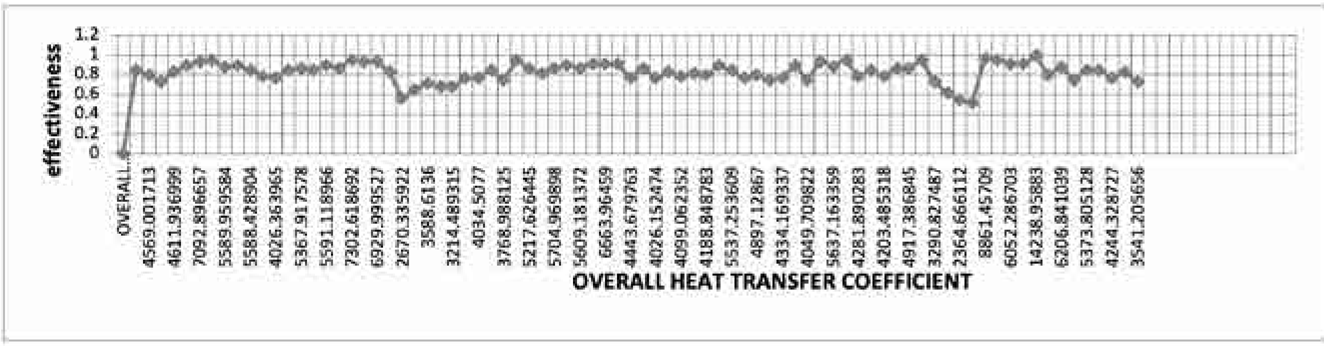


FIGURE 4. Graph between overall heat transfer coefficient vs effectiveness for plate type heat exchanger

The graph between overall heat transfer coefficient vs. effectiveness is used to define the working condition of the plate heat exchanger. For the complete analysis of plate heat exchanger pressure drop and mass flow rate of hot and cold fluid were shown on the graphs as given below.

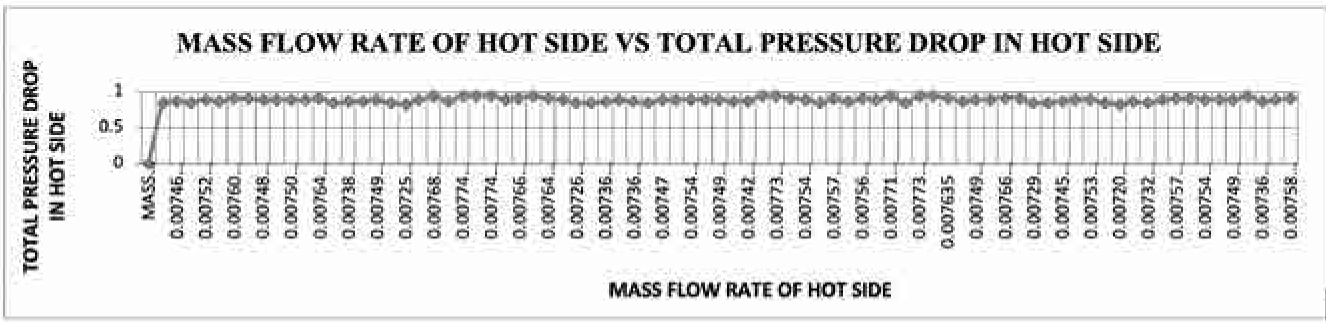


FIGURE 5. Graph between Mass Flow rate of the hot fluid (Milk) VS Pressure drop in hot fluid for Plate Type Heat Exchanger

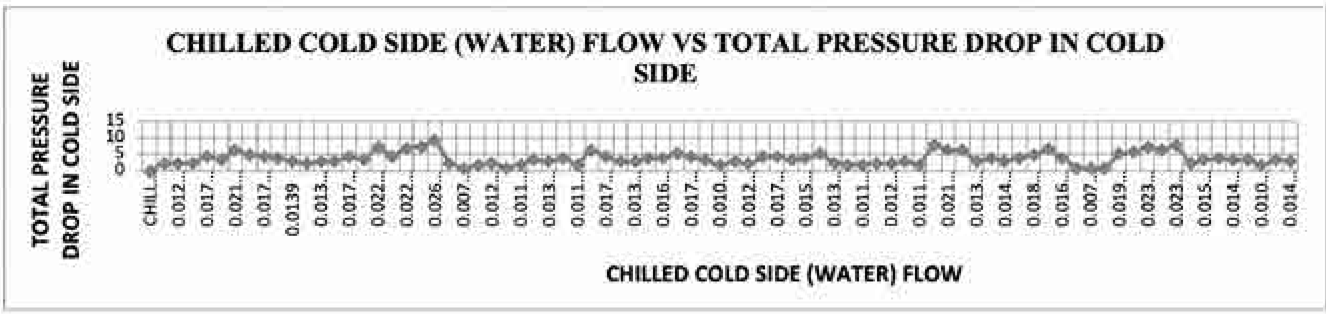


FIGURE 6. Graph between Mass Flow rate of the cold fluid (chilled water) VS Pressure drop in cold fluid for Plate Type Heat Exchanger

Also, non dimensional numbers like Reynolds number and Nussle numbers are also considered for the study. The further analysis of the Plate type exchanger can be performed to improve the productivity and sustainability of Dairy [12].

The following table is prepared for each and every reading which has been taken during the experiment on Plate Type Heat Exchanger.

Result Table for one reading

The effective number of the plate (N_e)	107
Effective flow length (L_{eff})	1.227m
Plate pitch (p)	4mm
Number of channel per pass (N_p)	52
Mass velocity (G_{ch})	G_c=9.961m/s G_h= 5.557 m/s
Reynolds number (R_e)	R_{ec} = 27150 R_{eh} = 13694
Nusselt number (N_u)	Nu_C = 602.9 Nu_h = 331.64
Heat transfer co-efficient (h)	h_c = 52352.08 W/m^2.k h_h = 2046.67 W/m^2.k
Pressure drop analysis	P_c = 1.74 bar P_h = 0.717 bar
Port pressure drop	P_{pc} = 0.76 bar P_{ph} = 0.2433 bar
Total frictional pressure drop	P_{th} =0.9603 bar P_{tc} = 2.5 bar
Overall heat transfer without fouling	10141.88 w/m^2 .k
Overall heat transfer with fouling	9868.65 w/m^2 .k

TABLE 2. Result table for Plate Heat Exchanger

Above stated graphs are used to derive the following conclusions.

Conclusion:

After completion of all experimentation and calculation work on the corrugated plate type heat exchanger the preeminent mass flow rate & temperature readings of both fluids could be determined, so the maximum heat transfer coefficient can be achieved which leads to energy savings.

The optimum condition has been derived from running the Heat exchanger where heat transfer co efficient is 14238.95 w/m^2.K with the effectiveness of 0.9964 with a temp of milk inlet and outlet 13.8°C and 4°C as well as chilled water temp of inlet and outlet are 18°C and 10.28°C.

The following conclusions are also derived from this study:

1. From the result, it can be finding out that Reynolds's number changes the variation in pressure drop occurred.
2. It has been noticed that during varying the mass flow rate of the hot side (Milk) fluid the changes in a pressure drop on hot side fluid (Milk) is notice approximately the same.
3. On the same, if the variation is occurred in the mass flow rate of cold side fluid (water), the changes in pressure drop are high, so it leads to loss of the energy of the flui though the mass flow rate on the cold side fluid should be constant or may not fluctuate during the process.

Acknowledgment

We express our deep sense of gratitude to Mr. Vishal P. Bhagatwala, Assistant Professor of F.E.T.R, Bardoli for providing precious guidance and inspiring discussion.

Gajanan D, S. Premkumar D, B. Sreedhara Rao, R.C. Sastry (2016). Optimization of channel spacing for the heat transfer performance of corrugated plate heat exchangers. 2395 -0056.

Fatih Akturk*, Nilay SEZER-UZOL**, Selin ARADAG** and Sadik KAKAC(2015). Experimental Investigation and Performance Analysis of Gasketed-Plate Heat Exchangers. 1300-3615.

Vishal R. Naik, V.K. Matawala(2013). Experimental Investigation of single phase Chevron Type Gasket Plate Heat Exchanger.

Dardour. H., S. Mazouz, and A. Bellagi (2009). Numerical Analysis of Plate Heat Exchanger Performance in Co-Current Fluid Flow Configuration. IJPMS magazine

Xie, G.N., B. Sunden, Q.W. Wang (2008) Optimization of compact heat exchangers by a genetic algorithm. Applied Thermal Engineering 28 895–906.

Jamal, A., & Syahputra, R. (2016). Heat Exchanger Control Based on Artificial Intelligence Approach. International Journal of Applied Engineering Research (IJAER), 11(16), 9063-9069.

Taghizadeh-Tabari, Z., Heris, S. Z., Moradi, M., & Kahani, M. (2016). The study on application of TiO2/water nanofluid in plate heat exchanger of milk pasteurization industries. Renewable and Sustainable Energy Reviews, 58, 1318-1326.

Soufiyn, M. M., & Aghbashlo, M. (2017). Application of exergy analysis to the dairy industry: A case study of yogurt drink production plant. Food and Bioproducts

Processing, 101, 118-131.

O'Reilly, A. J. (2017). Dairy processing heat and energy recovery: an analysis of energy usage within the dairy processing sector in Ireland.

Soufiyan, M. M., & Aghbashlo, M. (2017). Application of exergy analysis to the dairy industry: A case study of yogurt drink production plant. Food and Bioproducts Processing, 101, 118-131.

Taghizadeh-Tabari, Z., Heris, S. Z., Moradi, M., & Kahani, M. (2016). The study on application of TiO2/water nanofluid in plate heat exchanger of milk pasteurization industries. Renewable and Sustainable Energy Reviews, 58, 1318-1326.

Ramesh K. Shah,Dusan P. Sekulic(2003). Fundamentals of Heat Exchanger Design.

References

Gajanan D, S. Premkumar D, B. Sreedhara Rao, R.C. Sastry (2016). Optimization of channel spacing for the heat transfer performance of corrugated plate heat exchangers. 2395 -0056.

Fatih AKTURK*, Nilay SEZER-UZOL**, Selin ARADAG** and Sadik KAKAC(2015). Experimental Investigation and Performance Analysis of Gasketed-Plate Heat Exchangers. 1300-3615.

Vishal R. Naik, V.K. Matawala(2013). Experimental Investigation of single phase Chevron Type Gasket Plate Heat Exchanger.

Dardour. H., S. Mazouz, and A. Bellagi (2009). Numerical Analysis of Plate Heat Exchanger Performance in Co-Current Fluid Flow Configuration. IJPMS magazine

Xie, G.N., B. Sunden, Q.W. Wang (2008) Optimization of compact heat exchangers by a genetic algorithm. Applied Thermal Engineering 28 895–906.

Jamal, A., & Syahputra, R. (2016). Heat Exchanger Control Based on Artificial Intelligence Approach. International Journal of Applied Engineering Research (IJAER), 11(16), 9063-9069.

Taghizadeh-Tabari, Z., Heris, S. Z., Moradi, M., & Kahani, M. (2016). The study on application of TiO2/water nanofluid in plate heat exchanger of milk pasteurization industries. Renewable and Sustainable Energy Reviews, 58, 1318-1326.

Soufiyn, M. M., & Aghbashlo, M. (2017). Application of exergy analysis to the dairy industry: A case study of yogurt drink production plant. Food and Bioproducts Processing, 101, 118-131.

O'Reilly, A. J. (2017). Dairy processing heat and energy recovery: an analysis of energy usage within the dairy processing sector in Ireland.

Soufiyan, M. M., & Aghbashlo, M. (2017). Application of exergy analysis to the dairy industry: A case study of yogurt drink production plant. Food and Bioproducts Processing, 101, 118-131.

Ramesh K. Shah,Dusan P. Sekulic(2003). Fundamentals of Heat Exchanger Design.

Niyant P. Thakkar, Mithilesh Kumar
Uka Tarsadia University, Department of Mechanical Engineering, Surat, India

Nomenclature

U	Overall heat transfer coefficient, W/m^2 °C
T	Temperature of fluid
M	Mass flow rate of fluid
C_p	Specific heat of fluid
ΔT_m	Log mean temperature difference
ΔT	Temperature difference
A	Area of given object

Subscripts

0	Reference value
i	Reference value

Greek Symbols

€	NTU Effectiveness

Non-dimensional Numbers

Re	Reynolds number, [UD/]
Nu	Nusslet Number, [hL/k]

2

STUDY OF PLATE HEAT EXCHANGER PERFORMANCE WORKING WITH THREE TYPES OF REFRIGERANTS EXPOSED TO HOT AIR FLOW

Mustafa Ahmed Abdulhussain

University of Technology, Department of Mechanical Engineering, Baghdad, Iraq

ABSTRACT: The thermal effectiveness of plate heat exchanger exposed to uniform hot air flow working with three Refrigerants (R134a, R290 and R513a) that are heat exchanged with cold water assuming constant flow rate have been calculated via the AUTODESK CFD 2019 package using the standard K-ε turbulence model, the variation effect of the Refrigerants inlet temperature range (35-50)°C on the effectiveness is investigated considering the hot air flow inlet temperature range between (45-50)°C. The results showed that the PHE effectiveness is maximumly decreased by (14%) for the R513a and by (17%) and (19%) for R134a and R290, respectively.

KEYWORDS

Plate heat exchanger, Hot air flow, Effectiveness evaluation

Introduction

One of the most efficient heat exchangers that are the best alternative ones to the shell and tube type in the mobile and the compact air-conditioning units is the plate heat exchanger (PHE) [4] due to its small size, and efficient heat exchange rate consists of several pressed metal chevron or pillow plates with or without adjusting hard rubber gaskets between them. J.F. Seara et al. [1] implemented an experimental evaluation of the heat transfer rate and the overall heat transfer coefficient of the water-water ethylene mixture in the titanium brazed offset strip fins PHE. They developed a general correlation for the heat transfer coefficient in PHE channels in terms of Reynolds number for isothermal outbound conditions, and the overall heat transfer coefficient increased with increased fluids mass flow rate.

The Hydro Fluro Olefins (HFO's) refrigerants attains high heat transfer rate, non-flammability and lower pressure drop are the R1234yf-ze Refrigerants where several researches have been performed to evaluate their performance and formulate convection heat transfer correlations. J. Zhang et al. [2] performed experimental tests on the brazed PHE working as an evaporator in an organic Rankin cycle using the HFO's in addition to the HFC R134a, they measured the boiling heat transfer coefficient and the pressure decrease for variable inlet saturation conditions, mass flux and attained outlet vapor qualities. They developed an evaporation correlation for the heat transfer coefficient.

The PHE thermal effectiveness is calculated numerically using the NTU method in parallel flow process by H. Dardour et al. [3] using water liquid as the hot and the cold fluid. The numerical solution is performed using the Runge-Kutta method involving Newton Raphson convergent criteria. The results showed that the effectiveness is decreased with the increased thermal flow rate ratio of the heat-exchanged fluids, while it remains nearly constant for NTU greater than [4].

The main objective of the present research is to evaluate the typical PHE thermal effectiveness (using the NTU method) subjected to forced convection by means of uniform hot air flow from both sides of the plates with variable inlet temperature range from (45-50°C), considering three types of Refrigerants in a superheated state; R134a, R290 and the (R1234yf/R134a) mixture R513a, respectively. The heat exchange of the Refrigerant passage flow through the HE will be with cold water by adopting the counter-flow process, the CFD numerical simulation solution is performed using the AUTODESK CFD 2019 student version considering the K-ε as the turbulence model considering the refrigerants inlet temperature range between (35-50)°C.

Heat exchanger geometry

The chevron non-corrugated pattern shape of seven plates typical heat exchanger with stainless steel 316 material selection and inserted nitrile hard rubber gaskets between each plate is sketched using the Solidworks CAD 2016 shown in Fig. (1). Table (1) denotes the geometry main selected dimensions for the PHE.

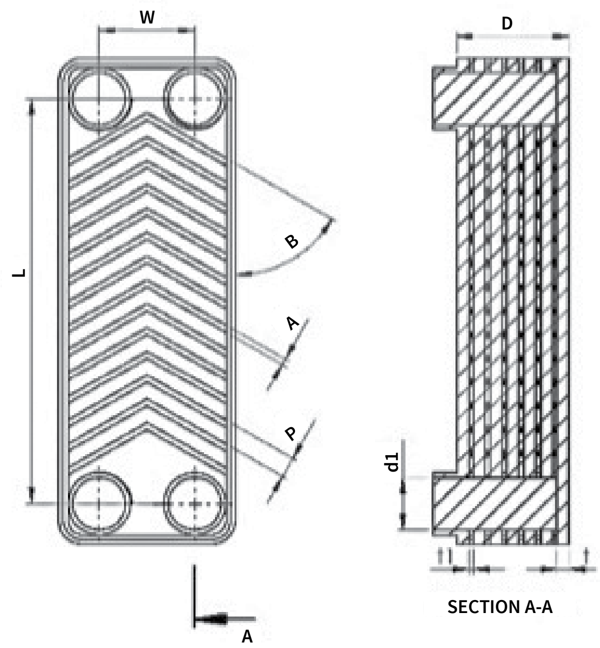


FIGURE 1. PHE geometry

Dimension	Value (m)
Chevron thickness (A)	1.227m
Chevron angle (B)	60°
PHE depth (D)	0.05
Flow inlet diameter (d1)	0.02
Inlet/outlet height (L)	0.17
Chevron pitch (P)	0.01
Plate thickness (t)	0.01
Gasket thickness (t1)	0.002
Refrigerant/water inlet width (W)	0.05

TABLE 1. PHE main dimensions

Solution methodology

Prior to evaluate the PHE thermal effectiveness, it is necessary to simulate the heat exchange process transitionally until reaching the steady-state condition. The continuity, momentum, the energy in addition to the K-ε turbulence model is utilized to calculate the flow domains, where the counter flow process has been adopted as shown in Fig. (2). The external air flows normal to the both sides of the heat exchanger plates and exits upwards the PHE.

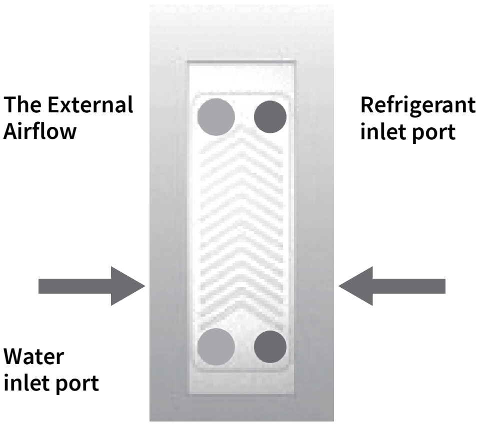


FIGURE 2. The fluids flow adopted directions

Numerical Simulation Procedure

Geometry Mesh Generation

The PHE with the three fluids flow volumes have been meshed using the tetrahedrons method with automatic sizing and activation of surfaces refinement option, the total mesh statistics were more (410K) nodes and (1280K) elements, respectively.

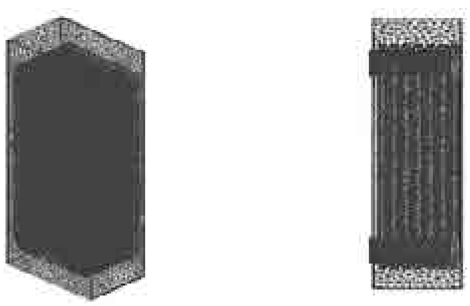


FIGURE 3. The generated mesh PHE

Applying Turbulence Model

The standard K-ε turbulence model differential equations is utilized to calculate the flow turbulence using the finite element method.

$$\frac{\partial(\rho K)}{\partial t}+\frac{\partial}{\partial x}(\rho UK)=\frac{\partial}{\partial x}\left[\left(\mu+\frac{\mu_c}{\sigma_k}\right)\frac{\partial K}{\partial x}\right]+P_k-\rho\varepsilon \quad (1)$$

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial}{\partial x}(\rho U\varepsilon)=\frac{\partial}{\partial x}\left[\left(\mu+\frac{\mu_c}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x}\right]+\frac{\varepsilon}{K}[C_{\varepsilon1}P_\varepsilon-C_{\varepsilon2}\rho\varepsilon] \quad (2)$$

Assigning Boundary Conditions

It is necessary to assign the inlet conditions of the internal (water/Refrigerant) flow and the out-bonding air in addition to the convection heat transfer coefficient with the PHE surfaces as well as the initial PHE volume temperature, then the transient solution is adopted until reaching the steady state condition. Table (2) denotes the estimated boundary conditions for the simulated case.

Flow domain	Inlet condition	Temperature (°C)	Pressure (KPa)
Refrigerant	Velocity (5) m/sec	(35-50)	300
Water	Velocity (5) m/sec	(10)	atm
Air	Velocity (2) m/sec	(45-50)	atm

TABLE 2. Boundary conditions for the flow domains

To compute the film convection heat transfer for the flow field during the iteration run execution, the Wu-Little correlation is utilized in the CFD package.

$$Nu = C \times Re^a \times Pr^b \quad (3)$$

Where the values of the constants are:
C=0.0022, a=1.04 and b=0.4.

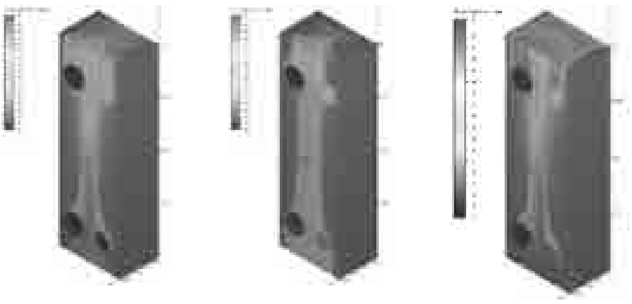
Solution scheme

The modified Petrov-Galerkin solution method is selected as the turbulence modeling advection scheme in the iteration procedure setting the residual target for the numerical solution to (1e-3) in the governing equations.

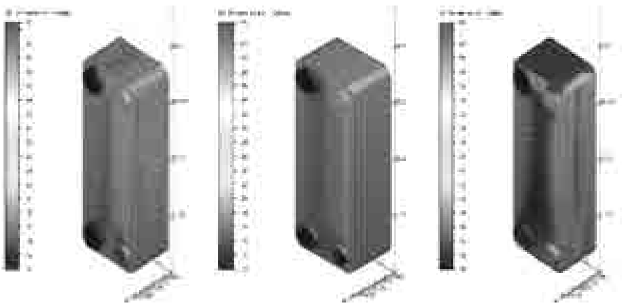
Results and discussion

PHE transient response:

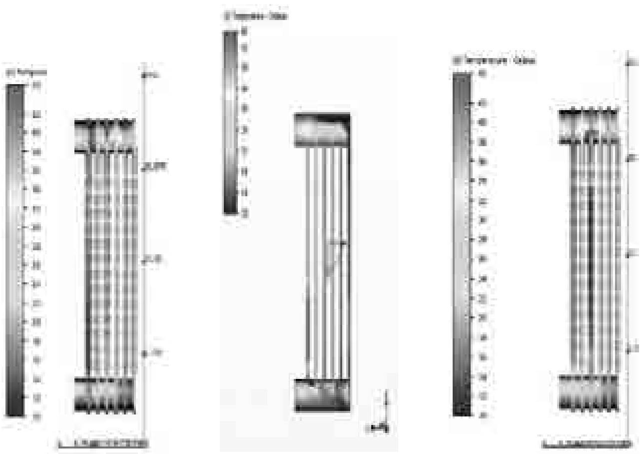
Figs. (4-9) demonstrates the transient heat exchange for the air flow at (45°C) with the PHE body and the cooling water effect for 12 seconds of simulation using the R134a noticing increased gradual heating on the PHE side and upper surfaces, while the water cooling becomes more significant with the passage of time. Figures (10-12) represent the comparison between the Refrigerants subcooling (R134a, R290 and R513a) with water after reaching the steady-state condition. The R513a refrigerant gives relatively better subcooling degree (12)°C to the traditional R134a and the propane gas R290 (10-9)°C.



FIGURES 4-6. Transient response for the air flow with time



FIGURES 7-9. PHE transient response with time



FIGURES 10-12. R134a, R290 and R513a T-contours

Thermal effectiveness calculation:

The PHE effectiveness (η) is defined as the percentage ratio of the Realistic to maximum permissible heat transfer rate between the cold and the hot flow streams, [3] is represented by:

$$\eta = \frac{m_H \times C_{pH} (\Delta T_H)}{m_{min} \times C_{pmin} (\Delta T_{in})} \quad (4)$$

Table.3 shows the calculated PHE effectiveness subjected for the air temperature range (40-50)°C for corresponding Rerigerants inlet temperature (35-50)°C taking into consideration constant velocity for the three incorporated fluids flow. From the tabulated results, it is obvious that the effectiveness is lowest afftected with utilizing R513a as the ambient temperature rises up, while the two other refrigerants gives nearly equivalent result. Also, the increase in inlet refrigerant temperature had caused a gradual decline in the PHE effectiveness that's for the dual heating effect from both sides of the PHE.

Tair (°C)	R134a		R290		R513a	
	Tin	η	Tin	η	Tin	η
40	35	0.84	35	0.81	35	0.86
	42	0.75	42	0.72	42	0.79
	50	0.70	50	0.68	50	0.74
45	35	0.78	35	0.76	35	0.81
	42	0.71	42	0.69	42	0.75
	50	0.68	50	0.66	50	0.71
50	35	0.71	35	0.69	35	0.75
	42	0.63	42	0.59	42	0.68
	50	0.58	50	0.55	50	0.67

TABLE 3. Effectiveness calculation results

Solution validation:

The comparative evaluation of the Refrigerant wall film heat transfer coefficient using the utilized empirical correlation Eq.(3). Table. 4 shows a percentage error range between (12-17)% for R134a inlet temperaure of 35°C when compared with the energy equation residual calculation method.

Flow Velocity	h (Wh&Little)	h (Thermal residual)
5	4623	5306
10	6237	7538

TABLE 4. Wall film heat transfer coefficient

Conclusions

1. The bounding hot air flow effect on the PHE effectiveness have a maximum of (14%) when the R513a is the working fluid and around (17&19)% for R134a and R290, respectively.
2. Both of the increased air and the refrigerants inlet temperature causes decline in the PHE effectiveness.

Acknowledgment

I give my thanks and gratitude to the AUTODESK Corporation for their valuable CFD package.

References

Seara J.F, Diz R. and Uhia F.J. (2013) Pressure drop and heat transfer characteristics of a titanium brazed plate-fin heat exchanger with offset strip fins. Applied Thermal Engineering; 51:502-511.

Zhang J., Desideri A., Kaern M.R, Ommen T.S, Wronski J. and Haglind F. (2017). Flow boiling heat transfer and pressure drop characteristics of R134a, R1234yf and R1234ze in a plate heat exchanger for organic Rankine cycle units. International Journal of Heat and Mass Transfer;18:1787-1801.

Dardour H., Mazouz S. and Bellagi A. (2009). Numerical Analysis of Plate Heat Exchanger Performance in Co-Current Fluid Flow Configuration. International Journal of Physical and Mathematical Sciences; 3:213-217.

Hesselgreaves, J.E, Law R. and Reay D.A. (2017). Compact Heat Exchangers, Selection, Design and Operation: Elsevier Ltd.

Mustafa Ahmed Abdulhussain
University of Technology,
Department of Mechanical Engineering, Baghdad, Iraq

Nomenclature

a, b	Nusselt number correlation
C	Coefficients
Cp	Specific heat (KJ/kg.°C)
h	Film heat transfer coeff. (W/m^2K).
K	Kinetic energy (Kg/m^2sec^2)
m	Mass flow rate (Kg/sec)
T	Temperature (°C)
t	Time (sec)

Subscripts

H	Hot fluid
min	Minimum value
in	Inlet flow ports

Greek Symbols

K-ε	Turbulent viscosity, kg/m.sec
ε	Dissipation of kinetic energy
σ_k, σ_ε	Turbulent model constants

Non-dimensional Numbers

Nu	Nusselt number
Pr	Prandtl number, [Cpμ/k]
Re	Reynolds number, [ρUD/μ]

3

HELIOSTAT DESIGN FOR LOW WIND TERRAIN

Rakesh Singhai[1], Dr. Nitin Banker, Dr. Harender

Department of Mechanical Engineering, Shiv Nadar University, Dadri, India

ABSTRACT: Concentrated solar thermal power tower plants (PT) have a great potential for generating electricity on a large scale for places with high DNI. They are highly relevant due to their ability to store energy in an inexpensive manner by way of high temperature thermal storage. However they are quite capital intensive. The largest capital outlay in a PT plant is on account of heliostats. Heliostats constitute 45-50% of the total cost of a PT plant and their design is highly influenced by wind loads. This paper looks at a few locations in India where the DNI is high but the wind speed is quite moderate. The analysis shows that significant cost reduction is possible by sizing and suitably redesigning the heliostats.

KEYWORDS

Heliostats, Design wind speed, Wind loads, Heliostat costs

Introduction

The demand for electricity continues to grow in developing countries like India. To keep pace with the demand, more and more thermal power plants fired by coal are being added. At the same time for environmental reasons as well as under pressure from global community for its growing greenhouse gas emissions, the renewable energy capacity is also being added. Indian government has targeted to install 100000 MW of solar capacity by the year 2022 (Ross, 2016). However solar power in India is virtually synonymous with solar photovoltaic (PV). The reason for this is the rapid reduction in the price of electricity from PV. But due to its intermittent nature, solar from PV cannot address the peak electricity demand which in any case peaks in the evenings when solar is not available. This necessitates the setting up of fossil fuel thermal plants. This means that peak demand in the grid is met almost entirely by fossil fuel plants except for some hydro and wind and solar PV only forces the fossil fuel plants to back down and thus reduce their capacity factor which in turn increases their cost per unit of electricity generated. Appropriate strategy would be to make renewable energy like solar to be available as and when demand is there, so that coal based plants can be phased out completely. As per current strategy, setting up more and more coal based plants is a necessity to meet the growing energy needs of the country. This issue can only be overcome if solar energy could be stored and supplied as per demand. This stored energy will then be put into the grid as per demand and dependence on coal plants will come down. The storage can be created in Solar PV plants too by using batteries, but this is a very expensive proposition and also the batteries need to be replaced at regular intervals ("Battery Storage for Renewables : Market Status and Technology Outlook" 2015). This makes Solar PV with storage a very expensive solution. It is in this context that the concentrated solar thermal power with storage becomes a potential alternative. Concentrated solar thermal power plants utilize a eutectic mixture of salts for storage of solar energy in the form of heat. This salt mixture is environmentally benign unlike batteries, whose disposal creates electronic waste (Way Julie, 2008). Concentrated solar thermal power plants are of two types, namely, Parabolic Trough and Power Tower (PT). Both of these can store solar energy in the form of heat and convert it to electrical energy using steam turbines.

Parabolic trough plants without storage have been widely used and capacity to produce several thousand MW is in place worldwide (Sargent & Lundy LLC Consulting Group Chicago Illinois 2003). PT is a relatively new entrant but it is also now booming with several new projects at a commercial scale in the operational and construction phase (Solar Paces 2016). However where the PT plants score immensely over the parabolic trough plants is in their ability to store thermal energy (Turchi et al. 2010). By storing thermal energy using molten salts, PT plants can be designed to operate 24 hours a day and thus be operated like a base load plant similar to a coal fired thermal power plant. PT plants could also be designed to operate for peaking power requirement and thus save capital expenditure for coal fired plants being planned. Parabolic trough plants too can store energy but because of their design involving several kilometers of horizontal pipelines, it is extremely cumbersome and unviable to use them with molten salt. Experts predict that the future belongs to PT (Turchi et al. 2010). Latest 110 MW solar tower plant at Crescent Dunes in USA, built by Solar Reserve is an excellent testimony to above prediction. It is now fully integrated into the grid and running successfully (Solar Reserve 2016). It produces power to meet demand with storage capacity of 10 hours of full rated output. This plant is already supplying power to the grid at 13.5 cents/ kWh, which is at a significant discount to earlier tower plants with typical prices of 22-25 cents/kWh. PT plants obviate the need for back up fossil fuel plants, which is a prerequisite for solar PV. However to make the PT plants a mainstay of electricity production, it is very important to further reduce the levelized cost of energy from such plants. In fact SunShot Initiative from Department of energy of USA is a well planned effort to bring the levelized cost of electricity from PT plants down to 6 cents/kWh by year 2020 and it appears that this target may actually be exceeded (Sun Shot Vision Study 2012). One of the key goals of this initiative is to bring down the cost of heliostats used in a PT plant very aggressively. This paper is an attempt in that direction. It suggests a way to reduce LCOE by bringing down heliostat field cost, which is a very large component of PT plant cost. (kolb etal., 2011). It focuses on locations in India, but is applicable at other similar locations too.

The heliostat field consists of thousands of heliostats around a high tower. They all direct the solar radiation falling on them to the tower. A heliostat is essentially a mirror which is tracked in two axes continuously to ensure that the solar radiation falling on it is directed towards the receiver located at the top of the tower. The cost of the heliostat field could be up to 40-50% of the total project cost of a tower project (Blackmon 2012).

During the literature survey, it became increasingly clear that the design of the heliostat is highly dependent on the wind loads (Murphy 1980). In fact the wind loads are the decisive factors for dimensioning of heliostats (Pfahl, Buselmeier, and Zaschke 2011). A heliostat is designed to track the sun and accurately reflect the radiation onto the receiver on a high tower. Due to the long distance between the tower and a heliostat, the accuracy of reflection has to be very high and hence, the loads on heliostat play a very important role. Among the early heliostats, 148 m2 ATS heliostat developed in late 80s was considered a good safe design as it had been used for several years and withstood extreme weather and wind loads too (Strachan and Houser 1993). Also at that time, it was felt that bigger the heliostat, lower would be the cost of heliostat field as lesser numbers of heliostats would be required for the same area (Kolb et al. 2007). But this view was challenged later by Blackmon (Blackmon 2012) who did a detailed cost analysis of the ATS heliostat. Blackmon developed algorithm to parametrically determine the heliostat cost as a function of its mirror area and determined that smaller heliostats in the range of 40-50m^2 would be much more economical.

While Blackmon looked at the area of a heliostat as an attribute to be optimized, he did not consider wind speed of a location as an equally important variable. So Blackmon found an optimum value of heliostat reflector area for standard design wind condition.

However the wind speed and its turbulence vary a great deal from place to place and since wind loads are proportional to square of wind velocity, the wind speed should be considered as another attribute while designing a heliostat.

In this paper, an attempt has been made to first identify the prevailing wind speeds at a few locations in India, where direct normal irradiation DNI is high and then apply the optimization procedure to obtain the optimum area and optimum cost per unit area of such heliostats.

Content

Methods

Input data

PT plants can only use direct normal irradiance and diffused radiation cannot be used in this technology. It is thus necessary to locate these plants in places where DNI is around 2000 kWh/year or higher (Emes, Arjomandi, and Nathan 2015). DNI data can vary significantly from place to place and before a plant is planned to be setup, at least a year's data is collected using accurate instruments like Pyrheliometer. However for our purpose of heliostat size determination, exact data is not necessary. For this research, satellite data was instead used for analysis.

National renewable energy laboratory of USA in collaboration with Ministry of Renewable Resources of India had commissioned an exercise to collect solar and other data over Indian peninsula through the use of Meteosat satellite over several years. This data is available up to year 2014 and can be freely downloaded. This satellite data for the year 2014 was used as an input to identify areas with highest DNI potential (Maps India Solar Resource 2016). The satellite data also provides hourly wind speed data and this was used to calculate the estimated wind loads in the respective locations. For a real project, it is necessary to do a detailed onsite investigation of solar radiation and atmospheric conditions over a long period of time, however the satellite data is accurate enough for our investigation of cost assessment of heliostats. Hourly data of DNI and wind speed for five locations with DNI > 2000 KWH/year was downloaded for these locations for year 2014. The Weibull probability distribution function is used to fit a frequency curve to the range of recorded data (Belhamadia, Mansor, and Younis 2013). Weibull distribution is universally used for the purpose of wind data analysis (Blackmon 2014).

Site identification

After looking at the DNI map of India, the areas of high DNI marked in deep red colour were clearly identified. Locations in Ladakh region were not considered due to inhospitable terrain there. Five locations in Karnataka, Gujarat and Rajasthan, having DNI around 2000 KWH/year are chosen and hourly wind data and DNI data are downloaded from NREL website for this analysis ("India Solar Resource Maps and Data" 2018).

Meteosat satellite data from NREL has been used for site identification. This satellite data provides hourly readings of DNI as well as wind speed for a grid of 0.10 Latitude x 0.10 Longitude viz. approximately an area of 10 km x 10 km for India. Based on the highest DNI data, a few locations with good DNI in the states of Karnataka, Gujarat and Rajasthan were selected. Satellite data for year 2014 is used for the analysis.

Wind data analysis

Wind speed plays a very important role in load on the heliostat. The load is directly proportional to square of the wind velocity. Also the load on a heliostat is dependent on its orientation. It is important to note that the heliostat need not be designed for the maximum wind speed prevalent at a location. The wind load is a function of wind load coefficient too and this coefficient varies with heliostat orientation.

During the day, the heliostat can be in any orientation due to operational requirement based upon sun position, but at night the heliostats are parked flat with their reflectors parallel to the ground. This minimizes the wind loads on heliostats as wind load coefficients are much lower in the flat position.

This ability of heliostat to go into parking position rapidly is effectively utilized to put them in parked position in case the wind speed goes above the maximum safe operating speed of the heliostats. This will cause a loss of energy in case the high wind event occurs during the day when solar radiation is available but since its probability is very low, the loss is offset by the reduction in capital cost due to lower design wind speed of heliostats. However for this analysis, only maximum wind speed has been considered as design wind speed. By choosing a design wind speed lower than maximum, further optimization is possible (Emes, Arjomandi, and Nathan 2015).

The probability of occurrence of a wind speed is determined using the Weibull probability distribution curve. Weibull probability distribution is the most appropriate statistical method for wind data where typically the probability of maximum values is much lower than mean and minimum values. The Weibull function is used to fit a frequency curve to the range of recorded data. The Weibull distribution requires computation of two parameters namely shape factor and the scale factor (Odo, Offiah, and Ugwuoke 2012) .

Weibull probability distribution function was calculated using equation 1.

Weibull probability distribution function was calculated using equation 1.

$$f(U)=\left(\frac{k}{c}\right)\left(\frac{U}{c}\right)^{k-1}\exp\left[-\left(\frac{U}{c}\right)^{k}\right] \quad (1)$$

Where, shape factor (k) and scale factor (c) are as per equations 2 and 3 respectively.

$$k=\left(\frac{\sigma_U}{\overline{U}}\right)^{-1.086} \quad (2)$$

$$c=\frac{\overline{U}}{\left(\Gamma\left(1+\frac{1}{k}\right)\right)} \quad (3)$$

The purpose of determining Weibull probability curves is to establish the range of desihn wind speed (DWS) for which analysis is to be carried out.

Optimum area of square heliostat

Blackmon has shown that the optimum azimuth-elevation heliostat cost can be determined by analyzing cost relationships in terms of heliostat area parametrically, distributed among three distinct categories. Advance Thermal System's ATS 148 m^2 heliostat is considered to be very well designed, proven heliostat by National Renewable Energy Labs. Of USA. Using the detailed cost break up of ATS 148 m^2 heliostat as a benchmark, he divided the cost/m^2 (CSM) into three categories. The three categories are described as below.

Category (C1): These costs are constant costs per unit area and are independent of heliostat size for a given heliostat field mirror area (e.g. mirrors).

Category (C2): These costs are size-dependent and are determined by the wind loads imposed which increase the cost/m^2 (CSM) as the area increases. (E.g. structure, pylon, foundation, elevation and azimuth drives). Size dependent costs follow the so called three halves power law suitably amended for non-uniform wind speed.

Category 3 (C3): These costs are fixed costs for components used on each individual heliostat, irrespective of its size; for a given field size. This fixed cost/m^2 increases linearly with the number of heliostats, and thus the cost per unit area increases as the size decreases, and vice versa. (E.g. Controllers, position sensors, limit switches etc.). Given below is flow chart for area optimization process.

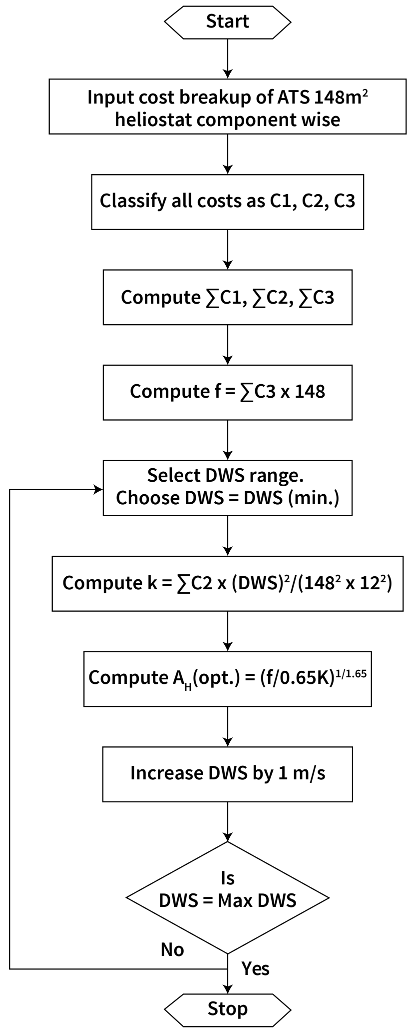


FIGURE 1. Flow chart to calculate optimum area of the heliostat

C2 category components costs (like structure, pylon, foundation, drives) have been demonstrated to be proportional to their weights, which in turn are proportional to the bending moment on the respective components in this category. Since, bending moments are also directly proportional to the square of wind speed, the maximum bending moments on each element have been determined as a function of DWS. While, Blackmon had restricted himself to a single DWS and thus, found an optimum heliostat area, DWS has been added as a variable in this paper and the optimum area (least cost/m2) has been calculated as a function of DWS using above mentioned algorithm.

Cost of heliostat field per sq. meter, CSM was calculated by using following equation from (Blackmon 2013).

$$CSM = C_1 + kA_H^{0.65} + \frac{f}{A_H} \quad (4)$$

CSM is cost/m² for a heliostat for a non-uniform wind speed (Wind speed varying with height). AH is the area of heliostat, k is a constant for each DWS and f is the fixed total cost per heliostat. The constants were computed using Advanced Thermal Systems (ATS) 148 m² heliostat data as benchmark. ATS 148 m² heliostat is a very well accepted benchmark, which has been subjected to expensive durability test by Sandia National Laboratory. The detailed cost breakup of ATS heliostat cost of individual parts is freely available. ATS heliostat has been projected to have a CSM of $129 for a volume production of 50,000 units per year. Based upon the ATS 148 m² cost breakup by Blackmon, the constants C1, C2 and C3 are calculated. (Important to note that these costs are inclusive of installation costs).

C1 =$34.44 / m.²

(C1 is taken as fixed cost/m2 irrespective of its size).

$$k = \frac{86.26 * DWS^2}{12^2} \quad (5)$$

Basis for k is the C2 cost of $86.26 for ATS 148 m² heliostat for DWS of 12m/s.

$$f = \$1332 \quad (6)$$

f is fixed cost per heliostat, irrespective of its size.

By differentiating the equation (4) with respect to A_H and setting the derivative to zero, we obtain the optimum area (least cost per sq. m.) of a square heliostat (Blackmon 2013). This is a function of DWS as 'k' is a function of DWS.

$$A_{H/OPTIMUM} = \left(\frac{f}{0.65}k\right)^{1/1.65} \quad (7)$$

Using the above derived optimum area, the optimum cost/m² for a sq. heliostat was computed. A range of optimum values for varying DWS was calculated. The value of constant k increases as DWS increases and thus the optimum value of A_H decreases. So the optimum area (Least cost/m²) reduces as DWS increases.

Results & Discussion

Analysis of wind speed data

Fig.1 shows the probabilistic distribution of wind speed throughout the year for five different sites chosen for this study. It is apparent that maximum possible mean DWS is 8 m/s whereas typically heliostats like ATS heliostat is designed for 12 m/s operational wind speed (Murphy 1980). This shows that heliostats could be designed for much lower wind speeds to reduce costs. There are places where speeds are even lower than 8 m/s, but it may not be economically prudent to design for each specific wind speed as high volumes mean better economy of scale.

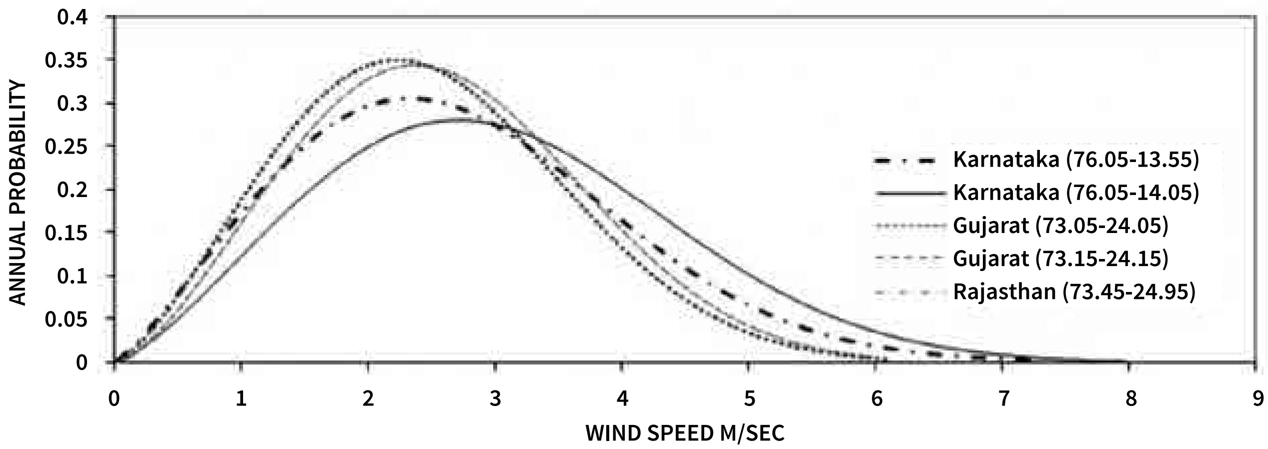


FIGURE 2. Mean wind speed probability distribution at six sites for year 2014

2.2.2 Optimum area & cost/m2 of a heliostat

Fig. 2 shows the cost/m² (CSM) and optimum area as a function of DWS from 6 m/s to 12 m/s. At 12 m/s wind speed, the CSM is US$103.7 if area is kept at 49 m² compared to US$129.7 for the ATS heliostat with area of 148 m² (Blackmon 2012). At the maximum speed of 8 m/s observed at the six locations, CSM is US$77 and the corresponding area is 80 m². This shows a reduction of nearly 40% compared to ATS heliostat.

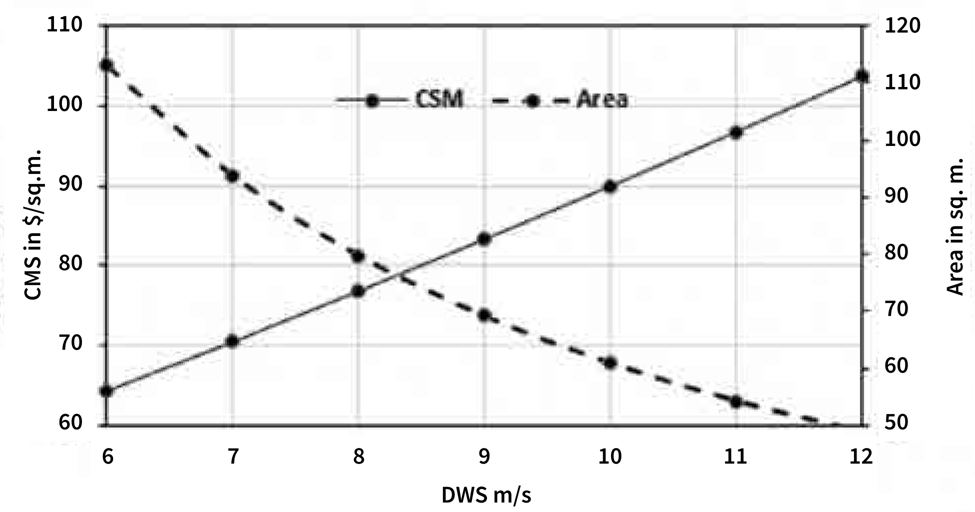


FIGURE 3. Optimum cost/m² and reflector area of heliostat vis-à-vis design wind speed

Conclusions

Heliostats designed for low wind areas can be significantly cheaper than current standards. The heliostat design should be based upon the wind speed data of the location. The optimum area of a heliostat and sizing of its components are both determined by the wind data. This will play a vital role in improving the viability of PT plants viable in these location. While this paper has focused on Indian locations only, the methodology is applicable for any other part of the world.

References

Battery Storage for Renewables : Market Status and Technology Outlook. 2015.

Belhamadia, Ahmed, Muhamad Mansor, and Mahmoud A. Younis. (2013). Assessment of Wind and Solar Energy Potentials in Malaysia. CEAT 2013 - 2013 IEEE Conference on Clean Energy and Technology, 152–57.

Blackmon, James B. (2012). Heliostat Size Optimization for Central Receiver Solar Power Plants. In Concentrating Solar Power Technology SAIC, 536–77.

Blackmon. (2013). Parametric Determination of Heliostat Minimum Cost per Unit Area. Solar Energy 97 (November). Elsevier Ltd: 342–49.

Blackmon. (2014). Heliostat Drive Unit Design Considerations - Site Wind Load Effects on Projected Fatigue Life and Safety Factor. Solar Energy 105. Elsevier Ltd: 170–80.

Emes, Matthew J, Maziar Arjomandi, and Graham J Nathan. (2015). Effect of Heliostat Design Wind Speed on the Levelised Cost of Electricity from Concentrating Solar Thermal Power Tower Plants. Solar Energy, 441–51.

India Solar Resource Maps and Data. 2018. Accessed May 23. https://www.nrel.gov/international/ra_india.html.

Kolb, Gregory J, Clifford K Ho, Thomas R Mancini, and Jesse A Gary. (2011). Power Tower Technology Roadmap and Cost Reduction Plan.

Kolb, Gregory J, Scott A Jones, Matthew W Donnelly, David Gorman, Robert Thomas, Roger Davenport, and Ron Lumia. (2007). Heliostat Cost Reduction Study.

Maps India Solar Resource. (2016). India Solar Resource Maps & Data (Updated March 2016).

Murphy, L M. (1980). Wind Loading on Tracking and Field Mounted Solar Tracker. Golden,Colorado.

Odo, F C, S U Offiah, and P E Ugwuoke. (2012). Weibull Distribution-Based Model for Prediction of Wind Potential in Enugu , Nigeria. Advances in Applied Science Research 3 (2): 1202–8.

Pfahl, A, M Buselmeier, and M Zaschke. (2011). Wind Loads on Heliostats and Photovoltaic Trackers of Various Aspect Ratios. Solar Energy 85 (9). Elsevier Ltd: 2185–2201. doi:10.1016/j.solener.2011.06.006.

Sargent & Lundy LLC Consulting Group Chicago Illinois. (2003). Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts. http://www.nrel.gov/docs/fy04osti/34440.pdf.

Solar Reserve. (2016). Crescent Dunes Solar Energy Plant.

Strachan, John W, and Richard M Houser. (1993). Testing and Evaluation of Large Scale Heliostats.

Sun Shot Vision Study. (2012). SunShot Vision Study. Sun Shot Vision Study. doi:SunShot, Energy Efficiency and Renewable Energy, U.S. Department of Energy. NREL Report No. BK5200-47927; DOE/GO-102012-3037.

Turchi, Craig, Mark Mehos, Clifford K Ho, and Gregory

J Kolb. (2010). Current and Future Costs for Parabolic Trough and Power Tower Systems in the US Market Preprint.

Way Julie. (20080. Storing the Sun : Molten Salt Provides Highly Efficient Thermal Storage. Renewable Energy World, June. http.

Rakesh Singhai[1], Dr. Nitin Banker, Dr. Harender
Department of Mechanical Engineering, Shiv Nadar University, Dadri, India

Corresponding author: Rakesh Singhai
Email: rs362@snu.edu.in

4

ENERGY SECURITY & SUSTAINABILITY: ROLE OF NATURAL GAS IN INDIAN CONTEXT

Sambhaji Kadam[1], Sanjay Kumar Kar[2]

1 PhD Scholar in Management (Energy Economics & Policy)
2 Head of the Department and Associate Professor, Department of Management Studies

ABSTRACT: The paper has been developed to analyse the role of natural gas in energy security, sustainability & economic growth of country. Usually, only three aspects of energy considered for energy security i.e. availability, accessibility and affordability. In this paper authors have developed a framework of energy security based on literature review and classroom discussion in PhD course-work and added acceptability and sustainability to above mentioned aspects of energy security. In the proposed framework sustainability occupies the central position and acceptability has been added as a desirable dimension to energy security. The authors apply the proposed framework to assess the role of natural gas in sustainability and energy security of India. Natural gas is billed as the transition fuel between oil and renewable being the cleanest fossil fuel. Currently, natural gas contributes only 6% in the primary energy mix of India vis-a-vis 24% globally. India has an ambitious target to move towards gas based economy by increasing share of natural gas up to 15% by 2030 in the primary energy mix to meet Paris commitment. Further, authors analysed role of government in infrastructure development, policy reforms & recommend actionable measures to improve availability, accessibility, affordability and acceptability of natural gas to achieve energy security & sustainability goal.

KEYWORDS

Energy Security, Sustainability, Gas Based Economy, Transition Fuel, Energy Policy

Introduction

India is second largest country by population with 1.21 billion people (Census, 2011) and 3rd largest economy in the world. India has 18% of world population but it uses only around 6% of world energy consumption (IEA, 2017). Indian economy is growing rapidly with average growth rate of approximately 7% in last two decades. Energy is the key input for economic growth and Indian Energy sector play a vital role in country's Economy. Energy is a key input to the production processes that transform inputs to goods and services (Subhes, Bhattacharyya, 2007) contributing to Gross Domestic Product (GDP). Increase in GDP along with change in structure of the Indian economy resulted in a significant growth in energy consumption in last three decades and will grow in future also (Kaushik, Paul, 2015).

India's energy consumption has surpassed Russia in 2016 and India became the third largest energy consumer in the world after United States and China (BP, 2016). Key drivers for increasing energy demand in India are population growth, industrialization and urbanization.

Energy security and sustainability are interdependent because emissions from energy consumption contributes to climate change in greater extend globally.

Energy Mix play vital role in energy security and India's energy mix(Figure-1) shows dominance of fossil fuels Coal & Oil (82%) with only 6% Natural Gas. Natural gas is the cleanest fossil fuel which emits negligible particulate matters and lowest air pollutants as compare to Coal & Oil. Globally, Natural gas contributes around 24% in World energy mix as shown in Table-1 and Gujarat state in India have 25% natural gas share in energy mix. Hence, Indian government is also committed to increase the share of natural gas in country's energy mix up to 15% by 2030 and Ministry of Petroleum and Natural Gas intervening with policy reforms in natural gas sector.

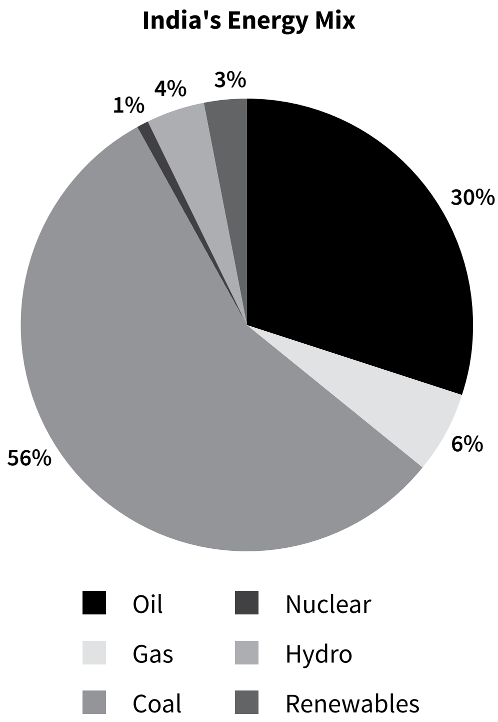


FIGURE 1. India's Energy Mix (Source: BP Statistics, June 2018)

India's fast economic growth needs more energy consumption that will lead to the increase in emissions causing climate change & concern for public health. Hence to address not only energy demand but also climate change, we need to adapt green and clean energy sources in our energy mix. This will help India to achieve sustainable development & help to fulfil the commitment to Paris Climate Agreement (COP21) ratified on October 2, 2016 (UN, 2016).

Globally, natural gas is considered as transition fuel due to its availability, affordability, environment friendliness and ability to support renewable in pick demand time. For India, International market dynamics and country's energy policies are supporting Natural Gas to become fuel of choice in present scenario and address the energy security & climate change in the future.

Energy Security

Authors have defined the Energy Security by using four-A as "In order to meet energy demand, energy should be **Available** in required quantity, it should be **Accessible** in most economical way, it should be **Affordable** to consumers and last but not the least it should be **Acceptable** by the consumers for **Sustainable** future".

Energy Security is the at most important in line with international security of any country. As India is more depends on energy import (especially petroleum) from international market, hence there is geopolitics involved in international energy relations causing threat to national security. Also, to achieve sustainable economic growth we need to ensure energy security. Hence, authors believe Energy security is vital for National Security & Economics Security. To achieve energy security, India has to address the geopolitical issues and domestic policy reforms.

Literature Review & Energy Security Framework

Authors have developed following Energy Security framework on the basis of the discussions and deliberations on “Global Energy Scenario Course” in the classroom of PhD at Rajiv Gandhi Institute of Petroleum Technology, India. Authors have reviewed and discussed the papers focused on energy security, energy policy, energy sustainability, energy poverty and came up with this concept paper to analyse the role of Natural Gas in Energy Security & Sustainability.

Our observations from various literatures are described briefly in this para. There is always a risk in supply of energy and we need to look after sources of insecurity developing over a time along with development of energy system (Andre, Bengt, Lars J.,2014). Long term dependence on energy import make economy vulnerable leading to socio-economic unrest in country and availability of energy at affordable price with desired quality is the key to ensure energy security (Kar.S.K., Sinha. P.K., 2014). To ensure the availability& continuous supply we have to diversify energy sources in our energy mix, Energy policies within energy mix should supplement each other to ensure energy security to the Nation and energy system should be integrated with social & environmental objective for future generation (Benjamin K. Sovacool, Harry Saunders., 2014) which leads to the Sustainability of energy. Energy efficiency plays a vital role in energy security; authors believe that a unit energy saved is more than one unit energy because it reduces consumption by one unit and quantity of energy needed for one unit production. The co-benefits of energy efficiency are reduction in CO_2 emissions, local air pollutants SO_2 and NO_x emissions (Sujeetha, Bundit,2013).

After detailed discussion on Energy Security and Sustainability, authors have concluded that the Sustainability should be taken into consideration while addressing the Four-As of Energy Security (i.e. A-Availability, A-Accessibility, A-Affordability, A-Acceptability). Sustainability should be at the centre of Energy Security Framework; hence, as a result authors have developed following Energy Security Framework (Figure-2).

FIGURE 2. Proposed Energy Security Framework

Role of Natural Gas in Energy Security & Sustainability

To analyse the role of natural gas in India's Energy Security and Sustainability, authors applied the energy security framework (Figure-2). Authors kept sustainability at the centre of a framework and performance of natural gas on key parameters like availability, accessibility, affordability, and acceptability has been carefully evaluated. A brief overview of analysis is presented below:

Availability

Availability of any energy source is at most important in energy security and Natural Gas is not an exceptional. Hence, authors have analysed the worldwide availability of Natural Gas and how it will be available to India. Also, authors examined domestic availability of Natural Gas in Indian context. Though, India unable to meet demand of natural gas from domestic supply, authors found that natural gas is abundantly available globally and it's available to import in India from global market with respect to market dynamics and economics. Currently, India consumes around 50.38% of imported Liquefied Natural Gas (LNG) due to shortage in domestic production. Authors have analysed the same in following section.

Natural Gas Reserves & Supply

Globally, it has observed that, there has been significant increase in natural gas reserve from 119.9 TCM in 1995 to 186.9 TCM (BP, 2017).Also, Global Natural Gas production has been increased significantly from 2876.7 BCM in 2006 to 3551.6 BCM in 2016 (BP, 2017). Also, it has observed that India has 1227.23 BCM of conventional Natural Gas reserves as on 2016 (MoSI, 2017) and around 61% are in offshore basin.

The production of domestic natural gas in India has been stagnant except peak production in 2010 to 2012 due to Reliance's KG production. Gross natural gas production has been decreased from 52200 MMSCM during 2010-11 to 32000 MMSCM during 2018-19 (PPAC, 2019) due to drastic decrease in production level of Reliance's KG basin. The trend has been shown in Figure-3.

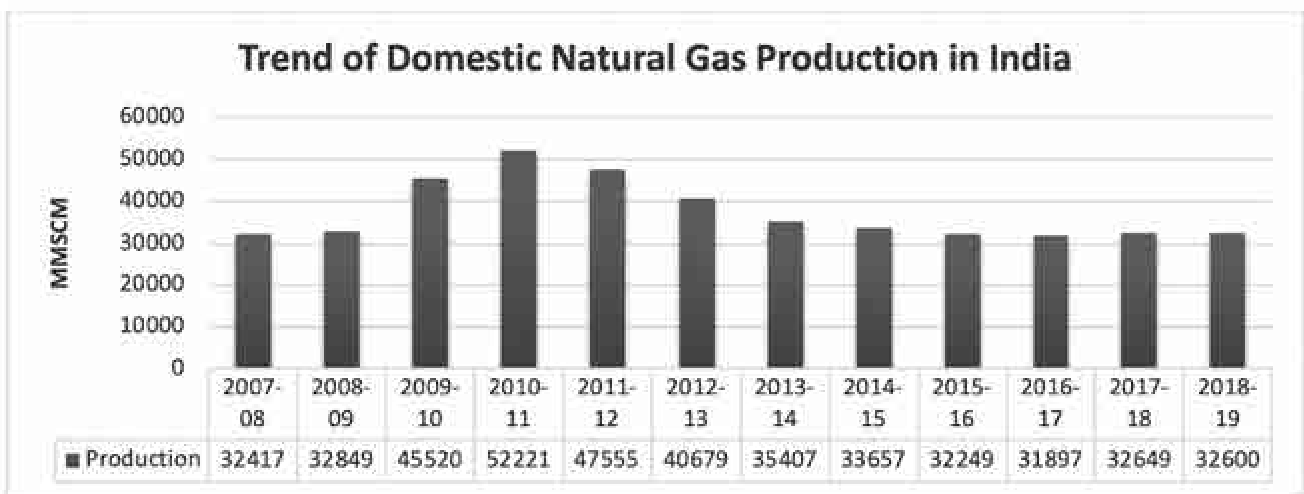


FIGURE 3. Trend of Domestic Natural Gas Production in India *(Source: Prepared from PPAC data)*

Source/Year	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
Dom Supply	127.89	114.36	95.41	80.51	74.39	70.3	69.42	72.03
LNG Imports	35.81	42.81	40.12	49.24	51.49	59.19	68.57	73.14
Total Supply	163.71	157.17	135.53	129.76	125.88	129.49	137.99	145.17
% LNG	21.88	27.24	29.6	37.95	40.9	45.71	49.69	50.38

TABLE 1. Trend of Natural Gas Supply/Consumption in India (MMSCMD)

(Source: Analysed by the authors based on PPAC data)

Total supply and consumption is being supported by imported LNG. Authors have tabulated the historical scenario of consumption and supply of natural gas in the country in Table-1.

Above trend shows that, LNG has increased its share in total Natural Gas supply/consumption in India and considering current scenario of international market it is going to increase its share in total gas supply in future as well. Due to limited domestic supply, LNG is playing vital role to meet India's demand and it would be playing more important role in future too.

3 to 5 decades of Natural Gas

From above mentioned reserve and production statistics, authors conclude that current Natural Gas reserves shall supply Natural Gas at least for 30 years in India (Domestic reserve) and 52 years (Global Reserve) at current rate of production and consumption.

In the future, increase in demand of natural gas will be compensated by more reserve discovery in world as seen in past trend.

Availability of natural gas in the domestic market in the short run could be a concern. But availability of natural gas in the international market could be helpful to address domestic shortage. In the context accessibility of natural gas in the short run and long run needs to be carefully evaluated.

Accessibility

Infrastructure is the key for accessing the natural gas from domestic and international market. To develop a natural gas market there should be well developed infrastructure throughout the natural gas value chain then only consumption of natural gas can be increased. (PwC, 2016).

Globally, countries with well-developed gas markets are characterised by the creation of infrastructure such as LNG terminals and gas transmission pipelines first. Infrastructure creation will de-risk gas importers, gas marketers and LNG terminal investors. Over time, the network will provide a push to setting up gas-based industries and promote the development of industrial zones, corridors and clusters.

It has been learnt that, Gujarat state has 25% of natural gas share in their energy mix vis-a-vis 6% in India (PNGRB, 2018). This is due to well established infrastructure by state owned entities and Government's pro-activeness in policy implementation. Authors, understands from Gujarat's state gas grid development scenario that, availability of infrastructure leads to generation of more natural gas demand.

Hence, as Infrastructure is the key for accessing Natural Gas in India, authors have analysed the different perspective of Natural Gas Infrastructure as follow,

Locations of Gas Reserves and Consumptions centres:

Globally, gas reserve and the natural gas consumers are geographically separated. In India, as per the Energy Statistics 2016 by MoSPI, it has been observed that 66.44% (988.89 BCM) of domestic Natural Gas reserve are in offshore and only 33.56% (499.6 BCM) are on onshore. Hence to transport the Natural Gas from offshore to consumption centre requires huge infrastructure development ranging from processing platform, offshore pipeline, cross-country pipeline and distribution pipeline.

Gas Pipeline Infrastructure:

Indian Government has set target of completing 30,000 Km of National Gas Grid (PIB, 2015) to enable continuous supply of natural gas across the country. Currently, India has only 16,250 Km of pipeline and need to develop another approximately14,000 Km to complete the National Gas Grid. The existing, under construction and proposed Natural Gas pipeline are shown in following figure.

Also, to enhance Natural Gas supply in country, Government is optimistic to have TAPI and IPI as on land transnational natural gas pipeline. Beside these two pipelines, South Asia Gas Enterprise Pvt. Ltd. (SAGE) is undertaking a path-breaking project, to build the Deepest Underwater Transnational Gas Pipeline. Also known as "Middle East to India Deepwater Pipeline (MEIDP)", this will be a Gas Highway that will connect the Gas Rich Gulf & Middle East regions to India, for the transportation of Natural Gas to secure India's Energy Needs (SAGE).

LNG Infrastructure:

India need huge LNG infrastructure to complement the domestic production and fulfill the rapidly increasing Natural Gas demand in country.

LNG infrastructure scenario in India for Existing and proposed LNG terminals is summarized in Table-2 as follows.

Sr.	Location of Terminal	Owner	Capacity (MMTPA)
1	Dahej, Gujarat	Petronet LNG Ltd.	10
2	Hazira, Gujarat	Hazira LNG Pvt Ltd.	5
3	Kochi, Kerala	Petronet LNG Ltd.	5
4	Dabhol, Maharashtra	GAIL	5
Total			**25**

TABLE 2. Existing Operational LNG Terminal Capacity

Source: Ministry of Petroleum and Natural Gas

Around 75% capacity of LNG import terminal is along the West Coast of India with two key terminals in Gujarat State. Existing terminal of Petronet LNG at Dahej and Hazira LNG Ltd at Hazira are under expansion process. GSPC's LNG terminal at Mundara with capacity of 5 MMTPA and Indian Oil's Ennore LNG terminal with capacity of 5 MMTPA have been commissioned in FY 2018-19 and are ready for operation. Besides the existing re-gasification LNG terminals, about 35.5-36.5 MMTPA are being planned and under construction on the eastern and western coasts of India by different entities.

Also, development of planned projects would depend on their techno-commercial feasibility considering natural gas demand supply scenario in the country.

Distribution Infrastructure and CGD Market:

City Gas Distribution (CGD) is emerging as a key driver to move towards gas based economy in India. Till 9th CGD BID Round, CGD coverage in India is tabulated in Table-3.

As on December 2018, CGD infrastructure in the country supply gas to 4,928163PNG (Domestic) household, 27364 PNG Commercial, 8354PNG Industrial, 1500 CNG Stations & more than 3million CNG Vehicles (PNGRB, 2019).

Total gas consumptions in CGD is 26.04 consist of 15.5 MMSCMD of Domestic Gas (PNG&CNG) & 10.54 MMSCMD of imported RLNG (PPAC, Feb 2019). Under revised, allocation policy of Government of India, Domestic gas has been allocated for Domestic PNG & CNG consumption under no cut category. Government is proactive in supplying PNG & CNG to the citizen across country & has taken strong steps through CGD bidding.

No. of States/UT	No. of GA	% of Population	% Area	No of Players
18	91	19%	11%	25

TABLE 3. CGD players, demography & geography covered as on 01.04.2018

Source: PNGRB

During FY 2018-19 PNGRB, has taken aggressive step in 9th & 10th Round of CGD bidding offering 86 & 50 Geographical Areas (GA) respectively.

Summary of 9t h& 10th CGD Bid round is tabulated in Table-4, and integrated coverage of CGD in India is tabulated in Table-5.

Bid Round	No. of GA	% of Population	% Area
9	86	26.38	23.82
10	50	24.23	17.92

TABLE 4. 9th & 10th CGD Bidding Round Summary

Source: PNGRB

No. of GA	% of Population	% Area
228	70.47	52.73

TABLE 5. Integrated Picture of CGD sector in India after 10th Round

Source: PNGRB

Gujarat is leading the CGD development in India due to availability of State Gas Grid, LNG Terminals and other associated natural gas infrastructure. Now entire state (all districts) has been authorized for CGD development.

Affordability

Natural Gas supplied from domestic sources is affordable to Households &Transport (CNG) and LNG is affordable to industrial and commercial customers in India. Authors have analysed the affordability of Natural Gas as follows:

Natural gas prices in Asia & India

As per the International Energy Outlook-2016 by EIA it has been observed that, in Asian markets, unlike those in the United States, natural gas prices typically reflect contracts that are indexed to prices for crude oil or petroleum products. The declines in crude oil prices between August 2014 and January 2015 and low oil prices since then had a significant effect on Asian natural gas prices and markets. In Asia, major quantity of natural gas is imported as LNG, with LNG prices traditionally indexed to crude oil on a long-term, contractual basis. The average spot price of Asian LNG for the month of May 2016 has been declined to 4.24 $/MMBTU which was lowest average monthly price since July 2009. This is due to the change in Natural Gas Demand & Supply in international market specially USA & Australian LNG projects. Hence, spot LNG price for India also reduced to 5.4 $/MMBtu in 2016 and then increased to around 9 $/MMBtu in 2018. Currently scenario in international LNG market shows the spot LNG prices reduced below 6 $/MMBtu for mid-2019 delivery. Historical trend in Spot LNG Prices (DES) at West India is shown in Figure-4 & alternate fuels prices shown in Figure-5.

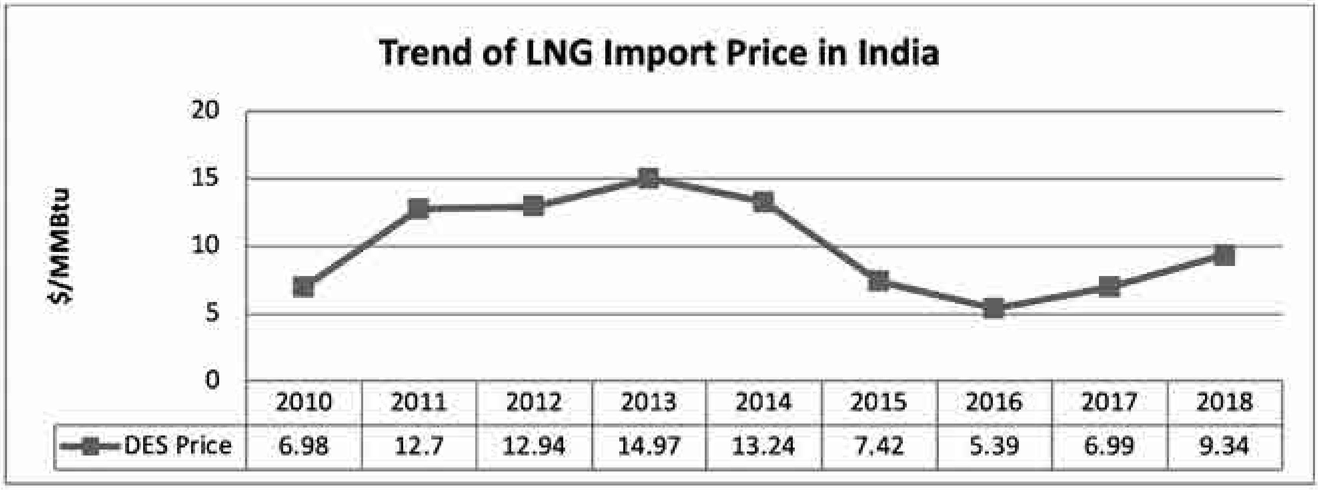


FIGURE 4. Trend in Indian Spot LNG Prices (DES) at West India *Source: Platts LNG Daily*

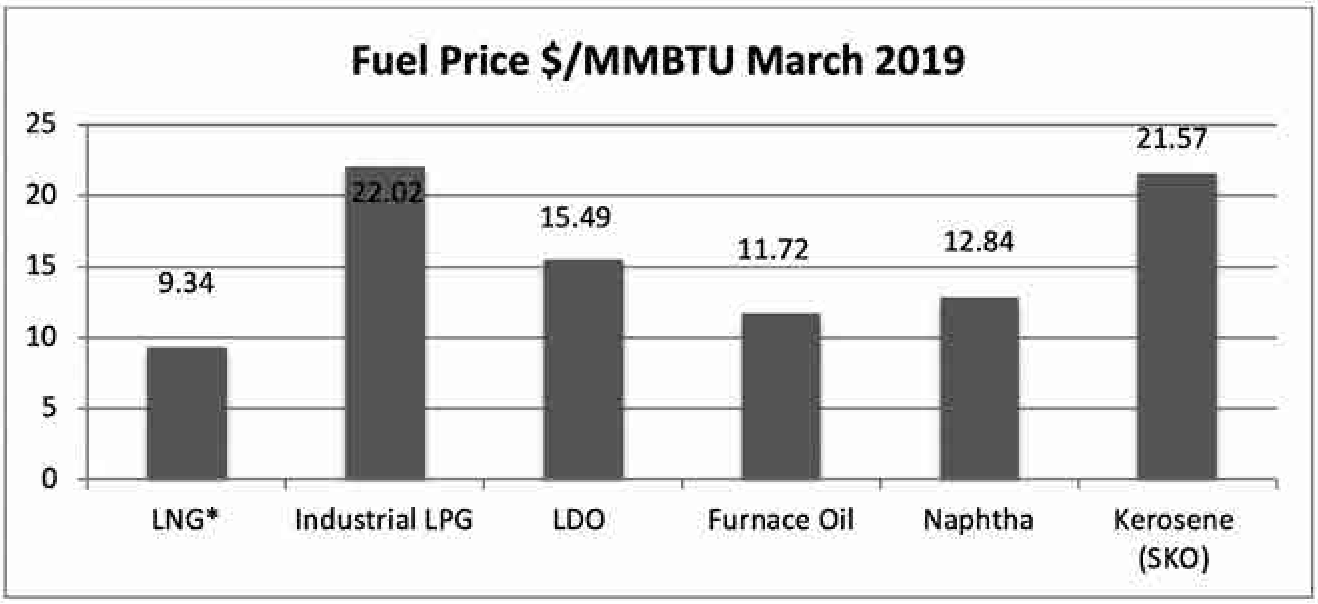


FIGURE 5. Base prices of Fuels in May 2018 *Source: BPCL, Platts & Authors Analysis*

**Annual average of 2018 DES West India LNG price is considered*

As represented in above Figure-4 & Figure-5, it is clear that LNG is competitive over all liquid fuels used in industries. This economic benefit encourages industrial units to use natural gas as fuel instead of other polluting liquid fossil fuels. Hence, natural gas is affordable to all industries using liquid fuels.

Gas Price trend for Domestic Gas

Domestic gas is being priced as per Domestic new Natural Gas Pricing Guidelines, 2014, by Ministry of Petroleum and Natural Gas.

Yearly average for April 2017 to March 2018 was 2.68 ($/MMBtu) & 3.21 for April 2018 to March 2019 is 3.21 ($/MMBtu). Below Figure-6 shows the decreasing trend of domestic gas price up to mid-2017 since 2014 & then increased to 3.69 $/MMBtu. As per new policy initiatives in last couple of years by Government of India, 100% allocation of domestic gas is done for domestic PNG and CNG segments for faster roll out of PNG connections and CNG stations in given City/Geographical Areas. This makes natural gas more affordable vis-a-vis domestic LPG & liquid fuels (petrol & diesel) in transport.

From decreasing trend of Natural Gas price of Domestic and imported LNG in India, it could be conclude that, Natural Gas is becoming more affordable vis-a-vis other expensive liquid fuels like LPG, Naphtha, LSHS, FO, LDO and Petrol in respective segment of customers (Household PNG, Transport (CNG), Commercial and Industrial).

Acceptability

In current state of Indian economy, natural gas is acceptable across all customer segments such as industrial, transport, commercial, domestic/households due to various benefits it offers like cleanest fossil fuel, convenience of use, less technological up gradation needed in industrial use and its affordability vis-a-vis other liquid fuels.

Sustainability

Sustainability of natural gas an energy source can be defined as, "It can fulfil the energy need of present generation at present scenario with less effect on environment & society". Authorsbelieve that, Natural Gas is sustainable and cleaner alternative to coal and liquid fossil fuels because it emits substantially negligible particulate matters, mercury, NOx, SOx vis-a-vis liquid fossil fuels and releases up to 50% less CO2 than coal & 20-30% less than oil (IGU, 2009). It results into both immediate and long-term benefits for public health, the environment and society at large. Methane leakage throughout gas supply chain has considered hazardous but it can be manage.Also, use of natural gas in Transportation offers a significant contribution to improve local air quality and address the public health issue.

Further, authors have analysed the role of natural gas as a sustainable energy source for India in different consumer segments

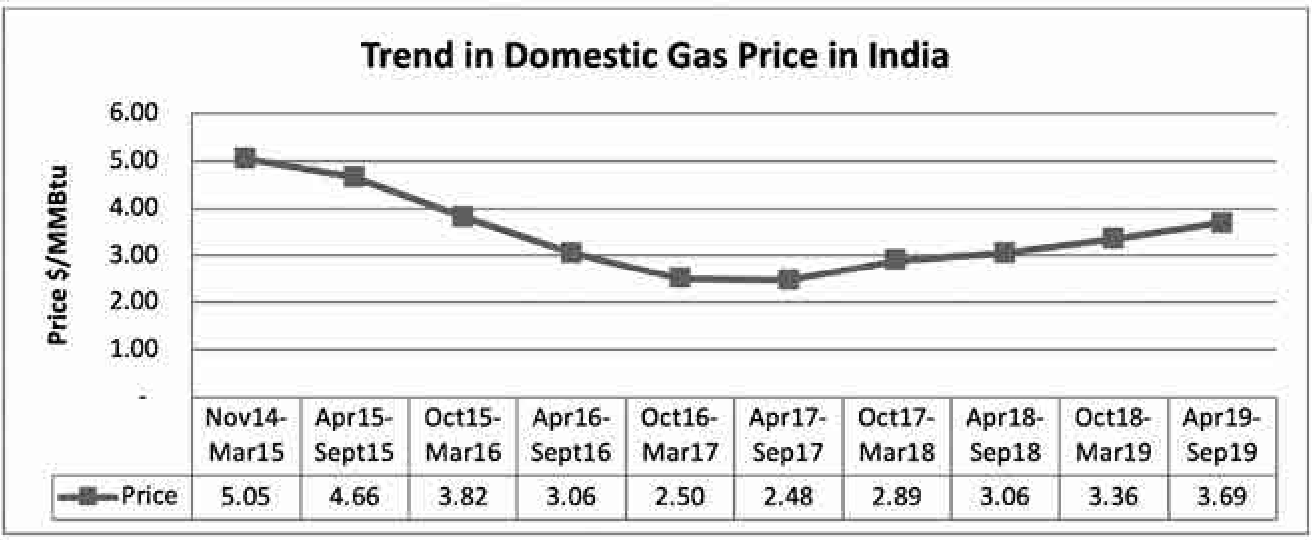


FIGURE 6. Trend in Domestic Gas Price in India *Source: Prepared from PPAC notification*

Electricity Generation

Indian power sector with total installed capacity of 330260 MW (CEA, 2017) has dominance of coal based plants (59% of total capacity) which is causing damage to the environment and society at large. Hydro and other renewables are most favoured energy sources as per environmental benefits are concerned. But these sources have their own constraints like weather conditions, geographic disadvantages, unable to meet pick demands and cost of productions. Hence to address the pick demand load and reduced environmental hazard, natural gas play vital role and act as transition fuel supporting renewables.

Gas based power plants can be set up with less cost, quicker and produces 50% less CO2 & 90% less air pollutants as compared to coal based power plants (Shell, 2015). India has total gas based installed capacity of 25185.38 MW (7.6% of total capacity) and due to supply shortage of domestic natural gas & un-viable LNG price some plants are idle and others are running on low Plant Load Factor (PLF).

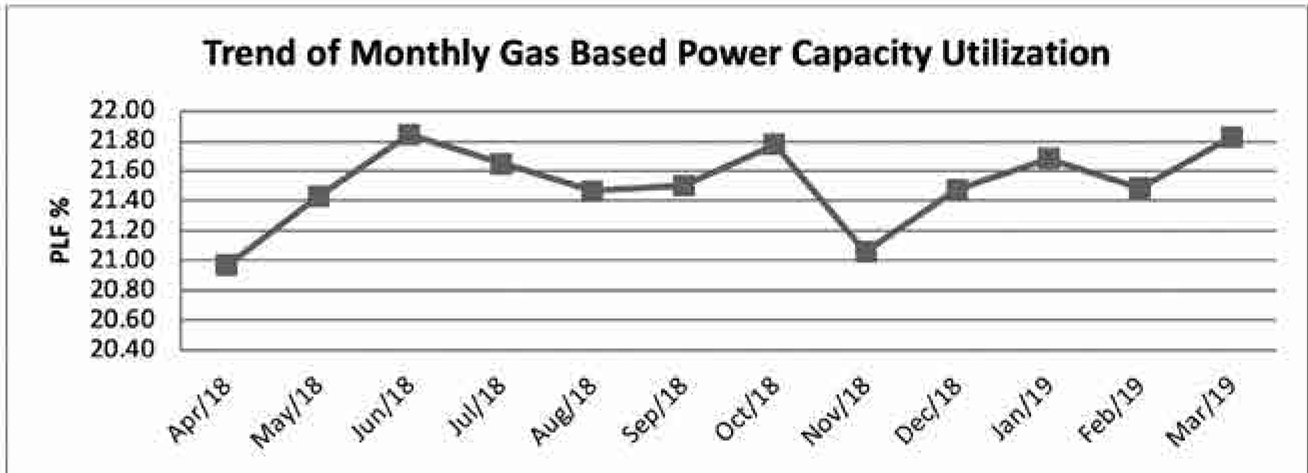
Considering the benefit of gas fired power plant, Indian government is focusing on supporting gas based power plants in country and came up with Power Sector Development Fund (PSDF) to revive the sector. PSDF has help power players to source LNG through open bidding on pooled price. Even after PSDF support gas based power sector could not perform well and were operating at an average PLF of 24.46% in November 2017 producing 4452 MW electricity (CEA, 2017).

Annual average PLF(April 2018-March 2019) is 21.51%, the monthly capacity utilization trend of natural gas based power generation capacity is as showed in Figure-7.

Utilization of available power capacity is vital to secure the uninterrupted electricity supply in peak load demand. Hence, to revive & enhance the utilization of stagnant power plants, India needs to work on gas sourcing strategy and build the LNG import capacity to meet the demand with competitive LNG price to reduce the cost of electricity production.

Recently, Japan's Tokyo Gas has set precedent with an unusual move for pricing long term LNG for gas based power by signing a deal with Royal Dutch Shell for the long-term supply of LNG using a coal-linked pricing formula (Bloomberg, 2019). India being predominantly coal based power generation economy, may try for this type of deal which would definitely help to improve capacity utilization in power sector.

This would ensure clean and affordable electricity generation to meet peak load demand and address the energy security in sustainable way.



	Apr/18	May/18	Jun/18	Jul/18	Aug/18	Sep/18	Oct/18	Nov/18	Dec/18	Jan/19	Feb/19	Mar/19
PLF %	20.96	21.42	21.84	21.65	21.47	21.50	21.78	21.06	21.48	21.68	21.48	21.82

FIGURE 7. Trend of Monthly Gas Based Power Generation Capacity Utilization *Source: CEA, 2019*

Industrial Fuel

LNG is used as replacement fuel for liquid fuels in industries and from current market scenario and authors observed that LNG is competitive against all liquid fuels used in India. Currently, in India around 8354 small & medium industrial units are using natural gas through CGD (PNGRB, 2019). These industries are contributing to reduce the emissions and address the climate change issue with business sustainability.

Transportation

CNG in Car, Buses & Light commercial vehicles:

Use of Compressed Natural Gas (CNG) is economical and the cleanest alternate fuel for transportation. Currently 3045268 vehicles are running on CNG in India. The geographical presence of CNG vehicles across country are as shown in Figure-8 as below.

No. of CNG Vehicles in India

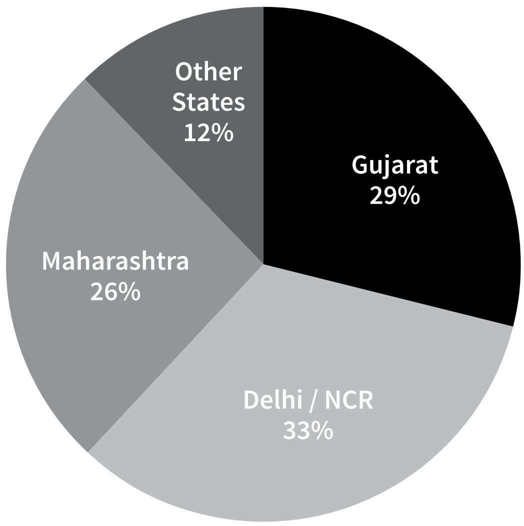


FIGURE 8. No. of CNG vehicles in India

Source: PPAC, CGD Report, April 2018

Gujarat is leading state having around 29% of CNG vehicles in India because of well developed local natural gas infrastructure across the state & Government policy in vehicle conversion.

LNG in Heavy Transport:

LNG should be use as preferred fuel in Heavy Vehicles and Railways because LNG is an environmentally friendly fuel with less number of Nox, Sox and particulate matters, as compared to any other automotive fuel. CO2 emission from LNG is also lesser than diesel. Ministry of Petroleum and Natural Gas has taken bold steps in this regard and launched pilot project of running Bus on LNG in Kerala on 8th November 2016 with the support of Tata Motors, Indian Oil, Petronet LNG & Kerala State Government.

Petronet LNG limited is setting up 20 LNG stations at existing petrol pumps along the highways en-route of west coast. This LNG highway would connect National Capital Delhi with Thiruvananthapuram covering a total distance of 4,500 km via Mumbai and Bengaluru (Times of India, 2017).

Government should bring policy for infrastructure development to enable use of LNG in Transport and Railways. The introduction of LNG in the transport sector will definitely help India to meet its commitment towards COP21 by reducing emissions from heavy vehicles which are currently being run on diesel.

CNG in Two Wheeler:

On 1st January, 2017 in presence of Hon'ble Minister for State, Ministry of Petroleum & Natural Gas, Mahanagar Gas Limited Mumbai in association with M/s Eco Fuel has launched CNG fuelled two-wheelers at Mumbai (NEWS18, 2017). Also in one more step towards curbing pollution caused by vehicles, the regional transport office and the Automotive Research Association of India (ARAI), Pune has approved compressed natural gas kits for scooters in the Pune City. The CNG kit has a maximum capacity to hold two Kg of CNG fuel and expected mileage of around 60 km per Kg.

This new horizon of green fuel in transportation is long way to go but it will definitely help India to curb the pollution level caused by vehicles in cities once commercialized.

Households:

Piped Natural Gas (PNG) is most reliable, safe and affordable source of energy for cooking by households in India. Currently around 4928163 households have PNG connections across the country (PNGRB,2019). The geographical distribution of PNG connections are as shown in Figure-9. Gujarat is leading state with 43% of PNG connections in India because of proactive state government policy in building local natural gas infrastructure across the state through state PSU.

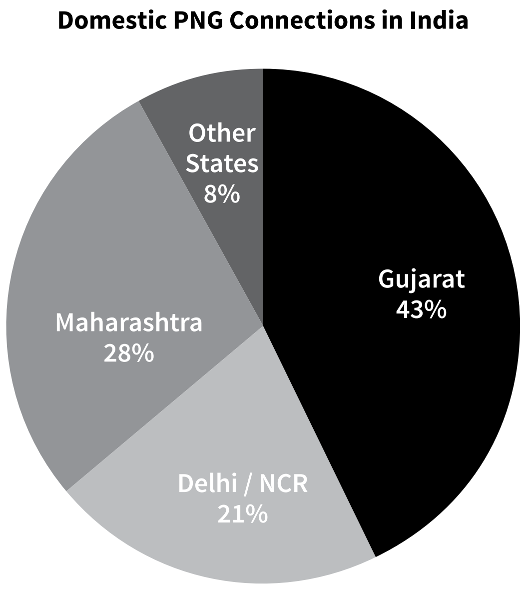


FIGURE 9. Domestic PNG Connections in India

Source: PPAC, CGD Report, April 2018

Summing-up the role of natural gas in all consumer segments

After detailed analysis it has been observed that, natural gas is not only affordable but also plays a vital role in providing clean energy to all consumer segments across country. Natural gas is convenient for cooking, economical and environmental friendly for industrial segment, reduces urban pollution through use of CNG/LNG as a fuel in vehicles. Hence, authors believe, natural gas being clean fossil fuel is definitely going to play sustainable role in Electricity, Household, Transport & Industries and act as transit fuel. It has been proven from historical trend in natural gas industry around the globe that, infrastructure is key backbone for development of natural gas market and it is capital intensive affairs. So we believe that, government should take a proactive steps in supporting infrastructure development in India.

Role of Government in Natural Gas Infrastructure Development

As infrastructure development being highly capital intensive subject to market dynamics, many players are unable to perform as per their commitment across entire natural gas value chain, hence there is need of hours where government should support these infrastructure development through various schemes, Some of the initiatives we have noted and recommended as follow,

Capital Grants:

Capital grant should be provided to the critical infrastructures like cross country pipeline to complete National Gas Grid. (recently, the Cabinet Committee on Economic Affairs, chaired by Hon'ble Prime Minister Shri Narendra Modi has approved viability gap funding / partial capital grant (PIB, 2016) at 40 percent (Rs. 5,176 crore) of the estimated capital cost of Rs. 12,940 crore to GAIL for development of 2539 km long Jagdishpur-Haidia and Bokaro-Dhamra-Gas-Pipeline).Such Capital Grant support should be provided to other Pipeline projects which are facing viability problem due to current market scenario.

This will definitely help government to fulfill its goal of completing 30,000 Km National Gas Grid in India and increased natural Gas Share up to 15% in Energy Mix of country.

Sovereign Guarantee Funding from Multilateral Agencies

The Multilateral Organizations like World Bank, ADB, Asian Infrastructure Investment Bank, JICA which provides Sovereign Guarantee Funding to develop energy infrastructure in all developing countries at discounted rates as compare to commercial banks. As India is the member in most of these Multilateral Agencies and has good sovereign rating so Government of India should provide Sovereign Guarantee for getting funds from Multilateral Agencies at discounted rates which may lead to natural gas infrastructure projects become viable and sustainable.

Industrialization Policy initiatives

Government of India may take an initiative to set up new Urea Fertilizers Plants along the planned cross-country pipeline which will reduce Urea import dependency reducing subsidy and also help the natural gas pipeline to be viable due to increase in capacity utilization.

Also, current Natural Gas price in international market favours the Indian power sector and expected to be stable or decrease in future. Hence Government may continue its scheme of PSDF to run the idle gas based power plant and also may plan more gas base power capacity in country to ensure the 24*7 electricity to its citizens.

CGD in Smart Cities

Government of India has accorded highest priority & placed under No-cut category for domestic gas allocation to PNG(Domestic) and CNG(Transport) segments of CGD networks. This policy reforms opens the opportunity for Smart Cities to get Natural Gas as a clean fuel to make the smart cities cleaner. Hence, Ministry of Petroleum and Natural Gas has taken the initiatives to rollout CGD bidding for proposed Smart Cities(MoPNG, 2017). Under stage-1 of Smart City Mission98 cities has been announced, 38 Cities amongst these 98 had existing CGD network and most of the other cities has been covered under 9th& 10thround of CGD bidding by PNGRB.

All smart cities should be covered under CGD network which would reduce vehicular emissions in urban areas and will help Government of India to fulfill the commitment towards Climate Change Agreement (COP21).

Conclusions

Natural Gas is Available globally in sufficient quantity to cater at least for 3-5 decades, Accessible via infrastructure, Affordable vis-a-vis other liquid fuels and Acceptable by Society. Hence, for meeting rapidly increasing energy demand in immediate future, it is not feasible to switch over to renewable sources like Solar, Wind which has its own challenges but at least for coming two-three decades there is a need of hours to adapt natural gas as a Transit Fuel for reducing carbon emission and contribute to Sustainable Development Goals while addressing energy security of the country.

Considering the current scenario of infrastructure development in natural gas value chain and policy initiatives & regulatory intervention being taken in India, authors believe that uses of natural gas will definitely increase in coming decades. This would definitely help in increasing the share of natural gas upto 15% in India's energy mix by 2030. It is observed that in the next two to three decades, natural gas would play a vital role in energy mix of India subject to development of natural gas infrastructure across the country. Current, international scenario of natural gas supply & pricing supports development of natural gas market in India.

For time being researcher are interested to see that how Indian Government would play its role in framing and implementing energy policies for making India a gas based economy by 2022 with 15% share of natural gas in energy mix. To achieve this target, lessons from Gujarat state needs to be learn in development of natural gas infrastructure and proactive involvement of the Government to boost the natural gas sector. Also, natural gas infrastructure developments should be supported through capital grants and sovereign guarantee funding from multilateral agencies to the entities.

In Indian context natural gas poised to be a game changer; further it would play an important role in driving towards gas based economy in the near future. Gas based economy is going to address energy security in the country and help India to fulfill its INDC commitment towards Paris Climate Agreement by reducing emissions.

References

Andre Mansson, Bengt Johansson, Lars J. Nilsson.(2014). assessing energy security: An overview of commonly used methodologies. Journal of Energy. Elsevier.

Benjamin K. Sovacool, Harry Saunders. (2014). Competing policy packages and the complexity of energy security. Journal of Energy. Elsevier.

BP (2018). Statistical Review of World Energy June 2018.

BP Statistics (2017). Statistical Review, India's Energy market.

Bloomberg (2019), article dated April 5, 2019. Available at https://www.bloomberg.com/news/articles/2019-04-05/shell-breaks-market-mold-with-deal-linking-gas-prices-to-coal

Business Line (2018). article dated 14th June, 2018. Available at https://www.thehindubusinessline.com/economy/policy/safety-regulations-for-lng-vehicles-to-be-out-this-year-pngrb-chief/article24160167.ece .

CEA (2017). All India Installed Capacity of Power Stations Monthly Report, January 2018.

CEA 92017). Energy Generation Monthly Report, June 2017. Dr. A.W. Karim (2009). Natural Gas as a Transportation Fuel, The alternative choice for cleaner energy. International Gas Union. Malaysian IGU Presidency (2009-2012).

Economic Times (2017), article dated 16th March, 2017. Available at https://auto.economictimes.indiatimes.com/news/oil-and-lubes/nod-to-lng-as-auto-fuel-lng-fuel-pumps-to-come-up-nitin-gadkari/57668584 .

Economic Times (2017), article dated 17th May, 2017. Available at https://energy.economictimes.indiatimes.com/news/renewable/railways-speeds-up-plans-to-shift-towards-gas-fuelled-locomotives/58710577 .

Financial Express (2017), article dated 1st September, 2017. Available at https://www.financialexpress.com/

industry/png-set-to-flow-like-power-water-in-homes-narendra-modi-government-looks-to-tweak-building-rules/835968/ .

IEA (International Energy Agency) 2016. World Energy Outlook-2015.

IEA (International Energy Agency) 2017. India Energy Outlook.

Kar.S.K., Sinha. P.K. (2014). Ensuring Sustainable Energy Security: Challenges and Opportunities for India. Oil, Gas & Energy Law Intelligence. (Vol. 12 - issue 4), October

Kaushik Deb, Paul Appleby (2015). India's Primary Energy Evolution: Past Trends and Future Prospects.

MoPNG (2017). "convergence of CGD Network development in Smart Cities". Presentation

MoSPI (2017). "Energy Statistics-2017".

NEWS18 (2017). article dated 2nd January, 2017. Available at http://www.news18.com/news/auto/mahanagar-gas-limited-launches-cng-kits-for-two-wheelers-in-mumbai-1330252.html (Accessed on January 21, 2018).

ORGI (Office of the Registrar General & Census Commissioner, India), Census (2011), Government of India.

PIB (2015). "National Gas Grid", dated 13-May-2015 available at http://pib.nic.in/newsite/PrintRelease.aspx?relid=121645. (Accessed on March 21, 2018).

PIB (2016). "Cabinet approves Capital Grant to GAIL for development of Gas Infrastructure in Eastern part of the country" dated 21-September-2016. Available at http://pib.nic.in/newsite/PrintRelease.aspx?relid=150960 (Accessed on March 15, 2018).

PIB (2017). "Launch of NDR and OALP is historic occasion for India's E&P Sector" dated 28-June-2017. available at http://pib.nic.in/newsite/PrintRelease.aspx?relid=166950

PIB (2018)."Cabinet approves Discovered Small Fields (DSF) Policy Bid Round-II" dated 7th Feb 2018. available at http://pib.nic.in/newsite/PrintRelease.aspx?relid=176357.

Petroleum & Natural Gas Regulatory Board (2018). 9th CGD Bidding Round Presentation

Petroleum & Natural Gas Regulatory Board (2019): CGD booklet

Petroleum Planning & Analysis Cell (2018). CGD Report.

Petroleum Planning & Analysis Cell (2019). Monthly Gas Report, February.

PwC (2016). The gas play: India Gas Sector Survey 2016.

Subhes C. Bhattacharyya (2007). Energy sector management issues: an overview, International Journal of Energy Sector Management.

SujeethaSelvakkumaran, BunditLimmeechokchai (2013). Energy security and co-benefits of energy efficiency improvement in three Asian countries. Journal of Renewable and Sustainable Energy Reviews. Elsevier.

Shell (2015). "Integrated Gas: The Case For Gas".

Times of India (2017). Article dated 26th August 2017, available at https://timesofindia.indiatimes.com/business/india-business/india-trucking-into-gas-age-as-govt-clears-norms-for-lng-stations/articleshow/60227399.cms .

Times of India (2017). Article dated 5th May 2017, available at https://energy.economictimes.indiatimes.com/news/oil-and-gas/-waterways-authority-initiates-discussion-with-firms-to-set-up-lng-infra/58532716 .

UN NEWS centre (2016), available at http://www.un.org/apps/news/story.asp?NewsID=55185#.WDwjcbJ97IU(Accessedon January 21, 2018).

UNFCC website: http://unfccc.int/paris_agreement/items/9444.php

World Bank (2016). available at http://www.worldbank.org/en/news/press-release/2016/10/03/south-asia-growth-potential-realized-through-investment (Accessed on January 15, 2018).

Mounted Solar Tracker. Golden,Colorado.

Odo, F C, S U Offiah, and P E Ugwuoke. (2012). Weibull Distribution-Based Model for Prediction of Wind Potential in Enugu , Nigeria. Advances in Applied Science Research 3 (2): 1202–8.

Pfahl, A, M Buselmeier, and M Zaschke. (2011). Wind Loads on Heliostats and Photovoltaic Trackers of Various Aspect Ratios. Solar Energy 85 (9). Elsevier Ltd: 2185–2201. doi:10.1016/j.solener.2011.06.006.

Sargent & Lundy LLC Consulting Group Chicago Illinois. (2003). Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts. http://www.nrel.gov/docs/fy04osti/34440.pdf.

Solar Reserve. (2016). Crescent Dunes Solar Energy Plant.

Strachan, John W, and Richard M Houser. (1993). Testing and Evaluation of Large Scale Heliostats.

Sun Shot Vision Study. (2012). SunShot Vision Study. Sun Shot Vision Study. doi:SunShot, Energy Efficiency and Renewable Energy, U.S. Department of Energy. NREL Report No. BK5200-47927; DOE/GO-102012-3037.

Turchi, Craig, Mark Mehos, Clifford K Ho, and Gregory

J Kolb. (2010). Current and Future Costs for Parabolic Trough and Power Tower Systems in the US Market Preprint.

Way Julie. (20080. Storing the Sun : Molten Salt Provides Highly Efficient Thermal Storage. Renewable Energy World, June. http.

Sambhaji Kadam[1], Sanjay Kumar Kar[2]

Affiliations:
Rajiv Gandhi Institute of Petroleum Technology (An Institute of National Importance), Jais, Amethi, Uttar Pradesh, India.

1 PhD Scholar in Management (Energy Economics & Policy)
2 Head of the Department and Associate Professor, Department of Management Studies

Corresponding author's email: pm1606@rgipt.ac.in

5

EFFECT ON PROTECTION SCHEME BY DG IN ETAP

Preyansh Sharma[1], Kashyap Mehta[2], R. Venkata Rama Raju[3]

1 B.Tech, Department of Electrical Engineering,
Pandit Deendayal Petroleum University, Gandhinagar
2 B.Tech, Department of Electrical Engineering,
Pandit Deendayal Petroleum University, Gandhinagar
3 Assistant Professor, Department of Electrical Engineering,
Pandit Deendayal Petroleum University, Gandhinagar

ABSTRACT: This paper discusses the analysis and coordination of protection equipment's in a power system when Distributed Generations (DG) are incorporated in it. The study of the problems faced and its various protection techniques are conducted on IEEE 30 bus test system in Electrical Transient Analyzer Program (ETAP) simulation software. An IEEE 30 bus test system without any DG source is considered, and its protection analysis is carried out with Over-Current (OC), and Directional Over-Current (DOC) relays. This ensures the system is working normally. Further, the DGs are then incorporated and the changes, as well as problems faced by the protection system, are studied, and the respective solution is presented for this scenario in IEEE 30 bus test system. Short circuit fault current contribution, blinding of protection and sympathetic tripping are addressed in this paper.

KEYWORDS

IEEE 30 Bus system, Protection Coordination, ETAP, Distribution Generation

Introduction

The power system network is increasing with the increasing load demand. This leads to an increase in the frequency of faults. Therefore, protection relaying plays a vital role to isolate the fault within any power system. Moreover, relay coordination must ensure fast, selective and reliable relay operation to isolate the faulted section of the power system (Zeineldin et al., 2015; Oza et al., 2010). For the protection of interconnected sub-transmission systems, DOC relays are an attractive choice economically (Zeineldin, et al., 2015; Coster & Kling, 2010).

Electric power systems were until now known by their system of centralized production units, i.e., a huge generating station, a high voltage transmission grid, medium or low voltage distribution grid (Moore, 2008). However, this trend has changed significantly in the past decade. Nowadays to reduce the CO2emission, renewable sources such as wind turbines, micro-turbines, and photovoltaic panels are used as small generation sources in the distribution grid (Coster & Kling, 2010). Moreover, by generating the power locally in the distribution system, the transmission line losses are reduced (Vijeta & Sarma, 2012) and the voltage profile is improved. Due to increasing penetration of DG, distribution systems are transforming from the commonly radial structure toward a meshed and looped structure (Zeineldin et al., 2015). However, the negative impact of DG is to increase the fault current level and multiple current flow paths during the fault condition. These conditions decrease the capability and reliability of the existing design of power system protection for the radial distribution network.

The protection issues by introducing DGs are faulted current contribution, reverse power flow, single phase connection and reduction in reach of impedance relays. The major concerns of the protection system are fault current contribution, sympathetic tripping, blinding and islanding (Deuse et al., 2007; Driesen & Belmans, 2006; Hadjsaid et al., 1999). Sympathetic under-voltage tripping occurs with more penetration of DGs into the power system (Jennett et al., 2011).To avoid such problems into the power system protection, generally, DGs are disconnected rapidly during the fault in order to have the normal operation of conventional protective devices. Disconnecting DGs would lead to under-utilization of the benefits for both utility and DG owners as well as mal-operation of the protective system. Solutions are discussed in (Moreno et al., 2012) based on fault detection and directional comparison scheme which works on high-frequency transient signals by applying wavelet transform. In (Bernardo et al., 2012), a model was proposed for improving the selectivity of protection relays by performing dynamic tuning of protection settings. One of the solutions for limiting the fault current by DG is to limit the inverter short circuit current contribution (Bhattacharya, 2014).

The connection of DG to distribution feeders changes the fault current in the faulted feeder. With the introduction of DG into the system, the fault current seen by circuit breaker gets increased, and hence the circuit breaker has to be replaced (Coster & Kling, 2010).

Sympathetic tripping is possible when a generator which is installed on a feeder, starts contributing to the fault in a nearby feeder connected to the same bus.The DG contributes to the thefault current which will exceed the pick-up value of the OC relay and ultimately it will cause tripping of the healthy feeder even before the fault is cleared. The solutions to this are discussed in (Kauhaniemi & Kumpulainen, 2004) and can be avoided by finding a relay setting or by changing the fault clearing time. In (Xu & Jiao, 2014) it is discussed that sympathetic tripping can be prevented by reducing the fault level which can be reduced by the use of current limiting reactors.

During the fault, contribution by utility gets reduced due to penetration of DG into the grid. Due to this decrement of current levels, the fault stays undetected as the utility fault current contribution never reaches the pick-up level current of the feeder relay (Coster & Kling, 2010). This phenomenon is called blinding of the relay, or the relay is blind to detect the fault. Solution to this is given in (Chilvers et al., 2010) which is done by changing the X/R ratio of distance protection with the change in fault current.

In this paper, we have first of all considered IEEE 30 bus system for study and then carried out load flow in order to determine and verify the system parameters like voltage, active power, reactive power, etc. Then we further study the short circuit analysis which helps find out the minimum and maximum short circuit current. The relay coordination is studied &protection of the entire system of IEEE 30 bus is then carried out and ensured that it is working normally.

Further, DGs are introduced in the system, and the system behavior in terms of protection analysis is studied, and some key problems are addressed in the study. Also, the solutions to their respective problems are found and been verified using the ETAP software.

System Description

An IEEE 30 bus distribution system is considered for the study. Fig. 1 shows the single line diagram of the IEEE 30 bus system (IEEE). It consists of 30 buses, 6 generators, 41 branches, 24 loads and 4 transformers. Generator 1 is considered as swing bus, Generator 2 as a voltage control bus and the rest four are synchronous condensers. The parameters of the system are given in Appendix 1. The DGs are connected at bus numbers 14, 15, 16 & 24 with a respective interconnecting transformer. The rating of DGs is also given in Appendix 1.

Load Flow Analysis

In order to study the power flows in the system, a load flow study is carried out. The advantage in studying the power flow analysis is in planning the future expansion of power systems as well asin determining the best operation of existing systems. In ETAP software load flow analysis is carried out using Newton-Raphson keeping 0.0001 as the precision of solution. Using load flow study the unknown parameters such as activepower, reactive power, voltage, and phase angle are determined. Results of the load flow analysis are shown in Table. 1.

Bus Data						
	Bus		Initial Voltage		Power	
Sr. No.	Bus ID	kV	%Mag	Ang.	MW	Mvar
1	Blaine 13_7	132	100.217	-12.3	22.899	10.947
2	Bus 15 3_15	33	103.316	-14.2	8.753	2.669
3	Bus 14 3_14	33	103.874	-12.3	6.690	1.726
4	Bus 16 3_16	33	103.779	-12.9		
5	Bus 17 3_17	33	103.379	-14.1	9.619	6.199
6	Bus 18 3_18	33	102.252	-15.0	3.346	0.941
7	Bus 19 3_19	33	101.954	-15.2	9.875	3.534
8	Bus 20 3_20	33	102.361	-15.1	2.305	0.733
9	Bus21	33	103.484	-13.1	3.748	1.928
10	Bus 21 3_21	33	102.625	-14.7	18.431	11.796
11	Bus 22	0.400	100.000	0.00	15.719	-3.050
12	Bus 22 3_22	33	102.687	-14.7		
13	Bus23	0.690	98.872	-12.0	2.000	-1.239
14	Bus 23 3_23	33	102.186	-14.7	3.341	1.671
15	Bus 24	33	100.353	-14.8	8.762	6.747
16	Bus 24 3_24	33	101.563	-14.9	0	-4.435
17	Bus 25	0.690	104.204	-11.5	2.000	0
18	Bus 25 3_25	33	101.277	-14.8		
19	Bus 26 3_26	33	99.519	-15.3	3.466	2.278
20	Bus 27	0.690	103.696	-11.0	2.500	0
21	Bus 29 3_29	33	100.000	-15.7	2.400	0.900
22	Bus 30 3_30	33	98.881	-16.6	10.364	1.858
23	Clayton 13_2	132	104.318	-5.1	23.615	23.615
24	Cloverdale 3_27	33	101.960	-14.5		
25	Cloverdle13_28	132	100.684	-11.0		
26	Fieldale 13_5	132	100.920	-13.8	95.941	19.351
27	Glen Lyn 13_1	132	106.000	0.0	247.835	-14.788
28	Hancock 1_13	11	107.1	-13.3		13.953
29	Hancock 3_12	33	105.276	-13.3	12.413	8.312
30	Hancock 13_4	132	101.254	-8.7	7.792	1.640
31	Kumis 13_3	132	102.150	-7.0	2.504	1.252
32	Reusens 13_8	132	101.000	-11.1	30.603	30.603
33	Roanoke 1_9	33	104.826	-12.9		
34	Roanoke 1_11	11	108.2	-13.0		17.552
35	Roanoke 3_10	33	103.920	-14.3	6.266	-18.359
36	Roanoke 13_6	132	101.053	-10.4		

TABLE 1. Load flow analysis of IEEE 30 bus distribution system with DGs

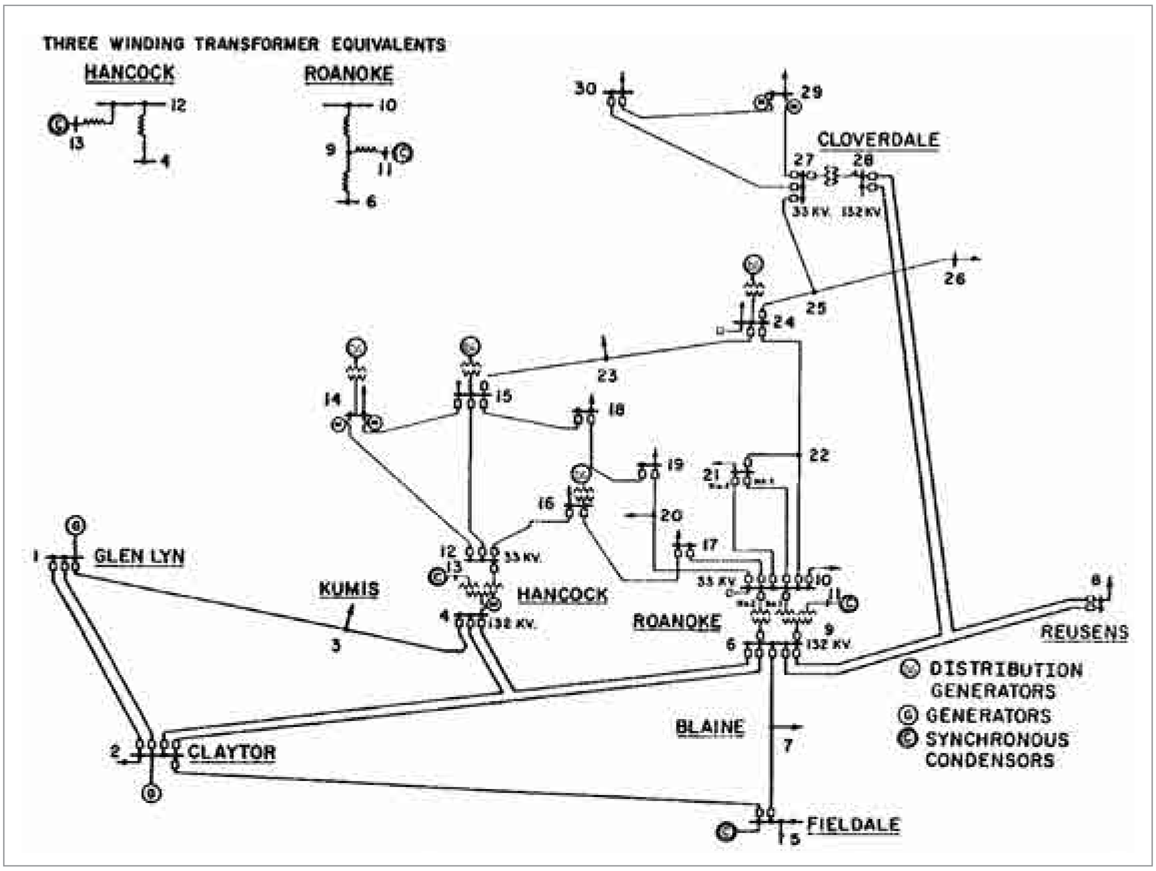


FIGURE 1. Single line diagram of IEEE 30 bus distribution system with DGs

Receiving end active and reactive power flows are given by (Stevenson, 1985):

$$P_R = \frac{|V_S|\times|V_R|}{|B|}\cos(\beta-\delta) - \frac{|A|\times|V_R|^2}{|B|}\cos(\beta-\alpha) \quad (1)$$

$$Q_R = \frac{|V_S|\times|V_R|}{|B|}\sin(\beta-\delta) - \frac{|A|\times|V_R|^2}{|B|}\sin(\beta-\alpha) \quad (2)$$

Where V_S is the sending voltage, V_R is the receiving end voltage, A & B are ABCD parameters while α & β are the phase angle of A &B respectively, and δ is the load angle.

Short Circuit Analysis

All the electrical equipment should be able to withstand the fault current for a specified time. Protecting equipment shall clear the fault within the withstand time of the device to be protected. Mostly, Short Circuit Calculation (SCC) is performed to find the maximum available fault current and minimum available fault current in the system. The maximum available fault current is used for selecting the short circuit withstanding capacity of all electrical equipment. The minimum available fault current is used for selecting the pick-up setting of the instantaneous OC relay (Prabhu et al. 2016). Using short circuit analysis in ETAP, Plug Setting Multiplier (PSM) and Time Dial setting of the relay are decided. PSM is given as:

$$PSM = \frac{I_F}{T I_p} \quad (3)$$

Where, I_F is the fault current, T is the Current Transformer (CT) ratio, and I_p is the primary current of the CT.

The fault current for different faults is calculated as:

Line to Ground fault: $$I_F = \frac{3E}{Z_1 + Z_2 + Z_0} \quad (4)$$

Line to Line fault: $$I_F = \frac{\sqrt{3}E}{Z_1 + Z_2} \quad (5)$$

Line to Line to Ground Fault: $$I_F = \frac{3E}{Z_1 + (Z_2 \parallel Z_0)} \quad (6)$$

Three phase fault: $$I_F = \frac{E}{Z_1} \quad (7)$$

Where E is the pre-fault voltage, Z0, Z1& Z2 are the zero, positive & negative sequence impedances respectively.

Relay Coordination

For OC relay coordination, time dial and pick-up value settings are necessary. These two settings decide the time of operation of OC relay for a particular fault current (Patel et al., 2015).

Pick-up value setting

The pick-up value setting of OC relay is different for the transformer and transmission line. The pickup value for transformer is given as

$$I_k = \frac{S}{\sqrt{3} V_L T} \tag{8}$$

Where, I_k is the pickup current, S is the rated VA of transformer, V_L is line to line rms voltage.

The pickup value for the transmission line is given as

$$I_k = 1.25\ I_{max} \tag{9}$$

Where I_{max} is the maximum current that the transmission line could withstand.

Time Dial

Time Dial setting depends on the time of operation and is calculated as

$$T_{op} = \frac{\gamma}{(PSM)^{\zeta} - 1} \times T_D \tag{10}$$

Where, T_{op} is the time of operation of the relay, γ and ζ are constants (Jennett et al., 2011) given in Table. 2, T_D is the time dial setting.

Over-current Curves	ζ	γ
Normal Inverse Relay	0.02	0.14
Very Inverse Relay	1.00	13.5
Extremely Inverse Relay	2.0	80.0

TABLE 2. Values of ζ & γ for different relay characteristics.

Relay Coordination with DG

While interconnecting the DGs into the power system, an interconnecting transformer is used (Arritt & Dugan, 2008). In general Delta (Utility) – Grounded-Wye (DG) (Fig. 2) interconnection transformer is used due to the advantages such as isolation from voltage sags for single line-ground faults at utility-side and allowing the DG to better ride through voltage sags. DGs are connected in Grounded-Wye as they are at the load end which requires neutral. Delta connection suppresses the harmonics to the utility and reduces the fault current contribution by the DG. The advantage is that it will not contribute to the fault current.

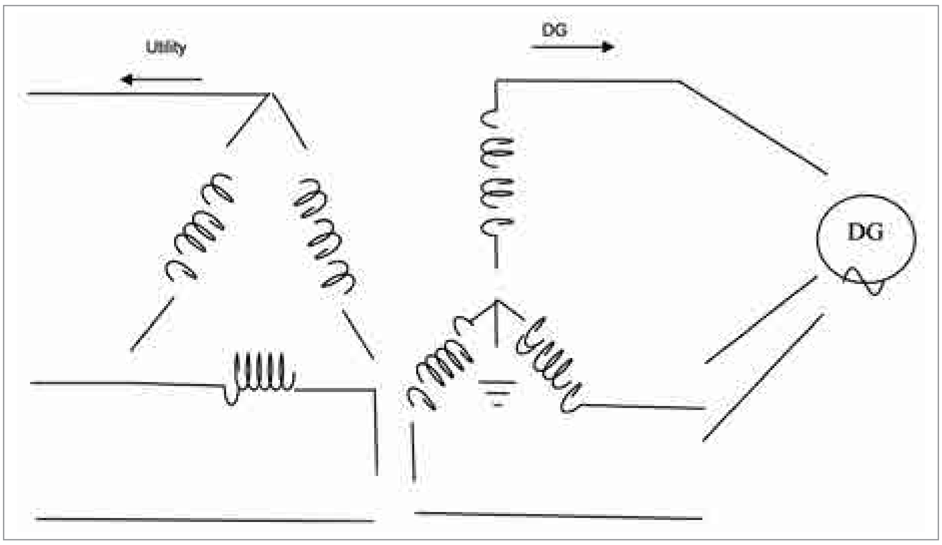


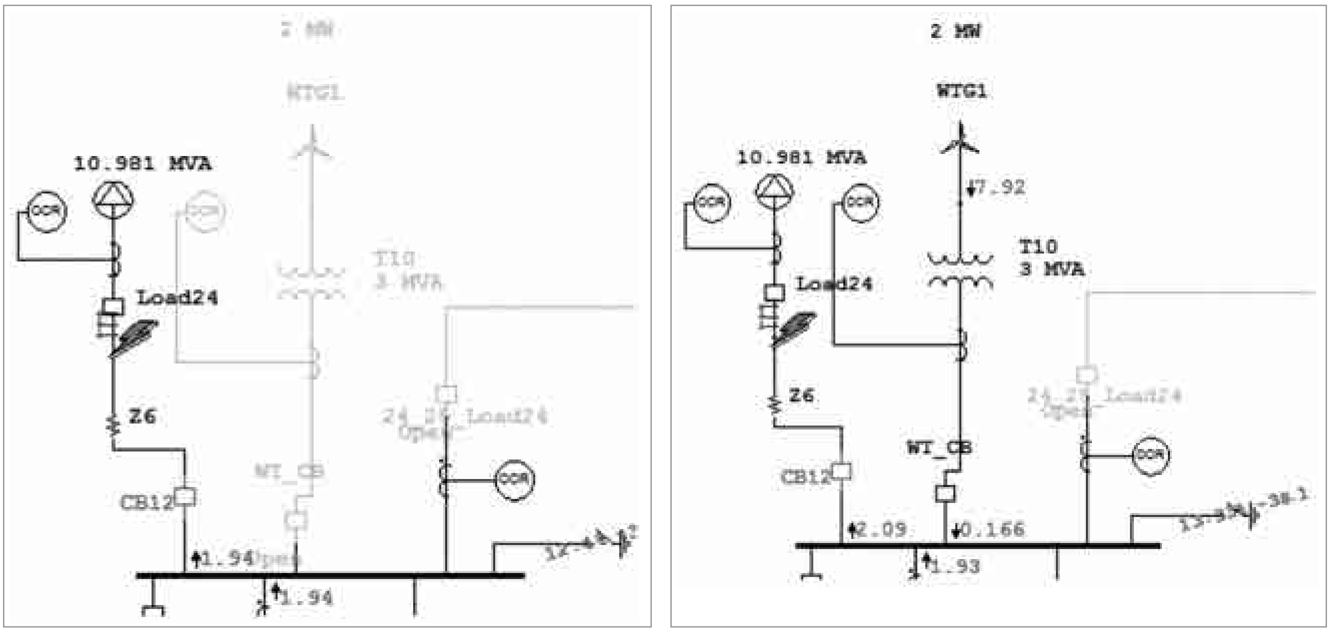
FIGURE 2. Interconnection transformer

Simulation Results

Simulation results are presented for fault current contribution, blinding, and sympathetic tripping cases. The solutions for each case are tested in ETAP software.

Fault current contribution

The connection of DG to distribution feeder changes the fault current in the faulted feeder. The rate of change of the fault current strongly depends on the ability of the DG to contribute to the fault (Zeineldin, et al., 2015). Whenever there is only one way to feed the load, then this kind of case may occur. For a 3-Φ fault at the terminals of CB 15_23_Load15 (circuit breaker connected between bus 15 and bus 23 at load 15) the fault current seen by the relay 15_23-Load15 is 5.96A. But now if a DG is connected to the bus 24 and the same fault occurs at the same location, then the fault current seen by the relay does not increase. But if the fault occurs at the terminals of Load24 and DG is disconnected then the fault current seen by CB12 is 1.94 kA as shown in Fig.3 (a). Now DG is connected to the bus 24, and the same fault occurs at Load24 then the fault current seen by CB12 is 2.09 kA (Fig. 3(b)). Hence the current seen by CB12 has increased due to the introduction of DG into the system. As before connecting DG, the CB had designed hence the short circuit current capability was designed was less but now as DGs are introduced the short circuit current capability should be increased by replacing the CB with the new one. Else a control strategy can be used to stop firing to the inverter of DG whenever it senses a fault. If DG connected is operating using an inverter or active networks like thyristors then the fault current could be limited, short circuit contribution or k-factor of an inverter is used to limit the fault current.



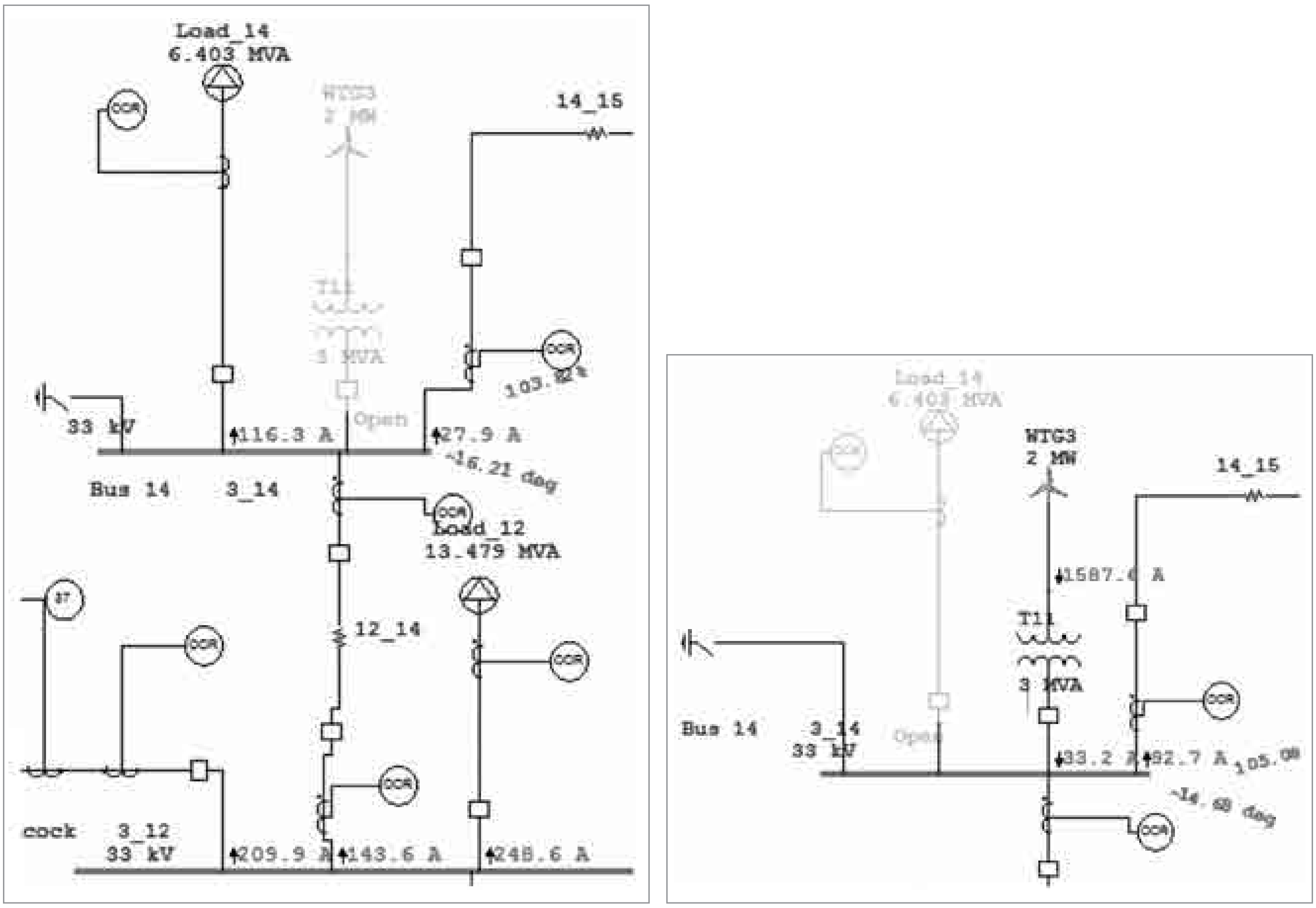
(a) (b)

FIGURE 3. Fault level contribution (a) without DG & (b) with DG

Sympathetic Tripping

The generator has a major contribution to the fault current when the generator and/or the fault are located near the substation. Especially in weak grids, false tripping can occur with long feeder length which is protected by definite OC relays. The settings of the protection relays have to ensure that fault at the end of the feeder is also detected which leads to a relatively small pick-up current. Here DG affects the security of the protective system.

Fig. 4 shows the load flow analysis of the section of Bus 14 of IEEE 30 bus system. Here the nominal current for the transmission line between bus 14 & bus 15 is 27.9 A (Fig. 4 (a)) and under worst scenario, the maximum nominal current is 70 A. Hence the pickup value is 85 A. Now, DG is connected to Bus 14 and load is removed. Under this condition, the nominal current flowing through the transmission line between bus 14 & bus 15 is 92.7 A as shown in Fig. 4 (b). Under the normal condition also the relay would give the trip signal as the nominal current is higher than the pickup value of DOC relay at bus 14 & bus 15.



(a) (b)

FIGURE 4. Sympathetic tripping (a) without DG & (b) with DG

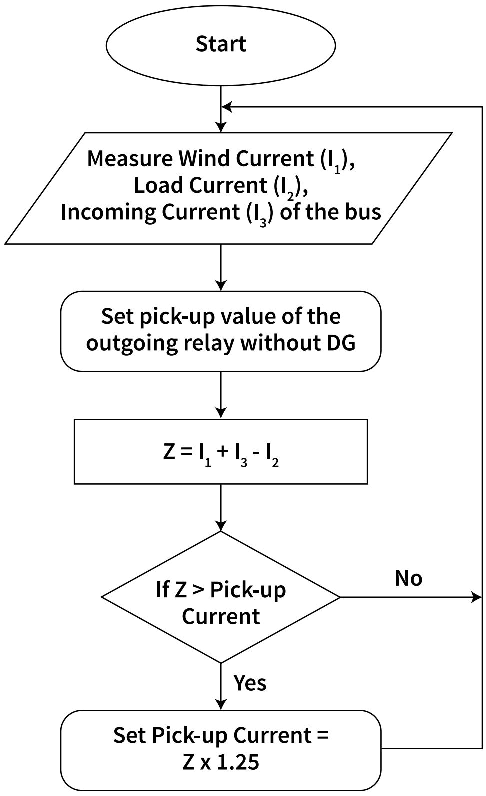


FIGURE 5. Flow chart to overcome sympathetic tripping

The solution is to increase the pick-up value of relay. However, the problem is DGs are renewable in nature and are not always available. If we increase the pickup value of relay and DGs are not supplying any power, then under some circumstances relay will not pick up. Another solution to this problem is to use a loop wherein we measure the incoming and outgoing currents of the bus and based on that we decide the relay pickup value. Fig. 5 shows the flowchart for this solution. First of all, we have to measure all the incoming currents using CTs, i.e. here it is transmission line between bus 12 & bus 14 which is 143.6A as shown in Fig. 4(a). Now measure the load current from the bus which is 116.3 A. Hence subtract the load current from current through transmission line between bus 12 & bus 14 which will give the current of a transmission line between bus 14 & bus 15 and that is 27.9 A. Thereupon increase the relay pickup setting based on value obtained using numerical relays or by SCADA system if the relay is connected to remote locations. Here, in this case, the relay pick-up setting would be 35 A (27.9 * 1.25). Now if DG is connected then the current in the transmission line between bus 14 & bus 15 is 92.7 A. Therefore, the relay pick-up current value would be 116 A (92.7 * 1.25). Now with the change in DG generation also the pick-up value will change. As in substation ammeters are available to measure the incoming currents and outgoing currents from the substation. Hence using these values in digital relay logic can be performed. First set the pick-up value of the relay without DG as in this case is 78 A. Now measure the value of Z (flow chart) and if its value is greater than pick-up value of the relay then set new pick-up value else same pick-up value will be retained. In this way, with a change in the DG generation, the pick-up value is set, and the problem of sympathetic tripping is overcome.

Blinding

Fig. 6 shows that the single line to a ground fault has occurred at the terminals of CB 15_23_Load15 with fault impedance 30 Ω. Now, as DG is not connected (Fig. 6(a)) the current seen by the relay 14_15_Load14 during the fault is 78 A. As seen in Fig. 6(a) relay 14_15_Load14 has pickup value of 78 A, and hence it will operate. Table. 3 shows the sequence of operations when DG is not connected. Now DG is introduced at the Bus 15 with 2.5 MW of Wind Turbine Type 4 system (Camm, 2009). LG fault is created at the terminals of CB 15_23_Load15 as shown in Fig. 6(b). The fault current seen by relay 14_15_Load14 is 72 A, and it will not operate as the pickup value is 78 A. This phenomenon is called as blinding or the relay is blind to operate with the incorporation of DG into the system. Table. 4 shows the sequence of operations with incorporating DG at Bus 15, and it clearly indicates that relay 14_15_Load14 is blind to operate.

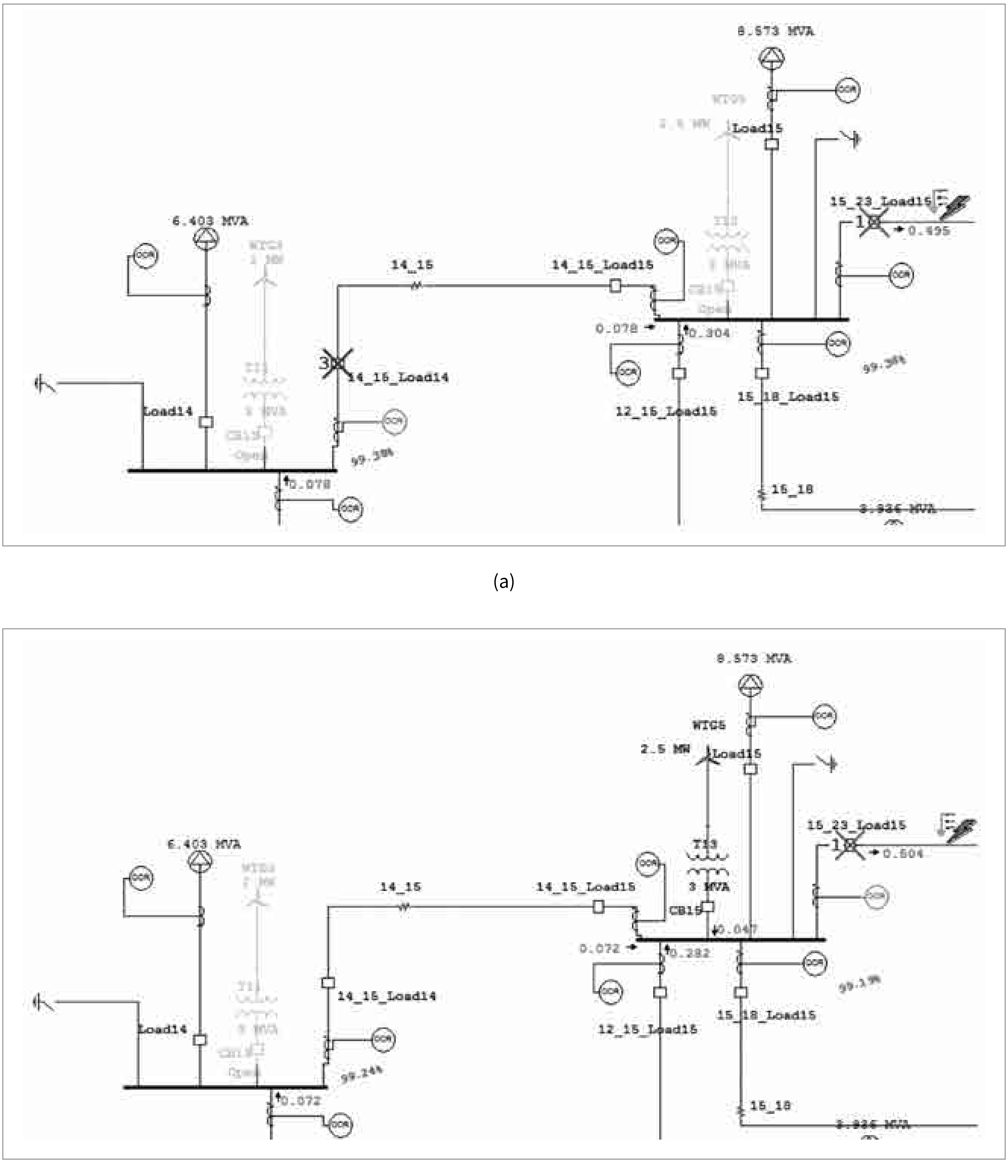


FIGURE 5. Blinding (a) without DG & (b) with DG

Line-to-Ground Fault between 15_23_Load15 and 15_23. Adjacent to Bus 15 3_15				
Total Time (ms)	**ID**	**If (kA)**	**T1 (ms)**	**Condition**
1237	15_23-Load15	0.501	1237	Phase - OC1 - 51 - Reverse
1320	15_23_Load15		83.3	Tripped by 15_23-Load15 Phase - OC1 - 51 - Reverse
11185	23_24-Load24	0.120	11185	Phase - OC1 - 51 - Forward
11268	23_24_Load24		83.3	Tripped by 23_24-Load24 Phase - OC1 - 51 - Forward
81100	14_15-Load14	0.080	>81100	Phase - OC1 - 51 - Reverse
81183	14_15_Load14		83.3	Tripped by 14_15-Load14 Phase - OC1 - 51 - Reverse

TABLE 3. The sequence of operations without DG

Total Time (ms)	**ID**	**If (kA)**	**T1 (ms)**	**Condition**
1225	15_23-Load15	0.504	1225	Phase - OC1 - 51 - Reverse
1308	15_23_Load15		83.3	Tripped by 15_23-Load15 Phase - OC1 - 51 - Reverse
12100	23_24-Load24	0.117	12100	Phase - OC1 - 51 - Forward
12183	23_24_Load24		83.3	Tripped by 23_24-Load24 Phase - OC1 - 51 - Forward

TABLE 4. The sequence of operations with DG

Conclusion

In this paper, the protection coordination analysis of the system is performed with and without DGs to understand the effects of distributed generation on the protection system. The complete analysis is carried out on a modified IEEE 30 bus test system in ETAP software. Following were the main problems and conclusions derived from the study:

1. Protection System maloperates due to the introduction of DGs in the system, it is observed that false tripping of the breakers takes place due to change in system parameters.
2. Also, the protection system is seen to become resistant to the preset pickup parameters and gets blinded due to the incorporation of DGs in the system.
3. It is also concluded that the short circuit fault current level of the system increases with the introduction of DGs in the system.

To overcome the above mentioned problems in the system, various solutions for the same are presented and verified in ETAP simulation software. For sympathetic tripping, either the pick-up currents for the relaysshould be increased, or a control loop can be used wherein the input and output currents of the bus having DGs are measured. If DGs are active, then pick-up current of relay near DG is increased and vice versa.

For solving the problem of blinding of the protection system, one of the solutions could be to use Delta-Wye transformer as an interconnecting transformer between DG and utility with delta is on the utility side. This would prevent any fault current contribution from DGs during faulty conditions. Also, the control loop used for sympathetic tripping could be used to overcome blinding as well.

To avoid the effect of increased short circuit fault current level, either the rating of the circuit breakers can be increased or the inverter short circuit current limiting factor (k factor) value could be set as a percentage of rated current. Also, one of the methods could be to isolate the DG from the system before it contributes to the fault current by controlling or commuting the firing pulses of the inverter.

References

Arritt, R. F., & Dugan, R. C. (2008, July). Distributed generation interconnection transformer and grounding selection. In 2008 IEEE Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century (pp. 1-7). IEEE.

Bernardo, A., Silva, N., Delgado, N., Jorge, R., & Carrapatoso, A. (2012, May). DG behaviour and protection schemes in case of disturbances within the concept of distribution grid area. In CIRED 2012 Workshop: Integration of Renewables into the Distribution Grid (pp. 1-4). IET.

Bhattacharya, S. (2014). Power system protection problems caused by grid connected PV systems.

Camm, E. H., Behnke, M. R., Bolado, O., Bollen, M., Bradt, M., Brooks, C., ... & Klein, S. (2009, July). Characteristics of wind turbine generators for wind power plants. In 2009 IEEE Power & Energy Society General Meeting (pp. 1-5). IEEE.

Coster, E., Myrzik, J., & Kling, W. (2010). Effect of DG on distribution grid protection. In Distributed generation. IntechOpen.

Chilvers, I. M., Jenkins, N., & Crossley, P. A. (2004). The use of 11 kV distance protection to increase generation connected to the distribution network.

Deuse, J., Grenard, S., Bollen, M., Häger, M., & Sollerkvist, F. (2007). Effective impact of DER on distribution system protection. In International Conference on Electricity Distribution: 21/05/2007-24/05/2007. AIM.

Driesen, J., & Belmans, R. (2006, June). Distributed generation: challenges and possible solutions. In 2006 IEEE power engineering society general meeting (pp. 8-pp). IEEE.

Hadjsaid, N., Canard, J. F., & Dumas, F. (1999). Dispersed generation impact on distribution networks. IEEE Computer Applications in power, 12(2), 22-28.

Patel, H. A., Sharma, V. M., & Deshpande, A. (2015). Relay Coordination Using ETAP. International Journal of Scientific & Engineering Research, 6(5), 1583-1588.

Prabhu, J. A. X., Nande, K. S., Shukla, S., & Ade, C. N. (2016, March). Design of electrical system based on Short Circuit study using ETAP for IEC projects. In 2016 IEEE 6th International Conference on Power Systems (ICPS) (pp. 1-6). IEEE.

IEEE 30 bus data retrieved from http://www2.ee.washington.edu/research/pstca/pf30/pg tca30bus.html

Jennett, K., Booth, C., & Lee, M. (2011, October). Analysis of the sympathetic tripping problem for networks with high penetrations of distributed generation. In 2011 International Conference on Advanced Power System Automation and Protection (Vol. 1, pp. 384-389). IEEE.

Kauhaniemi, K., & Kumpulainen, L. (2004). Impact of distributed generation on the protection of distribution networks.

Moore, A. T. (2008). Distributed generation (DG) protection overview. University of Western Ontario, London, Canada.

Moreno, J. G., Perez, F. E., & Orduna, E. A. (2012, September). Protection functions for distribution networks with distributed generation applying wavelet transform. In 2012 Sixth IEEE/PES Transmission and Distribution: Latin America Conference and Exposition (T&D-LA) (pp. 1-5). IEEE.

Oza Bhuvanesh, Nair Nirmalkumar, Mehta Rashesh, Vijay Makwana, Power System Protection & Switchgear, New Delhi:Tata McGraw Hill Education Private limited, 2010.

Stevenson, W. D. (1985). “Elements of power system analysis.” Fourth Edition, McGraw-Hill International Book Company.

Vijeta, K., & Sarma, D. S. (2012, August). Protection of distributed generation connected distribution system. In 2012 International Conference on Advances in Power Conversion and Energy Technologies (APCET) (pp. 1-6). IEEE.

Xu, C. X., & Jiao, Y. J. (2014). Protection Scheme for Distribution Network with Distributed Generation. In Advanced Materials Research (Vol. 960, pp. 1376-1380). Trans Tech Publications.

Zeineldin, H. H., Sharaf, H. M., Ibrahim, D. K., & El-Zahab, E. E. D. A. (2014). Optimal protection coordination for meshed distribution systems with DG using dual setting directional over-current relays. IEEE Transactions on Smart Grid, 6(1), 115-123.

Appendix1

DG No.	Bus No.	Operation Mode	Type	Power rating	Voltage	Power-factor	Efficiency	Rpm	FLA
WTG3	Bus 14	Voltage Control	Type4, WECC	2MW	0.69kV	0.85	95%	1800Rpm	1969
WTG1	Bus 24	Induction Generator	Type1, WECC	2MW	0.69kV	0.85	95%	1800Rpm	1969
WTG5	Bus 15	Voltage Control	Type4, WECC	2.5MW	0.69kV	0.85	95%	1800Rpm	2461

TABLE A1. Wind turbine generation data

DG No.	X_{SC}	X_0	X_2	X/R	Inverter SC contribution (k factor)	I_{SC} = k * FLA
WTG3	16.667 (1/2 cycles)	16.667	16.667	40.333	150%	2954
WTG1	16.667 (1/2 cycles)	16.667	16.667	40.333	-	-
WTG5	16.667 (1/2 cycles)	16.667	16.667	45.094	150%	3692

TABLE A2. Wind Turbine impedance data

DG No.	V_{oc}	I_{SC}	Power (Watt/ Panel)	Irradiance	Temp	No. of panels in series	No. of panels in parallel	Total no. of panels in array	DC Voltage (V)	Power (kW)	Current (A)
PVA6 at Bus 16	46.3	9.32	340	1000 W/m^2	25°C	160	120	19200	6160	6527	1059.6

TABLE A3. PV panel data

Inv I_d	Bus No.	Operation Mode	DC load	DC volts	DC FLA	Efficiency	AC KVA	PF	kV	FLA	Inverter SC Contribution (k factor)	I_{SC} = k * FLA
Inv8	Dc bus1, AC bus 22	Swing	6250	6160	1015	90%	7031	80%	0.4	10149	150%	15223

TABLE A4. PV-inverter data

Preyansh Sharma
B.Tech, Department of Electrical Engineering,
Pandit Deendayal Petroleum University, Gandhinagar, India
Email: preyansh96@outlook.com

Kashyap Mehta
B.Tech, Department of Electrical Engineering,
Pandit Deendayal Petroleum University, Gandhinagar, India
Email: kashyap.mehta123@gmail.com

R. Venkata Rama Raju
Assistant Professor, Department of Electrical Engineering,
Pandit Deendayal Petroleum University, Gandhinagar, India
Email: ramaraju1010@gmail.com