Optimal Integrated Planning of Multi-Building Microgrids Using BIM and GIS

A thesis submitted to the
University of Petroleum and Energy Studies

For the Award of

Doctor of Philosophy

in

Electrical Engineering

by

Jasim Farooq

December 2020

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DECLARATION

I declare that the thesis entitled "**Optimal Integrated Planning of Multi-Building Microgrids Using BIM and GIS**", has been prepared by me under the guidance of **Dr. Rupendra Kumar Pachauri**, Assistant professor-Selection Grade, Department of Electrical and Electronics Engineering, University of Petroleum & Energy Studies and **Dr. Sreerama Kumar R**, Professor of Department of Electrical and Computer Engineering, King Abdulaziz University. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

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CERTIFICATE

This is to certify that the thesis entitled **"Optimal Integrated Planning of Multi-Building Microgrids Using BIM and GIS" done** by Mr. **Jasim Farooq** in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy (Engineering) is an original work carried out by him under our joint supervision and guidance. It is certified that the work has not been submitted anywhere else for the award of any other diploma or degree of this or any other University.

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Abstract

This thesis involves the development of a Building Information Modelling (BIM) – Geographical Information System (GIS) integrated platform for the optimal planning of microgrids for multi-building projects. A new genetic algorithm (GA) based planning approach is proposed for the minimization of the net life cycle cost of microgrids in the BIM platform. The microgrid considered in the thesis consists of solar and wind energy conversion systems together with the battery energy storage systems. Traditional multi-platform based 2D CAD approach for microgrid planning is a time consuming process and lack tools that can process both electrical infrastructure data and microgrid calculations simultaneously in a single platform. To tackle the issues in conventional approach, one of the solution is BIM and GIS based integrated microgrid planning process. In this research by utilizing the parametric information system of BIM and site suitability GIS data, a GA based approach is proposed for the renewable energy mix optimization by considering both the life cycle cost and the percentage energy conservation achievable through the use of energy efficient appliances. The proposed microgrid planning approach is implemented in the BIM platform through the development of an Autodesk's Revit based add-in tool, referred to as 'BGMG'. The BGMG tool is applied for the planning of a microgrid for a typical multi-building project located in the Northern part of Kerala and the results are validated. Compared to the traditional 2D CAD based method the proposed approach can minimize number of software platforms, cost, time and errors and the entire integrated optimal planning of microgrids can be performed in a single BIM platform.

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ABBREVATIONS

API	Application Programming Interface
BIM	Building Information Modelling
CAD	Computer Aided Design
DER	Distributed Energy Resources
DSM	Demand Side Management
ESD	Electrical System Design
ESECT	Electrical System Estimation and Costing Tool
ESRI	Environmental Systems Research Institute
GA	Genetic Algorithm
GBS	Green Building Studio
GIS	Geographic Information System
HVAC	Heating Ventilation and Air Conditioning
IFC	Industry Foundation Classes
kWh	Kilowatt-hour
MEP	Mechanical, Electrical and Plumbing
MG	Microgrid
NEC	National Electrical Code
PV	Photovoltaic
RE	Renewable Energy
SDK	Software Development Kit
SLD	Single Line Diagram
USD	United States Dollar
VD	Voltage Drop
WBS	Work Breakdown Structure
2D	2-Dimensional
3D	3-Dimensional

Major Symbols

A	Area of the installed solar panels
BC_{NC}	Total installed capacity in kW of bidirectional converter system of the microgrid.
B_{NC}	Total installed nominal kWh capacity of battery storage system
C_{AT}	Annualized total cost instalments for capital recovery within the project lifetime
C_{BL}	Total net present cost required for supply, installation, testing and commissioning of the complete battery storage system of a microgrid and its running cost, replacement cost and revenue from its salvage value in the microgrid life span.
C_c	Cost of cable in INR
C_{CL}	Total net present cost required for supply, installation, testing and commissioning of the complete bidirectional converter system of a microgrid and its running cost, replacement cost and revenue from its salvage value in the microgrid life span.
C_{DP}	Cost of distribution panels (DP)
C_{EP}	Total additional cost for the energy efficient models of the appliances to achieve required level of energy conservation.
C_{IL}	Total net present cost for setting up the renewable energy source systems required for the microgrid for the life time including replacement and salvage cost
C_{ILB}	BSS Installation cost/kW
C_{ILBC}	Total cost required to install one kW of bidirectional converter system of the microgrid
C_{ILI}	Initial investment cost for setting up the renewable energy system required for the microgrid.
C_{ILR}	Lifetime replacement cost of renewable energy system required for the microgrid
C_{ILRB}	Net present life time replacement cost for B_{NC} capacity (kWh) battery storage system
C_{ILRBC}	Net present life time replacement cost for BC_{NC} capacity (in Kw) bidirectional converter system
C_{ILS}	Salvage cost of renewable energy system required for the microgrid
C_{ILSB}	Net present life time salvage cost for B_{NC} capacity (kWh) battery storage system
C_{ILSBC}	Net present life time salvage cost for BC_{NC} capacity (in Kw) bidirectional converter system
C_{MGF}	Cost for all microgrid distribution feeders
C_{MGDP}	Cost of Microgrid Main Distribution Panel (MGDP)
C_{NC}	Cable network cost (Microgrid)

CPV_{ILR}	Total PV system replacement cost
CPV_{ui}	PVS Installation cost/kW of a PV source
CPV_{ur}	PVS replacement cost/kW
CPV_{uR}	Running cost /kW of PV source/year
C_{RL}	Total net present running cost of microgrid renewable energy sources installed for the microgrid for project life time
C_{RLB}	Net present life time running cost for B_{NC} ***capacity (kWh)*** battery storage system. Estimated as given by eqn. (4.13)
C_{RLBC}	Net present life time running cost for BC_{NC} capacity (in Kw) bidirectional converter system. Estimated as like (4.13).
C_{SL}	Cost credited by selling the additional energy generated from installed RE sources in the project area during the life cycle
C_{Ta}	Total cost of all cables by actual length method in meters
C_{TC1}	Cost for 1% energy efficiency improvement
C_{TCS}	Cost for all distribution panels
C_{TMR}	Total net present lifetime cost for microgrid source, storage and converters
C_{TMRmax}	Maximum possible value of C_{TMR}
C_{Ts}	Total cost of all cables by straight-line method in meters
C_{uc}	*Unit Cost of the component*
CWG_{ILR}	Total WTG system replacement cost
CWG_{ui}	Total WES Installation cost/kW
CWG_{ur}	WES replacement cost/kW
CWG_{uR}	Running cost of one kW of WG source /year
E_{Bi}	Energy stored in battery storage at time "i"
E_{BN}	Energy stored in battery storage at time "i"
E_{SM}	Maximum surplus energy available in any month of an year in kWh
f	interest rate
F_c	Cost of feeder cable installation per meter length
F_{CR}	**F**actor for Capital recovery
F_i^A	Maximum value of the actual current flow through a feeder
F_{max}^A	Rated maximum ampere capacity of the feeder
G	Average Global horizontal hourly irradiance of the project site
G_M	Rated Global horizontal hourly irradiance in kWh/m^2 of the selected solar panel at its standard test condition (=1 kW/m^2)

i	Inflation rate
L_{caT}	Total length of cable in according to actual site conditions
L_{csT}	Total length of cable in according to straight-line method
lf	load factor
L_f	Total Length of the feeder cable per meter between distribution panels and building panels
m	number of feeders
N	Project lifetime in chapter
N_{CL}	Life time of the component in years
N_{LR}	remaining life time of the component in years
N_{LRPV}	Remaining life time of the PV component in years
N_{LRWG}	Remaining life time of the WTG component in years
P_{BC}	Power charged to battery
P_{BCi}	Power available for battery charging from RE sources
P_{BD}	Power discharged from battery
P_{BDi}	Power available for battery discharging
P_{DTM}	Maximum load demand served by the microgrid
$P_{Grid-buy}$	Power purchased from grid, In this study $P_{Grid-buy} = 0$ and 100% renewable energy supply for the load.
$P_{Grid-sold}$	Power sold to grid. In this study entire surplus energy generated is exported to grid
P_{LT}	Total load demand of all the buildings served by the microgrid
PR	Performance Ratio of the selected PV systems at the project site
PV_{IC}	kWp installed capacity of PV systems at the project site
PV_{kWp}	Total PVS installed kW capacity
PV_{kWpM}	Maximum possible total kWp rating of PV energy sources from the project site
$P_{WGi}(v_{ci})$	Power generated by WTG @ cut in velocity
$P_{WGi}(v_{co})$	Power generated by WTG @ cut out velocity
$P_{WG}(r)$	Total sum of the rated power output of installed wind turbine
r	Real discount rate
R_n	Number of times the replacement is required for a component
S	Salvage value of the installed component

S_c	A constant for cable length as per the project conditions
SoC_i	State of charge of battery storage at time "i"
SoC_{max}	Maximum (selected) State of Charge of battery storage system
SoC_{min}	Minimum (selected) State of Charge of battery storage system
S_{uPV}	Salvage value/kW of PV system
S_{uWG}	Salvage value /kW of WTG system
v	wind velocity according to the hub height of the selected wind generator
v_{ci}	Wind generator cut in velocity
v_{co}	Cut out velocity
WG_{kWp}	Total WES installed kW capacity
WG_{kWpM}	Maximum possible total kWp rating of WTG energy sources from the project site
η_{bc}	Battery charging efficiency
η_C	Efficiency of converter
η_{ep}	percentage of energy efficiency achieved through the selection of a higher efficiency model for the appliance under consideration in the planning stage
η_{pv}	efficiency of solar panels
Δt	commitment period which is 1 h in this thesis
σ	self-discharge rate of the battery storage system

Chapter 1

Introduction

1.1. Background

Renewable energy technologies are becoming more and more cost-effective and promising to overcome the high dependency on polluting and depleting fossil fuels. Electric power from renewable energy sources distributed in a small physical area can be consumed on-site itself, which eventually leads to reduction in investments, energy loss and increase in reliability. Microgrid is an electrical network comprised of multiple power generation units, generally the renewable energy resources and loads which are distributed in a small geographical region. It can operate with the utility grid or work independently in islanded mode. For a desirable operation of microgrid an efficient control mechanism is mandatory. Significant improvements in energy saving, reliability and reduction in carbon emissions are possible by microgrid implementation which leads to a paradigm shift from centralized to de-centralized power generation. Significant developments in communication and monitoring mechanisms contribute to technology advances in microgrid development. This facilitates two-way communication between the control center and smart devices over smart meters for obtaining the desired system performance. Such a microgrid has the capability to respond to dynamic variations in energy supply by co-generation and demand regulations [1]. An Integrated Optimal Planning of Microgrid (IOPMG) problem attempts to solve the economic feasibility of microgrid deployment and evaluate the optimum generation mix of Distributed Energy Resources (DER) at various operating conditions by satisfying the engineering, financial, geographical and environmental constraints, which are conflicting to each other.

For maximum gain, it is preferred to perform the IOPMG at the early design stage of an infrastructural development. To do a complete building level integrated analysis a real conceptual modelling (semantic modelling) is required and each and every artifact including electrical network of that building is to be structured in such a way that changes in any one of the network parameters is to be propagated to other related building components (parametric modelling). As the conventional 2D CAD based IOPMG lack parametric modelling, an integrated analysis is not feasible. Concept of parametric and semantic model enables annual integrated building performance measurements by combining weather data and customer characteristics. Its availability at early phase of project planning can be useful for further optimization study at grid level. Currently most utility companies have limited installed capability for integration across the applications associated with system planning, power delivery and customer operations. In most cases, this information in each department is not accessible by applications and users in other departments [2]. If the documents used for planning, design and construction are utilized as it is for city energy modelling then it will be very beneficial for all stakeholders. However, Current 2D based system approach is an error-prone process leading to poor documentation [3].

Automated and fast computational platform which can combine infrastructure and IOPMG calculations in a single platform is desirable for the iterative microgrid planning optimization studies at the early phase of the project itself. The emerging Geographic Information System (GIS) and Building Information Modelling (BIM) integrated approach is one of the suitable platforms to retrieve and process huge data automatically and accurately. By using this 3D BIM model of a building, infrastructure effective planning, coordination and analysis can be done well before the real construction starts like daylight analysis and 3D coordination between various divisions. The major applications of BIM in electrical design are parametric modelling of systems where design changes are easy to handle such as lighting, wiring devices, panel boards and cable routing. The major electrical analysis done with BIM-based semantic building models are renewable energy potential assessment, integrated energy analysis and daylight analysis. BIM can execute precisely the integrated analysis at building level such that the range of outcomes from the same can be used at grid level for further optimization. “Bentley substation” is a BIM-based application which claims 30% faster design of substations with significant improvement in productivity and rework [4].

A geographic information system (GIS) enables us to visualize, query, investigate, and interpret data to understand associations, characteristics and trends. The major use of GIS in power utilities are analysis, management and mapping of the electrical network in geographical framework, automated route selection and optimization, load forecasting and optimizing planning of substation’s location[5]. Many power system applications are capable of reading electrical network in GIS platform and process them for analysis with or without editing [6]. Currently visualization techniques have a key role in microgrid design because they help the planners for visualization of data and information as a substitute for refereeing to a number of datasheets [7]. GIS basically reproduces an electrical network with its attributes so that a clear idea about load and generation nodes are available and analysis for most valuable load reduction is possible [8]. The research related to BIM and GIS integrated approach for power system modelling, design and IOPMG are limited and mostly based on statistical methods such as surveying rather than the actual quantifiable design approach.

Table 1.1 summarizes various major IOPMG studies reported in the literature. This thesis involves the utilization of both BIM and GIS for IOPMG. An overview of microgrid is given in the following section.

Table 1.1: *Summary of sizing methodologies of solar-wind renewable energy sources*

Optimization constraint	**Analysis**
Probability of loss of power supply and LCOE [9]	Technical and financial
Life cycle cost and Probability of loss of power supply [10]	Financial
Generation cost [11]	Financial
Energy index of reliability [12]	Probability based
Probability of loss of power supply [13]	Probability based
Cost/unit, automation level [14]	Technical and financial
Net present value [15]	Financial
Load power supply requirements and total cost [16]	Technical and financial

1.2. Microgrid

Microgrid improves system reliability and reduces power loss through a local-scale integration of generating sources, electrical loads, cable network and control mechanisms. Microgrid enhances distributed generation and decentralizes electric supply grids [17]. Microgrids can work together in clusters and these can work with supply grids. Typical components of microgrid are i) renewable energy sources such as solar and wind ii) fossil fuel based energy generating sources to increase the reliability of microgrid iii) storage mechanisms such as battery and pumped storage iv) electrical interconnecting network of low voltage cables and control wires and v) an intelligent control station [18]. Significant research has been carried for designing a microgrid under islanded mode [19], [20]. The major parameters considered during a microgrid design are i) Total number of buildings and their loads which requires supply from microgrid ii) geographical conditions and electrical network types iii) voltage and current types iv) power quality and reliability specifications and v) control strategies [21]. Suitable energy storage mechanism is necessary for increasing the reliability of microgrid especially in the islanded mode with supply fluctuations. Currently, micro-grid system design involves a multi-platform based manual process as shown in Fig. 1.1. By using GIS platform, project site suitability, restrictions and hazard assessments are conducted according to project specifications. By using 2D-CAD platform project drafting is done after manually gathering the results from design applications. After finalizing the drawings, generalized building electrical details such as load curve, feeder schedule and demand load are manually calculated by using MS excel based spreadsheets. By using application such as HOMER, renewable energy hybrid mix is estimated by entering the data collected from other platforms such as 2D-CAD.

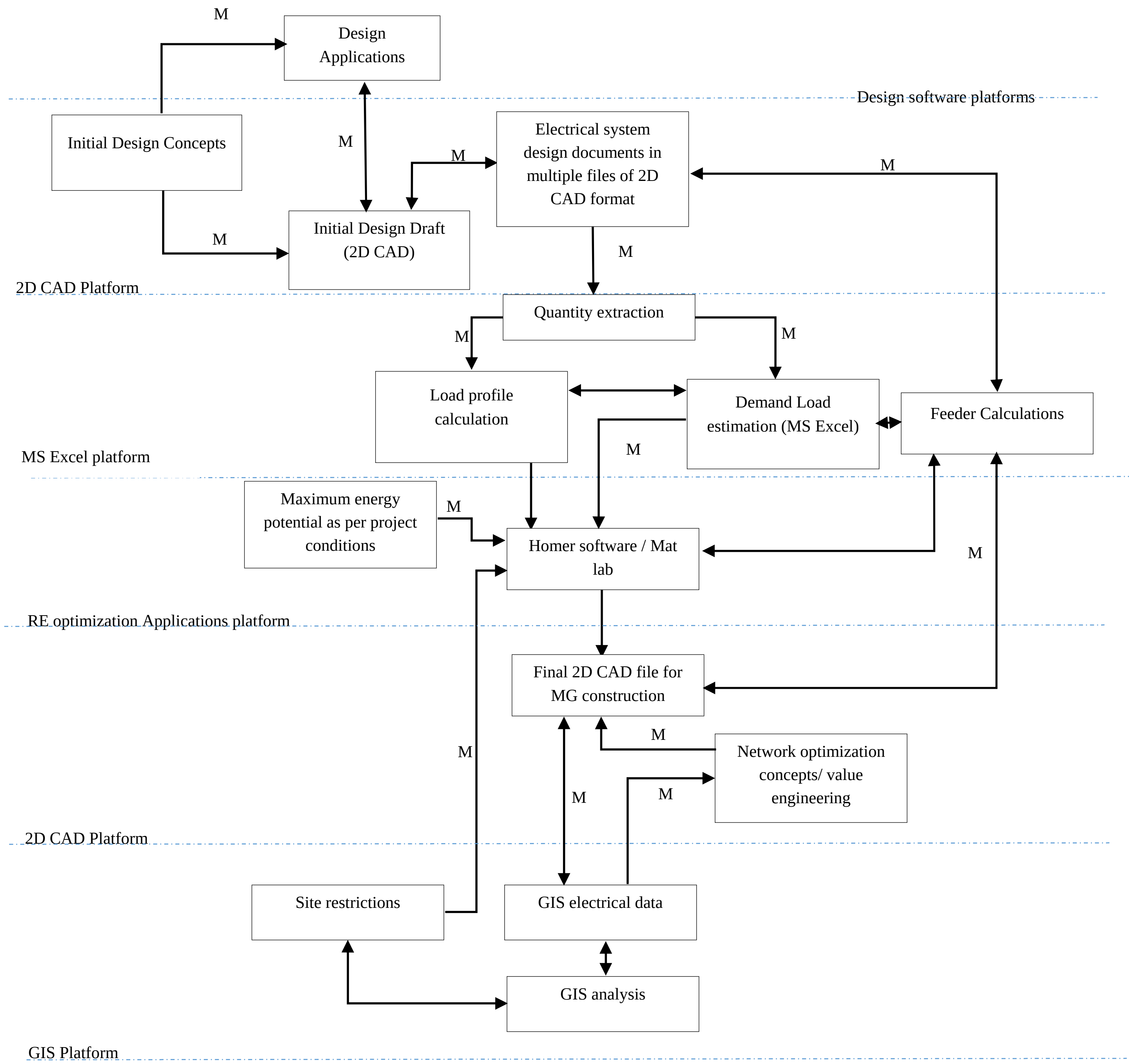

Fig 1.1: *Process information flow in 2D CAD based traditional IOPMG. "M" stands for manual data transfer*.

The major difficulty with the utilization of multiplatform 2D-CAD based approach for microgrid design and optimization is due to the requirement for the manual transfer of the results from one platform to another in sequence. The whole process in the 2-D platform is thus tedious, and error-prone and costly. Hence in this thesis, a hybrid BIM and GIS based approach is investigated for the design and optimization of electrical infrastructure systems so as to overcome these issues of the state-of-the-art practices. While the conventional method offers a manual / semi-automatic multi-platform process for electrical system design, BIM provides a consolidated information base on a single platform as given in Fig. 1.2.

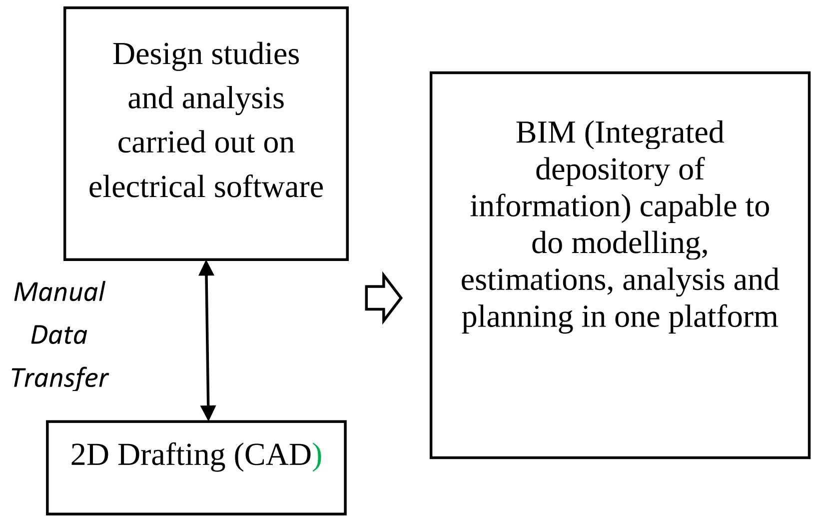

Fig 1.2: *Comparison between existing 2D CAD and BIM based electrical system design and modelling.*

1.3.Problem Description

The state-of-the-art approach for IOPMG is a multi-platform based laborious method with manual information transfer among various platforms. This leads to poor documentation and lengthy data retrieval process. Hence this thesis involves investigations for the development of a single Building Information Modelling (BIM) - Geographic Information System (GIS) integrated platform for planning and optimization of microgrids at the early building construction planning stage itself.

With such a facility, it becomes feasible to retrieve and process electrical infrastructure data and IOPMG calculations automatically and accurately from the BIM platform.

Thus the major objectives of this research are as follows:

- To develop a generalized representation of BIM-based building electrical characteristics for optimal energy planning of a microgrid, incorporating environmental constraints.
- To perform Optimal Integrated Planning and optimization of a multi-building microgrid system in the BIM-GIS platform.
- Application to practical microgrid projects in Indian Conditions

Fig.1.3 shows the major research activities envisaged in this thesis with reference to these objectives. The thesis outline is also given in the picture.

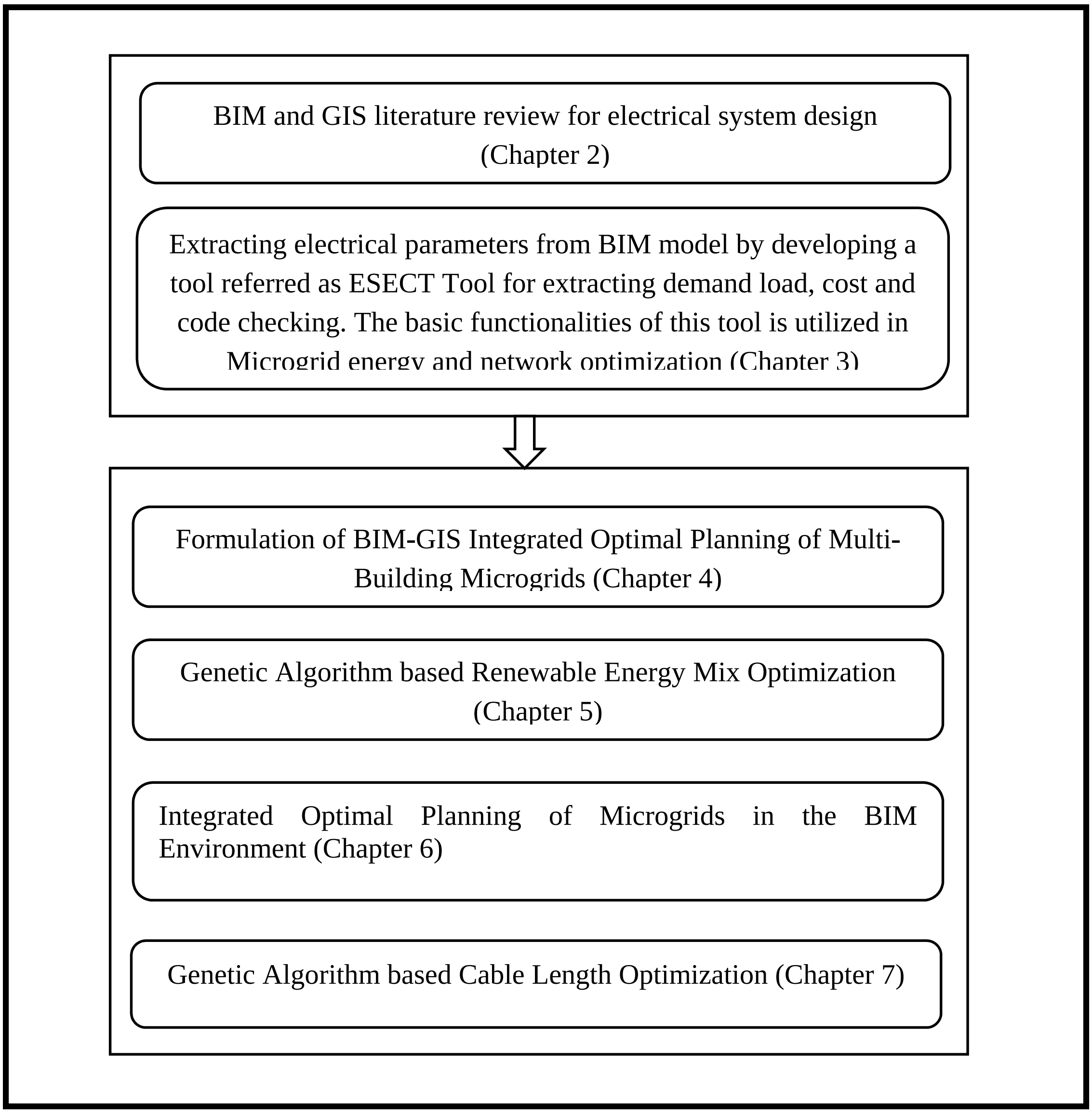

Fig.1.3. Research Objectives and the Thesis Outline

1.4. Thesis organization

As shown in Fig.1.3, this thesis is organized as follows:

- **Chapter 2: Literature Review***:* Provides the literature review related to BIM, BIM and Electrical System Design (ESD), BIM-based costing, quantity survey and code checking, BIM-based building energy and renewable energy assessment, BIM and GIS integrated approach for provincial level electrical infrastructure planning.

- **Chapter 3: Data Retrieval and Preliminary Calculations using BIM Add-in Tool:** a Revit based add-in tool development referred as ESECT is detailed in this chapter, followed by the methodology of BIM-based electrical data retrieval and related programming. A case study is also presented. By using the method described in this chapter, the required data for IOPMG is extracted and processed.
- **Chapter 4: BIM-GIS Integrated Optimal Planning of Multi-Building Microgrids:** This chapter proposes the formulation of BIM-GIS based IOPMG.
- **Chapter 5: Genetic Algorithm based Renewable Energy Mix Optimization:** This chapter proposes a genetic algorithm based optimization of microgrids performed in the BIM platform.
- **Chapter 6:Integrated Optimal Planning of Microgrids in the BIM Environment:**

  A Case Study: A multi-building microgrid optimal planning study of a project located in Chathamangalam Village of Kozhikode district, Kerala is presented.
- **Chapter 7: Genetic Algorithm based Cable Length Optimization:** BIM based optimal cable length optimization process by optimizing the number of distribution panel and its location is presented in this chapter. This method will minimize the total cost of microgrid.
- **Chapter 8: Conclusion and Scope for Further Work:** This chapter gives the conclusion and scope for further work.

Chapter 2

Literature Review

2.1 Introduction

This chapter discusses the importance of BIM and GIS in electrical system design. The applications of BIM for lighting and power system modelling, energy analysis, power system planning and load forecasting are presented. GIS capabilities for electrical network modelling, microgrid planning and the combined BIM-GIS integrated approach are also described in later sections.

2.2. Building Information Modeling (BIM) for Electrical System Design

Conventionally, Electrical System Design involves utilization of various design tools and presentation of final design details in 2D-CAD based drawings. For illuminating the building, lighting fixtures are selected for each area according to Lux requirements for a room/project and the illumination levels are calculated by using tools such as DIALux [22]. It is essential to gather indoor area measurements, door and openings details, appliances and furniture dimensions details and wall finish details from shop drawings to complete an illumination analysis in the DIALux. Due to the need to collect the required details, design process becomes tedious for an electrical system designer. The deployment of several software for electrical design process such as IOPMG, lead to possibility for compounding miscalculations and take more time to finalize the process. When the information is gathered from a hard copy catalog and drafted in 2D-CAD platform, the issue of double work occurs. There is no functional interlinking among the drawing elements when drawings are prepared in 2D-CAD. If design change occurs in one part, the relevant related change in other parts of 2D-CAD drawings are to be updated manually. The revisions in power or lighting panel schedule also results in corresponding manual changes of transformer and sub-distribution boards calculations. Also the corresponding feeder calculation sheets need to be updated accordingly. In general, there are revisions or changes in any design/modelling of the power system projects. Thus, manual updating of 2D-CAD drawings becomes an unwieldy task for developers. Consolidated all-inclusive final shop drawings for Mechanical, Electrical and Plumbing systems (MEP) coordination to identify intersection clashes and comply with rules and regulations between two trades generally have errors with 2D drawings.

BIM is a modelling technique that can effectively generate a building's 3D model that can perform precise engineering analyzes at early project stages. BIM has evolved to be a reliable platform for all kinds of construction related deeds and many governments have recognized it as a mandatory procedure for initiating actual construction [23], [24]. Industrial manufacturers provide BIM files for their electrical products [25]. Multi - discipline coordination, 3D visualization of design concepts and modeling for constructability assessment are the most significant activities that contractors attempt to leverage by using BIM [26].

BIM can be used for indoor and outdoor ventures, such as internal or external lighting systems. Researches are also carried out on the use of BIM in the manufacturing of ships, data centers and hydel dams [27], [28]. The key BIM centered studies of electrical trade comprises the assessment of building level renewable potential, integrated building energy assessments, continuity check and integrated coordination of MEP systems. The most important BIM-based applications are Autodesk's Revit [29] and Graphisoft's ArchiCAD [30] and both of these are mature packages with their own merits and demerits. Bentley Substation of Bentley Systems [31] and Primtech of Entegra [32] are the tools for BIM-based substation design. Major BIM-based application for electrical system modeling are given in Table 2.1.

Table 2.1: *Major use of BIM based electrical system design*

Type	BIM Applications
Electrical System Design	Modelling and analysis of illumination levels, conduits and cable trays, panel schedule design, lightning and earthing systems, n^{th} dimensional modelling and interpretations, bill of quantities and costing, site safety investigation.
Analysis	Coordination between systems, circuit inspection for continuity, cost assessment, LEED/BREEAM point valuation, Impact of daylight assessment, sustainability possibilities, building level renewable energy estimates, entire building energy investigations.
Electrical Infrastructure Planning	Semantic district energy information system and assessments for grid level impact of each building, electrical data collection and standardization, Microgrid cluster management.
Smart Built Infrastructure	Smart objects, Human activity and energy consumption, real time energy visualization, O&M, Smart activity assessment before and after construction.

There are only a limited research on the design and use of BIM electrical parametric modelling for power grid level calculations and developments of urban electrical information model [33]-[37]. As per McGraw hill construction report, BIM deployment in electrical systems is significantly less compared to mechanical systems both in 2010 and 2014 [26], [38]. There is a delay in the development of electrical BIM family files by industry compared to other trades. BIM models are created for improved coordination and prefabrication during complex power system projects such as power plants [39].

The utilization of BIM in electrical system design enables one to do the process of estimation, clash detection, coordination and manipulation prior to commencement of the real construction. The key virtues of BIM are easiness of accomplishing repetitive tasks due to revisions, developing alternatives for existing proposal, semantically and functionally inter-linked electrical network, automated coordination between systems and ease of information retrieval.

From civil engineering department a BIM file with construction details such as wall, building appliances and furniture are obtainable for insertion of lighting fixtures, wiring device and other power devices. This makes automated hosting of electrical elements [40] and coordination easier for quantitative and qualitative studies with 3D visualization and semantic interlinking. By inbuilt tools of BIM application or by third party add-in tools plugged to the BIM software all kind of modelling, designing and rendering can be possible and can eliminate manual data transfer between applications. BIM based Illuminating Engineering Society (IES) files with photometric data are gaining momentum analogous to DIALux lighting fixture plug-in applications from manufacturers [41]. Because of the availability of the geocoded BIM model, artificial and daylight collective illuminance analysis is possible in BIM platform [42].

Alike lighting networks, power networks can also be created by using BIM. With an auto-routing option, it is possible to model cable routing systems, electrical ducts, and electrical busway systems and can be drawn with precise scale. BIM based task centered custom-made template with predefined electrical data such as power supply voltage, wire sizes and types, various kinds of electrical distribution system when developed, calculation and modelling becomes easier. A recommended practice by government agencies is standardising the modelling by specifying the colour code for different sub-systems such as ducts, trays, power system and cable routing to a common code throughout the region [24]. By integrating BIM based temporal and spatial data, Chou, C . et al proposed an approach known as iARTS (interactive Augmented Reality system for Temporal and Spatial analysis) to categorise patterns of electricity usage and to identify possible correction plans to minimize electricity wastage[43]. BIM-authored applications for electrical system computing are increasing in the market [44],[45]. Enhanced visualization, precision, and ease of installation are the major benefits that electrical contractors claim through the usage of BIM for electrical prefabrication [46]. Using BIM has eased the process of prefabrication coordination in MEP trade and enhanced multi-level prefabrication [47]. BIM and prefabrication studies have been undertaken by [48] and [49] and their results suggest a positive effect on productivity. By using BIM, fabrication schedule can be prepared according to the project phase or building level. By combining BIM, holography techniques (concept of mixed reality) and computer virtual vision skills, productivity of construction, design communication, and ease of work related to critical construction such as power station is improved [50],[48]. Because of BIM's n^{th} dimensional conception and consolidated assessment abilities, labour safety communication becomes easier and well-organized, also construction related logistical arrangements and equipment deployment becomes inexpensive [51]. The BIM-based safety management has been proposed by [52]. For multidisciplinary coordination between engineering systems, user-friendly automatic intersection detecting inbuilt functionalities have been provided with BIM applications [53].

BIM based tools automatically perform material take-off and bill of quantity generation. By linking BIM and pricing software tools by the support of a third party/add-in tools, electrical costing such as substation-related costing can be easily achieved [54]. By following the necessary steps, existing power system data can be transformed to a BIM data by using 3D scanning technique [55]. BIM-based tools are available to calculate lightning protection [56]. GIS-tagged 3D-BIM model concept simplifies the calculation of lightning protection requirements. From BIM electrical model, 2D-CAD formatted schematic diagrams such as conventional single-line diagram can be generated using add-in tools [57]. BIM eases the static and dynamic site layout planning with automated layout generations [58]. MEP layout finalization and value engineering from its early conceptual stage to real construction phase is attainable by BIM leading to budget reductions [59].

In general, a developer's tab and external add-in tool interfacing opportunities are provided in BIM applications. Novel tools for conducting a specific activity, or linking to databases can be added to Revit by using Application Programming Interfacing (API) technique. A new BIM based tool is developed according to user's specific requirement, which facilitates his task and thus increases productivity. API tool can be created either as an external application or as an external or internal type of macro add-in tool. By using add-in tools it is possible to create, edit, add and retrieve the graphical / family attributes / edit the family parameter of a particular BIM document such as information for conducting electrical calculations, electrical grid calculations, pricing and power auditing. BIM based smart objects are those that can interact with other elements in BIM model and to capture information for a specific activity [60]. Revit offers a robust API method based on .NET languages and by using the same novel add-in application is developed to perform automated redundant activities. BIM - based API tools can identify and store process information such as coordination choices linked to BIM - centered modelling such as MEP clash detection [61].

BIM files act as base for getting information and conducting pre and post construction assessments. Combining historic, behavioral, consumption, climatic and location data by using a BIM based add-in tool it is possible to generate building level load curve. By using BIM functionalities or using BIM file supported third party applications it is possible to visualize the real-time energy use pattern as specified by the user [62] and real-time data can be integrated to BIM objects. By using BIM platform integrated modelling of microgrid related components such as sensor, meters and related algorithms can be integrated in a single platform [63]. [64] describe a BIM based method for combining real-time energy consumption information and energy saving concepts. [65] propose a BIM based sensor information integration for energy management by considering user behaviour, climatic conditions and comfort. BIM based smart objects are discussed in ref. [66]. Human behaviour simulation on a BIM platform have been described in ref. [67]. A technique for dividing the building according to occupants and by merging real-time sensor data for each occupant's to a BIM platform for visualization and assessments has been presented in ref. [68]. Similar to this real-time energy consumption visualization and assessment can be done at GIS platform [69].

2.2.1. Costing, quantity survey and code checking

Rules and regulations related to electrical system modelling, designing, installing, testing and commissioning are extensively documented by official organizations such as NFPA and IEC. Past studies reveal that the early project design specifications and choices can have a significant influence on building system requirements such as electrical KVA and life cycle costs. Design and modelling based solely on engineer's insight and perceptions is likely to be susceptible to errors [70]. 2D-CAD based drafting procedures are also being investigated by researchers and significant disadvantages such as difficulties in design coordination, exclusion of related systems and elements, lack of semantic modelling and labor-intensive manual process for estimation are acknowledged [71,72,73]. For more than 20 years, the concept of automated building code compliance checking for construction has existed [74]. Specially developed API methods, third party applications and online web installed methods are the different kinds of BIM automated applications created by developers. Many investigations related to automate BIM building code checking have been documented in [75]. Zhang et al has proposed an automated construction code checking procedure based on BIM in 2010[76]. [77] has described an automated rule-checking add-in tool for plumbing networks for Industry Foundation Class (IFC) based models. BIM based tool for HVAC systems has been proposed by [78] and construction safety rule compliance in [79]. [80] has suggested a framework for obtaining required data from Revit BIM models to verify compliance with energy code of the building envelope.

Inbuilt tools of BIM application provide quantities but to conduct user defined automated operations custom-built tools are required. Cost estimates may be for tendering stage or final design phase estimates [81]. By using the Google Sketch Up environment, a construction cost approximation method referred to as Low Impact Design Explorer (LIDX) has been proposed in ref. [82] for schematic BIM conceptual models. [83] has suggested a custom-made ontological procedure for BIM based costing. There are presently numerous add - in applications available in the market to obtain user defined data from REVIT building model created by various companies or individuals. BIM based tools for conducting specific activities such as power cables modelling, generating panel schedules, and automated laying out of selected electrical equipment are available as per [84].

2.2.2. Building energy consumption and renewable energy potential assessment

By combining weather data and user preferences, the concept of consolidated integrated BIM modeling allows cohesive performance measurements of the whole building. In BIM's realistic virtual building model, pre-construction energy scrutiny aids to analyse environmental considerations in an easy method compared to traditional method.

Instead of simplifying rules of existing energy analysis, the BIM method deploys real quantifiable information on a complete construction model. BIM project data with energy settings can be utilized for complete building energy assessments, renewable energy potential analysis, cooling/heat load estimations and daylight simulations. Using BIM – centered Building Performance Simulation (BPS), it is easy to find the appropriate measures according to project specifications and goals for energy use, mixture of renewable energy sources, environmental impact assessments and necessities and related choices for Leadership in Energy and Environmental Design (LEED). Conceptual modeling, building components based or combined analysis of both can be used to generate BIM based add-in applications and it can be an external program linked to BIM application, inbuilt functionality, or by exporting the BIM file into a 3rd party software in a necessary format. For example, in the EnergyPlus application, BIM file is to be exported to an Input Data Format (IDF) type [85]. There are different BIM based energy analysis applications with diverse capabilities like Green Building Studio (GBS) of Autodesk. The directory of Building Energy Software Tools (BEST) provide all kinds of building energy analysis, renewable energy potential assessment and sustainability analysis software tools [86]. Only a few tools can function autonomously (without the aid of BIM platform), some tools can be incorporated into BIM platform. Conclusions from BIM - centred energy assessment investigations indicates that the orientation optimization of an apartment can reduce electrical energy consumption significantly during its entire life span [87]. By utilizing BIM based API method combined with GIS, add-in tools can be developed to measure the potential of renewable energy utilization in the building.

2.2.3 Electrical load forecasting

One of the necessities for conducting microgrid planning and optimization is forecasting of building's electrical load profile. Building's load profile is varied by factors such as type of building, nature of occupants and location [88]. Various load forecasting methods have been discussed in Ref. [89] and [90]. Ref. [91] has proposed a BIM based activity pattern for buildings. In order to reduce energy consumption, BIM centered real-time analysis of power consumption and energy analysis have been performed in ref. [92] and in ref. [93] respectively. BIM based electrical power use pattern visualization has been presented in ref. [94]. Domestic building energy consumption forecasting by deploying BIM and ANN has been presented in ref. [95]. By processing BIM information in GIS platform, it is possible to estimate energy consumption characteristics according to specific conditions such as architecture types, socio-economic conditions and locations [96]. Using web-based GIS platform, every building's load profile information can be stored, processed and reproduced and can ease microgrid planning studies [97].

2.3 Geographical Information System (GIS) in Electrical System Design

Geographical Information System (GIS) are powerful tools utilized for problem identification and, decision making by capturing, storing, manipulating and analyzing geographical data [98]. GIS has been long used for many applications in electrical system development and management such as automated route selection for power utilities, load forecasting and substation size and location optimization [99]. As GIS is capable to represent the impacts associated with land use patterns, geomorphology, climate change and energy potential in an integrated way, it makes an attractive tool for project developers. GIS is an important planning and developing application for microgrid due to its capability to assist the decision-making process by providing essential data and assessments. As per literature review, various applications of GIS useful for its potential use associated with microgrid design, planning, construction, operation and standardization are given in Table 2.2.

Table 2.2: *GIS applications for MG related systems/ technologies / visualization /management.*

1	Project site suitability analysis
2	Fault historic occurrence information storing
3	Cluster microgrid management
4	Electrical network modelling with spatial and attribute data
5	Operation and rapid maintenance service of electrical systems [100]
6	Automated power distribution management integration with GIS [101]
7	Electrical Load Forecasting
8	Project site hazard assessments
9	Electrical network route optimization [102][103]
10	Precisely locate damage/faults[104]
11	Better communication among stakeholders
12	Integrated CAD, GIS and Genetic Algorithm (GA) approach [105]
13	Smart city modelling applications [106]
14	Optimization of distribution network by GA [107]
15	Substation Planning [108][109][110][111]
16	Regional level electrification planning tool[112][113][114]
17	Spatial optimization for the planning of sparse power distribution networks [115]
18	Integrated assessment model creation for city energy network system [116]
19	Hydropower resource assessment [117]
20	Dynamic power network planning [118]
21	Electrical device protection optimization [119]
22	Predicting the renewable energy potentials for the future utilization
23	Assessing the complementarity of renewable energy potential both spatially and temporally for a region [120]
24	Virtual reality based visualization of GIS models[121]
25	Length of transmission conductor measurements [122][123][124][125]
26	Optimization of renewable energy installation by GIS and lidar [126]

27	Power feeder connectivity models [127]
28	Cost estimations for MG initial planning studies[128]
29	Customer address database and automatic billing [129]
30	Economic feasibility analysis[130]
31	Weather forecasts
32	Network planning by minimum cost[131]
33	GIS data for Smart Grid analysis [132][133]
34	Potential analysis of wind and solar energies [134][135][136]
35	GIS based smart grid modelling and management [137]
36	GIS-based Estimation of Roof-PV[138]
37	Microgrid modelling with GIS[139][140][141][142][143]
38	GIS vehicle driving pattern generation[144]
39	Transmission Lines optimum path finding [145][146][147][148]
40	Microgrid zoning [149]
41	Smart Grid management [150]
42	GIS supply-demand model for the optimization study[151]
43	GIS database for smartgrids [152]
44	GIS based optimal sizes and locations of renewable energy sources [153][154][155]
45	GIS based resilient micro energy grids [156]
46	GIS database for renewable energy [157]
47	Interface the Meter Data Management System (MDMS) with the GIS [158][159][160]
48	GIS-based multi-factor scenario development of variable energy sources [161]
49	GIS for smart grid congestion management [162]
50	GIS based customer service map [163]
51	Visualization of discrete spatial grid resource data [164]
52	Feasibility study of renewable energy for a microgrid village [165]
53	GIS and asset management system integration [166]
54	GIS data for enterprise information integration [167]
55	Integrating other systems with GIS [168][169][170][106][171]
56	Optimizing the topologic observability of spatially distributed energy systems[172][173]
57	GIS applications for a residential microgrid [174][175]
58	Optimization of a residential microgrid demand side management [176][177][178]

59	BIM-GIS combined analysis[179]
60	Agriculture and smartgrid integration by the aid of GIS [180]
61	GIS based renewable energy potential analysis of surface areas [181]
62	Integration of big energy data and GIS for smart grid [182]
63	GIS based PV microgrid for national security [183]
64	GIS and neural network [184]
65	Integration of GIS, PV electricity and fuzzy logic for microgrid [185]
66	GIS based bio-energy assessments [186]
67	Geo-referenced building data for microgrids[187]
68	GIS data for pricing of network energy flow [188]
69	GIS based impact assessments of line outages in extreme events [189]
70	GIS data for solar tracking [190]
71	GIS application on transition process for smart grid [191][192]
72	Identify potential microgrid sites [193]
73	GIS for job scheduling[194]
74	GIS linking load profiles [195]
75	GIS web portals [196][197]
76	GIS based power communication resource supervision [198]
77	GIS data for the integrated technical planning of smart grids [199]
78	GIS application on smart energy management [200]

The electrical network can be modelled using GIS tools and the same enhances planning, design, operation and maintenance of power systems. Both geospatial data and electrical specification are to be collected for electrical mapping in GIS applications. For example, a transformer is an object in a GIS application with location information and electrical specification as its attributes. The attributes are to be added by the user manually. By predefined connectivity rules the electrical objects are connected in GIS modelling.

2.4 BIM-GIS combined approach

Table 2.3 shows the major reported research in which BIM and GIS combined platform is utilized for the engineering planning and analysis. From this Table, it can be observed that the BIM-GIS integrated approach for microgrid planning and optimization has not been investigated even though such a facility can contribute significantly towards the betterment of any microgrid project. Hence this thesis focus on this area of research.

Table 2.3: *Literature review of BIM GIS based integration in the context of IOPMG*

No	Area of Research	Description
i.	Smart city planning	By integrating BIM data with GIS [179] proposed a database based approach for analyzing city-level energy consumption planning and 3D visualization.
ii.	Energy-efficient building design	[201] proposed a web-based GIS and BIM information integration for energy-efficient building design and related visualization.
iii.	Shadow analysis	By combining the BIM semantic model with GIS data, [202] proposed an automated BIM data transforming to GIS platform method for shadow analysis.
iv.	Climatic assessments	[203] proposed an IFC’s Information Delivery Manual based approach for assessing geographical level climatic effect on buildings under planning.
v.	Pipeline management	BIM modeled pipeline network can be visualized along with GIS data by the help of a third-party application and can improve pipeline management [204]
vi.	Railway Maintenance	Preventive steps for railway maintenance can be developed by integrating GIS and BIM and will improve the maintenance activities [205]
vii.	District Modelling	By effectively tackling the interoperability issues, various systems for district information modelling can be done by using BIM and GIS and can be used for analysis such as district-level energy saving studies [206]

2.5 Summary

BIM and GIS applications for electrical system design have been presented in this chapter. BIM and GIS are capable and proven technologies for construction planning, modelling and project management and its integrated approach can offer a better method for electrical system design compared to conventional 2D-CAD method. The research related to BIM and GIS integrated approach for electrical system modelling, calculations for microgrid planning are limited and mostly based on statistical methods rather than the actual quantifiable design approach. There are only inadequate researches on BIM application for electrical system modelling, data retrieval, specialized electrical BIM based add-in developments, BIM and GIS integrated approach for microgrid design and modelling and its use for provincial level multi-grid planning. Compared to the conventional 2D CAD method, the capabilities of BIM and GIS based integrated planning of microgrid for data retrieval, automation, design calculations, network optimization and site suitability analysis are to be explored.

Chapter 3

Data Retrieval and Preliminary Calculations using BIM Add-in Tool

3.1. Introduction

For the microgrid energy planning studies, it is necessary to do the calculations related to the estimate of the connected and load demand as per load types, load curve and monthly energy consumption of the various buildings to be supplied from the microgrid. One of the major issues of using 2D-CAD approach for microgrid planning is the significant manual labour involved in the retrieval of the necessary data from the 2D drawings of the associated project. Hence, in the proposed BIM based model, the retrieval of the necessary data required for the estimation of the load curve and energy consumption is done automatically through the development of an add-in tool. This chapter gives the details of the development of a new BIM add-in tool, referred to as 'Electrical System Estimation and Costing Tool' (ESECT), for the automatic data retrieval and the initial computations required for the planning and optimization of microgrids. The developed BIM add-in tool ensures the automated data retrieval by comparing the results with standardised data.

3.2. Development of Add-in Tool 'ESECT'

Basic Calculations

Assessing the electrical load and cost of the electrical system components and matching it with construction requirements at the preconstruction stage itself is the basic requirement for the microgrid design. Early design phase assessment of electrical connected load, monthly energy consumption, load demand, total budget and rules and regulations compliance provide a perception of the proposed load features of building's electrical system design, tariff and financial requirements for its construction. Project level electrical connected load is assessed by summing the elementary loads as per their load classification and multiplying with demand factors based on regulations that is applicable in the respective locations. According to NEC code, load demand rules is applied to individual load types such as lighting and motors separately, and the whole building demand load is calculated as

$$\text{Load Demand, Pd} = \sum_{t=1}^{n}\left(\left(\sum_{i=1}^{k} \text{Ei}\right) * \text{df}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(E-4-1)}$$

Where

E: VA rating of electrical load

df: demand factor according to load type

t: Load type

k: total number of electrical load of a particular type

The monthly electricity bill for the building can then be obtained as

Monthly electricity Price, Pe= *dl* * *lf* * 30*24 *tariff ………………………… (E-4-2)

lf: load factor

dl: load demand

Generally for domestic buildings, *lf* is in the 10 to15% range.

The material and installation cost for the electrical work in the building is calculated as

Building electrical material and installation cost $C_{Total} = (\sum_{i=1}^{n} \text{Ei x Ci})$ ……… ..(E-4-3)

where

E_i: Quantity of specific electrical outlet/equipment

C_i: Unit cost with material, fitting and wiring

Programming Aspects

Presently, several fully-fledged BIM applications are available in the market such as Revit [207] and ArchiCAD [208] and as per literature review, Revit is one of the leading BIM software [209]. Hence the Revit platform and its Software Development Kit (SDK) are utilized to develop the add-in tool, referred as “ESECT”. By using developed add-in tools it is possible to create, edit, add and retrieve the graphical / family attributes / edit the family parameter of a particular BIM document such as information for conducting electrical calculations, electrical grid calculations, pricing and auditing. There are no interoperability issues concerns with the Application Programming Interfacing (API) - based tools as it mines the required data from the BIM application platform itself.

One of the significant necessities for efficient add-in tool development is the classification of BIM elements according to various engineering divisions and sub-divisions, and this process is known as Work Breakdown Structure (WBS). “OmniClass” is one such WBS which classify construction elements accordingly. For instance, “23-35 13 00” means “Electrical transformers” as per OmniClass material classification [210]. There are default OmniClass number parameter for each and every Revit element of a BIM model. ESECT tool is programmed to retrieve information such as electrical VA (Volt Ampere), phase voltage data, cost, OmniClass number of all the electrical elements automatically identifying these elements as per the project requirements.

Table 3.1 shows the process of extraction the relevant data required for the preliminary calculations related to the microgrid planning studies in ESECT. The corresponding flow chart of the data retrieval and preliminary calculations is given in Fig. 3.1. ESECT add-in program creates a new functionality in Revit application. ESECT’s user interface is created by Windows form method as shown in Fig.3.2. The details of the message box in the flowchart, (given in Fig.3.1), are provided in Table 3.2. The main programming consists of three steps as given in Fig.3.3.

Table 3.1: *Programming steps for extracting parameters*

Extracting parameter	Programming method
Project name	Using the method of “projectinfo” type function and extracting its Name value, display it by a ‘Textbox”.
Type of Building	Using the method of “EnergyDataSettings” type function and extracting its type value, display it by a ‘Textbox”.
Floor area	Using “elementcategoryfilter” method extract all “spatial elements” and collect it to list. For every list item, extract the parameter “area” using a “foreach” loop and sum it for total area. In a similar method extract the areas of vertical wall’s bottom face area and sum it for total area. Sum both total areas.
Extracting electrical elements and lighting fixtures	Electrical “BuiltinCategoryFilter” is specified to an “ElementCategoryFilter” filtering method and then adding the filtered elements to an “ilist”.
VA (Volt-Ampere) value	By using a “foreach” loop search the term “ElectricalData” in element parameter set. From the extracted “ElectricalData” get the value for VA and number of phases by splitting the string method.
Load Classification	By using a “foreach” loop search the term “Load Classification” in element parameter set.
Cost of the elements	By using a “foreach” loop search the term “ALL_MODEL_COST” in the element parameter set.
OmniClass number	For an extracted element, get the parameter “OMNICLASS_CODE” by using “builtinparameter” method.

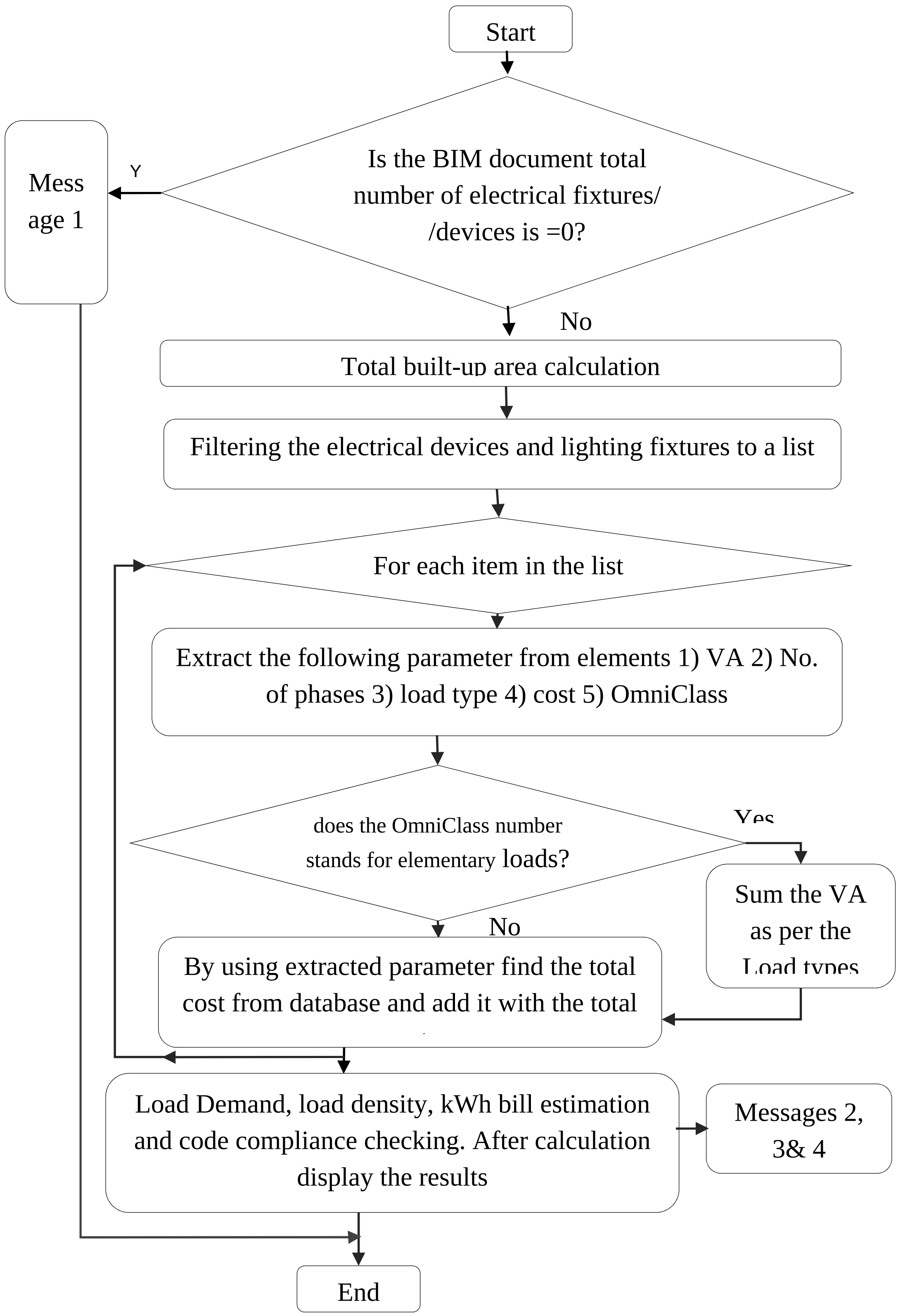

Fig.3.1: *Flowchart of ESECT data retrieval and preliminary calculations*

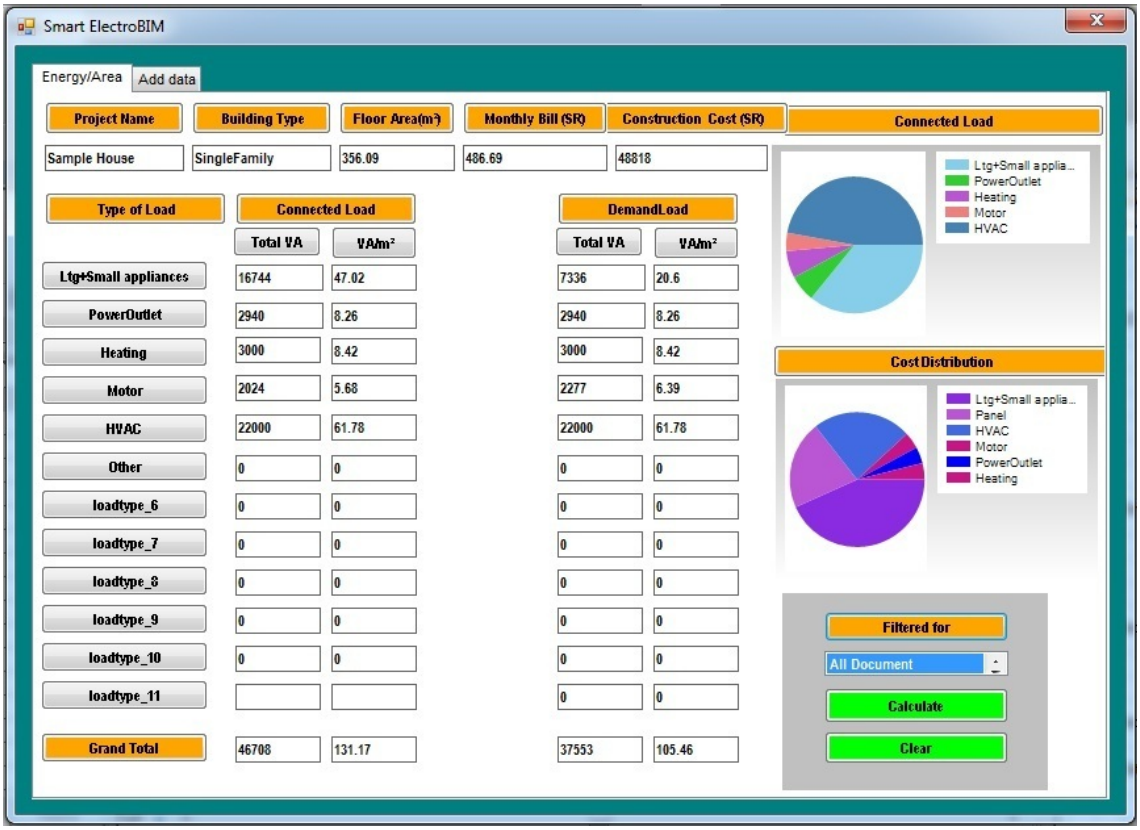

Fig.3.2: *ESECT user interface results.*

Table 3.2: *The description of the message box used in the flowchart (Fig.3.1.)*

Message Box number	rules for pop-up
Message1 (M1)	Pop-up, if the number of filtered electrical elements/connector=0.
Message1 (M2)	Pop-up, if the load types of extracted elements are not matched with the ESECT's predefined values.
Message1 (M3)	Pop-up at the last stage, with the number of items having the material cost=0 or null. .
Message1 (M4)	Pop-up at the last stage if the load density comply with the predefined values (In this research, coded only for Volt-amperes/square meter lighting load value for a residential building as per NEC table 220.12)

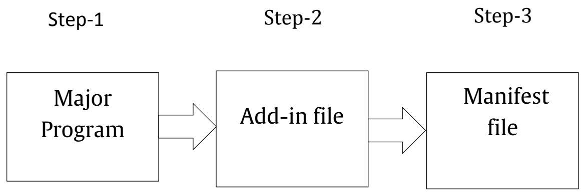

Fig.3.3: *Three steps of ESECT coding*

The first step in coding the main C # program is to choose a project type and construct a new Class Library and save the program. Interconnecting the main C# program with Revit program is accomplished by connecting both interfacing DLL library files named as "RevitAPI.dll" and "RevitAPIUI.dll" from the Autodesk program data at the computer’s product installation folder by the method of “Add reference” at the “Solution Explorer” section of C# platform. Then C# coding as per Table 1 and flowchart (Fig.1).

In the second step, the program is developed in C # language to create a novel ESECT button in the Revit screen. The ESECT icon image is specified in this step. In the final step the manifest file for ESECT is developed. In Notepad, needed programming is done and converted it to an ".add – in” file format. The created file is to be stored in an appropriate file specified by Revit API. This step is required for the automatic starting of ESECT tool when Revit opens. Thus through these three steps, the ESECT programming is completed. A typical case study to show the use of the ESECT add-in tool is discussed in the following section.

3.3. Case study

The ESECT add-in tool developed in this chapter is applied to a building shown in Fig.3.4. The architectural BIM file is taken from Autodesk Revit sample files. In that architectural model electrical systems such as lighting, small power outlets for appliances and HVAC are added. A panel board for the above systems are also designed in Revit. Each and every family type of electrical fixtures used for modelling contains the OmniClass number and material cost. Each and every electrical elementary load are coded with appropriate load classification data in accordance with ESECT requirements. The results are given in Fig.3.2.

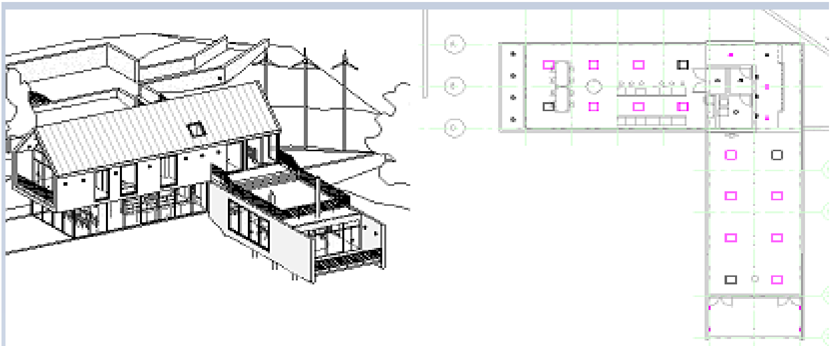

Fig.3.4: *3D view of the case study along with a lighting system plan view*

The identification and extraction of end loads are the crucial steps for the calculation of connected and load demand. Panel board, transformer, disconnect switch and generator can cause double-counting errors in load estimation. Estimated demand data is compared with NEC 220.12 table and compliance information is popped up message box as shown in Fig.3.5 and the comparison of estimated data is given in Table 3.3 and. Automated load density compliance will confirm the accuracy of the data extracted for microgrid planning.

Table 3.3: The code compliance between ESECT and NEC table 220.12

Description	**Data**
Volt-amperes/square meter lighting load value estimated by ESECT	11.5
Volt-amperes/square meter lighting load value for a residential building as per NEC table 220.12	33
Comply with code	Yes

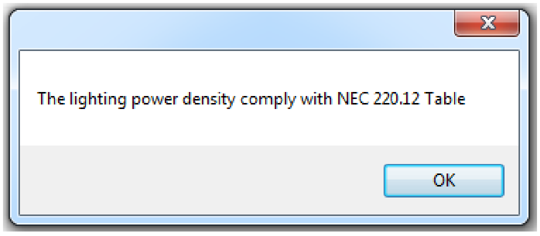

Fig.3.5: *ESECT message box related to code compliance checking*

3.4. Summary

Microgrid planning requires the extraction of the electrical system variables from the developed BIM models as and when necessary. In 2D-CAD platform, this task has to be performed manually. This is a tedious and error-prone process. In this chapter a Revit based add-in tool, 'ECECT', has been developed so as to use in a BIM environment for automatic extraction of the necessary electrical variables which can then be utilized for various computations such as load demand, electrical construction cost and monthly energy consumption. This tool offers a quicker method when compared with the 2D-CAD based method and it makes the rigorous repetitive tasks simpler.

Chapter 4

BIM-GIS Integrated Optimal Planning of Multi-Building Microgrids

4.1. Introduction

This chapter proposes a methodology for BIM and GIS based Integrated Optimal Planning and Optimization of Microgrid (IOPMG) for multi-building construction projects. The major sequence of various activities to be performed in the proposed IOPMG approach is as follows:

i Site suitability assessment

ii Renewable energy mix optimization, and

iii Distribution panels location optimization and cable network length optimization.

The details of Site suitability assessment and formulation of renewable energy mix are discussed in the following sections, and finally converging to the development of a BIM-GIS based Revit add-in tool referred to as "BGMG" for integrated microgrid planning activities. The BGMG add-in tool is developed by using Visual Basic C# language. The thesis proposes the application of genetic algorithm for the

i Determination of optimal mix of renewable energy resources

ii Determination of optimal location of distribution station, and

iii Optimization of cable length in the microgrid.

The details of the problem formulation of the Integrated Optimal Planning of Microgrids (IOPMG) with solar PV and wind energy conversion systems together with the battery are discussed in this chapter. The proposed genetic algorithm based renewable energy resource mix optimization is discussed in the following chapter. A practical application of this methodology for the planning of a microgrid in a multi-building residential campus at a typical location at Chathamangalam in the Kozhikode district of the State of Kerala, India, is discussed in Chapter 6. A genetic algorithm based distribution panel number and location optimization for electrical network in BIM platform is presented in Chapter 7.

4.2. Site Suitability Assessment

The first step in the planning and design of a microgrid is the site suitability assessment. The land identified for a microgrid must not be in the government restricted areas such as conservation forests. Further, it would be better if the areas prone to natural calamities such as frequent flood are avoided. Such details can be obtained with the utilization of GIS. Hence in this thesis, GIS is integrated with BIM for easing the for further computations related to microgrid planning and optimization. As these computations are performed in the BIM platform, it is necessary to convert the relevant GIS data to the BIM environment through appropriate interfacing programs. Fig.4. 1 shows the basic steps of data conversion from GIS to BIM for regulatory and environmental restricted area modelling. After modelling the land related restrictions in ArcGIS, the data is converted to the database format and linked to the developed BGMG add-in tool. In this thesis, only the site restrictions due to forest, lakes and rivers and flood-related hazards are considered. The data corresponding to a protected area and water bodies restriction modelling is shown in Fig. 4.1. A similar method is applied for flood hazard mapping as shown in Fig.4.2. The restricted area, mentioned in Fig.4.1, is mainly the government conservation forests and the national parks. The GIS data related to such restricted area are extracted in this thesis from National Renewable Energy Laboratory (NREL) database [211]. Similarly the GIS data related to rivers and lakes in the region are also similarly extracted for use in BGMG. Once the required data is extracted, a buffer region is created around the restricted areas so as to take into consideration of any government regulations related to the prohibition of any construction/installation within a specified limit from such restricted regions.

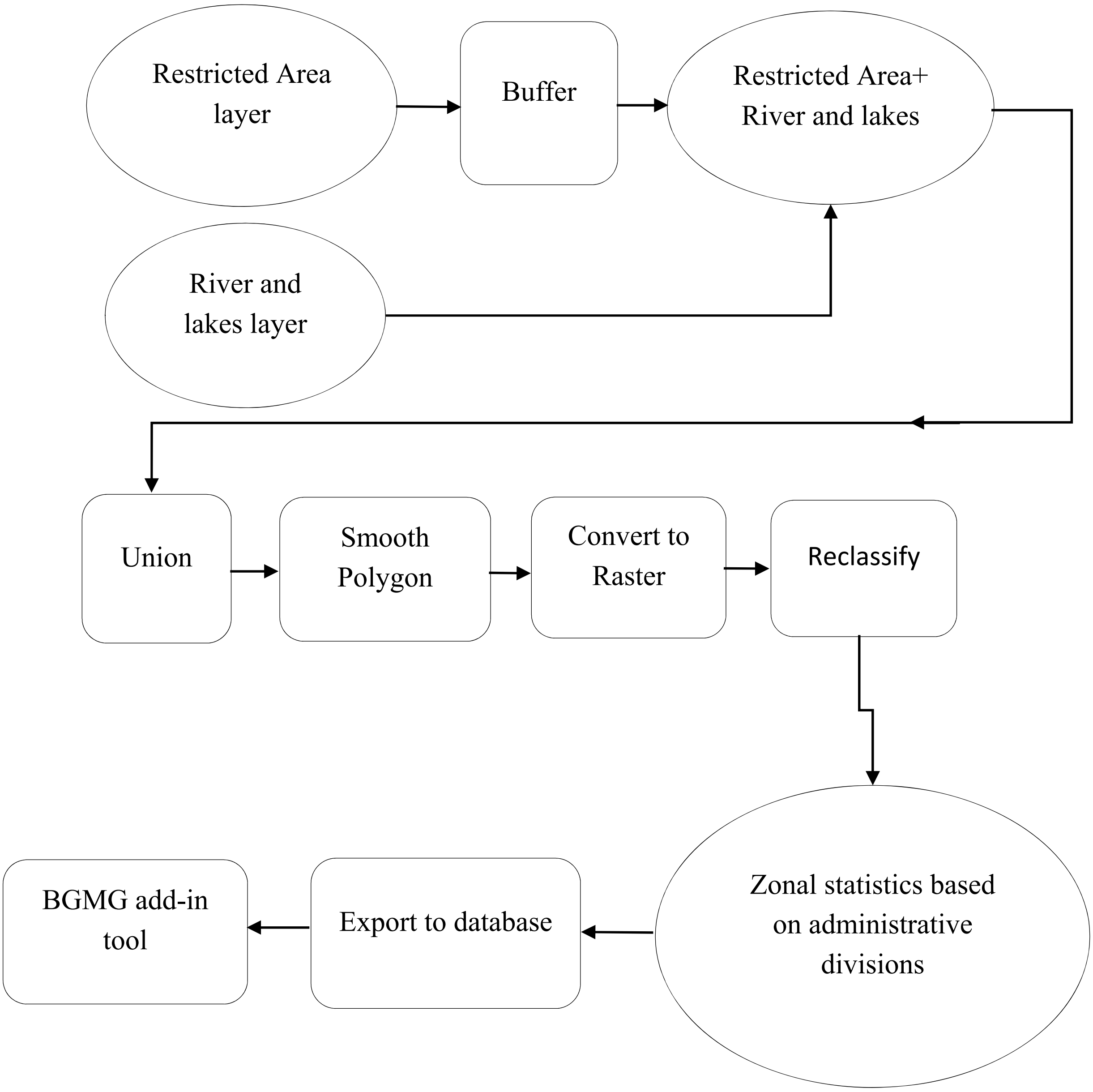

Fig.4.1: *Flow chart of GIS restriction data to BIM*

The union of GIS layer of both restriction and water bodies is done using GIS tools, followed by the application of the smooth polygon method on the combined restriction layer so as to get a natural view. Smooth Polygon geoprocessing tool [212] helps to smooth sharp angles in polygon features to enhance visual appeal. Then a binary raster is created from the smoothed restriction layer followed by a binary raster reclassification [213] by using GIS tools. The reclassified layer is combined with the administrative layer of project region to conduct zonal statistics according to administrative divisions. As per the Percentage of Restrictions (PR) in administrative divisions, the classifications are given in Table.4.1.

Table.4.1: *Percentage of Restrictions (PR) and its classifications*

Percentage of Restrictions (PR)	Classifications
PR= 0	*No restrictions*
0< PR<10%	*Low level restrictions*
10%<PR<40%	*Medium level restrictions*
40% >PR	*High level restrictions*

Then by zonal statistics tool [214], the PR according to administrative divisions (zones) is calculated and data is exported to excel format. The results from the zonal statistics study is exported to a database format and stored at a specific computer location for automated reading by the BGMG add-in tool. The BIM based BGMG tool reads this database file when this tool is invoked by the user. It is necessary to take into account the natural calamity related GIS data for further refining the site suitability assessment. The flowchart of flood GIS data conversion to BIM is shown in Fig.4.2.

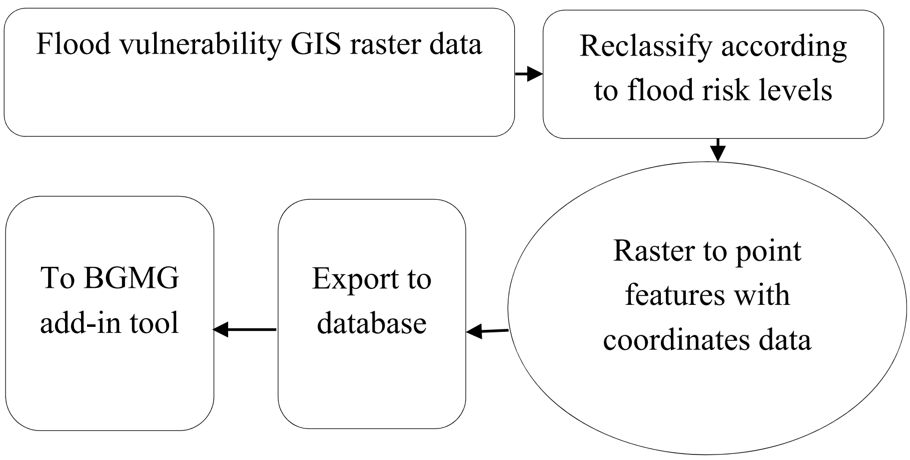

Fig.4.2: *Flow chart of flood GIS data transfer to BIM.*

By using raster reclassification tools, the resultant flood map was categorized into 3 zones – no risk, moderate risk and high risk zones. Using GIS Conversion tools, 'Raster to Point features' convert the flood raster to point features with the appropriate distance [215]. By using "Features toolset of Data Management tools" XY coordinates are added to point features. The resultant point feature's attribute table is exported to a database format and stored at a specific computer file location for automated reading by the BGMG add-in tool. The BIM based BGMG tool reads the database file when this tool is invoked by the user.

4.3. Renewable Energy Mix Optimization

The microgrid considered in this thesis has solar and wind energy conversion systems together with a battery energy storage setup as shown in Fig.4.3. The battery energy storage system can take care of the intermittency and the consequent fluctuations in the power output from the solar and wind energy conversion systems in the microgrid. The capacities of the solar and wind energy conversion systems in the microgrid is decided based on the average values of the solar insolation and the wind velocity at the identified location over a specific time period. The optimal capacity of the available renewable energy resources at the identified location is proposed to be done such that the life cycle cost of the microgrid project is the minimum. The life cycle cost involves two parts: the first part is the capital cost covering components & installation cost and the second part is its operation and maintenance cost. Once the components required are identified and the quantity required is estimated, the microgrid project net present capital cost can be computed with the knowledge of the labour charges in the locality of the project. On the other hand, the computation of the operation and maintenance charges of the microgrid at the project planning and design stage itself necessitates the knowledge of the load variation in the various associated buildings, the hourly variation of the solar irradiation and the wind velocity in the region and also the battery charging and discharging cycles over a period of time. Hence, towards this requirement, in this thesis, first an estimate of the load variation is done based on the connected load, load factor and diversity factor. Similarly, the solar irradiation and the wind velocity variations are estimated based on the currently available historical data.

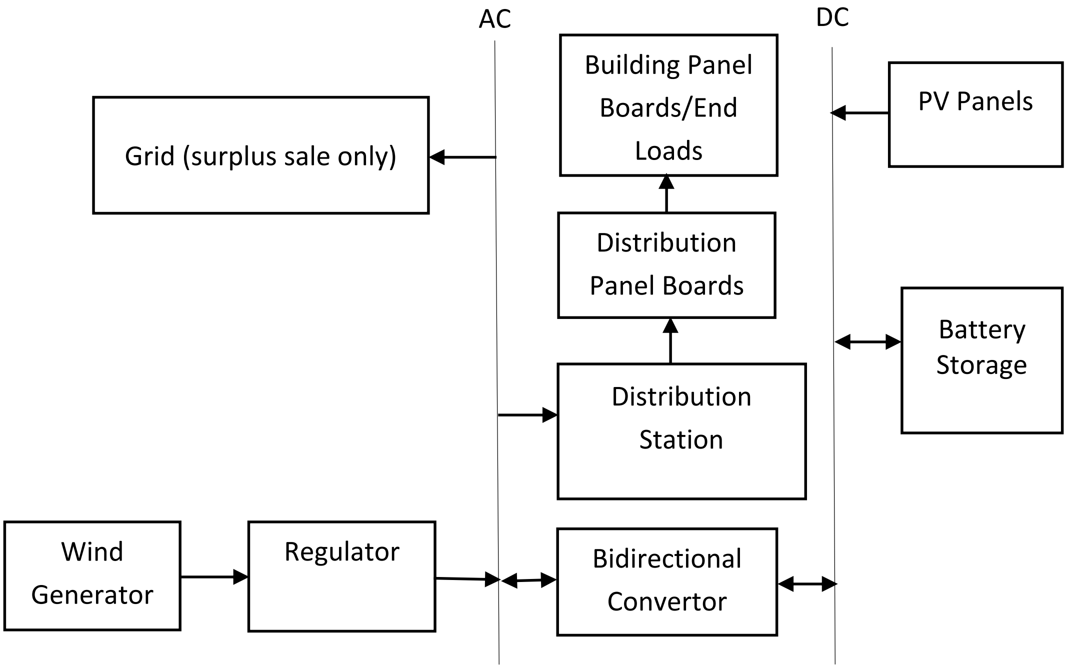

Fig.4.3: *schematic diagram of the proposed microgrid*

With this data, the BGMG tool proceeds with the determination of the optimum capacity allotment of the solar PV system and wind energy conversion system using genetic algorithm as discussed in chapter 5. The proposed approach involves the minimization of the total life cycle cost such that the generation-load balance and the other system & component constraints are satisfied. The mathematical formulation is as follows and reference is [216]-[224]

Minimize Total net present cost, $C_{TMR} = C_{IL} + C_{RL} + C_{BL} + C_{CL} + C_{EP} - C_{SL}$ .... (4.1)

Where

Table 4.2: Symbols in Equation 4.1

Symbol	Description	Unit
C_{TMR}	Total net present lifetime cost for microgrid source, storage and converters	INR
C_{IL}	Total net present cost for setting up the renewable energy source systems required for the microgrid for the life time including replacement and salvage cost	INR
C_{RL}	Total net present running cost of microgrid renewable energy sources installed for the microgrid for project life time	INR
C_{BL}	Total net present cost required for supply, installation, testing and commissioning of the complete battery storage system of a microgrid and its running cost, replacement cost and revenue from its salvage value in the microgrid life span.	INR
C_{CL}	Total net present cost required for supply, installation, testing and commissioning of the complete bidirectional converter system of a microgrid and its running cost, replacement cost and revenue from its salvage value in the microgrid life span.	INR
C_{EP}	Total additional cost for the energy efficient models of the appliances to achieve required level of energy conservation.	INR
C_{SL}	Cost credited by selling the additional energy generated from installed RE sources in the project area during the life cycle	INR

C_{IL}: Total net present cost for setting up the renewable energy system required for the microgrid for the life time including replacement and salvage cost.

$$C_{IL} = C_{ILI} + C_{ILR} - C_{ILS} \quad (4.2)$$

Table 4.3: Symbols in Equation 4.2

Symbol	Description	Unit
C_{ILI}	Initial investment cost for setting up the renewable energy system required for the microgrid.	INR
C_{ILR}	Lifetime replacement cost of renewable energy system required for the microgrid	INR
C_{ILS}	Salvage cost of renewable energy system required for the microgrid	INR

$$C_{AT} = F_{CR} * C_{TMR} \quad (4.3)$$

Table 4.4: Symbols in Equation 4.3

Symbol	Description	Unit
C_{AT}	Annualized total cost instalments for capital recovery within the project lifetime	INR
F_{CR}	**F**actor for Capital recovery	-

$F_{CR} = r*(1+r)^N / [(1+r)^N-1]$ …………………………………………………………………… (4.4)

Table 4.5: *Symbols in Equation 4.4*

Symbol	Description	Unit
r	Real discount rate	%
N	Project lifetime	Years

$r = (i-f)/(1+f)$ …………………………………………………………………………… (4.5)

Table 4.6: *Symbols in Equation 4.5*

Symbol	Description	Unit
i	Inflation rate	%
f	interest rate	%

$C_{ILI} = (CPV_{ui} * PV_{kWp}) + (CWG_{ui} * WG_{kWp})$ ……………………………………… (4.6)

Table 4.7: *Symbols in Equation 4.6*

Symbol	Description	Unit
CPV_{ui}	PVS Installation cost/kW of a PV source	INR
PV_{kWp}	Total PVS installed kW capacity	kW
CWG_{ui}	Total WES Installation cost/kW	INR
WG_{kWp}	Total WES installed kW capacity	kW

C_{ILR}: Lifetime replacement cost of renewable energy system required for the microgrid.

$C_{ILR} = CPV_{ILR} + CWG_{ILR}$ …………………………………………………………… (4.7)

Table 4.8: *Symbols in Equation 4.7*

Symbol	Description	Unit
CPV_{ILR}	Total PV system replacement cost	INR
CWG_{ILR}	Total WTG system replacement cost	INR

$CPV_{ILR} = \sum_{t=1}^{Rn}[(CPV_{ur} * PV_{kWp}) * ((1+f)/(1+i))^{(t*N_{CL})})]$ ……………………… (4.8)

Table 4.9: *Symbols in Equation 4.8*

Symbol	Description	Unit
CPV_{ur}	PVS replacement cost/kW	INR
PV_{kWp}	Total PVS installed kW capacity	kW

N_{CL}	Life time of the component in years	years

$$CWG_{ILR} = \sum_{t=1}^{Rn}[(CWG_{ur} * WG_{kWp}) * ((1+f)/(1+i))^{(t*N_{CL})})] \quad (4.9)$$

Table 4.10: *Symbols in Equation 4.9*

Symbol	Description	Unit
CWG_{ur}	WES replacement cost/kW	INR
WG_{kWp}	Total WES installed kW capacity	
f	Inflation rate	%
i	$interest\ rate$	%

$$S = C_{uc} * N_{LR} / N_{CL} \quad (4.10)$$

Table 4.11: *Symbols in Equation 4.10*

Symbol	Description	Unit
S	Salvage value of the installed component	INR
C_{uc}	$Unit\ Cost\ of\ the\ component$	INR
N_{LR}	remaining life time of the component in years	Years

$$N_{LR} = N - (R_n * N_{CL}) \quad (4.11)$$

Table 4.12: *Symbols in Equation 4.11*

Symbol	Description	Unit
N_{LR}	remaining life time of the component in years	Year
R_n	Number of times the replacement is required for a component	-
N_{CL}	Life time of the component in years	Year

$$C_{ILS} = (S_{uPV} * PV_{kWp})((1+f)/(1+i))^{N-N_{LRPV}}) + (S_{uWG} * WG_{kWp})((1+f)/(1+i))^{N-N_{LRWG}}) \quad (4.12)$$

Table 4.13: *Symbols in Equation 4.12*

Symbol	Description	Unit
S_{uPV}	Salvage value/kW of PV system	INR
S_{uWG}	Salvage value /kW of WTG system	INR
N_{LRPV}	Remaining life time of the PV component in years	Years
N_{LRWG}	Remaining life time of the WTG component in years	Years

a) C_{RL}: life cycle net present running cost of microgrid renewable energy sources installed for project life time is

$$C_{RL} = \sum_{y=1}^{N}[(\mathbf{CPV_{uR}} * \mathbf{PV_{kWp}})((1+f)/(1+i))^{y}] + \sum_{y=1}^{N}[(\mathbf{CWG_{uR}} * \mathbf{WG_{kWp}})((1+f)/(1+i))^{y}] \quad \text{.......} (4.13)$$

Table 4.14: *Symbols in Equation 4.13*

Symbol	**Description**	**Unit**
CPV_{uR}	Running cost /kW of PV source/year	INR
CWG_{uR}	Running cost of one kW of WG source /year	INR
C_{BL}	Total net present cost required for supply, installation, testing and commissioning of the complete storage system of a microgrid and its running cost in the microgrid life span.	INR

$$C_{BL} = B_{NC} * C_{ILB} + C_{ILRB} - C_{ILSB} + C_{RLB} \quad \text{.......} (4.14)$$

Table 4.15: *Symbols in Equation 4.14*

Symbol	**Description**	**Unit**
B_{NC}	Total installed nominal kWh capacity of battery storage system	kWh
C_{ILB}	BSS Installation cost/kW. Estimated as given by eqn. (4.6)	INR
C_{RLB}	Net present life time running cost for B_{NC} ***capacity (kWh)*** battery storage system. Estimated as given by eqn. (4.13)	INR
C_{ILRB}	Net present life time replacement cost for B_{NC} ***capacity (kWh)*** battery storage system. Estimated as given by eqn. (4.8)	INR
C_{ILSB}	Net present life time salvage cost for B_{NC} ***capacity (kWh)*** battery storage system. Estimated as given by eqn. (4.12).	INR

C_{CL} : Net Present cost of Converter

$$C_{CL} = BC_{NC} * C_{ILBC} + C_{ILRBC} - C_{ILSBC} + C_{RLBC} \quad \text{.......} (4.15)$$

Table 4.16: *Symbols in Equation 4.15*

Symbol	**Description**	**Unit**
BC_{NC}	Total installed capacity in kW of bidirectional converter system of the microgrid.	kW
C_{ILBC}	Total cost required to install ***one kW of bidirectional converter*** system of the microgrid. Estimated as like (4.6).	INR
C_{RLBC}	Net present life time running cost for BC_{NC} capacity (in Kw) bidirectional converter system. Estimated as like (4.13).	INR

C_{ILRBC}	Net present life time replacement cost for BC_{NC} capacity (in Kw) bidirectional converter system. Estimated as like (4.8).	INR
C_{ILSBC}	Net present life time salvage cost for BC_{NC} capacity (in Kw) bidirectional converter system. Estimated as like (4.12).	INR

With no grid connection

$BC_{NC} = P_{DTM} / \eta_C$ .... (4.16)

Table 4.17: *Symbols in Equation 4.16*

Symbol	Description	Unit
P_{DTM}	Maximum load demand served by the microgrid	kW
η_C	Efficiency of converter	%

With grid connection

If the entire surplus energy is to be injected into grid then

$BC_{NC} = E_{SM} / \Delta t$ .... (4.17)

Table 4.18: *Symbols in Equation 4.17*

Symbol	Description	Unit
E_{SM}	Maximum surplus energy available in any month of an year in kWh	kWh
Δt	commitment period which is 1 h in this thesis	hour

b) C_{EP}: Total cost for the energy efficient models of the appliances

$C_{EP} = \eta_{ep} * C_{TC1}$ .... (4.18)

Table 4.19: *Symbols in Equation 4.18*

Symbol	Description	Unit
η_{ep}	percentage of energy efficiency achieved through the selection of a higher efficiency model for the appliance under consideration in the planning stage	%
C_{TC1}	Cost for 1% energy efficiency improvement	INR

C_{SL}: Cost credited by selling the additional energy generated from installed RE sources in the project area during the life cycle.

$C_{SL} = \sum_{y=1}^{N} \sum_{1}^{365} \sum_{\Delta t=1}^{24} * [[[P_{PVi}/\eta_c + P_{WGi} - P_{LTi}] * \Delta t] - (SoC_{max} - SoC_i) * E_{BN} / (\eta_{bc} * \eta_c)] * tarrif * ((1+f)/(1+i))^y]$ .... (4.19)

Table 4.20: Symbols in Equation 4.19

Symbol	Description	Unit
E_{BN}	Energy stored in battery storage at time "i"	kWh
E_{Bi}	Energy stored in battery storage at time "i"	kWh
η_C	Efficiency of converter	%
SoC_i	State of charge of battery storage at time "i"	%
σ	self-discharge rate of the battery storage system	-
P_{BCi}	Power available for battery charging from RE sources	kW
P_{BDi}	Power available for battery discharging	kW
Δt	commitment period which is 1 h in this thesis	hour
SoC_{max}	Maximum (selected) State of Charge of battery storage system	%
SoC_{min}	Minimum (selected) State of Charge of battery storage system	%
η_{bc}	Battery charging efficiency	%

B_{NC} capacity in kWh $=E_{BN}$ (both are same)

Subject to

i. Power generation - load demand balance constraint at any instant

In a grid connected solar PV-Wind Turbine-BESS system, the power balance equation to be satisfied at any instant is given by

$$\mathbf{P_{PV} + P_{WG} + P_{Grid-buy} + P_{BD} = P_{LT} + P_{BC} + P_{Grid-sold}} \quad \text{……………………… (4.20)}$$

Table 4.21: Symbols in Equation 4.20

Symbol	Description	Unit
$P_{Grid-buy}$	Power purchased from grid, In this study $P_{Grid-buy}$ =*0* and 100% renewable energy supply for the load.	kW
P_{BD}	Power discharged from battery	kW
P_{BC}	Power charged to battery	kW
$P_{Grid-sold}$	Power sold to grid. In this study entire surplus energy generated is exported to grid	kW
P_{LT}	Total load demand of all the buildings served by the microgrid	kW

ii. For any RE source type in the microgrid

$$PV_{kWp} \leq PV_{kWpM} \quad \text{……………………………………………………………… (4.21A)}$$

$$WG_{kWp} \leq WG_{kWpM} \quad \text{……………………………………………………………… (4.21B)}$$

__Table 4.22:__ Symbols in Equation 4.21A&B

Symbol	Description	Unit
PV_{kWpM}	Maximum possible total kWp rating of PV energy sources from the project site	kW
WG_{kWpM}	Maximum possible total kWp rating of WTG energy sources from the project site	kW

iii. Generation constraints of renewable energy sources

$P_{WGi}(v_{ci}) < P_{WGi}(v) \leq P_{WGi}(v_{co})$ ………………………………………………………… (4.22)

__Table 4.23:__ Symbols in Equation 4.22

Symbol	Description	Unit
$P_{WGi}(v_{ci})$	Power generated by WTG @ cut in velocity	kW
$P_{WGi}(v_{co})$	Power generated by WTG @ cut out velocity	kW

iv. Ideal Battery model state of charge constraints

At any time Battery State of Charge (SOC)

$SoC_{min} \leq SoC \leq SoC_{max}$ ………………………………………………………………… (4.23)

__Table 4.24:__ Symbols in Equation 4.23

Symbol	Description	Unit
SoC_{min}	Minimum (selected) State of Charge of battery storage system	%
SoC_{max}	Maximum (selected) State of Charge of battery storage system	%

In this thesis, the renewable energy sources considered are (i) photovoltaic energy conversion system and (ii) wind energy conversion system. Thus P_{RE} is the power outputs from these sources. In addition to this, the power flow during charging and discharging times of the battery energy storage system is also considered. The power outputs from these sources are computed as follows:

i. **Photovoltaic Energy Conversion System** :

kWp installed capacity of PV systems at the project site

$(PV_{IC}) = G_M * A * \eta_{pv} * PR$ ……………………………………………………………… (4.24)

The power (kW) output from a photovoltaic energy conversion system is given by $(P_{PV}) = (G/G_M) * PV_{IC}$ ……………………………………………………………… (4.25)

Energy generated from PV systems (E_{PV}) during time "Δt" $= P_{PV} * \Delta t$

Table 4.25: *Symbols in Equation 4.24 & 4.25*

Symbol	Description	Unit
A	Area of the installed solar panels	m^2
η_{pv}	efficiency of solar panels	%
PV_{IC}	kWp installed capacity of PV systems at the project site	kW
G	Average Global horizontal hourly irradiance of the project site	kWh/m^2
G_M	Rated Global horizontal hourly irradiance in kWh/m^2 of the selected solar panel at its standard test condition (=1 Kw/m^2)	kWh/m^2
PR	Performance Ratio of the selected PV systems at the project site	--

According to the location and installation, hourly "H" values are to be added to BGMG. Cost data and PV component data according to the selected PV model is to be added to BGMG.

ii. **Wind Energy Conversion System:** the kW power output of a wind energy conversion system is given by

$$P_{WG}(v) \quad \begin{cases} 0 & \text{if } \text{“}v \leq v_{ci}\text{”} \\ P_{WG}(r) * (v - v_{ci})/(v_r - v_{ci}) & \text{if } \text{“}v_{ci} < v \leq v_r\text{”} \\ P_{WG}(r) & \text{if } \text{“}v_r \leq v \leq v_{co}\text{”} \\ 0 & \text{if } \text{“}v > v_{co}\text{”} \end{cases} \quad \text{.......... (4.26)}$$

Table 4.26: *Symbols in Equation 4.26*

Symbol	Description	Unit
$P_{WG}(r)$	Total sum of the rated power output of installed wind turbine	kW
v	wind velocity according to the hub height of the selected wind generator	m/s
v_{ci}	Wind generator cut in velocity	m/s
v_{co}	Cut out velocity	m/s

Energy generated from WTG systems (E_{WG}) during time "Δt"= $P_{WG} * \Delta t$

According to the location hourly wind speed values are to be fed to BGMG. As per the selected model, cost data and component life details are to be fed to BGMG.

iii. **Battery charging/discharging equation**

Energy stored in kWh in battery storage system is

$$E_{Bi} = E_{B(i-1)} (1-\sigma)+(P_{BCi}*\eta_{bc}- P_{BDi}/ \eta_{bd})* \Delta t \text{.......... (4.27)}$$

$$SoC_i = E_{Bi}/E_{BN} \text{.......... (4.28)}$$

Table 4.27: Symbols in Equation 4.27 to 4.39

Symbol	Description	Unit
E_{BN}	Energy stored in battery storage at time "i"	kWh
E_{Bi}	Energy stored in battery storage at time "i"	kWh
SoC_i	State of charge of battery storage at time "i"	%
σ	self-discharge rate of the battery storage system	-
P_{BCi}	Power available for battery charging from RE sources	kW
P_{BDi}	Power available for battery discharging	kW
Δt	commitment period which is 1 h in this thesis	hour
SoC_{max}	Maximum (selected) State of Charge of battery storage system	%
SoC_{min}	Minimum (selected) State of Charge of battery storage system	%

$P_{BCi} = 0$ if $SoC=SoC_{max}$

$P_{BDi} = 0$ if $SoC=SoC_{min}$

Battery storage capacity available at time "i" $= (SoC_{max} - SoC_i) * E_{BN}$……………. (4.29)

Battery discharge capacity available at time "i" $= (SoC_i - SoC_{min}) * E_{BN}$…………. (4.30)

Battery charging and no surplus energy is available at time "i" if

" $[[P_{PVi}*\eta_c+P_{WGi} - P_{Li}] * \Delta t]]$" is positive and "$< [((SoC_{max} - SoC_i) * E_{BN}) / \eta_{bc}]$" ……………………………………………………………………………………………………. (4.31)

Battery charging and energy available for export at time "i" if

" $[[P_{PVi}*\eta_c+P_{WGi} - P_{Li}] * \Delta t]]$" is positive and "$> [((SoC_{max} - SoC_i) * E_{BN}) / \eta_{bc}]$" ……………………………………………………………………………………………………. (4.32)

Battery fully charged and no energy available for export if

" $[[P_{PVi}*\eta_c+P_{WGi} - P_{Li}] * \Delta t]* \eta_{bc}$" is positive and "$=[((SoC_{max} - SoC_i) * E_{BN}) / \eta_{bc}]$" ……………………………………………………………………………………………………. (4.33)

ηc : Efficiency of converter

ηbc : Efficiency of battery charging

Surplus energy available for export in kWh

Energy available for export= $[[P_{PVi}*\eta_c+P_{WGi} - P_{Li}] * \Delta t] - (SoC_{max} - SoC_i) * E_{BN} / (\eta_{bc}*\eta_c)]$ ……………………………………………………………………………. (4.34)

Battery discharging if

" $[[P_{Li} - (P_{PVi}*\eta_c+P_{WGi})] * \Delta t]$" is positive and "$\leq [((SoC_i - SoC_{min}) * E_{BN}) / \eta_{bd}]$" ……………………………………………………………………………………………………. (4.35)

Battery discharging and constraint unsatisfied if

" $[[P_{Li} - (P_{PVi}*\eta_c+P_{WGi})] * \Delta t]$" is positive and "$\leq [((SoC_i - SoC_{min}) * E_{BN}) / \eta_{bd}]$" ……………………………………………………………………………………………………. (4.36)

Battery fully discharged if

" $[[P_{Li} – (P_{PVi}*\eta_c+P_{WGi})] * \Delta t]$" is positive and "$\leq [((SoC_i - SoC_{min}) *E_{BN})/ \eta_{bd}]$" …………………………………………………………………………………………………….. (4.37)

Battery discharge/hour ($B_{DC\text{-}0\text{-}1}$) $= (([[P_{PVi}*\eta_c+P_{WGi} - P_{Li}] * \Delta t]/(\eta_c * \eta_{bc}))$ …….. (4.38)

Battery Charge/hour ($B_{C\text{-}0\text{-}1}$) $= (([[P_{PVi}*\eta_c+P_{WGi} - P_{Li}] * \Delta t]*(\eta_c * \eta_{bc}))$ ………….. (4.39)

Estimating the Minimum initial depth of charge of the battery storage in battery system for a typical day in month and other related calculations are given in Appendix 1. Method of load profile estimation is described in Appendix 2.

4.4 Summary

A BIM and GIS based methodology and problem formulation for IOPMG is discussed in this chapter. Initial section of this chapter details the methodology for integrating GIS data with BIM platform. Later sections describe the net present lifecycle cost estimation of the microgrid, Power output from renewable energy sources, Load profile estimation, sizing of battery storage system and converter. Based on this formulations, the fitness function of Genetic Algorithm is formulated in next chapter.

Chapter 5

Genetic Algorithm based Renewable Energy Mix Optimization

5.1 Introduction

The problem formulation of the Integrated Optimal planning of microgrid (IOPMG) has been discussed in the previous chapter. In this chapter, a genetic algorithm based method is proposed for the determination of the optimal combination of the capacities of the renewable energy resources identified at the location of the microgrid such that the net present cost of the microgrid is the minimum. The details of the net present cost of the microgrid together with the system constraints have been presented in the previous chapter. The IOPMG is performed in the BIM platform utilizing the BGMG add-in tool developed in this thesis. Coding is done using C# language to develop this BIM based add-in tool, referred to as BGMG.

5.2 Proposed Genetic Algorithm based Renewable Energy Mix Optimization

Genetic Algorithm (GA) searches for global optimum and it gives approximate solution without getting trapped at the local optimum solution points. The GA starts with a population of randomly generated solutions and then continuously improves the existing possible solutions through an evolutionary procedure. The GA picks up any solution, referred to as 'chromosome' from the present possible set of solutions known as population based on the evaluation of the fitness of each individual chromosome in the population.

In the renewable energy mix optimization problem considered in the thesis, it is intended to obtain the optimal real power ratings of the solar PV system and wind energy system to be installed in the location of the microgrid. The percentage of energy efficiency that can be achieved by the use of energy star rated appliances is also form a part of the solution. Hence a typical chromosome is a binary string formed by the concatenation of these solution parts as shown in Fig. 5.1. As shown in the figure, a chromosome consists of a binary string concatenation of the nominal kW rating of the solar PV system, nominal kW rating of the wind energy conversion system and the percentage of energy efficiency that can be achieved by the use of energy star rated appliances.

Nominal kW rating of solar PV system	Nominal kW rating of wind energy system	% Energy efficiency that can be achieved with the use of energy star rated appliances

Fig.5.1: *Typical Chromosome for renewable energy mix optimization*

The length of the binary number corresponding to each of these solution components depend upon the individual maximum expected values. Assuming the maximum ratings of solar PV and the wind energy conversion systems to be1000kW respectively, these variables are allotted 10 bits each. Further, as the maximum % energy efficiency that can be achieved with the use of energy star rated appliances is 100, this is allotted 7 bits. Thus the chromosome length becomes 27 as shown in Fig.5.2.

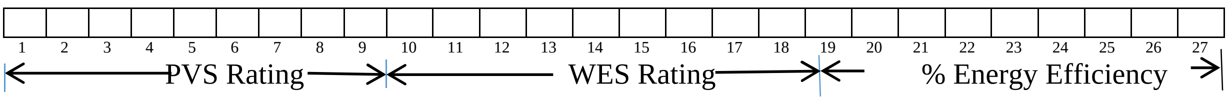

Fig. 5.2*: Bit Allotment in an RE Mix Chromosome*

In the genetic algorithm, it is necessary to evaluate the fitness of each such chromosome by means of a fitness function. This function is to be such that it is a function to be maximized and also its calculated value is to be positive. Accordingly, in this thesis, the proposed fitness function developed out of the augmented cost function is as follows:

$$f(Ppv, Pws, pbs) = 1 - \frac{C_{TMR}}{C_{TMRmax}} \quad \text{.......} \quad (5.1)$$

Where C_{TMR} : Total net present cost

C_{TMRmax} : Maximum possible value of C_{TMR}.

C_{TMRmax} can be obtained by setting a 1 at each bit position in the chromosome structure shown in Fig.5.2.

The fit chromosomes are selected for performing cross-over and mutation operations to generate the new off-springs. This fitness-based selection yields better offsprings with desired qualities leading to better solution pool. Further, elitism [225] is utilized so as to keep a particular number of fittest chromosome the same, in the new generation of the solution pool. If the elitism rate is 5% and the population size is 100, then 5 chromosomes will be selected as elite and will go to next-generation unchanged. In this work, one point crossover is used. In order to avoid local optimum, through mutation operation, randomly selected genes are flipped such that if existing gene is 0, then it is replaced by 1 and vice versa. The process is continued either until the solution attains an acceptable fitness value, or until the number of generations reaches a pre-specified value as shown in the flowchart shown in Fig. 5.3.

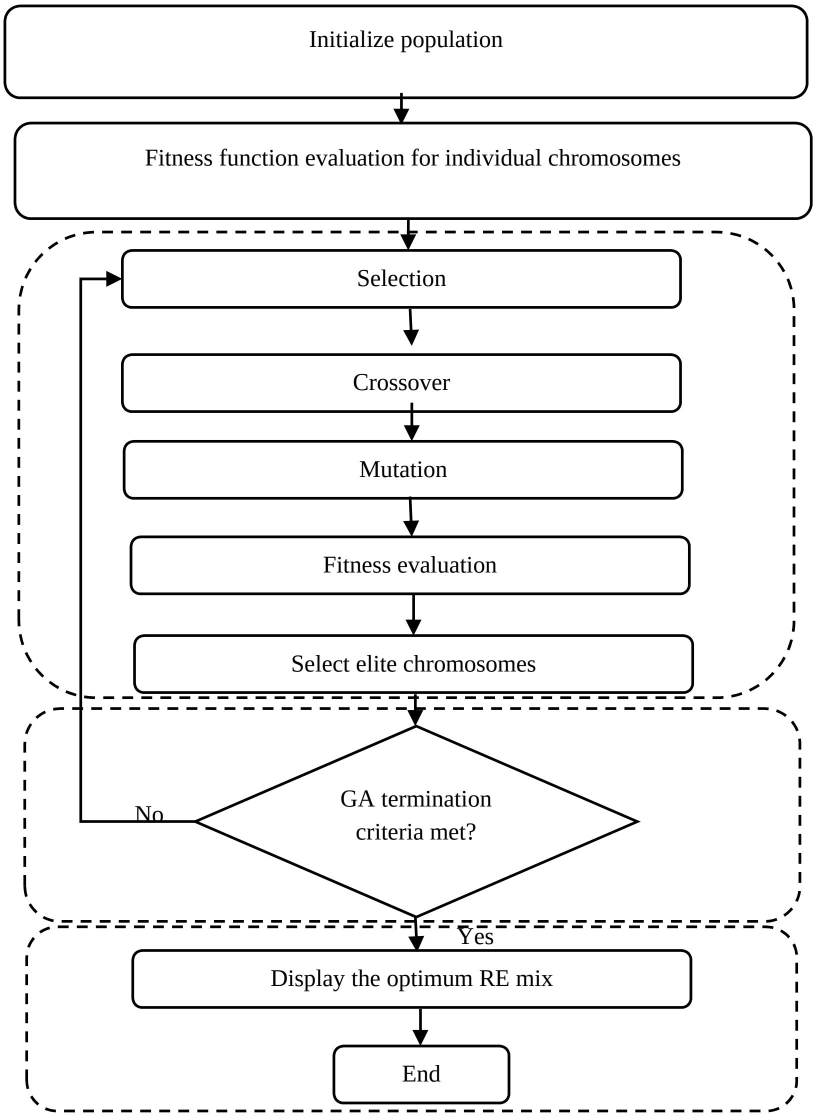

Fig.5.3: *a General Framework of GA based Renewable Energy Mix Optimization*

While genetic algorithm is applied for Renewable Energy Mix Optimization, the other major issues to be taken care of are the following:

i. Generation of initial population of possible solutions
ii. Verification of the individual chromosome to check whether it satisfies the system constraints discussed in Chapter 4.
iii. Removal of the invalid individuals which do not satisfy the system constraints, from the population in each generation
iv. Generation of more individuals to compensate the removed invalid ones, such that the number of valid individuals in each generation remains the same.

Thus the sequence of major computations to be performed at any time instant in the proposed GA based renewable energy mix optimization, considering these points, is as follows:

v. Read the solar irradiance, wind velocity, battery charge status, grid power supply (Pgrid) at the time instant.
vi. Obtain the maximum of solar PV System power output and wind energy system power output, maximum and minimum battery energy storage system discharge: Ppv-max, Pws-max, PBS-max and the respective min. values
vii. Read the Load Demand at Time instant T.
viii. Read Max. Population Size and Max. Number of Generations
ix. Initialize current population size = 0, Current no. of generation =0
x. For x= 1 to (Max. specified population size – current population size)
xi. Generate Random Population (Ppves-Pwes-energy efficiency) as follows:
xii. Ppv = Ppv-min+ (Ppv-max-Ppv-min) x Rand (0, 1); PVES
xiii. Pws = Pqs-min+ (Pqs-max-Pqs-min) x Rand (0, 1); WES
xiv. Ee = Ee-min+ (Ee-max-Ee-min) x Rand (0, 1)

xv. For each new individual generated in the population, validate each individual w.r.t the equality constraints

xvi. If all the equality constraints are satisfied, put them in the pool of valid individuals.

xvii. Current population size = current population size+1

xviii. If the current valid population size = specified max. Population size, go to step xiii.

xix. If any of the constraints are not satisfied, reject the individual from the pool,

xx. Current population size = Max. Population size-1, and go to step vi.

xxi. Check the fitness of each of the new valid individual in the population developed out of the augmented cost function

$$f(Ppv, Pws, pbs) = 1 - \frac{C_{TMR}}{C_{TMRmax}}$$

xxii. Current generation = Current generation+1

xxiii. If Current generation = Max. Specified generations, Then Identify the individual with maximum fitness value as the solution: Nominal kW rating of solar PV system, Nominal kW rating of wind energy system, % Energy efficiency that can be achieved with the use of energy star rated appliances and STOP.

xxiv. Apply elitism and choose the top 'n' best fit individuals from the previous pool to be used in the next generation. All these are valid individuals w.r.t the equality constraints.

xxv. Current population size = n

xxvi. Apply GA operators and generate new individuals

xxvii. Go to step vii.

The GA based Renewable Energy Source Mix Optimization Process in the BIM-GIS Integrated Microgrid Design Platform is shown in Fig.5.4. As shown in the figure, the

BGMG tool has an Input Section, Load Profile Estimate Section, GA Optimization Section and the Output Section. As shown in this figure, for the computations corresponding to a particular time instant by the BGMG tool, the major data to be input are as follows:

- Maximum possible kW capacity of the identified renewable energy sources at the project location by considering project location hazards and restrictions
- Project parameters such as project life time, inflation rate and deflation rate.
- Average solar radiation in kW/m^2
- Average hourly wind velocity in m/s
- Load data
- Battery and converter data

And the other data required as per the various equations presented in the problem formulation section of the previous chapter.

The genetic algorithm based optimization Section shown in this figure is further expanded in Fig. 5.5.

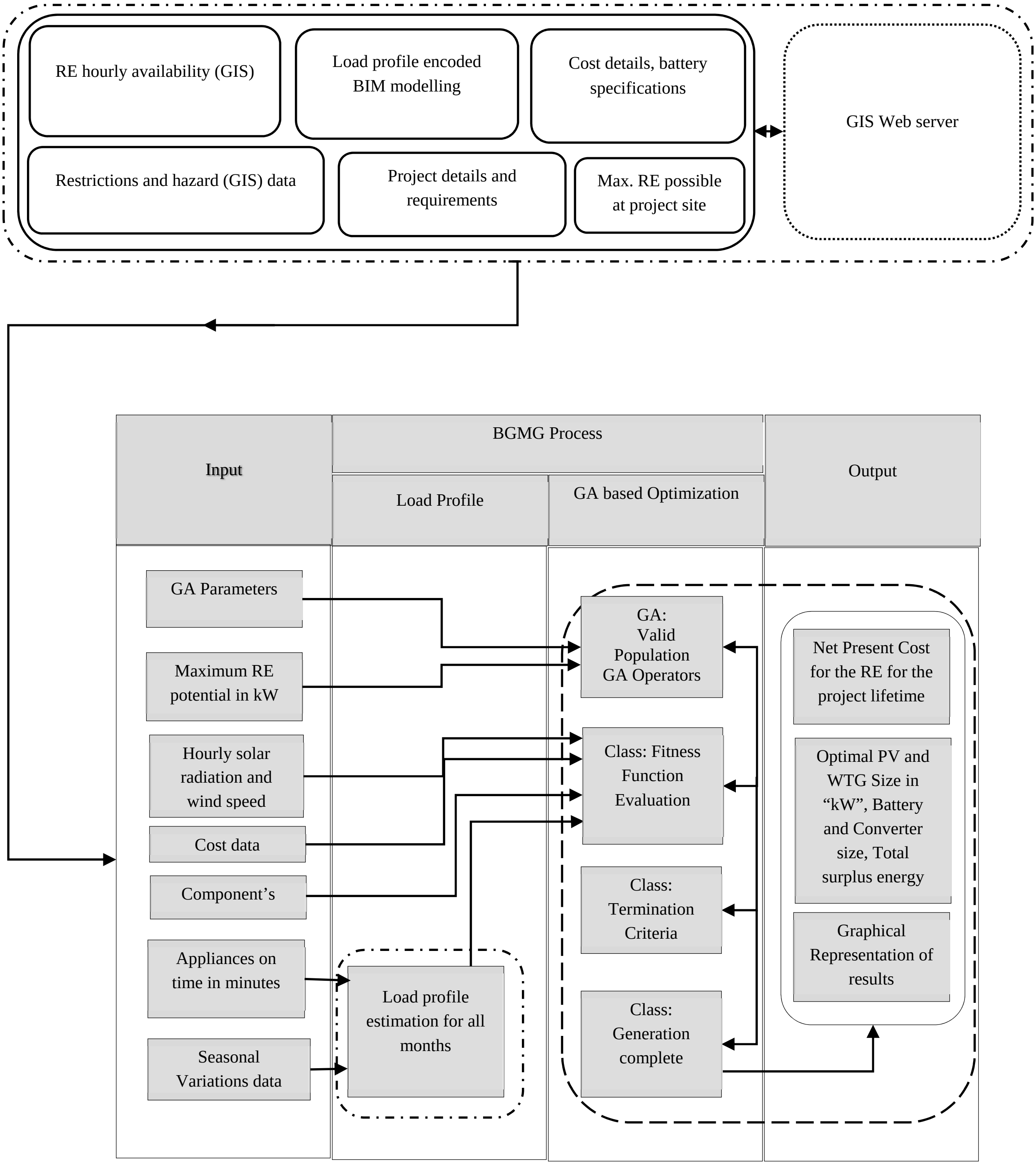

Fig. 5.4: *GA based Renewable Energy Source Mix Optimization Process in the BIM-GIS Integrated Microgrid Design Platform*

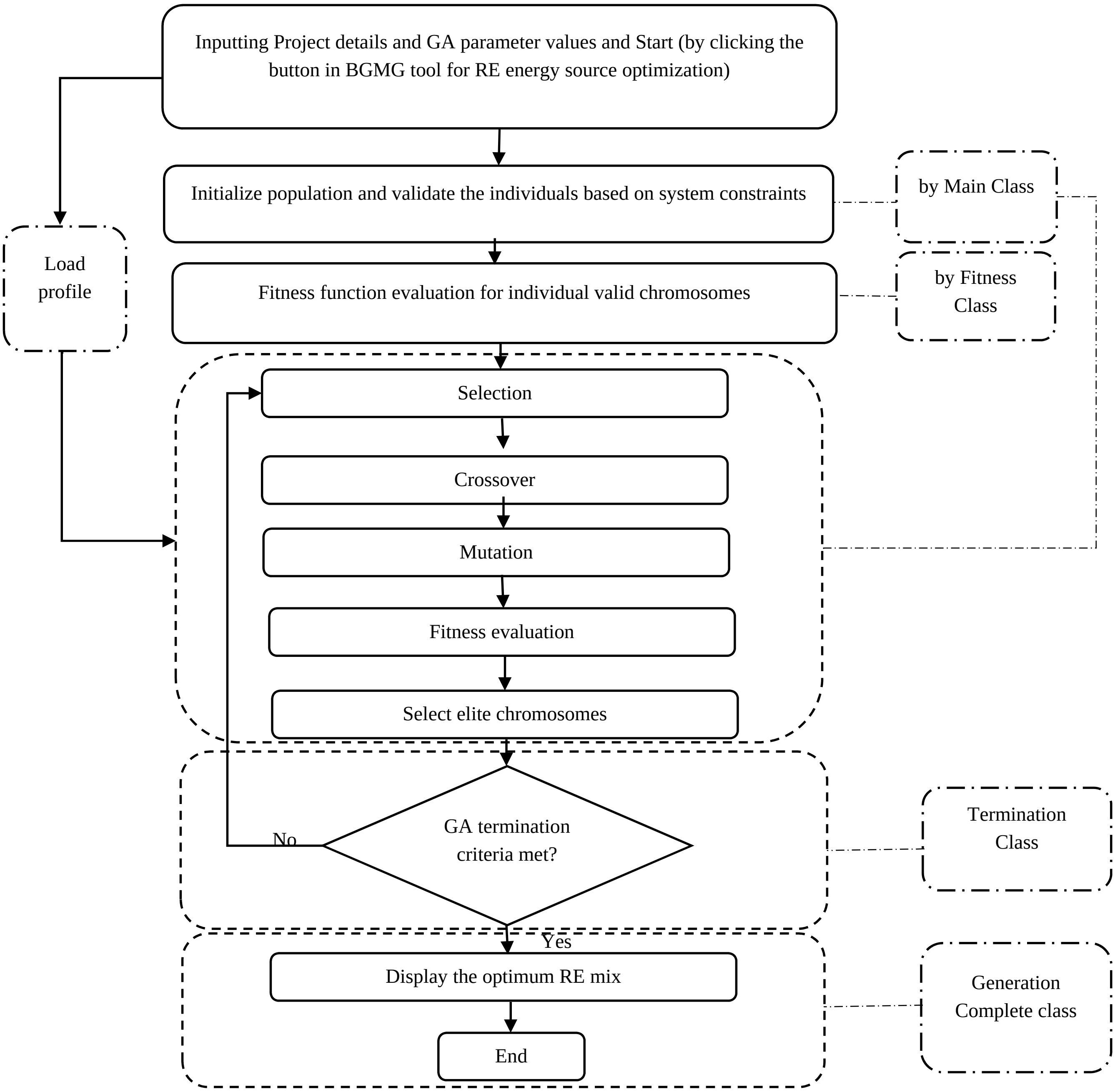

Fig. 5.5: *Genetic Algorithm Optimization Process*

The load profile estimate section in Fig. 5.4 generates an average daily load profile of the microgrid based on the typical On-time of each and every appliance, daily average value of the appliance starting frequency, its hourly starting probability as discussed in the problem formulation section. Once these daily load estimate is generated for each appliance, these are aggregated to get the monthly load estimate. This forms the base line data. To create the scaled data to incorporate the seasonal variations, each of the baseline data values are multiplied by a common factor that results in an annual average value equal to the value that is specified in Scaled Annual Average. To determine the value of this factor, divide the scaled annual average by the baseline annual average. The scaled data retains the shape and statistical characteristics of the baseline data, but may differ in magnitude. The default value for the scaled annual average is the baseline annual average. Thus the load profile for every month is generated as shown in the typical load variation in Fig. 5.6. More details about the load profile estimate are given in Appendix 2.

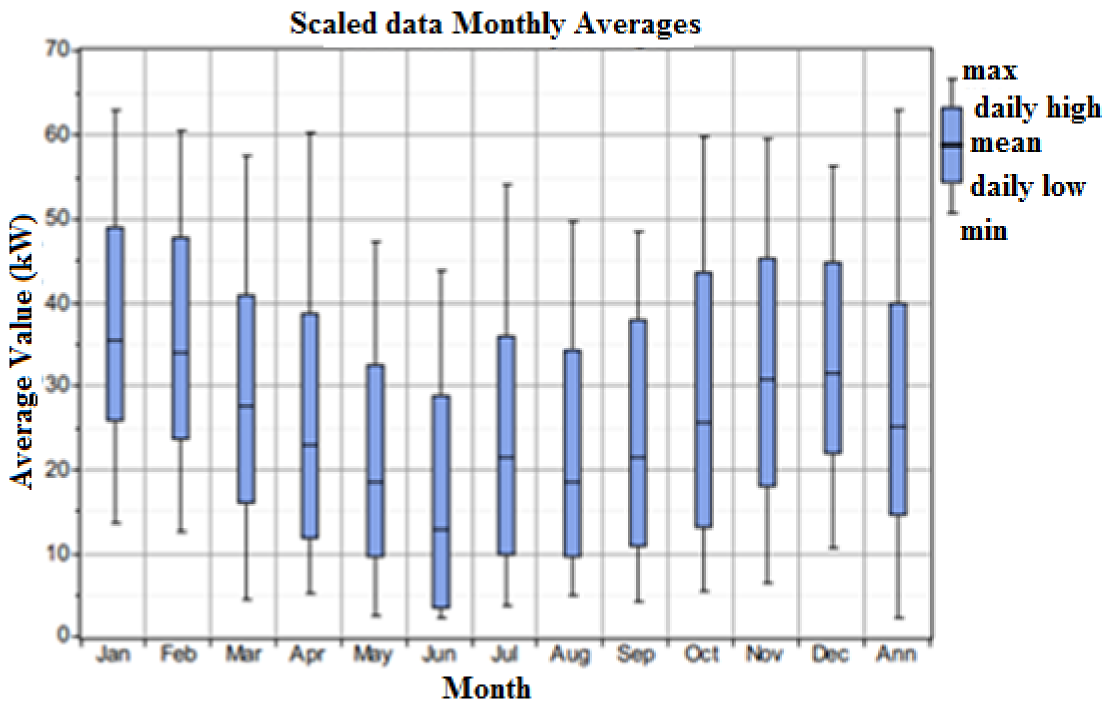

Fig.5.6: *Typical Scaled Annual Load Profile*

Instant to Instant, the battery charging and discharging status is taken into account in the renewable mix optimization. As discussed in the problem formulation part, this computation can be extended so as to compute the maximum battery utilization and the required converter size and also the surplus battery storage on a monthly basis over an year based on the microgrid, PV kW Optimal rating, Wind kW Optimal rating and % Energy Efficiency from GA RE Mix Optimization Section and the load profile data from the input section. The optimal battery size and the corresponding converter size are decided in this thesis based on this information.

5.3 Method **of BGMG RE Mix Optimization as Revit add-in Tool**

The proposed BIM and GIS-based microgrid optimization process is implemented through the application of multiple technologies, but at the same time integrated and automatically accessed from a single platform, the BIM environment, through the proposed BGMG add-in tool as shown in Fig.5.7.

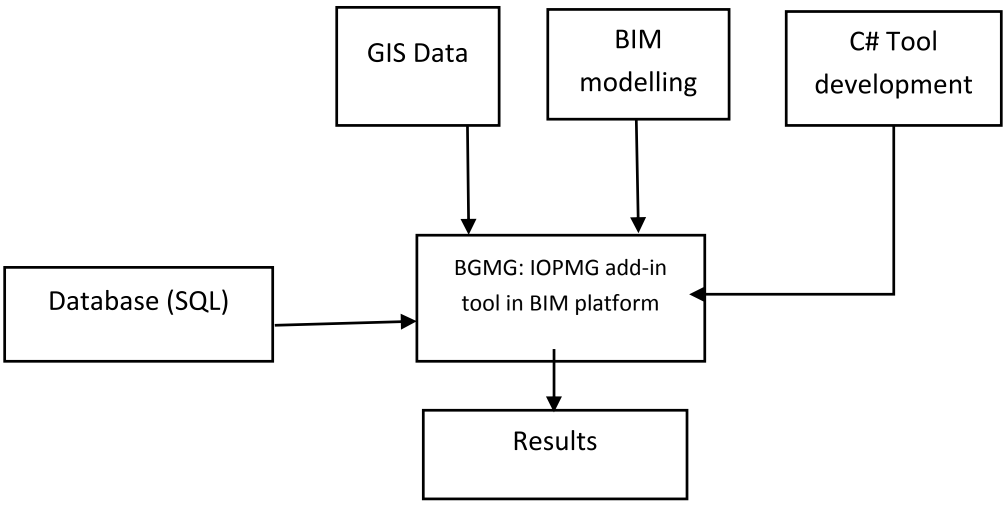

Fig.5.7: *Combination of technologies for developing BIM platform based IOPMG*

BGMG development has three steps of programming as shown in Fig.5.8. In the first step, major programming is done in Microsoft visual C# platform. In step-2, necessary programming for creating new add-in button at Revit's add-in panel is done in Microsoft Visual C# platform. In step-3, the registration of the program code written in steps 1 and 2 is done by writing a manifest file in Microsoft note file and saving it as ".addin" file. By following these steps BGMG add-in program is inserted to Revit, the BGMG button so developed appear as shown in Fig.5.9. Fig.5.10 to Fig. 5.12 show a few typical screenshots related to the load data input section, renewable energy source data input section and GA based renewable energy source mix optimization respectively. More details of the software utilized are given in Appendix 3.

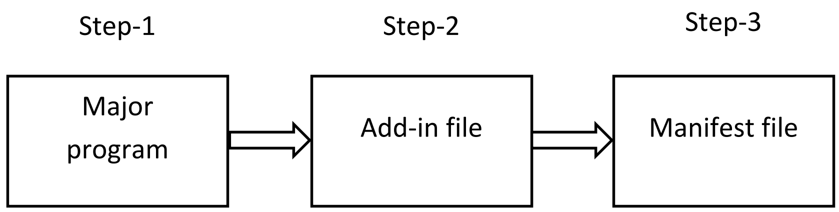

Fig.5.8: *BGMG programming steps*

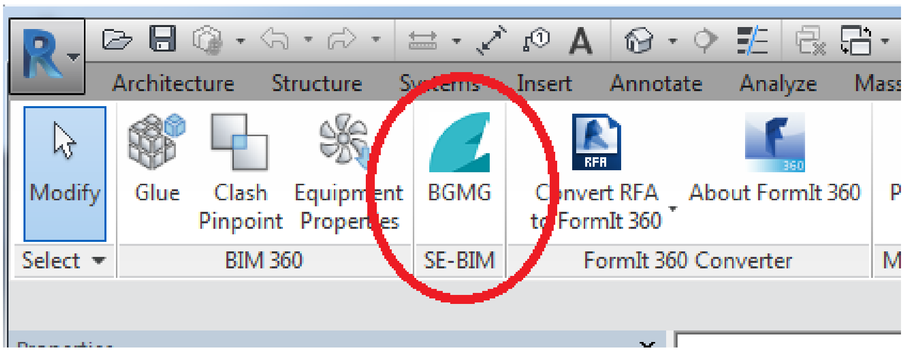

Fig.5.9: *BGMG button at Autodesk's Revit Opening Screen*

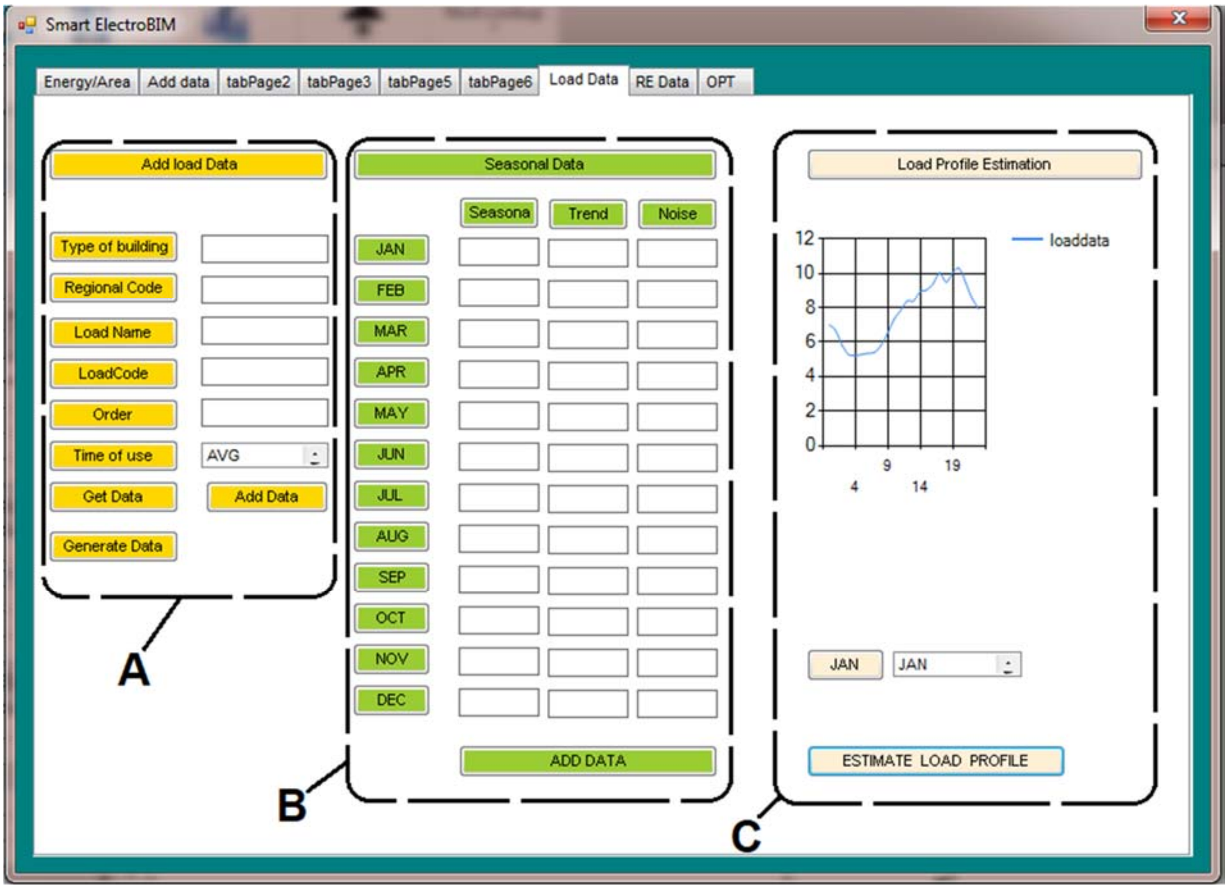

Fig. 5.10: *Screenshot: Load Data Input Section. A: Appliances On Time input section, B: Seasonal derating factor Input section and C: Load profile estimation Section.*

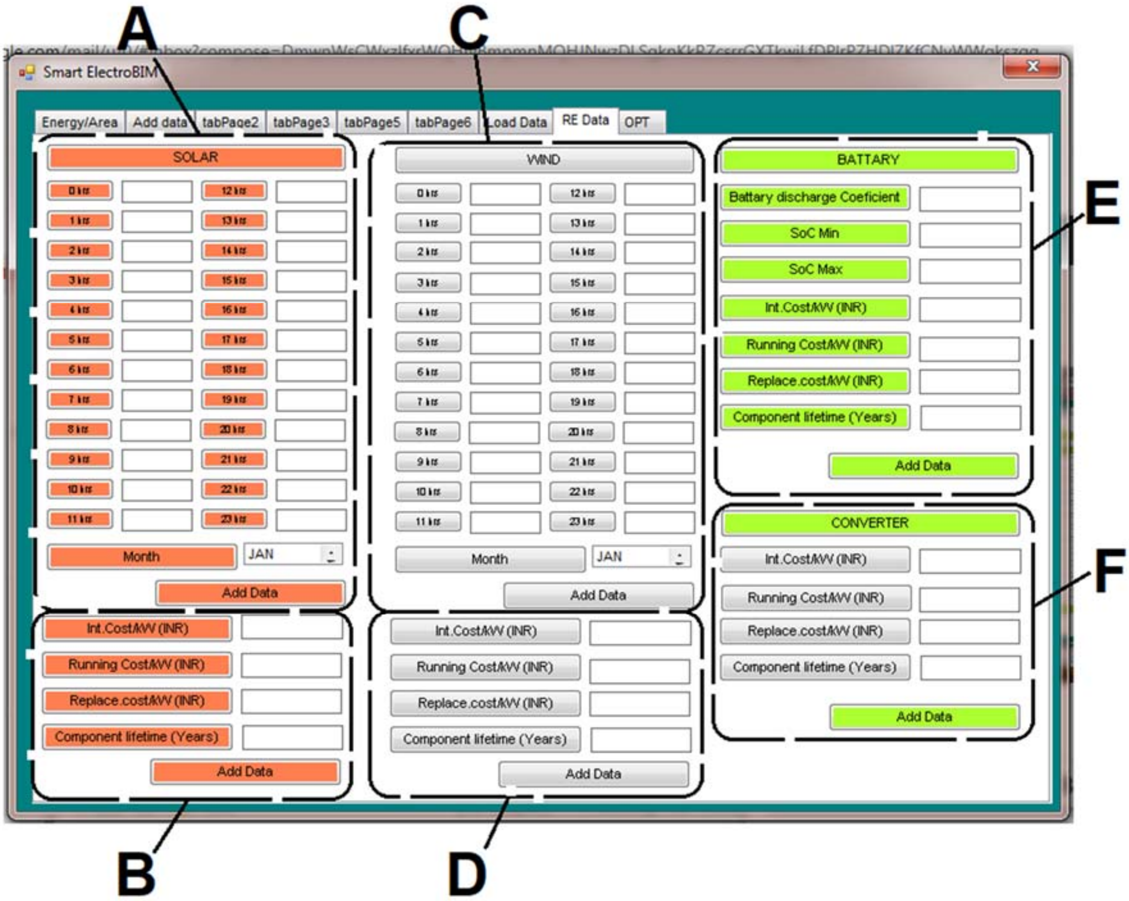

Fig.5.11: *Screenshot: Renewable Energy Source Data Input Section. A: Solar hourly radiation input section, B: PV System cost input section, C: Wind velocity input section, D: WTG system cost input section, E: Battery details and cost input section and F: converter details and cost input section.*

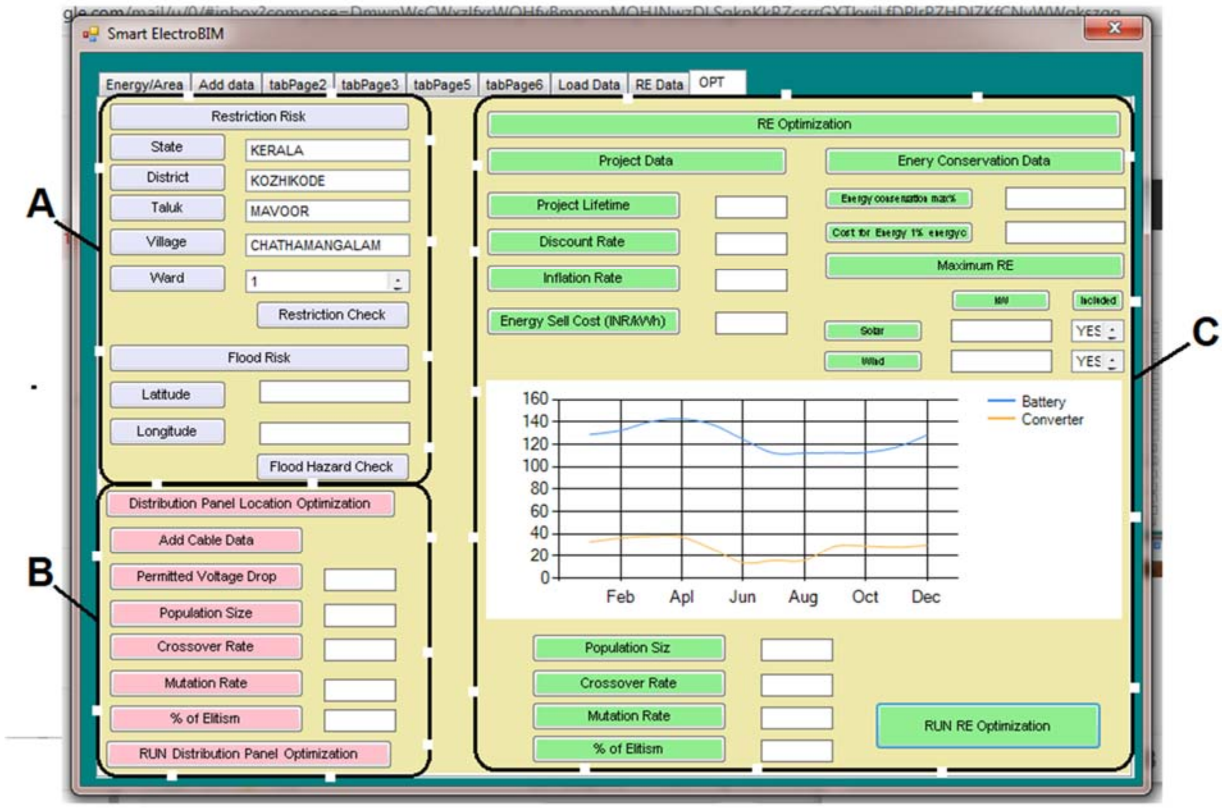

Fig. 5.12: *Screenshot: IOPMG Section. A) Site suitability checking section, B: Distribution panel total number and location optimization section (Chapter 7), C: RE mix optimization section.*

5.4 Summary

This Chapter has proposed an approach for planning and optimization of microgrids in a BIM-GIS integrated platform. As discussed in this chapter, the major sequence of stages in this process are site suitability assessment, renewable energy resource mix optimization and the cable length optimization. Site suitability assessment can be done from the BIM environment utilizing the GIS interface of the proposed BGMG add-in tool. Determination of the optimal capacity of the renewable energy resources in the microgrid such that the life cycle cost is the minimum has been proposed to be performed using genetic algorithm. The development of interfacing of various software platforms with the developed BGMG add-in tool in the BIM environment has been discussed. The BGMG add-in tool proposed in this chapter enables the engineers to perform all the necessary computations and decision making process related to the planning and optimization of microgrids, directly by the click of the BGMG button added in the BIM platform. The case study to establish the effectiveness of the proposed BGMG add-in tool is discussed in the following chapter.

Chapter 6

Integrated Optimal Planning of Microgrids in the BIM Environment: A Case Study

6.1. Introduction

As discussed in Chapter 4 and 5, the optimal planning and optimization of a microgrid proposed in this thesis involves the following major stages:

i. Establishment of the suitability of the site for the microgrid

ii. Evaluation of the resource potential at the project site

iii. Determination of the optimal capacity of the proposed installations of solar photo-voltaic systems, wind energy conversion systems and the battery energy storage systems such that the total net present life-cycle cost of the microgrid is the minimum.

iv. Determination of the optimal location and number of the distribution boards in the project site such that the length of the cable network is the minimum

In the current scenario, each of these procedures and computations are to be done in various computational platforms. This necessities manual transfer of the necessary data among these computational set ups. This manual process is seen to be very time consuming and error prone. Hence it is important to have a single platform in which all the required computational procedures related to microgrid planning and optimization are performed with the necessary automatic facility for the data retrieval from other the relevant platforms. Further, it would be better if the microgrid planner can be given a 3D visualization of this project. From these considerations, an add-in tool, referred to ‘BGMG tool’ is developed in the GIS-BIM integrated platform, as discussed in the previous chapters. This chapter gives a case study of a microgrid project at a site at Chathamangalam in the Kozhikode district in Kerala State, India.

6.2. Multi-Building Microgrid Project- An Overview

This project is located at Chathamangalam, Kozhikode district of Kerala state as shown in the Google Map in Fig.6.1. The total plot area is 12 acres. It has forty residential buildings of the same constructional features. The electrical system design for the project is done using Autodesk Revit application 2017 version. The 3D modelling of a typical residential building is shown in Fig.6.2. The site 3D view is shown in Fig.6.3 and plan view of the typical building is given in Fig.6.4. The major planning and design stages of the proposed microgrid applied to the project site are discussed in this chapter followed by the GA based RE mix optimization results and validation. The major screen shots of the application of the BGMG tool in this case study is presented at the end of this chapter.

Fig. 6.1: *Google map view of project site (rectangular area)*

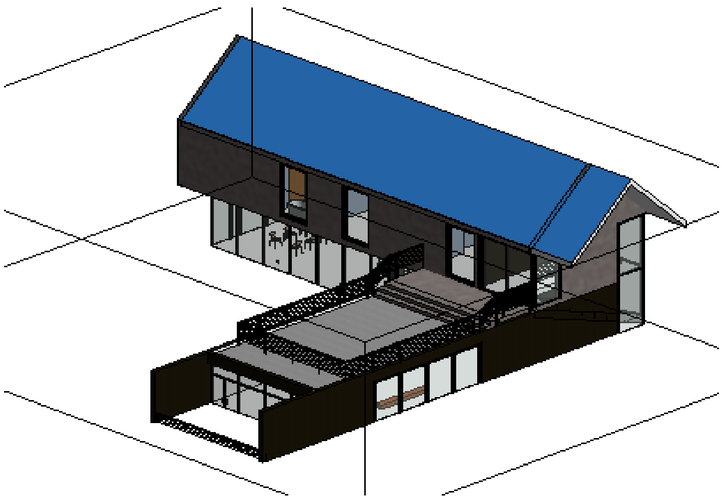

Fig.6.2: *3D view of typical building in Revit*

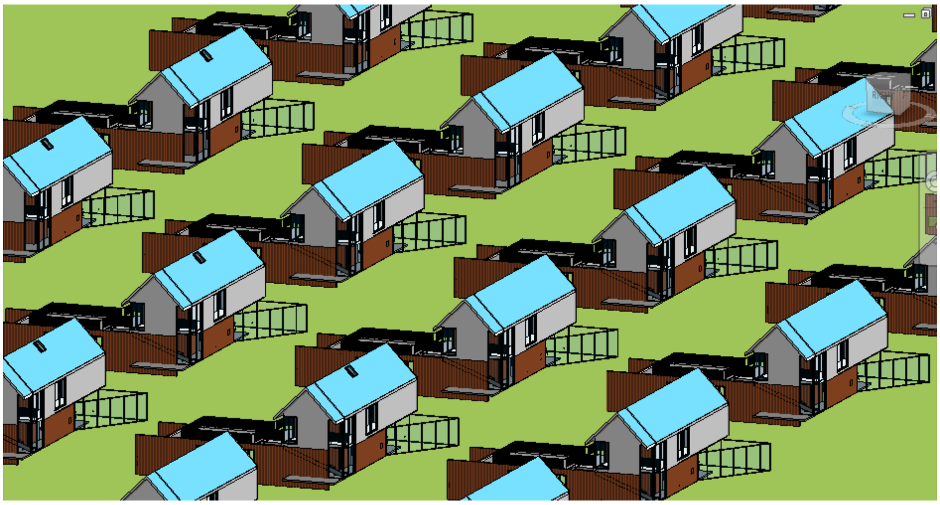

Fig.6.3: *Revit 3D modelling of multi-building project site with rooftop solar PV panels and wind generators*

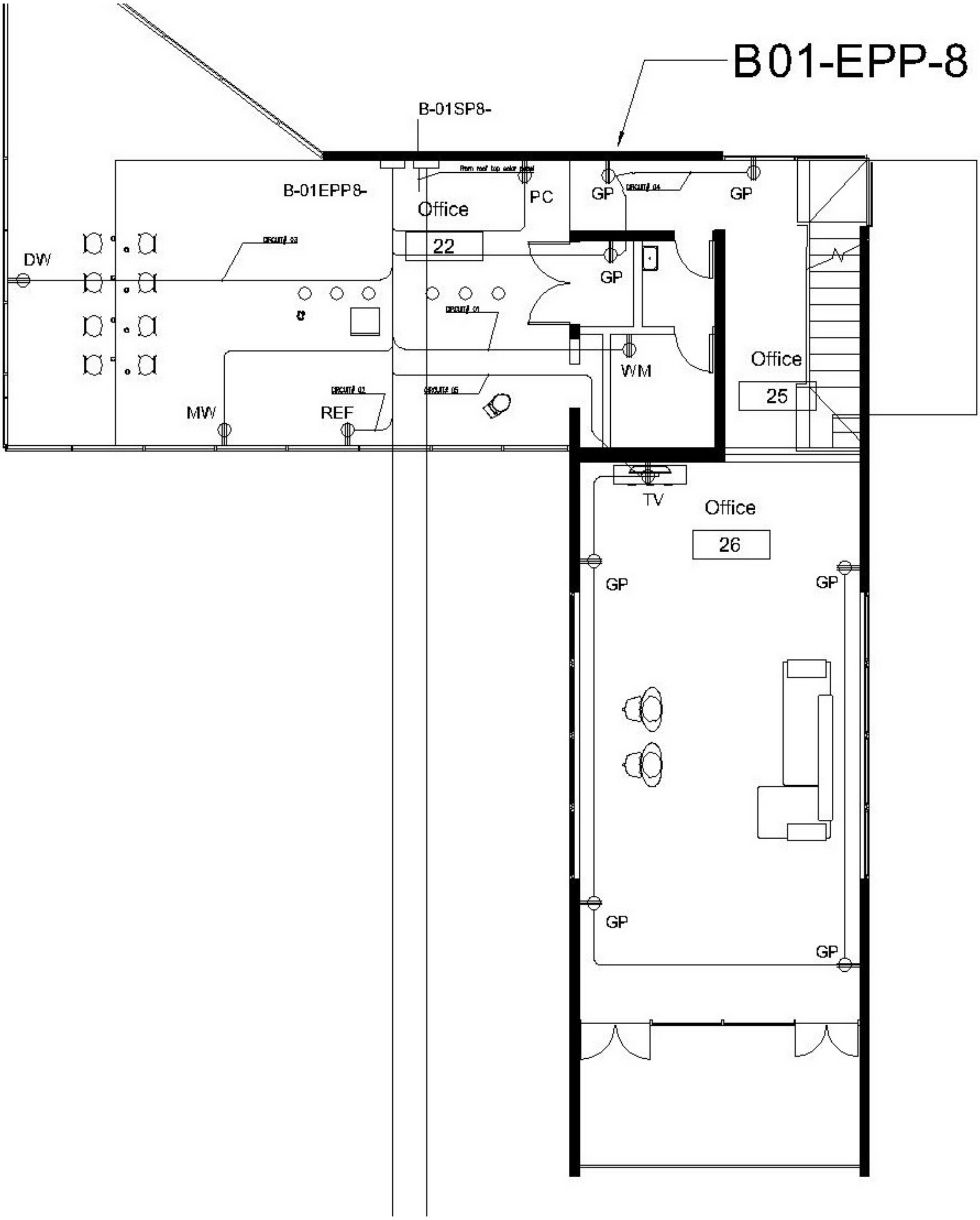

Fig.6.4: *Plan view of ground floor power system*

6.3 Site Suitability Assessment

Based on the methodology explained in Chapter 4, Kerala state GIS data for site suitability assessment is integrated with BIM. The detailed process is explained in Appendix 4. The BGMG screenshot for site suitability enquiry is given in Fig. 6.5 and Flood vulnerability risk at project site is given in Fig.6.6.

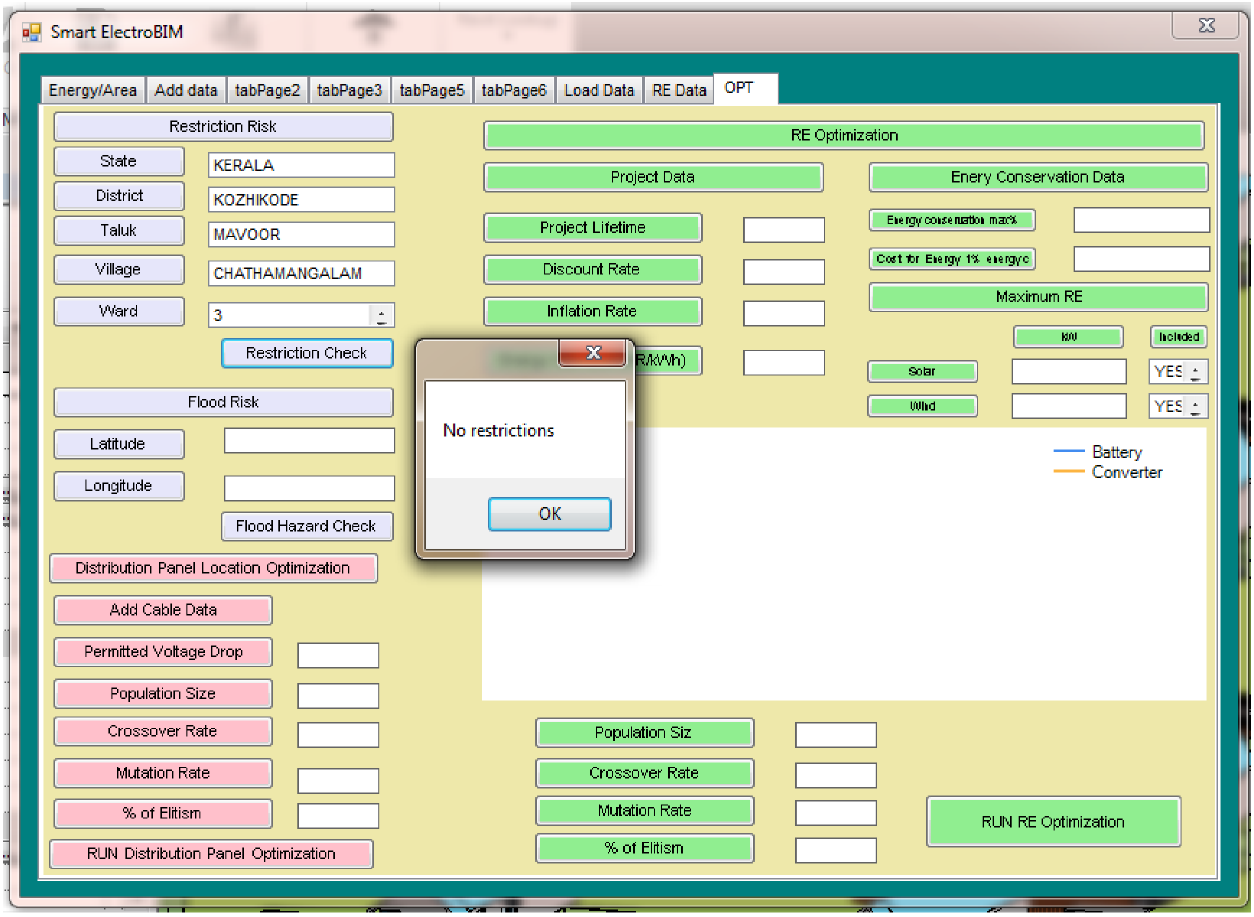

Fig.6.5: *Restriction checking in BIM platform*

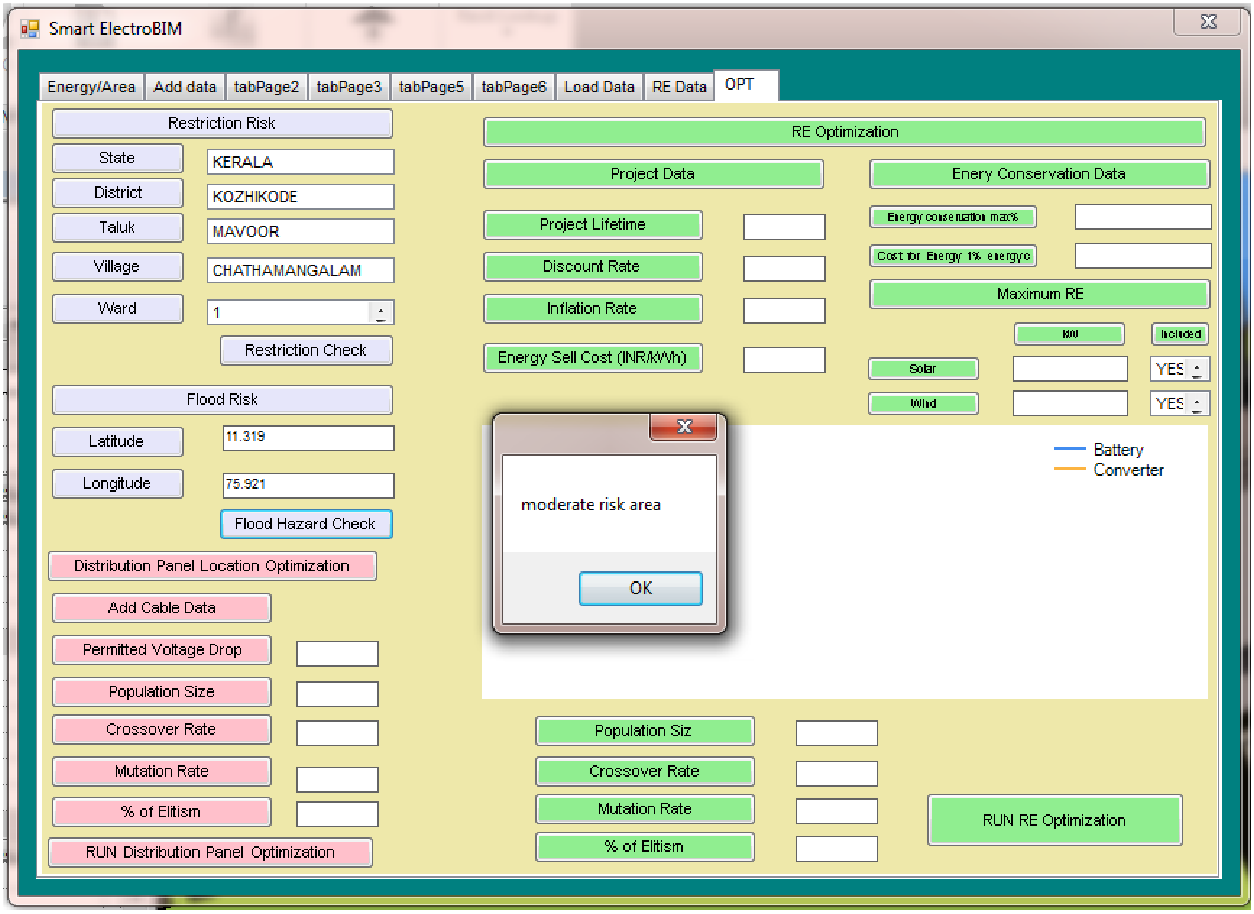

Fig.6.6: *Flood risk assessment at project site*

Validation of site suitability Results

The restricted modelling performed in ArcGIS as given in Appendix 4 and the comparison with the Google map are shown in Fig. 6.7 and 6.8 respectively. As the layers of the protected areas and water bodies are taken from NREL, the results are accurately matching.

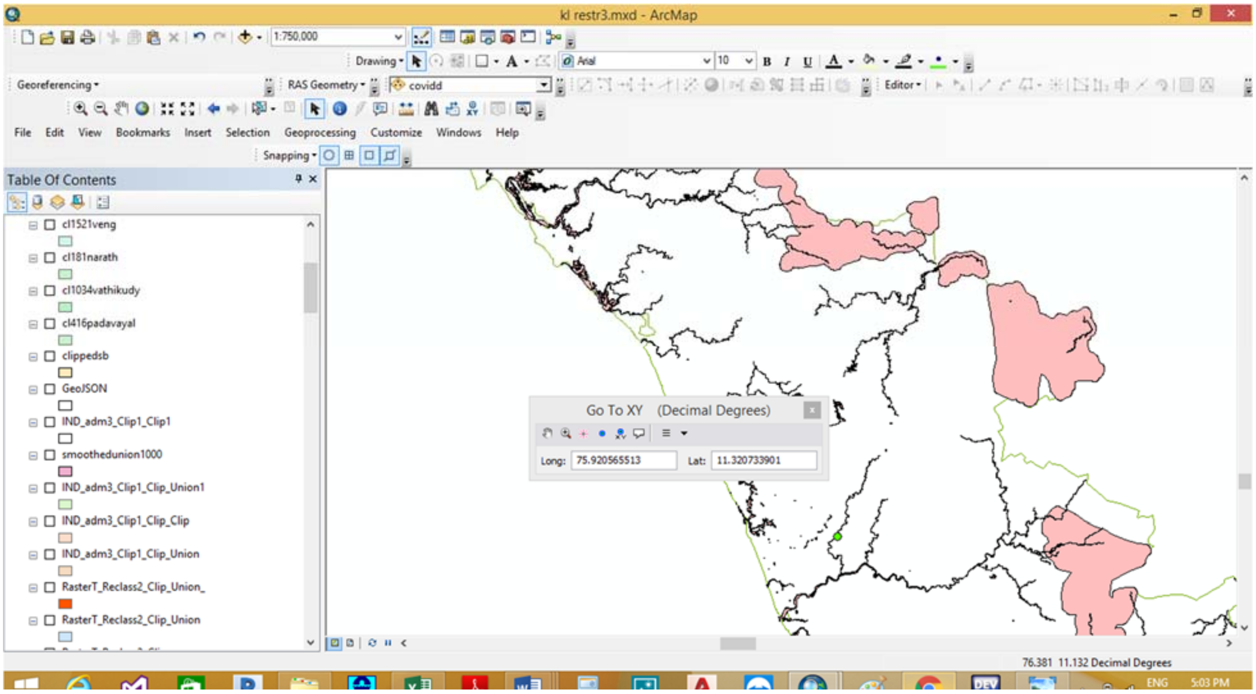

Fig.6.7: *Developed restriction modelling in ArcGIS showing a part of the river at the project site premises*

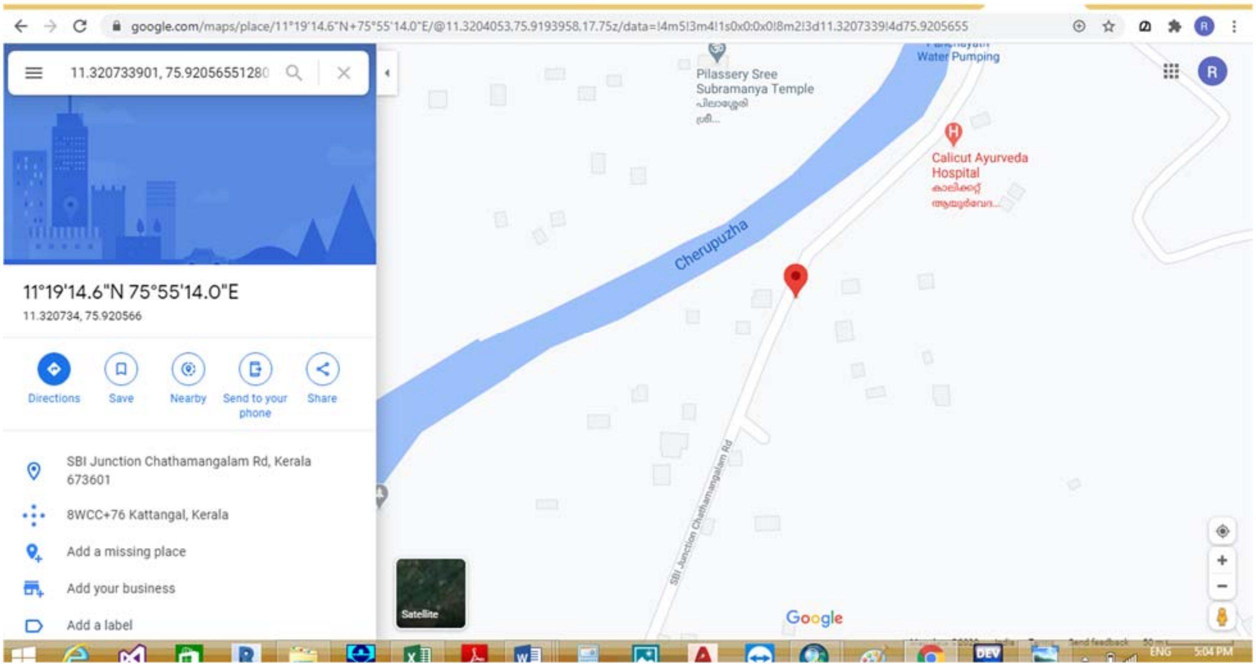

Fig.6.8: *The river part in Fig.6.7 is shown as the same as in Google map*

To validate the zonal statistics, four sub-administrative sections are clipped and the percentage values are calculated by using AutoCAD and ArcGIS tool as given in Table 6.1 and also in Fig. 6.9. The zonal statistics data is found accurate.

***Table 6.1** percentage Administrative restriction estimation*

Administrative division ID No.	% of restrictions from Zonal statistics	% of restrictions by clipping in ArcGIS platform	% of restrictions from AutoCAD based area estimation
181	11.15	11.24	11.2
241	97.25	97.23	97.2
416	52.11	52.12	52.1
1034	67.25	67.24	67.3

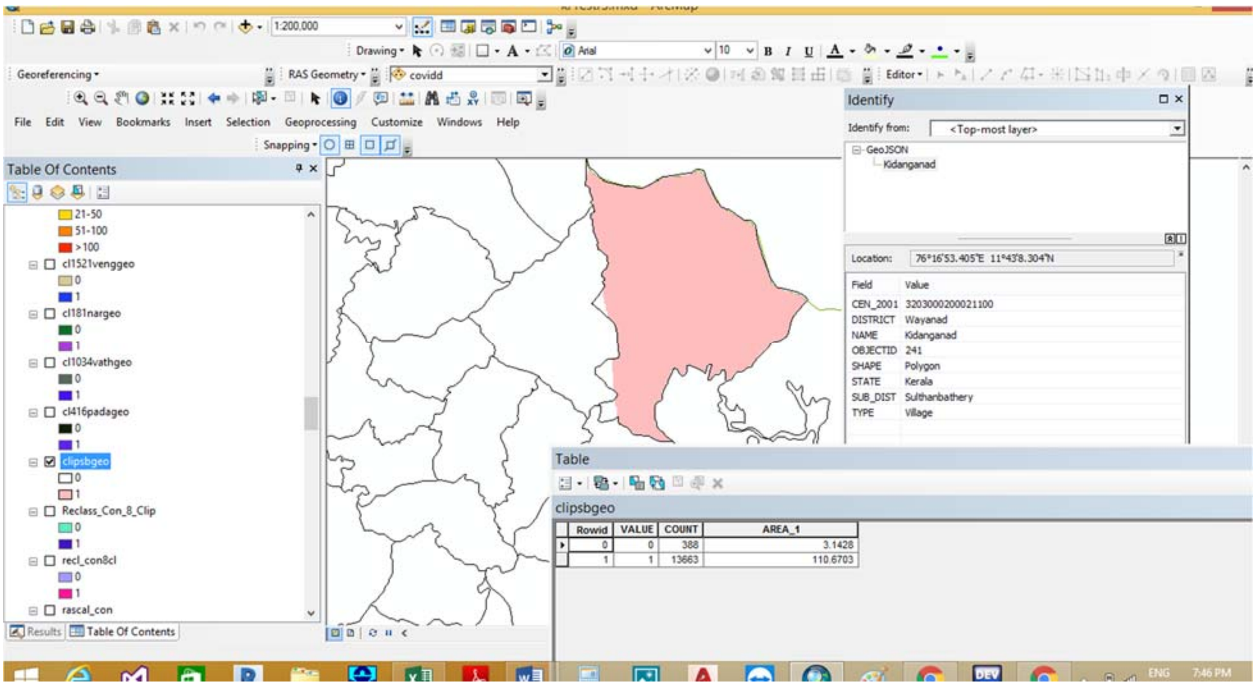

***Fig.6.9:** Percentage Administrative restriction estimation. Pink colored region is the restriction. It is almost surrounded by the corresponding administrative division. The area of restrictions and its related administrative boundary is measured using ArcGIS and AutoCAD for preparing Table 6.1*

To understand the flood risk of the project site, Kerala flood data is utilized [226]. Near to the project site there is a river stream locally known as "Cherupuzha River" As per the 2018 Kerala flood data, the areas near to Cherupuzha River was flooded as shown in Fig. 6.10. The extent of flooding is seen to be less than 10m from the river. Hence the microgrid is located at least 10m away from the river. Similar results of low level flooding is obtained as per the GIS based flood vulnerability perspective of the site suitability assessment as given in Fig.6.11.

Fig.6.10: *Flood mapping of the project site. The black marked areas are the flooded regions as per 2018 Kerala flood*

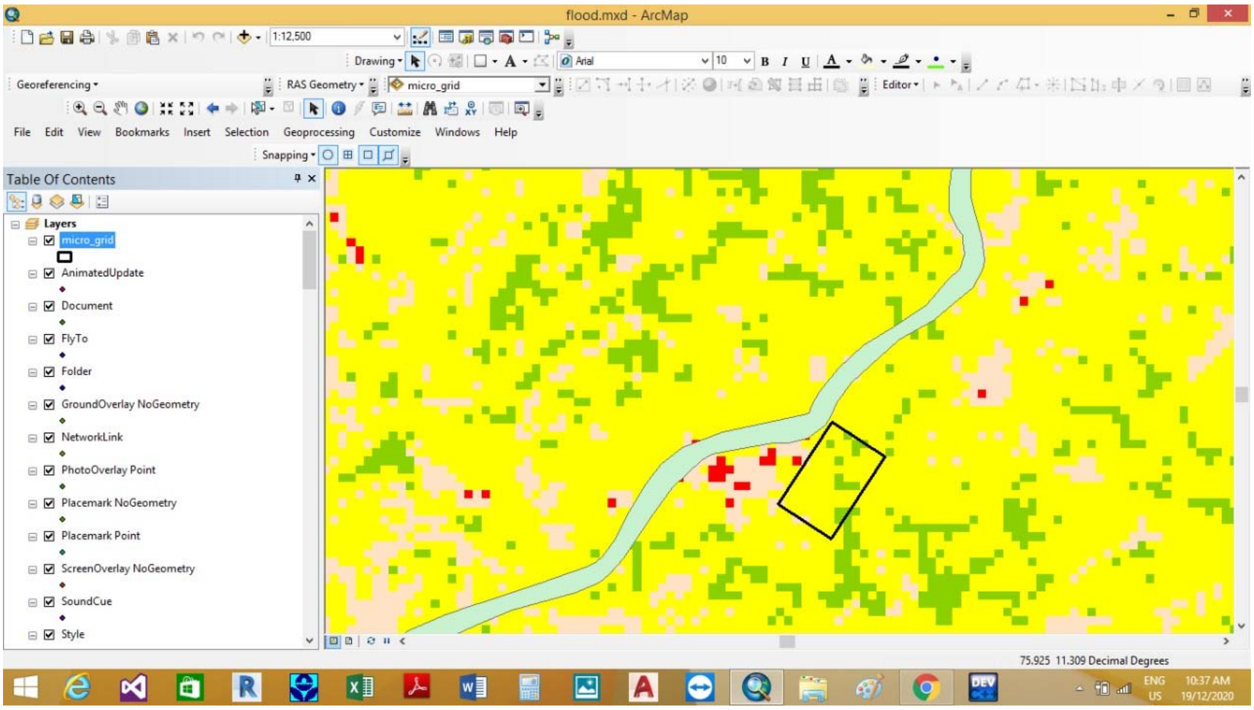

Fig.6.11: *Flood vulnerability of the project site.*

As per the 'protected area GIS data', retrieved through the developed BGMG tool, there are no protected regions at the project site. Thus from these investigations, it has been observed the project site is free from the administrative restrictions and having moderate level of flooding. Hence it is established that the site is suitable for the development of a microgrid. Ground level Installation of solar panel at site near to river is to be avoided or increase the installation height.

6.4. Resource Potential Evaluation

Once the site is assessed to be suitable for the development of a microgrid, the next stage is to evaluate the untapped potential of the renewable energy resources and also the societal impact. In this thesis, the three renewable resources, solar insolation, wind velocity and biomass, are considered for detailed evaluation.

Monthly average solar insolation and clearness Index at the project site is given in Table 6.2 [227]. From the Table, it can be seen that the annual average value of solar insolation is of the order of 5.1 kWh/m^2/day with a good clearness index. This implies that the project site has a good potential for the installation of solar PV system. Similarly, the monthly average wind velocity at the project site at a height of 50m, 30m and 20m at the project site is given in Table 6.3 [227]. Typically, the cut-in speed of a small wind turbine starting its power generation is 3.5 m/s, and the power generation reaches its maximum as the wind speed is in the range 10–15 m/s. From Table 6.3, it can be seen that the project site has a reasonable potential for wind energy conversion, particularly during the months of June, July and August.

Table 6.2: *Monthly average solar insolation at the project site*

Month	**Clearness Index**	**Monthly Average Solar Insolation (kWh/m^2/day)**
January	0.636	5.54
February	0.657	6.21
March	0.639	6.51
April	0.550	5.792
May	0.486	5.104
June	0.418	4.335
July	0.395	4.105
August	0.409	4.280
September	0.459	4.698
October	0.487	4.666
November	0.540	4.763
December	0.615	5.197

Table 6.3: *Monthly Average Wind Velocity at the Project Site*

Month	Monthly Average Wind Velocity in m/s @ 50m height	Monthly Average Wind Velocity in m/s @ 30m height	Monthly Average Wind Velocity in m/s @ 20m height
January	4.48	4.11	3.82
February	3.52	3.23	3.00
March	3.96	3.63	3.38
April	4.09	3.75	3.49
May	4.94	4.53	4.21
June	7.59	6.97	6.47
July	7.20	6.61	6.14
August	6.99	6.42	5.96
September	5.29	4.86	4.51
October	3.80	3.49	3.24
November	4.12	3.78	3.51
December	5.31	4.87	4.53

Other than the solar and wind energy potential, another renewable energy option at the project site is biomass. Hence a comparative evaluation of these energy resources are performed by using Analytic hierarchy process (AHP) [228] and the renewable energy resources, namely solar insolation, wind velocity and biomass is performed at the project site conditions as per the classification given in Table 6.4. AHP estimates the weightage for each of these alternatives. Normalized matrix obtained by summing the columns and dividing each column members by the row sum gives the comparative weightage [229]. . For every criteria the pairwise comparison matrix for an AHP is with m objectives is an m×m matrix (G) given by

$G = [g_{xy}]$

$g_{xy} > 0$ for x, y = 1, . . . , m, and……………………………………………………………(6.1)

$g_{yx} = 1/ g_{xy}$ for x, y = 1, . . . , m………………………………………………………………(6.2)

$g_{yx} = g_{xy} = 1$ for x=y……………………………………………………………………(6.3)

According to the comparative advantage g_{xy} value is estimated from Table.6.4.

Table 6.4: *g_{xy} comparative advantage values.*

g_{xy} values	**Description**
1	Equal significance
3	Moderate significance compared to the alternative
5	Strong significance compared to the alternative
7	Very Strong significance compared to the alternative
9	Extremely superior significance compared to the alternative
2,4,6,8	intermediate values

The results of AHP analysis are given in Table 6.5.

Source Availability (T1): The availability of each source is compared in an AHP matrix. As per laydown conditions and assessments the comparative advantage is estimated as per Table.6.4 and sequenced as per equation 6.1 to 6.3. As detailed in Table 6.3, wind energy potential is very less at project site at 30 meter height. So compared to wind, solar energy source is very Strong significance (=7).

Minimal Financial Risk (T2): Same as T1 but for minimal financial risk. As the urbanization is increasing and cultivation is decreasing, biomass source availability and its cost can be increased exponentially at project site premises. As the climatic conditions in Kerala are varying yearly due to global warming, wind energy availability at this project site cannot be forecasted accurately. Hence, it can be observed that solar energy source indicates shows a stronger significance than the wind/biomass sources at the project site.

Acceptance By Client (T3): Same as T1 but for acceptance by client. As the project is designed for upper middle class, the preference will be for low maintenance silent energy source with less pollution. Hence, solar energy source shows a stronger significance than the biomass sources at the project site.

Land Requirement (T4): Same as T1 but for land requirements. The cost of land is high at the project site. 1 crore rupees/acre is the minimum rate. So that roof top solar installation becomes a better option than the wind energy utilization.

T5: Weighted preference of T1, T2, T3 and T4 is given at T5.

T6: Weightage of each RE source is given at T6.

T7: The matrix multiplication of T5 * T6=T7.

From AHP analysis it is observed that the solar insolation as the preferred renewable energy source at this project site with the least financial risk when compared to the wind velocity and the biomass options.

Table 6.5: *AHP Assessment of Renewable Energy Resources for the Project Site*

Source Availability (T1)						
	Solar	Wind	Biomass		Weighted Preference	
Solar	1.00	7.00	7.00		3.66	76.62%
Wind	0.14	1.00	3.00		0.75	15.79%
Biomass	0.14	0.33	1.00		0.36	7.59%

Minimal Financial Risk (T2)						
	Solar	Wind	Biomass		Weighted Preference	
Solar	1.00	2.00	5.00		2.15	58.16%
Wind	0.50	1.00	3.00		1.14	30.90%
Biomass	0.20	0.33	1.00		0.41	10.95%

Acceptance By Client (T3)						
	Solar	Wind	Biomass		Weighted Preference	
Solar	1.00	5.00	5.00		2.92	70.89%
Wind	0.20	1.00	2.00		0.74	17.86%
Biomass	0.20	0.50	1.00		0.46	11.25%

Land Requirement (T4)						
	Solar	Wind	Biomass		Weighted Preference	
Solar	1.00	5.00	2.00		2.15	55.91%
Wind	0.20	1.00	0.20		0.34	8.87%
Biomass	0.50	5.00	1.00		1.36	35.22%

Alternative Matrix (T5)				
Source Type	Source Availability (T1)	Minimal Financial Risk (T2)	Acceptance By Client (T3)	Land Requirement (T4)
Solar	76.62%	58.16%	70.89%	55.91%
Wind	15.79%	30.90%	17.86%	8.87%
Biogas	7.59%	10.95%	11.25%	35.22%

Criteria Matrix (T6)	
Source Availability	25.00%
Minimal Financial Risk	25.00%
Acceptance By Client	25.00%
Land Requirement	25.00%

Advantage (T7)	
Solar	65.39%
Wind	18.36%
Biomass	16.25%

As shown in Table 6.6, untapped roof-top solar potential at the project site is 397.6 kW. As shown in Table 6.7, untapped wind energy potential at the project site is 200 kW.

Table 6.6: *Rooftop Solar PV Installation potential*

Description	**Data**
Roof area of Typical building	102 m^2
Actual available space for solar panel installation	71 m^2
The efficiency of polycrystalline-based solar panels	14%
Roof top kWp of PV possible in a typical building [as per Equation 4.24]	9.94 kWp
Total possible rooftop solar kWp for 40 buildings	397.6 kWp

Table 6.7: *Wind Energy Conversion system-Installation potential*

Description	**Data**
Wind Turbine capacity	100 kW
Radius	12.25 m
Swept area	471.19 m^2
Land requirements	0.5 Acre if Two diameter is the total clearance. This land will cost at least 0.5

	Crore rupees
Maximum number of 100kW WTG can be installed at project site having 1 acre of spare land available at Project site.	2

6.5 **Data Preparation**

6.5.1 Load Data: Fig.6.4 shows the connected loads in a typical building in the microgrid. The rating of the individual appliances and the calculation of the total connected load is shown in Table 6. 8. As seen from Table 6.8, the connected load of each of the building is 3.2 kW and thus the total connected load in the microgrid corresponding to 40 buildings is obtained as 128 kW. These loads are assumed to be fully supplied from the power generated at the microgrid location itself. The additional power generated, if any, is assumed to be sold to the Kerala power grid. The ON Time (A_{ot}) of Appliances assumed in the thesis is given in Table 6.9 [230]. The seasonal variations in the load curve is incorporated as discussed in Appendix 2 based on the load curve scaling values as given in Table 6.10. A typical daily load curve is given in Fig.6.12 and the total monthly average load for a typical day of the microgrid is given in Fig.6.13 respectively.

Table 6.8: *Connected Loads in a typical building*

No	Load	Quantity (No.)	Rating (Watts)	Total (Watts)
1	Refrigerator	1	220	220
2	Microwave Oven	1	400	400
3	Washing machine (WM)	1	600	600
4	Dish washer (DW)	1	500	500
5	Personal Computer	1	280	280
6	General outlets (emergency lighting and power)	8	151	1208
	Total Connected Load in a building			3.2kW
	Total Connected Load in the Microgrid			128 kW

Table 6.9: *.ON Time (A_{ot}) of Appliances. MW: Microwave, REF: Refrigerator, DW: Dishwasher, WM: Washing machine, TV: Television, PC: Personal Computer and GP: General purpose outlet for emergency lighting and power.*

Load type ON time (minutes)/hour	MW	REF	DW	WM	TV	PC	GP
0	0.24	24.32	0.47	0.20	11.35	6.52	5.41
1	0.09	24.32	0.26	0.11	9.95	5.71	4.28
2	0.01	24.32	0.00	0.00	5.67	3.26	2.23
3	0.00	24.32	0.00	0.00	2.54	1.46	2.07
4	0.00	24.32	0.00	0.00	2.25	1.29	2.07
5	0.00	24.32	0.00	0.00	2.54	1.46	2.23
6	0.04	24.32	0.00	0.00	2.84	1.63	2.91
7	0.40	24.32	0.00	0.00	2.84	1.63	3.58
8	0.62	24.32	0.37	0.16	4.27	2.45	5.96
9	1.03	24.32	1.04	0.45	7.11	4.08	6.84
10	1.40	24.32	2.41	1.03	9.95	5.71	6.70
11	1.64	24.32	3.66	1.57	11.35	6.52	6.33
12	1.85	24.32	3.77	1.61	14.19	8.15	6.67
13	1.86	24.32	3.77	1.61	14.19	8.15	6.84
14	1.68	24.32	3.83	1.64	17.35	9.96	7.51
15	1.50	24.32	3.83	1.64	17.93	10.30	8.35
16	1.39	24.32	3.83	1.64	19.89	11.42	10.08
17	1.59	24.32	3.88	1.66	19.89	11.42	10.62
18	1.74	24.32	3.88	1.66	19.89	11.42	11.49
19	1.72	24.32	4.04	1.73	22.73	13.05	12.33
20	1.70	24.32	4.04	1.73	24.13	13.86	12.70
21	1.63	24.32	3.88	1.66	19.89	11.42	11.41
22	0.96	24.32	3.19	1.37	15.62	8.97	11.21
23	0.54	24.32	2.04	0.87	14.19	8.15	8.13

Table 6.10: *Total seasonal load profile variations*

Month	Seasonal de-rating factor **(F_s)**	Trend derating Factor (F_T)	Noise de-rating factor (F_R)	Total derating factor =(F_T* F_S* F_R)
January	1.05	1.2	1.02	1.29
February	1.1	1.2	1	1.32
March	1.17	1.2	1	1.40
April	1.21	1.2	1	1.45
May	1.19	1.2	1	1.43
June	1.01	1.2	1.05	1.27
July	0.91	1.2	1.03	1.12
August	0.98	1.2	1	1.18
September	0.94	1.2	1	1.13
October	0.93	1.2	1	1.12
November	0.97	1.2	1	1.16
December	0.99	1.2	1.05	1.25

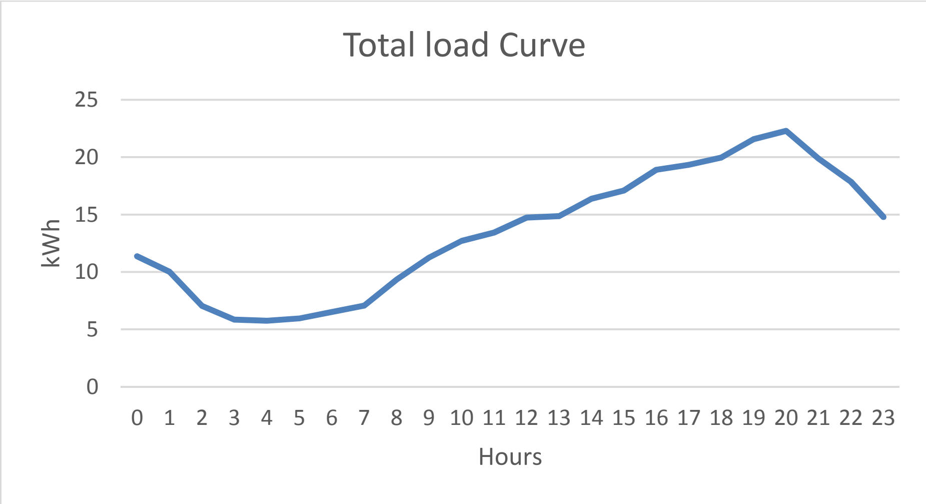

Fig. 6.12: *Daily Load Curve Estimate of the Microgrid*

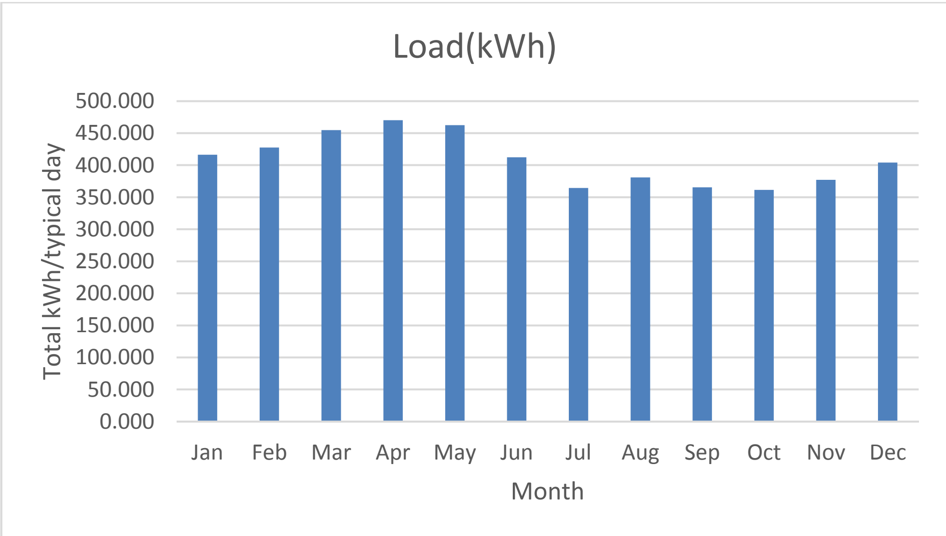

Fig.6.13: *Typical day of a month total daily scaled kWh consumption by all buildings in the project by incorporating the seasonal variations*

6.5.2 Cost for 1% energy conservation by the use of energy star appliances

Only refrigerator is considered to achieve the energy conservation as this is the biggest and continuous load. Energy consumption by a 400 litre capacity refrigerator according to star rating is given in Table 6.10A [231]. Cost data of the refrigerator according to energy star rating is given in Table 6.10B. From Table 6.10A and 6.10B, it can be concluded that the minimum 8% conservation of energy is possible per one energy star increment at a maximum cost of Rs.4000. The cost of 1% energy conservation for the total base load is estimated to be Rs.112900 and the details of the estimation are given in Table 6.10C and Table 6.10D.

Table 6.10A: *Energy consumption by a refrigerator according to star rating.*

Star Rating	Energy consumed by Refrigerator (400 liters) in kWh/year	% energy savings compared to base model
1 Star	685	100.00%
1.5 star	601	87.74%
2 Star	528	77.08%
2.5 star	463	67.59%
3 Star	406	59.27%
3.5 star	356	51.97%
4 star	313	45.69%

Table 6.10B: *Cost of refrigerator according to energy star*

Star Rating	Cost (INR)	Refrigerator capacity in Liters
2 Star	38120 [232]	394
3 Star	44548 [233]	394
4 star	49490 [234]	394

Table 6.10C: *Total kWh consumption by appliances selected for energy conservation*

Month	Total derating factor for Seasonal Variations	Per day baseline energy consumption by a refridgerator	No. of total refridgerator	No. of Days in months	Total energy (kWh) by all refridgerator /Month	Total baseline energy consumption by all loads in Microgrid (kWh)	Total energy (kWh) by all loads served by microgrid/Month
January	1.29	2.14	40	31	3410.41	323.9	12904.56
February	1.32	2.14	40	28	3163.78	323.9	11971.34
March	1.40	2.14	40	31	3725.65	323.9	14097.42
April	1.45	2.14	40	30	3728.74	323.9	14109.08
May	1.43	2.14	40	31	3789.34	323.9	14338.41
June	1.27	2.14	40	30	3268.04	323.9	12365.85
July	1.12	2.14	40	31	2984.66	323.9	11293.60
August	1.18	2.14	40	31	3120.63	323.9	11808.10
September	1.13	2.14	40	30	2896.70	323.9	10960.78
October	1.12	2.14	40	31	2961.42	323.9	11205.64
November	1.16	2.14	40	30	2989.15	323.9	11310.59
December	1.25	2.14	40	31	3310.10	323.9	12525.02
				Total	39348.62		148890.40

Table 6.10D: *Cost estimation for 1% energy conservation*

Energy rating	% Energy Conservation	Additional Cost of installation (INR)	Net present Replacement cost (INR)	No.of buildings	Total cost (INR)	% Energy conservation achieved compared to Total load	Cost per 1% of energy conservation
Star 1	8	4000	1972	40	238,889	2.11	112,991
Star 2	16	8000	3944	40	477,778	4.23	
Star 3	24	12000	5917	40	716,668	6.34	

6.5.3 Renewable Energy Resource Data:

Table 6.11 shows the solar insolation data at the project site. Table 6.12 details the specification of solar panels. Table 6.13 shows the wind velocity data at the project site. Fig.6.14 give the wind speed at 10 m height at the project site in the year 2019. Table 6.14 details the specification of wind turbine generators. Table 6.15 presents the component's cost and Table 6.16 shows the project details of the microgrid.

Table 6.11: *Monthly Average Solar radiation data at project site*

Month/hour	January	February	March	April	May	June	July	August	September	October	November	December
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0.03	0.04	0.03	0.06	0.06	0.06	0.03	0.03	0.03	0.019	0.02	0.01
8	0.17	0.19	0.24	0.26	0.22	0.18	0.17	0.16	0.16	0.15	0.15	0.15
9	0.38	0.44	0.48	0.46	0.38	0.35	0.29	0.29	0.33	0.34	0.33	0.36
10	0.58	0.65	0.66	0.62	0.53	0.45	0.37	0.43	0.49	0.5	0.54	0.56
11	0.72	0.81	0.81	0.78	0.65	0.55	0.47	0.51	0.6	0.6	0.67	0.68
12	0.79	0.86	0.9	0.84	0.75	0.56	0.57	0.61	0.7	0.67	0.69	0.75
13	0.81	0.89	0.93	0.9	0.8	0.6	0.63	0.65	0.72	0.71	0.72	0.77
14	0.76	0.84	0.88	0.86	0.73	0.53	0.55	0.54	0.67	0.67	0.65	0.69
15	0.63	0.71	0.75	0.69	0.61	0.41	0.37	0.44	0.54	0.55	0.54	0.58
16	0.43	0.5	0.54	0.47	0.43	0.32	0.27	0.33	0.37	0.36	0.36	0.41
17	0.2	0.25	0.24	0.23	0.24	0.18	0.17	0.17	0.19	0.15	0.17	0.17
18	0.04	0.03	0.05	0.06	0.09	0.06	0.04	0.05	0.04	0.04	0.03	0.02
19	0	0	0	0	0.01	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0

Table 6.12: PV panel data

Sl.No.	Specification of typical units of Solar Panel		
1	Rated Voltage of	6	V
2	Rated Power	1	kW
3	Component Lifetime	25	Years
4	Panel Type	Flat plate	
5	MPPT System	No	
6	Derating for Temperature and aging	100	%
7	Panel Slope	11.32	Degrees
8	Panel Azimuth	0	Degrees West of South

Table 6.13: Monthly average Wind velocity at 30m height @ project site [235]

Hour	Wind velocity at 30m Height in m/s											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	1.525	1.380	1.483	1.988	2.830	2.374	2.953	2.533	1.864	1.469	1.135	1.300
1	1.598	1.405	1.435	1.871	2.684	2.458	2.922	2.584	1.874	1.484	1.187	1.386
2	1.706	1.438	1.479	1.851	2.592	2.473	2.939	2.634	1.836	1.474	1.245	1.539
3	1.842	1.421	1.520	1.672	2.584	2.303	2.923	2.581	1.839	1.555	1.304	1.657
4	2.004	1.418	1.590	1.555	2.484	2.289	2.798	2.447	1.818	1.616	1.396	1.869
5	2.161	1.504	1.600	1.504	2.333	2.405	2.780	2.462	1.754	1.754	1.558	2.119
6	2.338	1.646	1.545	1.448	2.293	2.531	2.891	2.476	1.751	1.745	1.662	2.389
7	2.544	1.674	1.304	1.325	2.739	2.735	3.075	2.559	1.781	1.523	1.497	2.653
8	1.744	1.439	1.628	1.800	3.584	3.010	3.241	2.850	2.135	1.823	1.338	2.010
9	1.560	2.209	2.616	2.756	4.475	3.265	3.406	3.233	2.587	2.358	1.585	1.346
10	1.897	2.967	3.591	3.861	5.130	3.662	3.620	3.520	3.113	2.676	1.947	1.526
11	2.244	3.780	4.549	4.832	5.904	3.983	4.007	3.719	3.483	2.789	2.473	2.214
12	2.947	4.738	5.270	5.391	6.715	4.227	4.309	3.806	3.684	2.803	2.963	2.942
13	4.010	5.575	6.099	5.940	7.331	4.536	4.636	3.901	3.712	2.821	3.271	3.484
14	5.085	6.091	6.799	6.403	7.615	4.656	4.804	3.925	3.777	2.797	3.415	3.691
15	5.493	6.213	7.086	6.632	7.703	4.655	4.755	3.995	3.810	2.820	3.454	3.652
16	5.094	6.214	7.126	6.536	7.532	4.692	4.626	3.874	3.703	2.761	3.363	3.427
17	4.803	6.048	6.792	5.775	6.460	4.616	3.799	3.792	3.548	2.725	2.761	3.165
18	3.415	4.286	5.514	5.212	5.586	4.026	3.353	3.593	2.784	2.229	2.352	2.575
19	2.820	3.161	3.859	4.127	4.381	3.318	2.983	3.147	2.405	1.940	1.923	2.229
20	2.403	2.434	3.002	3.431	3.778	2.972	2.841	2.840	2.113	1.688	1.574	1.842
21	1.985	1.882	2.527	3.118	3.370	2.784	2.828	2.651	1.989	1.566	1.348	1.487
22	1.632	1.491	2.082	2.682	3.065	2.557	2.835	2.561	1.880	1.502	1.165	1.281
23	1.509	1.328	1.706	2.278	3.096	2.390	2.872	2.552	1.835	1.451	1.095	1.153

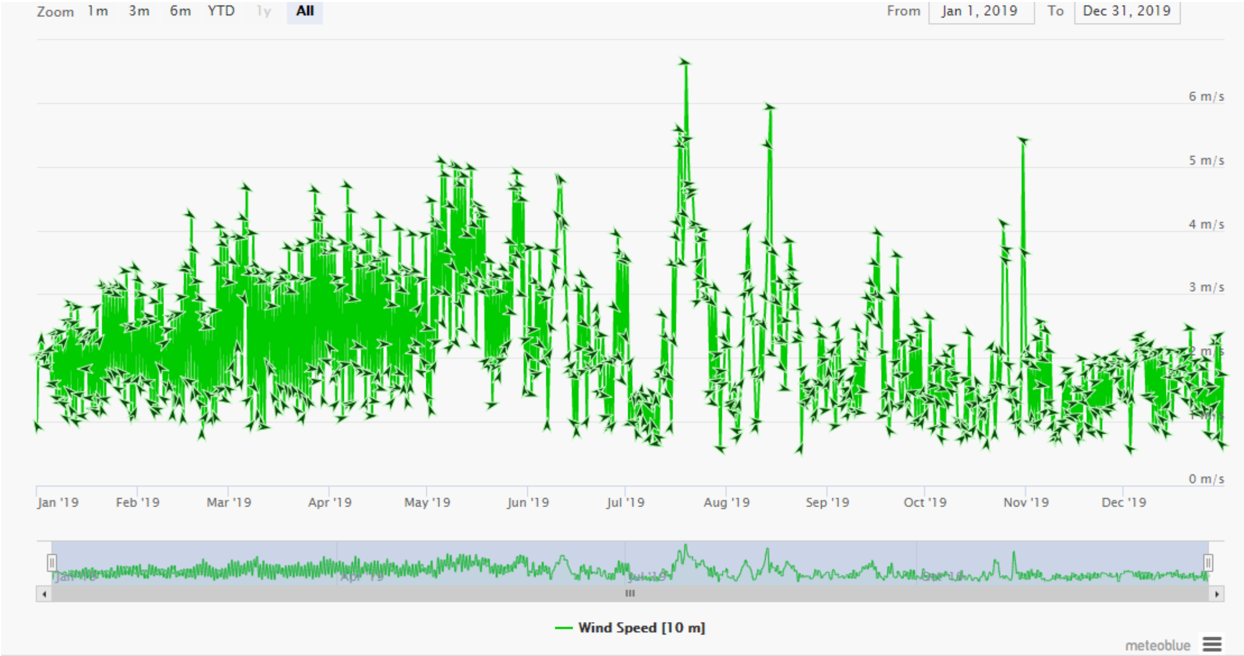

Fig.6.14: *Wind speed during 2019 at the project site [235]*

Table 6.14: *WTG Data*

Sl.No.	Specification of typical units of WTG		
1	Rated Power	1	kW
2	Cut in velocity	3	m/s
3	Cut out Velocity	14	m/s
4	Life Time	25	Years
5	Hub Height	30	m

Table 6.15: Battery data, converter data

Sl.No.	Specification of typical units of Battery		
1	Rated Voltage	6	V
2	Ah Capacity	167	Ah
3	SoC Minimum	20	%
4	Soc Maximum	100	%
5	DoD	80	%
6	Charging Efficiency	90	%
7	Discharging Efficiency	90	%
8	Round Trip Efficiency	81	%
Sl.No.	**Specification of typical units of Inverter**		
1	Efficiency	90	%

Table 6.16: *Cost data*

MG Components	Installation cost (INR/kW)	Total cost including structural work, wiring, testing and commissioning including overhead and profit.	Running cost (INR/k\	Replacement cost	Component Lifetime in Years
PV Panels	50000* [1,2]	75,000	1% of Installation cost [3]	100% of installation Cost	25
WTG	85000 [6]	120,000.00	1% of Installation cost	100% installation cost	25
BESS	10000 [4]	12,000	2% of Installation Cost	100% installation cost	10
Inverter	12500 [5]	15,000	1% of Installation cost	100% installation cost	15

Table 6.17: *Project data for the case study*

Sl.No	Project variables descriptions	Inflation Rate	Remarks
1	Discount Rate	10 [6-FRED]	%
2	Inflation Rate	4	%
3	Microgrid project lifetime	25	Years
4	Percentage of energy generated from Renewables for the proposed load	100	%
5	Energy utilized from Power Grid in kWh	0	kWh
6	Energy sell back to Power Grid in kWh	All Surplus Energy from Renewables	kWh
7	Energy sell back cost	2.75	INR/kWh [7-SEKE]
8	Yearly unmet load in kWh	0	kWh

6.6 Adding data to BGMG

Fig.6.15 to Fig.6.18 details the adding data to BGMG tool.

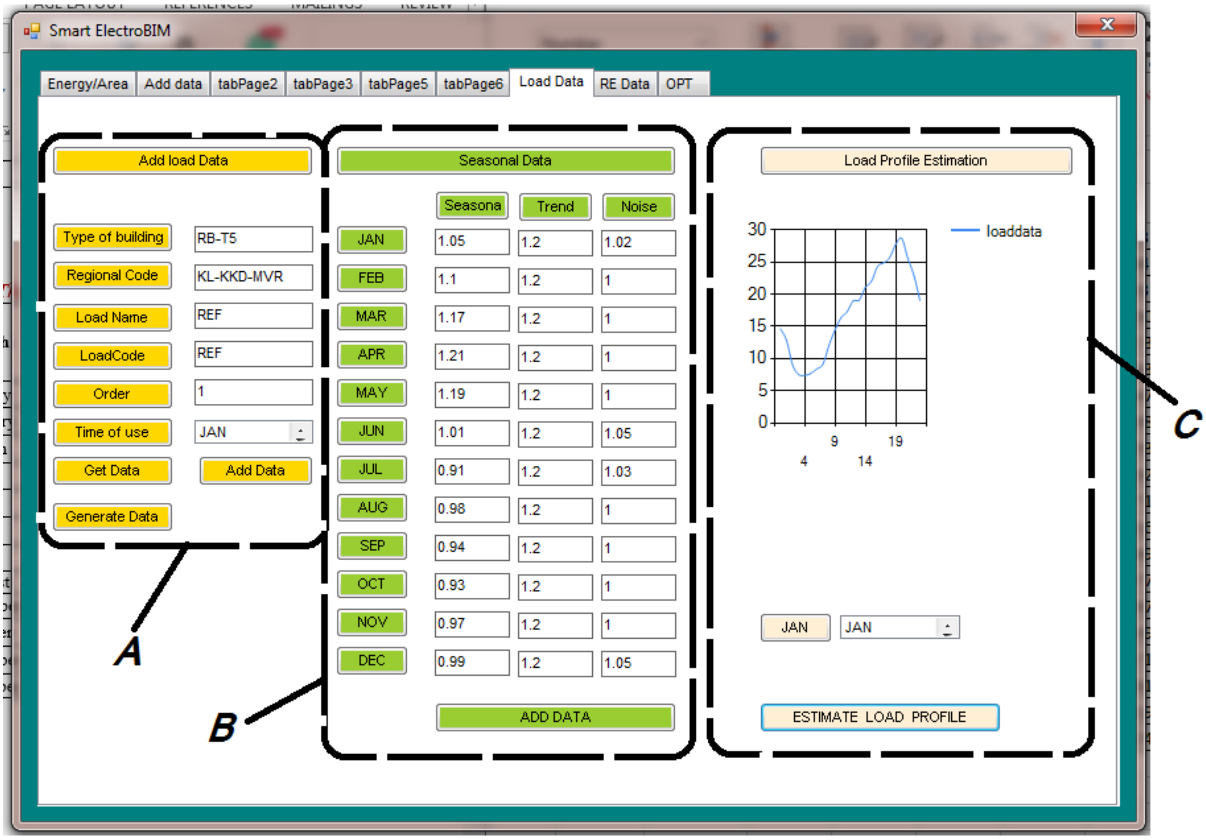

Fig. 6.15: *Screen shot of Adding Load profile data section of BGMG. A: Adding appliances ON-Time section according to load type. By clicking "Add data" button of this sub-section user interface as shown in Fig.6.16 will open. B: Seasonal derating factor adding sub-section. The values are from Table 6.10. C: Load profile is estimated according to the data entered in sub-section A and B and the load details extracted from BIM model (as explained in Chapter 3).*

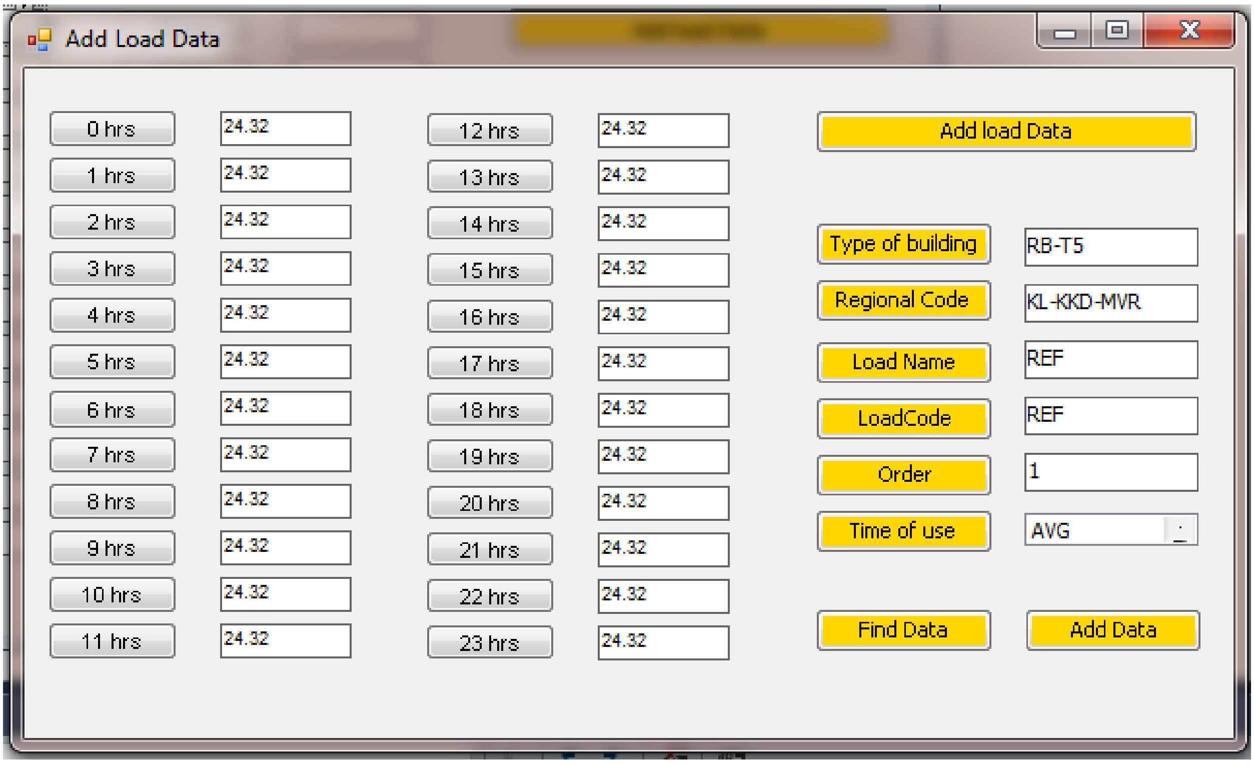

Fig. 6.16: *Screenshot of Adding Load profile data form. Hourly appliances On-Time according to load classification is added here and stored as SQL database. The data shown in Table.6.9 is entered here for this case study.*

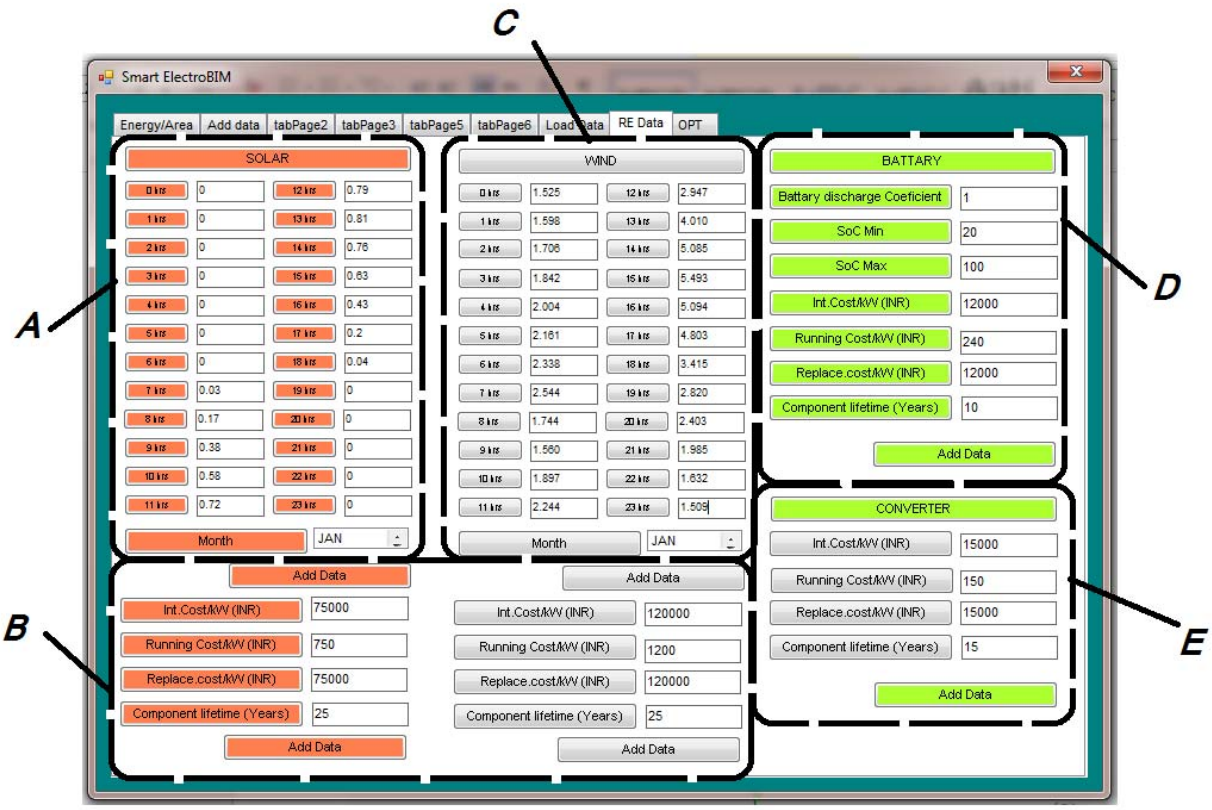

Fig.6.17: *Screenshot of: Adding RE data section.*
A: Solar hourly isolation data is entered according to Table 6.11.

B, D&E: Component cost data is entered according to Table.6.12, Table 6.14 and Table 6.15.
C: Hourly wind velocity for the project site is entered according to Table 6.13.

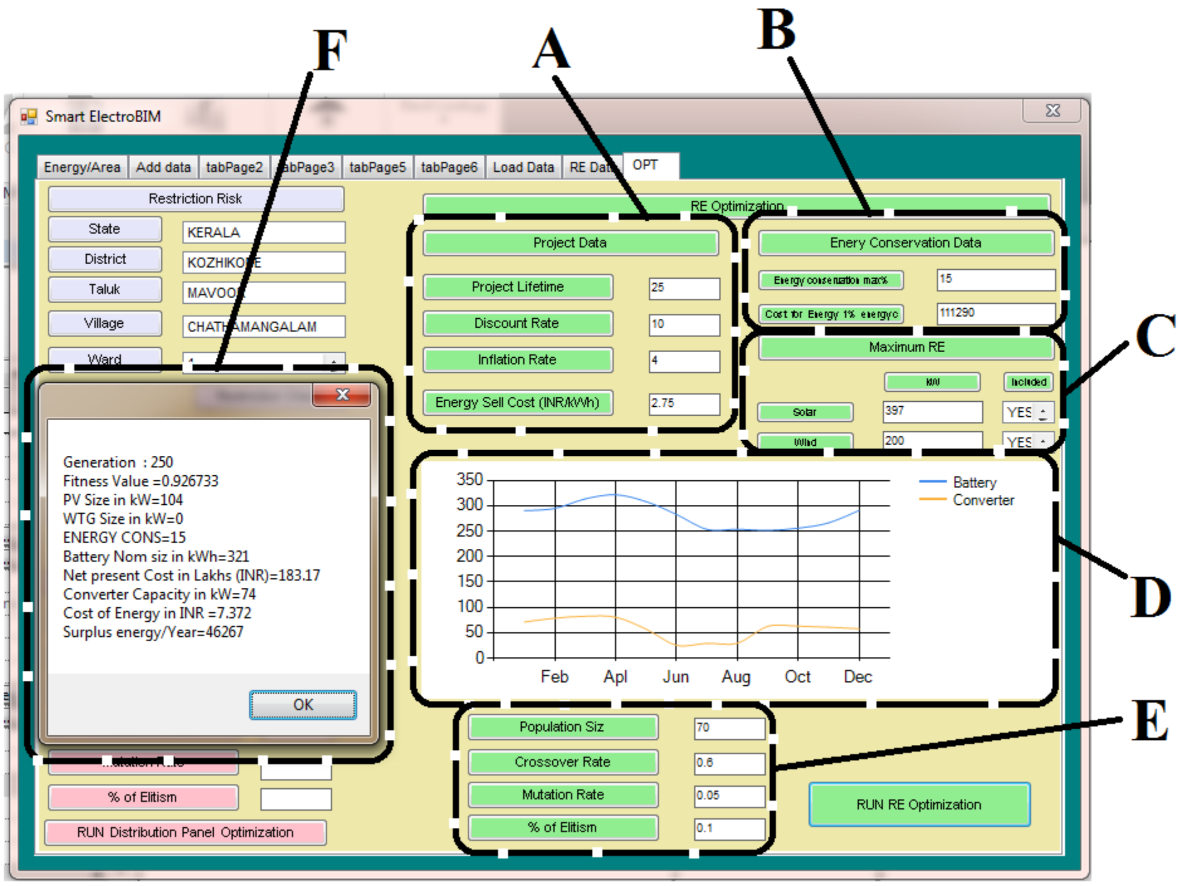

Fig.6.18: *Screenshot of RE optimization section. A: Project details according to Table 6.16. B: Cost of one percent energy conservation according to Table 6.10D. C: Maximum renewable potential according to Table 6.6 and Table 6.7. D: Graphical result of monthly battery and converter size requirements. E: Genetic algorithm parameters according to Table 6.17. F: Results from GA based optimization.*

6.7 GA Based RE Mix Optimization Results

A typical chromosome is made up of solar kWp, Wind kWp, % energy saving due to the utilization of energy efficient appliances. The binary form of a chromosome is as given in Fig. 6.19. Table 6.17 shows the data related to the proposed genetic algorithm. The genetic algorithm initialized to a population having seventy chromosomes. The fitness function utilized is given by eqn.6.1. The genetic algorithm proceeds through the application of the genetic operators, the cross-over and the mutation operators until the specified number of generations are developed. The chromosome with the maximum fitness value is identified as the optimal solution. Table 6.18 gives the GA process outcomes for selected generations. Fig.6.20 to Fig.6.27 shows the graphical representation.

Solar PV Rating (kWp)										Wind generator Rating (kWp)										% saving due to energy efficient appliances			
1	0	0	1	0	0	0	1	0	1	1	0	0	0	1	0	1	0	0	1	0	0	1	0

Fig.6.19: *Typical Chromosome*

Table 6.18: *Genetic Algorithm Data*

Description	**Value**
Population size	70
Elitism percentage	10%
Crossover probability	60%
Mutation percentage	5%
Stopping Criteria : Maximum Generations	250

Table .6.19: *Results Renewable Mix optimization*

Generation Number	Fitness Value	PV Size in Kw	Wind Size in kW	%Energy efficiency	Battery size in kWh	NPC in Lakhs	Converter Size in Kw	COE in Rupees	Surplus energy in kWh	NPC cost without the cost for energy cons. appliances
1	0.874655	124	104	11	297	313.36	128	9.036	128483	301.051
2	0.874655	124	104	11	297	313.36	128	9.036	128483	301.051
3	0.903298	120	45	1	340	241.75	104	8.958	79017	240.631
4	0.903298	120	45	1	340	241.75	104	8.958	79017	240.631
5	0.912880	144	18	15	299	217.8	114	6.191	122052	201.015
6	0.912880	144	18	15	299	217.8	114	6.191	122052	201.015
7	0.912938	124	26	15	297	217.65	101	6.904	96210	200.865
8	0.919976	104	15	11	323	200.06	80	8.213	48466	187.751
9	0.919976	104	15	11	323	200.06	80	8.213	48466	187.751
10	0.919976	104	15	11	323	200.06	80	8.213	48466	187.751
11	0.919976	104	15	11	323	200.06	80	8.213	48466	187.751
12	0.920424	104	14	11	324	198.94	79	8.184	48027	186.631
13	0.920424	104	14	11	324	198.94	79	8.184	48027	186.631
14	0.920424	104	14	11	324	198.94	79	8.184	48027	186.631
15	0.920424	104	14	11	324	198.94	79	8.184	48027	186.631
16	0.921205	101	14	13	317	196.99	77	8.084	46231	182.443
17	0.924088	115	2	11	331	189.78	83	7.242	61064	177.471

18	0.924088	115	2	11	331	189.78	83	7.242	61064	177.471
19	0.924088	115	2	11	331	189.78	83	7.242	61064	177.471
20	0.924088	115	2	11	331	189.78	83	7.242	61064	177.471
21	0.924088	115	2	11	331	189.78	83	7.242	61064	177.471
22	0.924088	115	2	11	331	189.78	83	7.242	61064	177.471
23	0.924088	115	2	11	331	189.78	83	7.242	61064	177.471
24	0.924088	115	2	11	331	189.78	83	7.242	61064	177.471
25	0.924088	115	2	11	331	189.78	83	7.242	61064	177.471
26	0.924088	115	2	11	331	189.78	83	7.242	61064	177.471
27	0.925696	104	3	15	318	185.76	75	7.38	48761	168.975
28	0.925696	104	3	15	318	185.76	75	7.38	48761	168.975
29	0.925696	104	3	15	318	185.76	75	7.38	48761	168.975
30	0.925696	104	3	15	318	185.76	75	7.38	48761	168.975
31	0.925696	104	3	15	318	185.76	75	7.38	48761	168.975
32	0.925696	104	3	15	318	185.76	75	7.38	48761	168.975
33	0.925696	104	3	15	318	185.76	75	7.38	48761	168.975
34	0.925696	104	3	15	318	185.76	75	7.38	48761	168.975
35	0.925696	104	3	15	318	185.76	75	7.38	48761	168.975
36	0.925696	104	3	15	318	185.76	75	7.38	48761	168.975
37	0.925696	104	3	15	318	185.76	75	7.38	48761	168.975
38	0.925696	104	3	15	318	185.76	75	7.38	48761	168.975
39	0.925696	104	3	15	318	185.76	75	7.38	48761	168.975
40	0.926224	110	0	15	318	184.4	78	6.966	57695	167.615
41	0.926224	110	0	15	318	184.4	78	6.966	57695	167.615
42	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
43	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
44	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
45	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
46	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
47	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
48	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
49	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
50	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
51	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
52	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
53	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
54	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
55	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
56	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
57	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
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59	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
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61	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145
62	0.926427	108	0	15	319	183.93	77	7.086	54054	167.145

63	0.926604	106	0	15	320	183.49	76	7.216	50331	166.705
64	0.926604	106	0	15	320	183.49	76	7.216	50331	166.705
65	0.926604	106	0	15	320	183.49	76	7.216	50331	166.705
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71	0.926604	106	0	15	320	183.49	76	7.216	50331	166.705
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96	0.926733	104	0	15	321	183.17	74	7.372	46267	166.385
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246	0.926733	104	0	15	321	183.17	74	7.372	46267	166.385
247	0.926733	104	0	15	321	183.17	74	7.372	46267	166.385
248	0.926733	104	0	15	321	183.17	74	7.372	46267	166.385
249	0.926733	104	0	15	321	183.17	74	7.372	46267	166.385
250	0.926733	104	0	15	321	183.17	74	7.372	46267	166.385

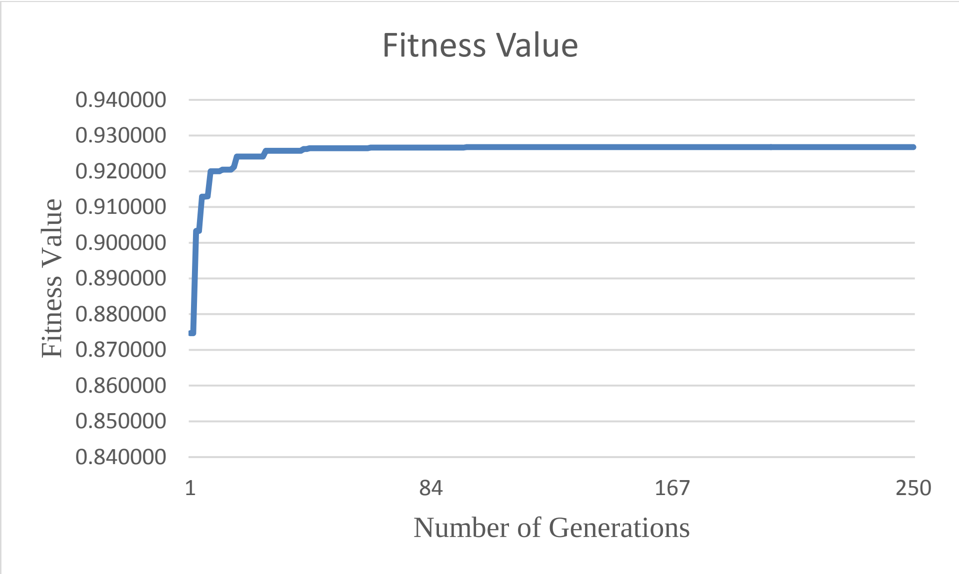

Fig.6.20: *The optimization results for Fitness value*

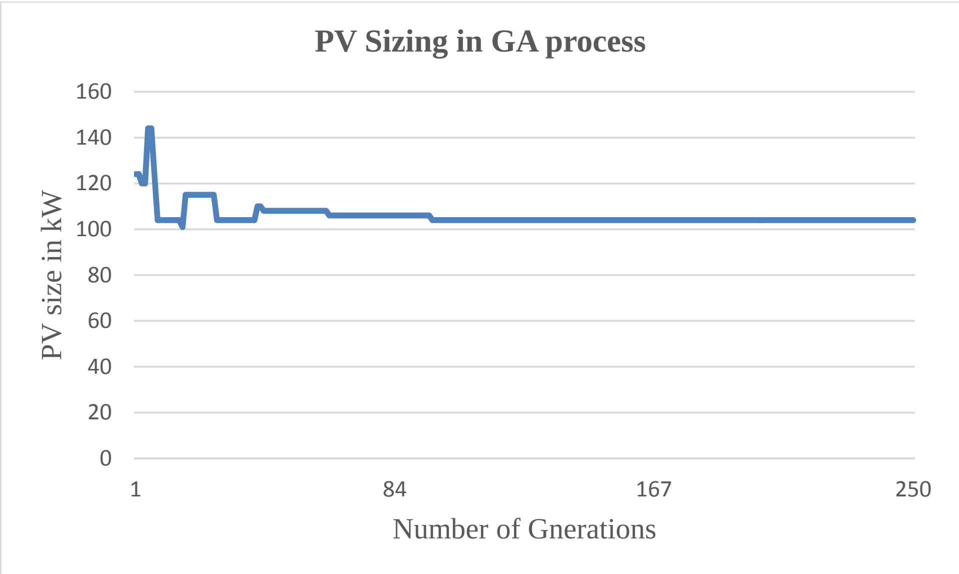

Fig.6.21: *PV Sizing in GA Process*

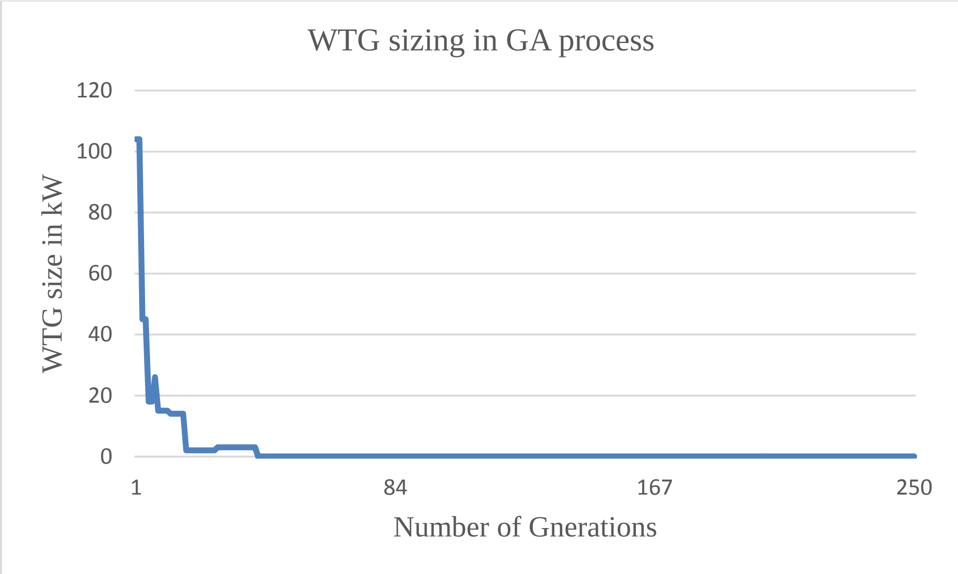

Fig.6.22: *WTG Sizing in GA Process*

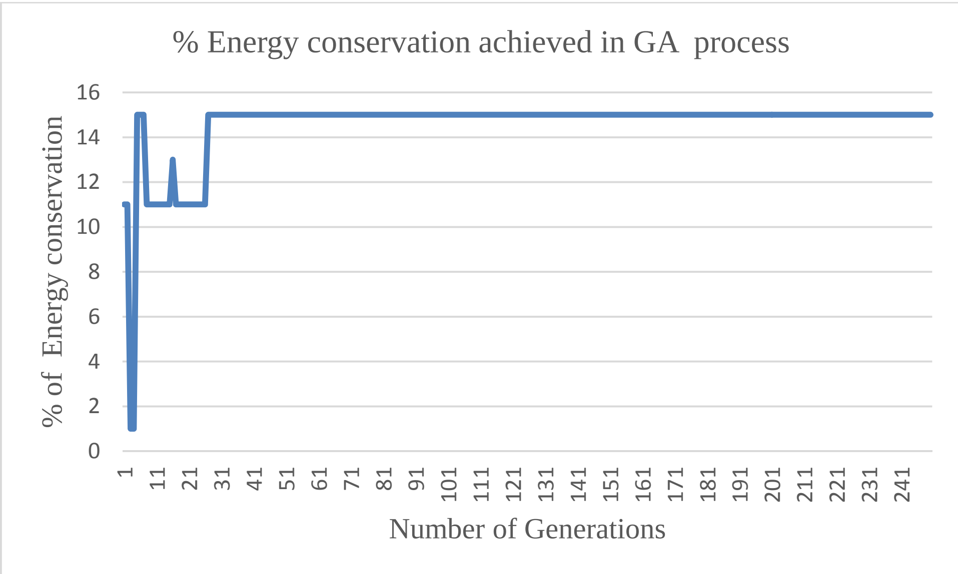

Fig.6.23: *% Energy conservation achieved in GA process*

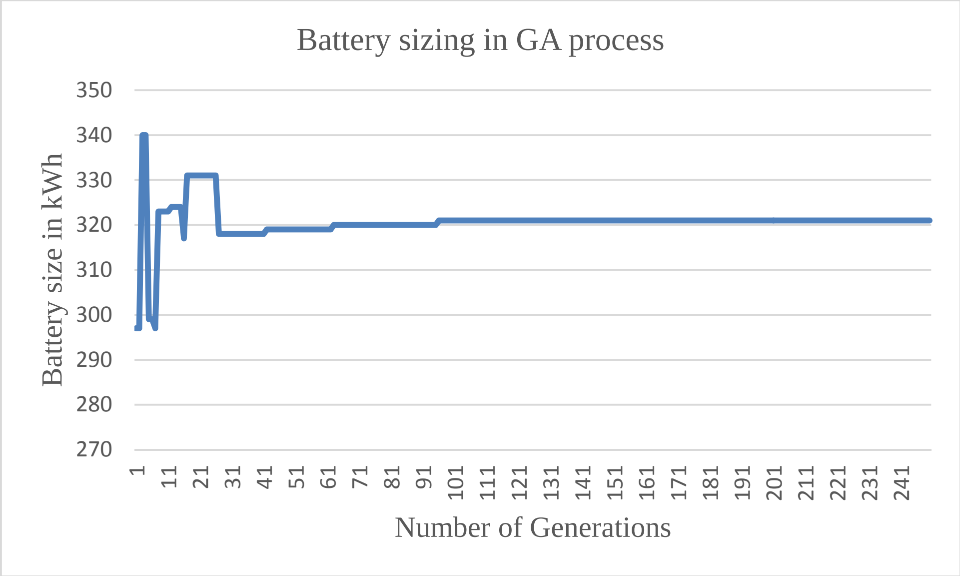

Fig.6.24: *Battery sizing in GA process*

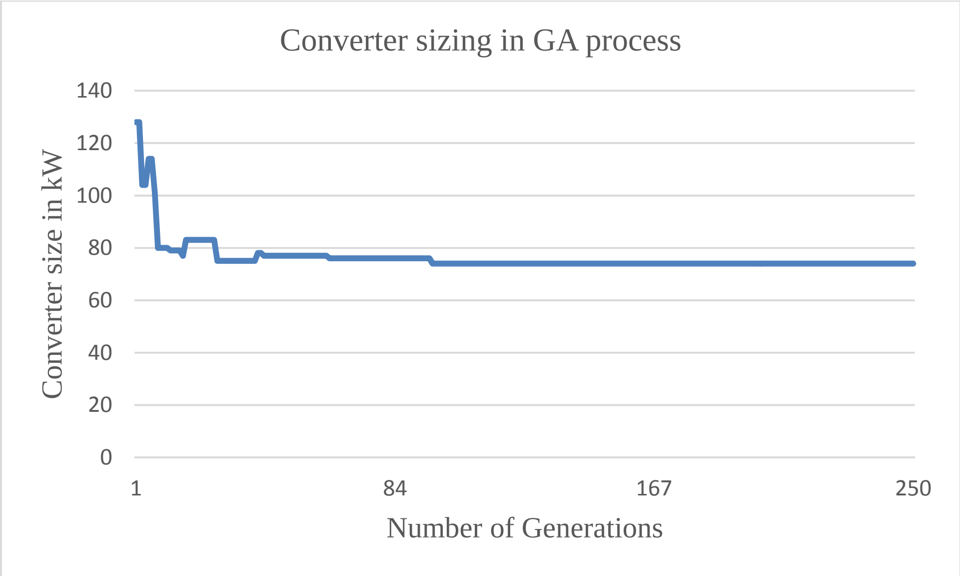

Fig.6.25: *Converter sizing in GA process*

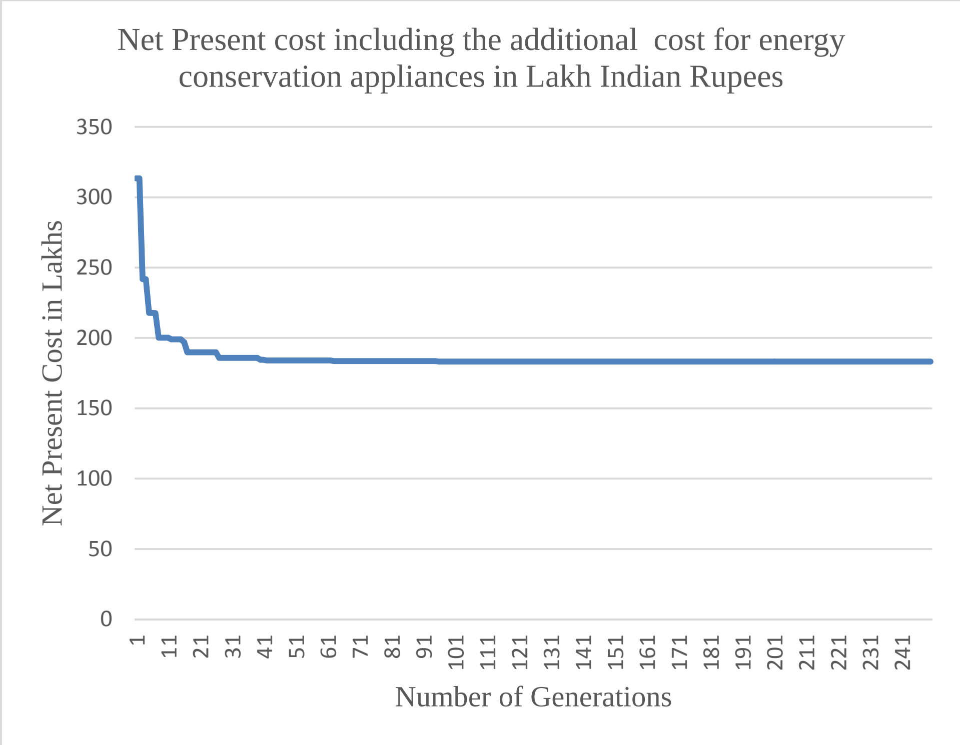

Fig.6.26: *Net Present cost including the additional cost for energy conservation appliances in Lakh Indian Rupees*

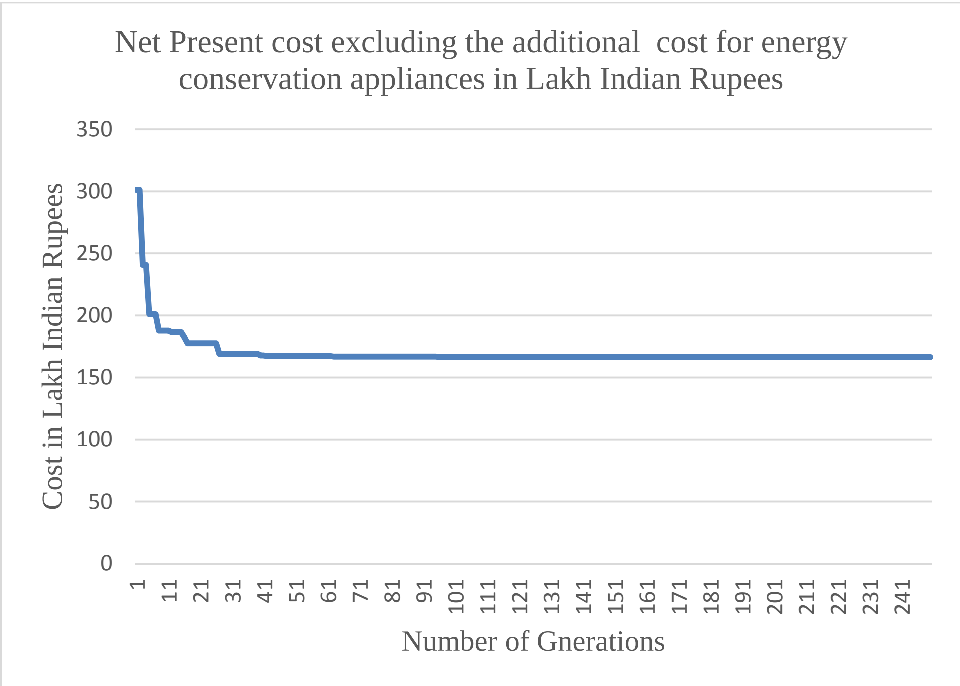

Fig.6.27: *Net Present cost excluding the additional cost for energy conservation appliances in Lakh Indian Rupees*

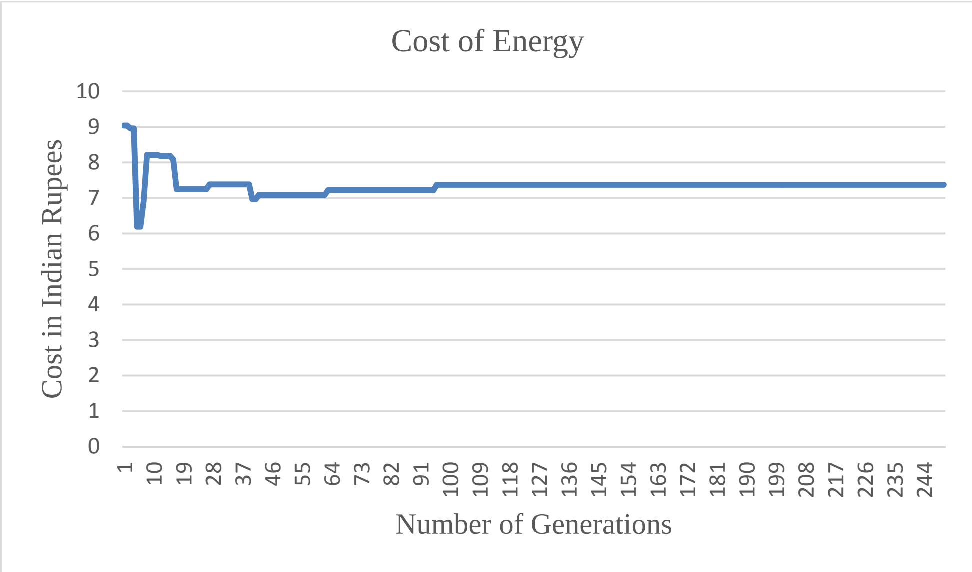

Fig.6.28: *Cost of Energy*

Based on the optimization studies the schematic diagram for the proposed Microgrid is given in Fig.6.29 with optimum component size details. 15% energy efficiency is to be achieved by installing energy efficient appliances and will cost around 16.8 Lakh Rupees.

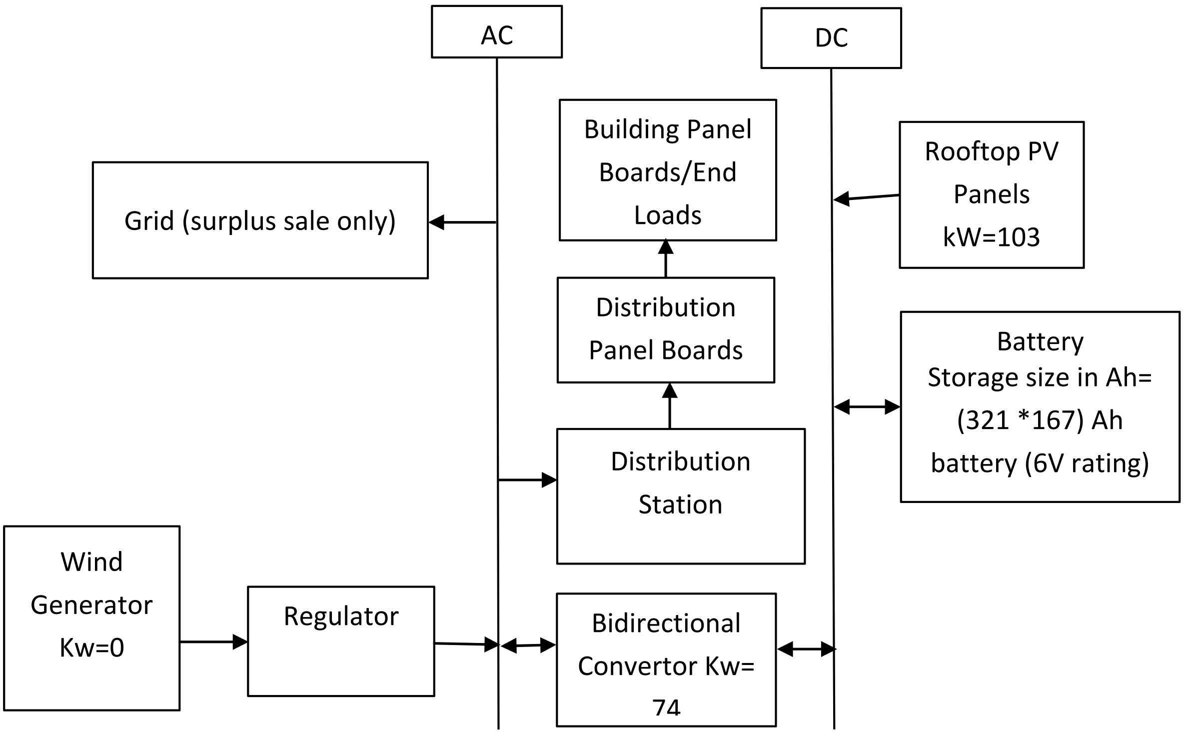

Fig.6.29: *Schematic diagram of the proposed microgrid at the project site*

Validation

The results obtained through the BGMG Tool utilizing the proposed genetic algorithm based renewable energy mix optimization is validated by comparing the results obtained from Homer- Pro microgrid planning tool. The schematic diagram of the system simulated in 'Homer' is shown in Fig. 6.30 and a part of the results is shown in Fig. 6.31. Table 6.19 shows the comparison of the results obtained from the BGMG Tool with the Homer output.

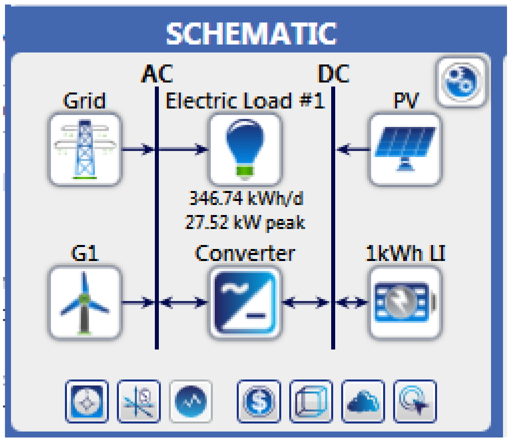

Fig.6.30: *Homer schematic diagram*

Architecture								
PV (kW)	G1	1kWh LI	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	C
103		329	0	74.0	CC	$7.67	$16.8M	$

Fig.6.31: *Homer results for the case study*

Table 6.20: *Validation of Homer and BGMG Results*

Description	**BGMG**	**Homer Pro**	**% Error** $\frac{(B-H)}{H} \times 100$
PV Size in kW	104	103	0.97%
WTG Size in kW	0	0	0%
Battery size in Ah	53607*Ah, 6V*	54833 *Ah, 6V*	-2.23%
COE (in INR)	7.37	7.67	-3.91%

6.8 Summary

BGMG tool based site suitability analysis and renewable energy optimization case study has been given in this chapter. Detailed description of the microgrid components and associated parameters have been presented. From the case study it has been found that the solar energy is the only suitable resource for this site according the project requirements. The results have been validated by comparing the same with those obtained from the Homer-Pro software. The method of distribution panel location optimization for least cable length is presented in next chapter.

Chapter 7
Genetic Algorithm based Cable Length Optimization

7.1. Introduction

In a microgrid, there will be a number of electrical distribution boards corresponding to each load center. These distribution boards are supplied from a distribution station. The optimal location of the distribution station can minimize the installation cost. In this thesis, a genetic algorithm based method is proposed for the determination of the optimal location of the distribution station. Further this is incorporated as another function in the BGMG tool developed in this thesis. The mathematical formulation is given in the following sub-section.

7.2 Mathematical Formulation

The problem is to minimize the total cost of the microgrid cable network such that the following constraints are satisfied:

i. Every feeder voltage drop is to be within the specified limit for the maximum load demand.
ii. Each cable selected for interconnecting distribution panel with a building panel is to have sufficient ampacity for carrying the maximum current through the respective cables
iii. Each distribution panel is to have enough outgoing breakers to feed the connected building panels

Mathematically, the problem can be given as follows:

Min. cable network cost $(C_{NC}) = C_{MGF} + C_{TCS}$ ………………………………………………………………… (7.1)

$C_{TCS} = C_{DP} + C_{MGDP}$

$C_{TCS} = \sum_{n=1}^{N} DP_n + C_{MGDP}$ ………………………………………………………………………… (7.2)

Where

C_{MGF} : Cost for all microgrid distribution feeders

C_{TCS} : Cost for all distribution panels

C_{DP} : Cost of distribution panels (DP)

C_{MGDP}: Cost of Microgrid Main Distribution Panel (MGDP).

N: Total number of distribution panels.

Cost for all microgrid distribution feeders

$$\mathbf{C_{MGF}} = \left(\sum_{\mathbf{DP=1}}^{\mathbf{N}} \sum_{\mathbf{f=1}}^{\mathbf{m}} (\mathbf{F_c} \ \mathbf{x} \ \mathbf{L_f})\right) * \boldsymbol{S_c} \quad \textbf{(7.3)}$$

Where

C_{MGF}: Cost of all feeder network installation.

F_c : Cost of feeder cable installation per meter length

L_f : Total Length of the feeder cable per meter between distribution panels and building panels.

m: number of feeders

S_c: A constant for cable length as per the project conditions

(An approximate value for S_c is calculated as discussed in section 7.4)

Subject to the Constraints

i. For any feeder

$$\mathbf{F_i^A / DrF \le F_{max}^A} \quad \textbf{(7.4)}$$

F_i^A : Maximum value of the actual current flow through a feeder

DrF: Derating Factor

F^{A}_{max}: Rated maximum ampere capacity of the feeder.

ii. For the full load current, the voltage drop of any feeder

F_{VD} ≤3% from distribution panels to distribution endpoint.................................. (7.5)

iii. Each distribution panel is to have enough capacity to feed the connected building panels**.**

Number of outgoing breakers of a distribution panel >= total distribution endpoints connected to it**.**

7.3 Genetic Algorithm Based Cable Length Optimization

Initial population $\{(S_1^1, S_2^1 .. S_n^1), (S_1^2, S_2^2 .. S_n^2), (S_1^3, S_2^3 .. S_n^3), (S_1^4, S_2^4 .. S_n^4), (S_1^5, S_2^5 .. S_n^{l5}), (S_1^p, S_2^p .. S_n^p)\}$... (7.6)

The binary string concatenation of all location points of distribution panels constitutes a chromosome as shown in Fig.7.1.

S_1	S_2	……….	S_n

Fig.7.1: *Typical chromosome*

n: number of distribution boards

S: Location of distribution boards

p : population size

For a distribution end point (D), there will be a choice of "n" number of distribution panels, out of which the lowest-cost cable feeder length that can be drawn from a distribution panels is selected as a feeder from that distribution panel and this will be done for all distribution endpoint (D).

Total number of distribution points from all distribution panels =k

The Set of all D, $S_D=\{ D_1, D_2,……..D_k \}$

Each distribution panels gets a unique subset S_{Di} from S_D.

= $S_{Di} \subseteq S_D$.

Collection of all unique subset gets S_D

$S_{D1} \cup S_{D2} \cup .... \cup S_{Dn} = S_D$

The fitness of each individual in a generation is evaluated based on the fitness function defined as $f(n) = 1/$ Cable Network Cost (C_{NC}) …………………………………………………… (7.7)

As the number of generation reaches a specified count, the algorithm stops, and then the most fit individual in the generation is identified as the solution. The genetic algorithm applied to the minimization of Cable network cost is given in the flowchart shown in Fig.7.2 and 7.3.

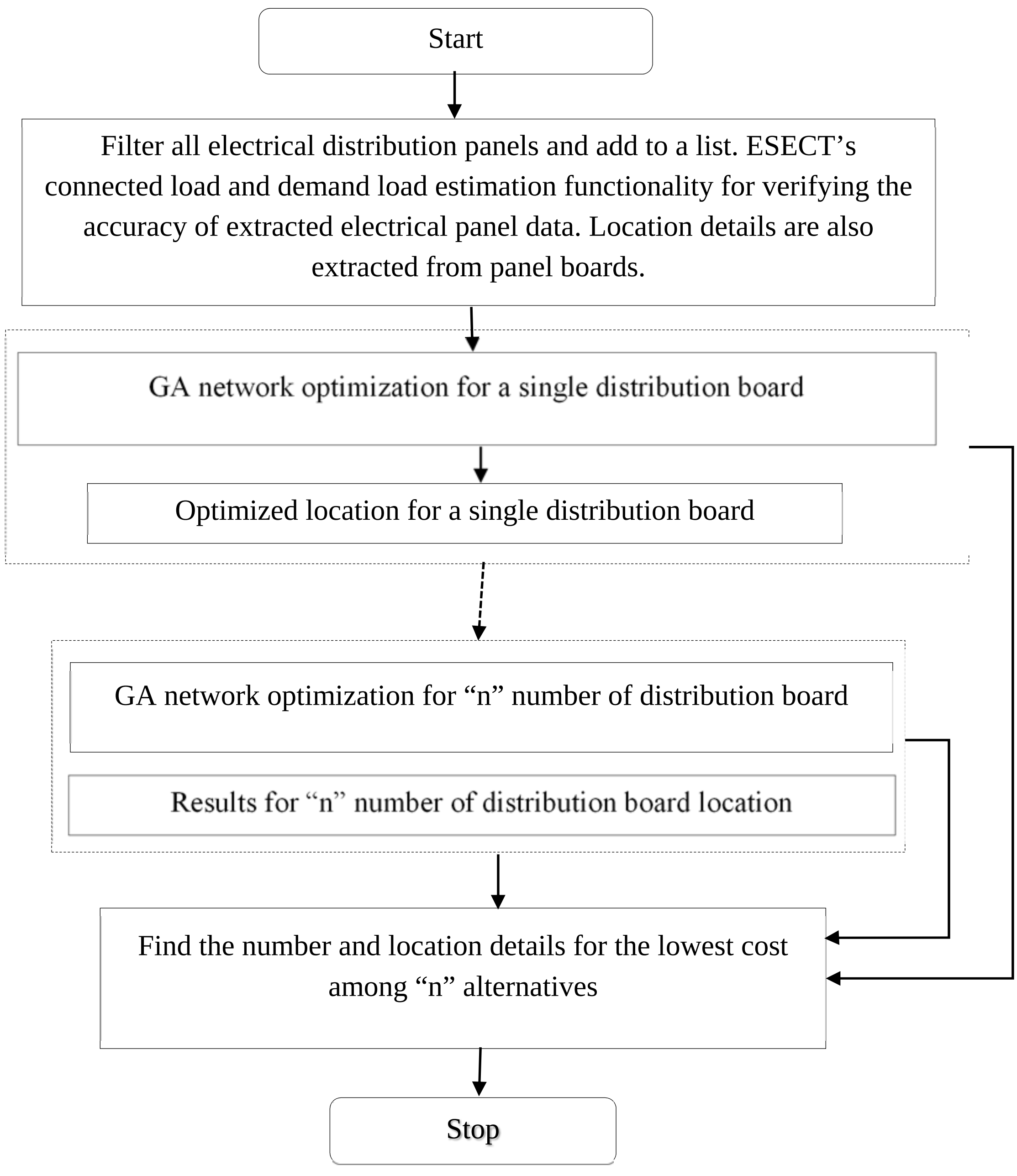

Fig 7.2: *Flowchart of distribution network optimization*

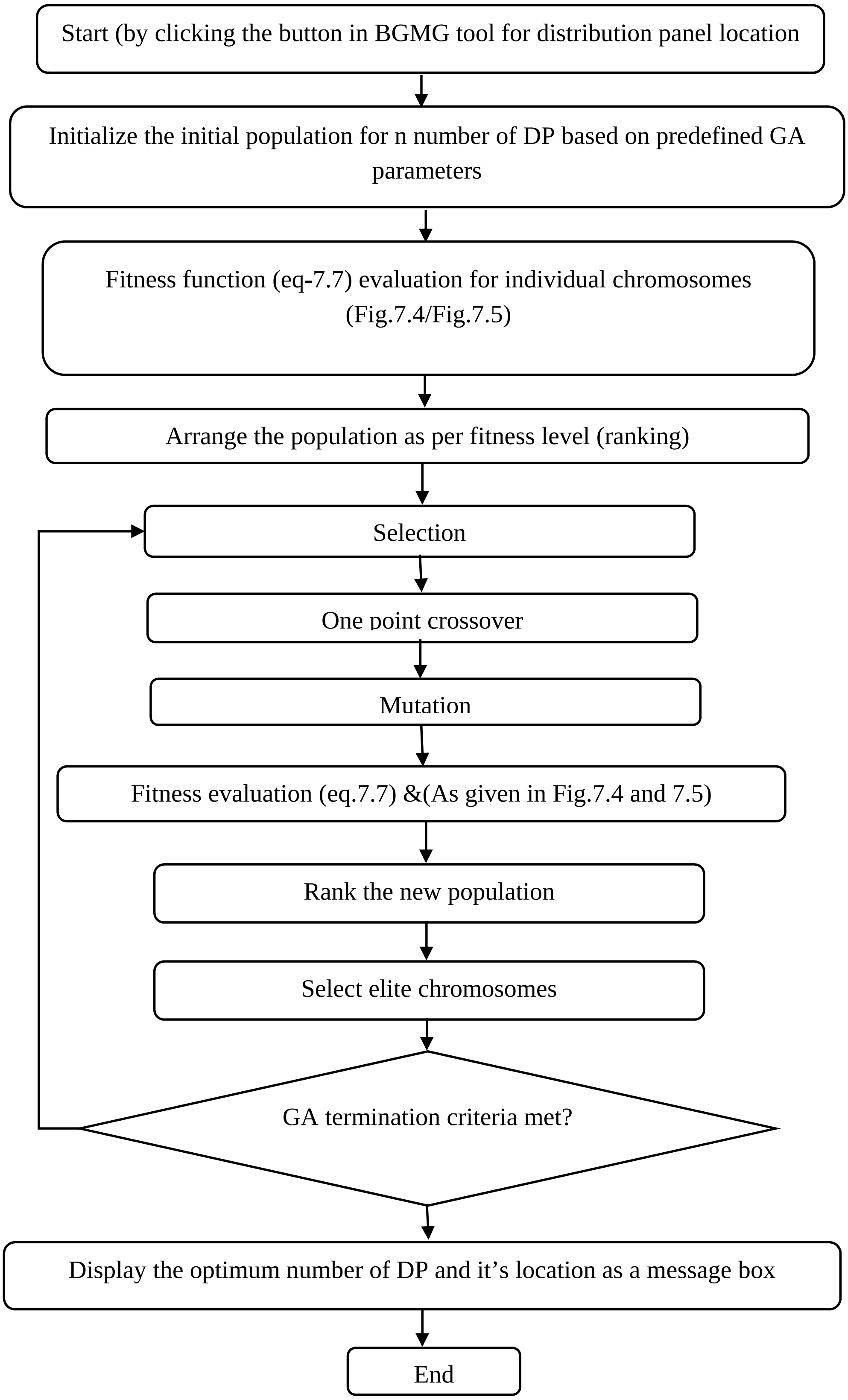

Fig. 7.3: *GA Flowchart*

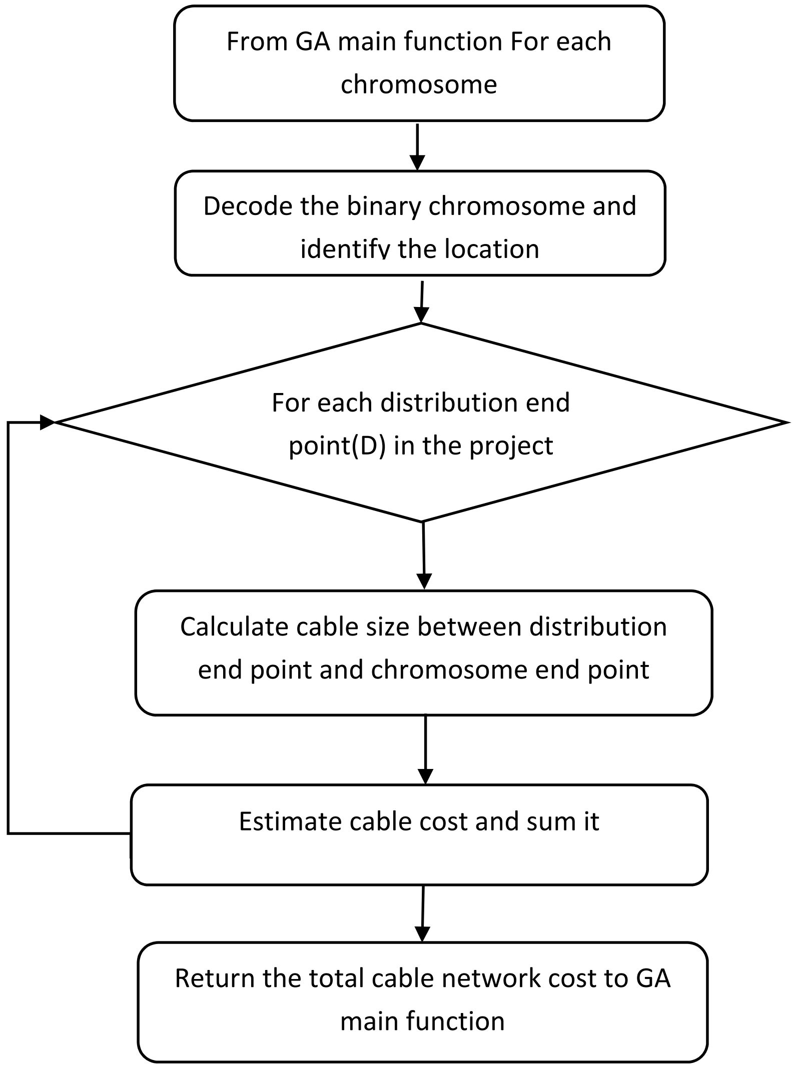

Fig.7.4: *flow chart for fitness function for a single distribution panel*

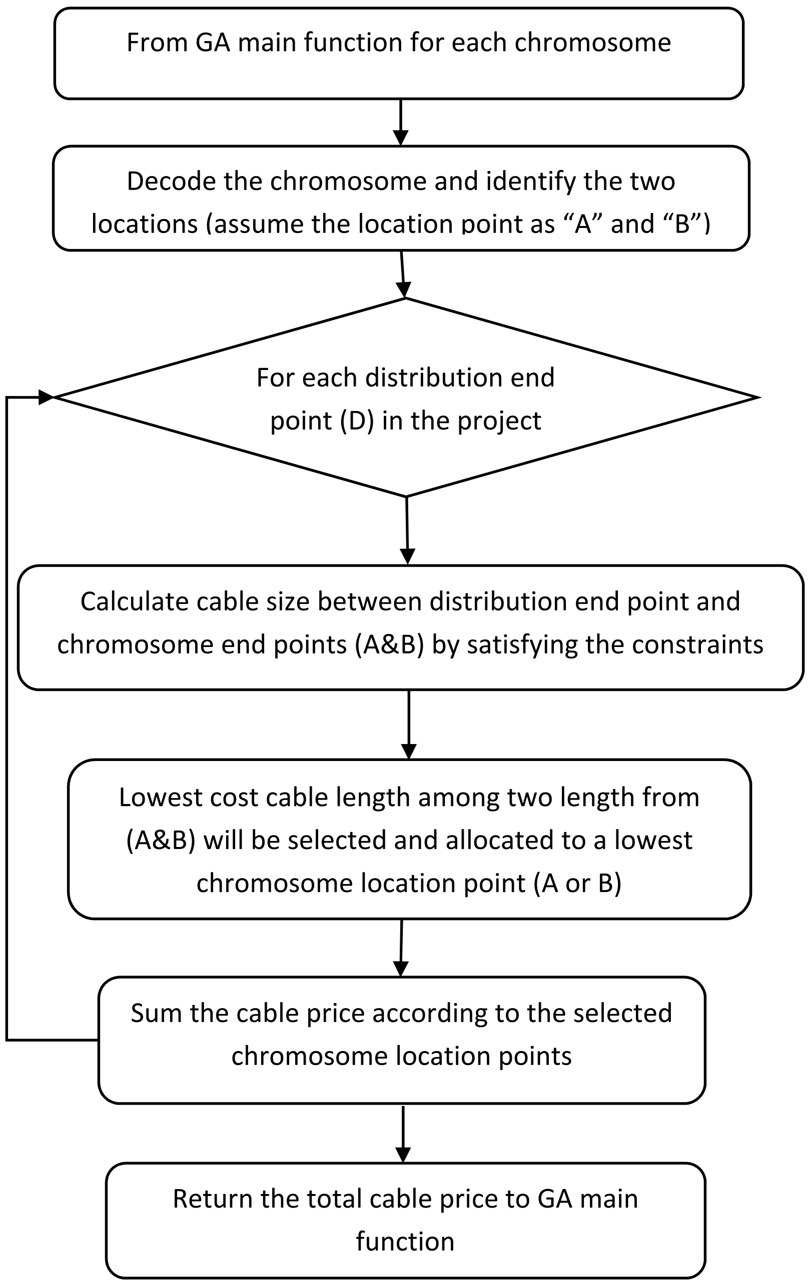

Fig.7.5: *flow chart for fitness function for two distribution panels*

7.4 Estimating average values for S_c (A constant according to site conditions)

To find out the average value of S_c, seven numbers of real projects feeder schedule data along with cable routing are collected. Calculations are done according to formula 7.8 and 7.9 to get an average value for S_c . Fig.7.6 describes the concept of straight line and actual length of cable routing between distribution panels and electrical distribution endpoint. By following the above method for estimating S_c, an average value from seven distribution routings given in Appendix 5 is 1.22.

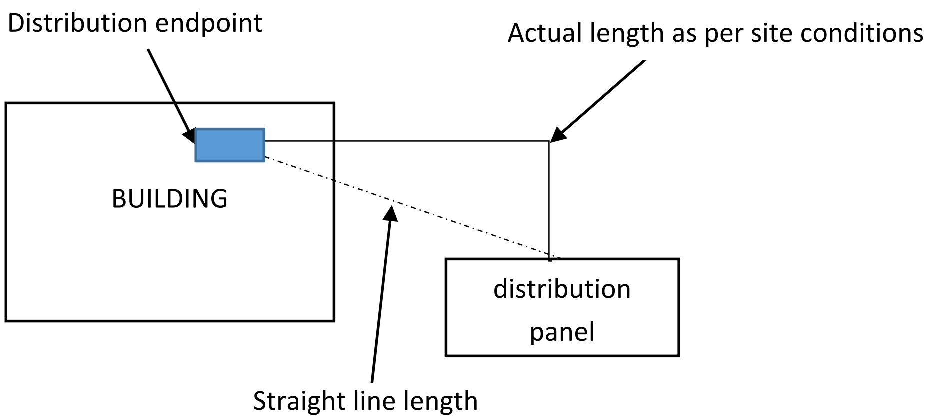

Fig.7.6: *straight and actual cable distance between distribution panel and electrical load*

L_{ca} : Actual length of cable run between distribution panel and distribution endpoint according to site conditions.

L_{cs} : Straight line distance between distribution panel and distribution endpoint without considering site conditions.

C_c : Cost of cable in INR.

C_{Ta} : Total cost of all cables by actual length method in meters

C_{Ts} : Total cost of all cables by straight-line method in meters

$$C_{Ta} = \sum_{i=1}^{n} C_{ci} L_{ca} \qquad (7.8)$$

$$C_{Ts} = \sum_{i=1}^{n} C_{ci} L_{cs} \qquad (7.9)$$

L_{caT}: Total length of cable in according to actual site conditions

L_{csT}: Total length of cable in according to straight-line method

Based on section 7.1 to 7.3, BGMG functionality for distribution board location and number optimization is developed by following the similar method of development explained in chapter 3 and 5.

Fig.7.7 shows the screenshot of BGMG tool for distribution panel number and location optimization. Fig.7.8 shows the window for adding cable details and data from Table 7.1 is added to this window to conduct the case study in this thesis and Table 7.2 shows the cost of distribution panels.

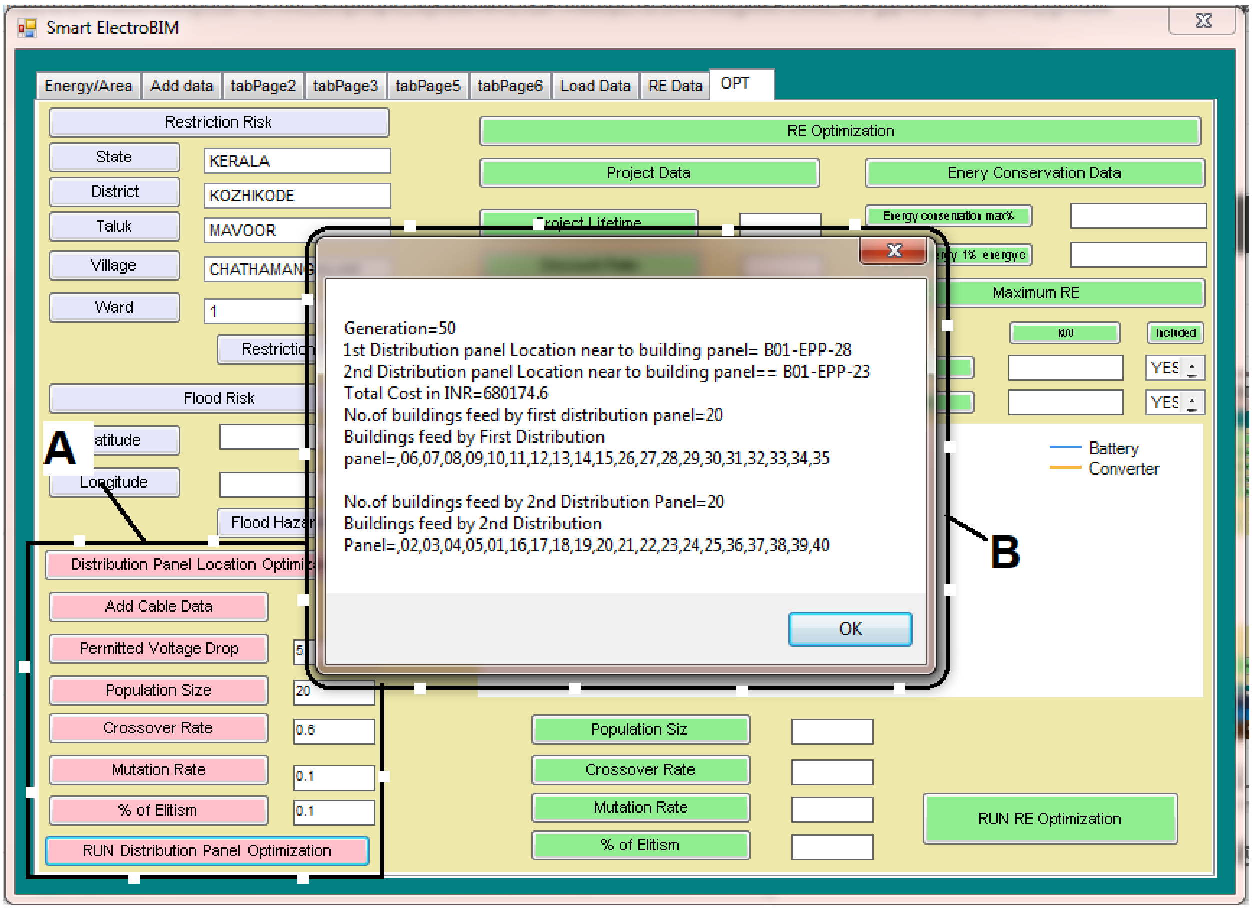

Fig.7.7: *Screenshot of BGMG. A: Distribution panel location optimization section. By clicking "Add Cable Data" button, new window will open to add-cable details and cost. "Add Cable Data" window is given in Fig.7.8. B: Showing the result for distribution panel number and location.*

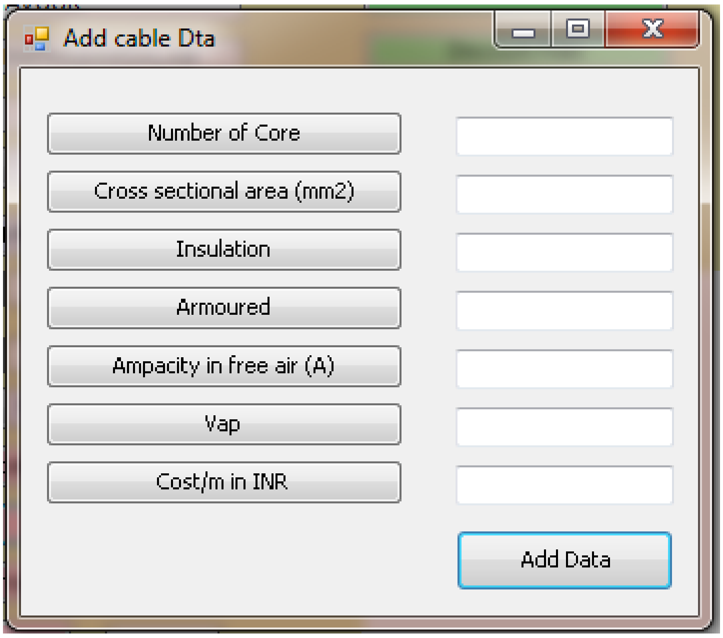

Fig.7.8: *Screenshot of Add Cable Data*

Table 7.1*: Cable specification and cost details*

Sl.No.	**Cable specifications**	**Cost (in INR) including installation with conduits, routing, termination, testing and commissioning**	**Cable Ampacity in free air (A)**	**V_{ap}** (mV/ampere/meter)
1	4Cx1.5 Cu/XLPE/SWA+1.5 Cu/PVC (G)	168	22	22.8
2	4Cx2.5 Cu/XLPE/SWA +2.5 Cu/PVC (G)	206	29	13.8
3	4Cx4 Cu/XLPE/SWA +4 Cu/PVC (G)	254	38	8.6
4	4Cx6 Cu/XLPE/SWA +6 Cu/PVC (G)	282	48	5.8
5	4Cx10 Cu/XLPE/SWA +10 Cu/PVC (G)	403	67	3.5
6	4Cx16 Cu/XLPE/SWA +16 Cu/PVC (G)	455	88	2.2
7	4Cx25 Cu/XLPE/SWA +25 Cu/PVC (G)	508	116	1.4

Table 7.2: cost of Distribution panel cost details

Sl.No.	**Main Circuit Breaker rating**	**No. of ways**	**Cost (in INR) including installation termination, testing and commissioning**
1	20-100A	12	14,525
2	20-100A	18	17,010
3	20-100A	24	20,160
4	20-100A	30	22,505
5	20-100A	36	24,010
6	20-100A	42	25,375
7	20-100A	48	27,580

7.5. Case study

Microgrid component's optimization is done in chapter 6. In this section, distribution panel location optimization is done for the same project's electrical distribution network required for the entire forty buildings shown in Fig.7.9. Each building have one Panel. The generated energy can be distributed by a centrally located single distribution board or a number of distribution panels. BGMG tool will extract the building panel and its location from BIM model and process it for getting optimum distribution panel location and number using the cable details added by using "Add Cable Data" section. The results of the case study is given in Fig.7.10. From the results the location and number of distribution panel is shown in Fig. 7.11.

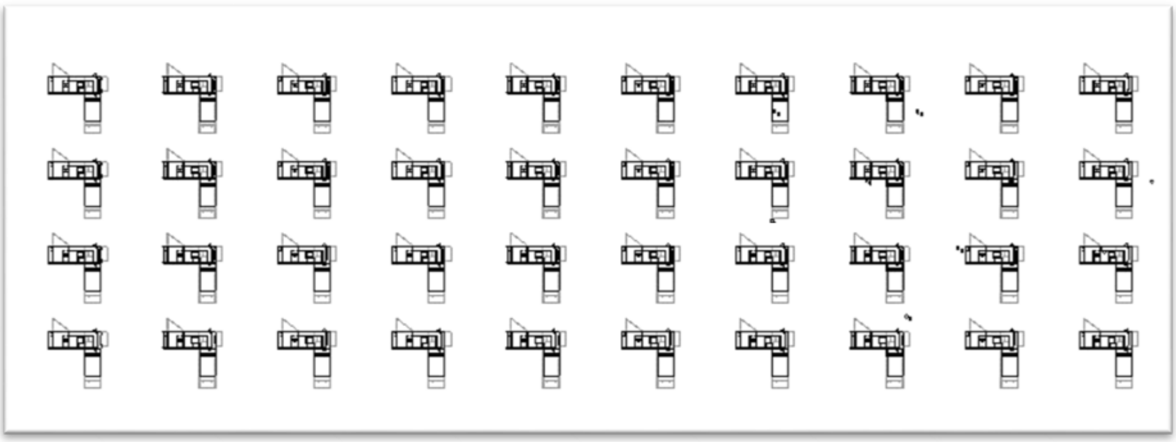

Fig 7.9: *Plan view of the proposed project*

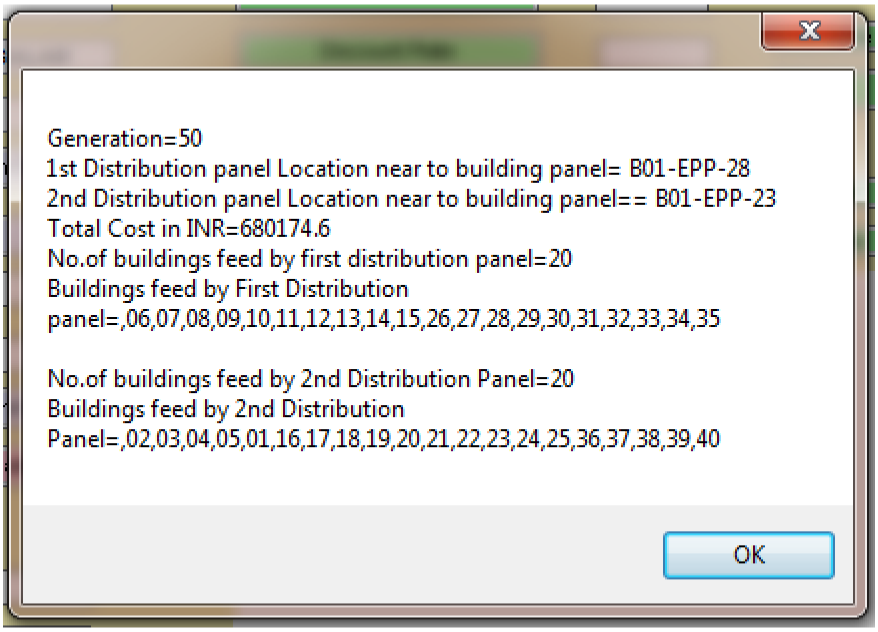

Fig.7.10: *BGMG cable length Optimization by optimally locating distribution panel case study result*

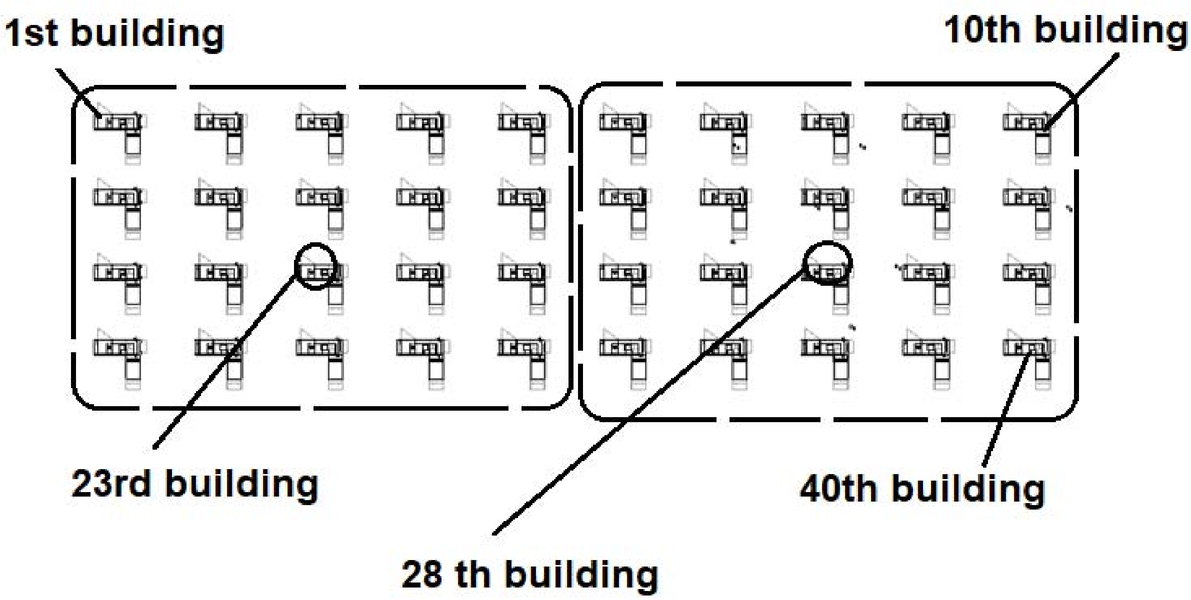

Fig.7.11: *BGMG propose two location for optimum cable routing. The first location at near to Building 28th and second at building number 23rd. The first and second distribution panel will serve 20 building panels.*

The step by step results of genetic algorithm optimization for microgrid network cost optimization according to Table 7.1 is given in Table 7.2.

Table 7.3: *GA parameter for cable network optimization*

GA Parameter set	Set 1
Size of the population	20
% of elitism	10
Crossover Probability	0.6
Mutation Probability	0.1

Table. 7.4: *Genetic algorithm results for selected generations*

Number of Distribution boards	***Generation number***	Distribution board-1 Location as building numbers	Distribution board-2 Location as building numbers	Total Cost ***(INR)***	No.of building fed from Distribution board-1	No.of building fed from Distribution board-2	Buildings fed from Distribution board-1	Buildings fed from Distribution board-2
One distribution panel location optimization								
1	1	26	-	11,49,040	40	-	All buildings	-
1	2	26	-	11,49,040	40	-	All buildings	-
1	3	25	-	11,48,959	40	-	All buildings	-
1	4	25	-	11,48,959	40	-	All buildings	-
1	5	25	-	11,48,959	40	-	All buildings	-
1	6	25	-	11,48,959	40	-	All buildings	-
1	7	25	-	11,48,959	40	-	All buildings	-
1	8	25	-	11,48,959	40	-	All buildings	-
1	9	25	-	11,48,959	40	-	All buildings	-
1	10	25	-	11,48,959	40	-	All buildings	-
Two distribution panel location optimization								
2	1	19	26	7,87,724	14	26	1,2,3,4,17,18,19,20,21,22,23,38,39,40	5,6,7,8,9,10,11,12,13,14,15,16,24,25,26,27,28,29,30,31,32,33,34,35,36,37
2	3	12	18	7,14,108	18	22	06,07,08,09,10,11,12,13,14,15,27,28,29,30,31,32,33,34	1,2,3,4,5,16,17,18,19,20,21,22,23,24,25,26,35,36,37,38,39,40
2	5	23	12	7,10,979	22	18	1,2,3,4,5,16,17,18,19,20,21,22,23,24,25,26,35,36,37,38,39,40	06,07,08,09,10,11,12,13,14,15,27,28,29,30,31,32,33,34

2	10	23	12	7,10,979	22	18	1,2,3,4,5,16,17,18,19,20,21,22,23,24,25,26,35,36,37,38,39,40	06,07,08,09,10,11,12,13,14,15,27,28,29,30,31,32,33,34
2	20	28	23	680175	20	20	06,07,08,09,10,11,12,13,14,15,26,27,28,29,30,31,32,33,34,35	1,2,3,4,5,16,17,18,19,20,21,22,23,24,25,36,37,38,39,40
2	25	28	23	680175	20	20	06,07,08,09,10,11,12,13,14,15,26,27,28,29,30,31,32,33,34,35	1,2,3,4,5,16,17,18,19,20,21,22,23,24,25,36,37,38,39,40
2	30	28	23	680175	20	20	06,07,08,09,10,11,12,13,14,15,26,27,28,29,30,31,32,33,34,35	1,2,3,4,5,16,17,18,19,20,21,22,23,24,25,36,37,38,39,40
2	40	28	23	680175	20	20	06,07,08,09,10,11,12,13,14,15,26,27,28,29,30,31,32,33,34,35	1,2,3,4,5,16,17,18,19,20,21,22,23,24,25,36,37,38,39,40
2	50	28	23	680175	20	20	06,07,08,09,10,11,12,13,14,15,26,27,28,29,30,31,32,33,34,35	1,2,3,4,5,16,17,18,19,20,21,22,23,24,25,36,37,38,39,40

Validation

The effectiveness of the proposed optimization approach is established by manually preparing the feeder schedule for possible substation location and comparing the BGMG results with those obtained with manual calculations. The recommendation from BGMG is manually calculated and is given in Table 7.5. The total cost is Rs. 709912 (including the cost of distribution panels and Main Distribution Panel) by 2D CAD actual length method for two control stations. By BGMG the cost is Rs.680175. The difference is due to straight-line method deployed by BGMG tool and small errors in length measurement.

Table 7.5: *2D CAD based feeder schedule estimation*

SL.No.	FROM	TO	Connc ted kW	Demand Kw	AMPS (A)	Ampacity required (A)	CABLE	CABLE TYPE	Feeder Length (Meters)	V_{ap}	%VD	Cost of cable (INR)/m	TOTAL Cost (INR)
1	DP @ BLDG#23	B01-EPP-01	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	149	22.8	2.45	168.00	25,032
2	DP @ BLDG#23	B01-EPP-02	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	107	22.8	1.76	168.00	17,976
3	DP @ BLDG#23	B01-EPP-03	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	71	22.8	1.17	168.00	11,928
4	DP @ BLDG#23	B01-EPP-04	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	107	22.8	1.76	168.00	17,976
5	DP @ BLDG#23	B01-EPP-05	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	149	22.8	2.45	168.00	25,032
6	DP @ BLDG#23	B01-EPP-16	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	116	22.8	1.91	168.00	19,488
7	DP @ BLDG#23	B01-EPP-17	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	76	22.8	1.25	168.00	12,768
8	DP @ BLDG#23	B01-EPP-18	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	34	22.8	0.56	168.00	5,712
9	DP @ BLDG#23	B01-EPP-19	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	76	22.8	1.25	168.00	12,768
10	DP @ BLDG#23	B01-EPP-20	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	116	22.8	1.91	168.00	19,488
11	DP @ BLDG#23	B01-EPP-21	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	100	22.8	1.65	168.00	16,800
12	DP @ BLDG#23	B01-EPP-22	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	57	22.8	0.94	168.00	9,576
13	DP @ BLDG#23	B01-EPP-23	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	0	22.8	0.00	168.00	0
14	DP @ BLDG#23	B01-EPP-24	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	57	22.8	0.94	168.00	9,576
15	DP @ BLDG#23	B01-EPP-25	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	100	22.8	1.65	168.00	16,800
16	DP @ BLDG#23	B01-EPP-36	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	117	22.8	1.93	168.00	19,656
17	DP @ BLDG#23	B01-EPP-37	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	70	22.8	1.15	168.00	11,760
18	DP @ BLDG#23	B01-EPP-38	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	33	22.8	0.54	168.00	5,544
19	DP @ BLDG#23	B01-EPP-39	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	70	22.8	1.15	168.00	11,760
20	DP @ BLDG#23	B01-EPP-40	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	117	22.8	1.93	168.00	19,656
21	DP @ BLDG#28	B01-EPP-06	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	149	22.8	2.45	168.00	25,032
22	DP @ BLDG#28	B01-EPP-07	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	107	22.8	1.76	168.00	17,976
23	DP @ BLDG#28	B01-EPP-08	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	71	22.8	1.17	168.00	11,928
24	DP @ BLDG#28	B01-EPP-09	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	107	22.8	1.76	168.00	17,976
25	DP @ BLDG#28	B01-EPP-10	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	149	22.8	2.45	168.00	25,032
26	DP @ BLDG#28	B01-EPP-11	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	116	22.8	1.91	168.00	19,488
27	DP @ BLDG#28	B01-EPP-12	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	76	22.8	1.25	168.00	12,768
28	DP @ BLDG#28	B01-EPP-13	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	34	22.8	0.56	168.00	5,712
29	DP @ BLDG#28	B01-EPP-14	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	76	22.8	1.25	168.00	12,768
30	DP @ BLDG#28	B01-EPP-15	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	116	22.8	1.91	168.00	19,488
31	DP @ BLDG#28	B01-EPP-26	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	100	22.8	1.65	168.00	16,800
32	DP @ BLDG#28	B01-EPP-27	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	57	22.8	0.94	168.00	9,576
33	DP @ BLDG#28	B01-EPP-28	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	0	22.8	0.00	168.00	0
34	DP @ BLDG#28	B01-EPP-29	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	57	22.8	0.94	168.00	9,576
35	DP @ BLDG#28	B01-EPP-30	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	100	22.8	1.65	168.00	16,800
36	DP @ BLDG#28	B01-EPP-31	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	117	22.8	1.93	168.00	19,656
37	DP @ BLDG#28	B01-EPP-32	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	70	22.8	1.15	168.00	11,760
38	DP @ BLDG#28	B01-EPP-33	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	33	22.8	0.54	168.00	5,544
39	DP @ BLDG#28	B01-EPP-34	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	70	22.8	1.15	168.00	11,760
40	DP @ BLDG#28	B01-EPP-35	3.2	1.6	2.89	4.44	4CX1.5+1.5	Cu/XLPA/SWA	117	22.8	1.93	168.00	19,656
												Total cost of Cable (INR)	578,592
												Cost of interconnecting cable (INR)	12,250
												Cost for Distribution Panel (INR)	40,320
												Cost for Main Distribution Panel (INR)	78,750
												Total (INR)	709,912

Summary

In this chapter a GA based distribution network optimization in platform has been discussed. BIM platform can automate the distribution network optimization compared to 2D CAD based approach. Both infrastructure data and microgrid component data can be processed together in BIM platform, such that IOPMG is possible with less time and software requirements.

Chapter 8

Conclusion and Scope for Further Work

8.1 Conclusion

The application of BIM and GIS are utilized extensively in the planning and design of building constructions by civil engineers and planners for over a decade. However, these are still at its infancy in the planning and design of practical electrical systems. In this thesis, the special features of both BIM and GIS have been utilized for a more realistic and refined planning of -microgrids. Thus this thesis involves the development of a BIM-GIS integrated single window platform for the planning of multi-building Microgrids taking into account the installation & operational costs, and energy conservation possibilities. With the administrative, environmental and natural disaster constraints already incorporated in the proposed solution technique, the BGMG tool becomes more effective and useful for both the planners and the designers. A BIM addin tool, referred to as BGMG Tool has been developed in this thesis which upon a single click can perform the tasks of the data retrieval and processing, system optimization using genetic algorithm and finally display of the multi-building microgrid design results.

Thus the major contribution of the thesis is the development of the Addin Tool, BGMG tool, in the BIM environment in 3D Revit with the following features:

- A new facility for automatic retrieval of necessary data related to microgrid planning from BIM model for IOPMG by combining infrastructure data and optimal planning process.
- A new genetic algorithm based mix optimization of the hybrid renewable energy resources of the microgrid minimizing the total life cycle cost incorporating the constraints related to cost and energy conservation.

- A new genetic algorithm based automated determination of the optimal location of the distribution panels such that the total life cycle cost of the microgrids is the minimum.

The effectiveness of the developed BGMG tool has been estasblished through its utilization for the planning of a typical multi-building microgrid project in the Northern part of the state of Kerala.

8.2 Scope for Further work

- Extending the capability of BGMG for processing different kind of MG architechures. The tool is to incoperate sources such as biofuel and fuel cells, microgrid modes such as bidirectional grid connected mode and to consider energy from nearby microgrids.
- Considering the orientation of building for optimization in the BIM platform, combining Artificial Intelligence (AI) for finding optimum location of distribution panels and incorporating Demand Side Management (DSM) and peak shaving concepts with BGMG functionalities. As like an experienced designer, AI algorithm can select most suitable location as an initial population for Genetic Algorithm (GA). The combined AI and GA approach can minimize optimization time and early convergence to solution. As BIM capable to address every elementary load with editing parameters and consolidated all data in a single platform, automated DSM rule generation and peak shaving can be possible with the aid of algorithms. Microgrid controller functionality is to be incorporated with BGMG tool.

- By using smart objects in BIM it is possible to run real-time energy usage of a building well before its construction, this capability can be used for demand response planning.
- Extensive use of the BGMG tool for multi-building multi-microgrid planning and design involves huge data interchange between BIM and GIS platforms, sophisticated data mining tools are required to gather appropriate information, demanding further research.

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Appendix 1

Estimation of the Minimum initial depth of charge of the battery storage in battery system for a typical day in month

Estimating the Minimum initial depth of charge of the battery storage in battery system for a typical day in month. Table AP1.1 details the details of abbreviations related to equations AP1.1 to AP1.12.

Table AP1.1: *Symbols in Equation AP1.1 to AP1.12.*

Symbol	Description	Unit
E_{BN}	Energy stored in battery storage at time "i"	kWh
E_{Bi}	Energy stored in battery storage at time "i"	kWh
SoC_i	State of charge of battery storage at time "i"	%
σ	self-discharge rate of the battery storage system	-
P_{BCi}	Power available for battery charging from RE sources	kW
P_{BDi}	Power available for battery discharging	kW
Δt	commitment period which is 1 h in this thesis	hour
SoC_{max}	Maximum (selected) State of Charge of battery storage system	%
SoC_{min}	Minimum (selected) State of Charge of battery storage system	%
CB_{DC}	Cumulative battery discharge	
S_{Ei}	Surplus energy available at hour "i"	

At 00.00 hours to 1 hours

If $(([[P_{PVi}*\eta_c+P_{WGi} - P_{Li}] * \Delta t]/(\eta_c * \eta_{bc})) <0$ [battery discharge]

Cumulative discharge ($CB_{DCi\text{-}0\text{-}1}$) =

$[[P_{PV0}*\eta_c+P_{WG0} - P_{L0}] * \Delta t]/(\eta_c * \eta_{bc})$ ………………………………………….. **(AP1.1)**

Else

$CB_{DCi\text{-}0\text{-}1} = 0$

At 1 hours to 2 hours

If $[(CB_{DCi\text{-}0\text{-}1}+ B_{DC\text{-}1\text{-}2}+ B_{C\text{-}1\text{-}2}) <0]$

$CB_{DCi\text{-}1\text{-}2} = CB_{DCi\text{-}0\text{-}1}+ B_{DC\text{-}1\text{-}2}+ B_{C\text{-}1\text{-}2}$

Else

$CB_{DCi\text{-}1\text{-}2} = 0$

……………………………………………………………….

At 23 hours to 0 hours

If [($CB_{DCi\text{-}22\text{-}23}$+ $B_{DC\text{-}1\text{-}2}$+ $B_{C\text{-}1\text{-}2}$) <0]

$CB_{DCi\text{-}23\text{-}0} = CB_{DCi\text{-}22\text{-}23} + B_{DC\text{-}23\text{-}0} + B_{C\text{-}23\text{-}0}$

Else

$CB_{DCi\text{-}23\text{-}0} = 0$

At 23 hours to 0 hours

If [($CB_{DCi\text{-}0\text{-}1}$+ $B_{DC\text{-}1\text{-}2}$+ $B_{C\text{-}1\text{-}2}$) <0]

Minimum Initial charge in kWh (CB_{ICm}) = $CB_{DCi\text{-}23\text{-}0}$ * -1 …..……..... **(AP1.2)**

Else

$CB_{ICm} = \min\{ CB_{DCi\text{-}0\text{-}1}, CB_{DCi\text{-}1\text{-}2}, \ldots, CB_{DCi\text{-}23\text{-}0}\} * -1$……….... **(AP1.3)**

Estimating E_{BN} for a typical day in month

At 0 hours to 1 hours

If [(CB_{ICm} + $B_{DC\text{-}0\text{-}1}$+ $B_{C\text{-}0\text{-}1}$) <0]

$CB_{DC\text{-}0\text{-}1} = CB_{ICm} + B_{DC\text{-}0\text{-}1} + B_{C\text{-}0\text{-}1}$

Else

$CB_{DC\text{-}0\text{-}1} = 0$

At 1 hours to 2 hours

If [($CB_{DC\text{-}0\text{-}1}$+ $B_{DC\text{-}1\text{-}2}$+ $B_{C\text{-}1\text{-}2}$) <0]

$CB_{DC\text{-}1\text{-}2} = CB_{DC\text{-}0\text{-}1} + B_{DC\text{-}1\text{-}2} + B_{C\text{-}1\text{-}2}$

Else

$CB_{DC\text{-}1\text{-}2} = 0$

………………………………

At 23 hours to 0 hours

If [($CB_{DC\text{-}22\text{-}23}$+ $B_{DC\text{-}23\text{-}0}$+ $B_{C\text{-}23\text{-}0}$) <0]

$CB_{DC\text{-}23\text{-}0} = CB_{DC\text{-}22\text{-}23} + B_{DC\text{-}23\text{-}0} + B_{C\text{-}23\text{-}0}$

else

$CB_{DC\text{-}23\text{-}0} = 0$

Depth of Discharge (DoD) = min { CB_{DC-0-1}, CB_{DC-1-2},........., $CB_{DC-23-0}$}*-1... (AP1.4)

E_{BN} = DoD /[SoC_{max}-SoC_{min}) .... (AP1.5)

Estimating Total Surplus energy for a typical day of a Month

Surplus energy available at hour "i"

S_{Ei}=[P_{PVi}*η_c+P_{WGi} - P_{Li}] * Δt] .... (AP1.6)

At 0 hours to 1 hours

If [($CB_{DCi-23-0}$+ B_{DC-0-1}+ B_{C-0-1}) >0]

S_{EE-0-1}=$CB_{DCi-23-0}$+ S_{E-0-1}

else

S_{EE-0-1}=0

At 1 hours to 2 hours

If [(CB_{DC-0-1}+ B_{DC-1-2}+ B_{C-1-2}) >0]

S_{EE-1-2}=CB_{DC-0-1}+ S_{E-1-2}

else

S_{EE-1-2}=0

....

At 23 hours to 0 hours

If [($CB_{DC-22-23}$+ $B_{DC-23-0}$+ B_{C-23-0}) >0]

$S_{EE-23-0}$=$CB_{DC-22-23}$+ S_{E-23-0}

Else

$S_{EE-23-0}$=0

If "Total Surplus Energy Exporting to Grid mode"

Surplus energy Total (S_{TEE}) for a typical day of the month= S_{EE-0-1}+ S_{EE-1-2}+......... + $S_{EE-23-0}$.. (AP1.7)

Converter Size for a typical day of the month = Max of { $S_{EE\text{-}0\text{-}1}/\Delta t$, $S_{EE\text{-}1\text{-}2}/\Delta t$,……… ,$S_{EE\text{-}23\text{-}0}/\Delta t$}…………………………………………………………………………… (AP1.8)

Else

Surplus energy Total=0

Converter Size (BC_{NC})= Max of { P_{L0} , P_{L1} , P_{L2} , P_{L3} , P_{L4} , P_{L5} , P_{L6} , P_{L7} , P_{L8} , P_{L9} ,…… P_{L24}}………………………………………………………………………………… (AP1.9)

P_L : Total load in kW

Δt : commitment period which is 1 h in this thesis

Estimating E_{BN} for the project life time by considering seasonal variations

As like E-S2-36F, Estimate E_{BN} for every month

Optimal minimum size of Battery storage for the entire project lifetime (E_{BN})= Max { $E_{BN\text{-}Jan}$, $E_{BN\text{-}Feb}$, $E_{BN\text{-}Mar}$, $E_{BN\text{-}Apl}$ …………… $E_{BN\text{-}Dec}$ }………………………………………… (AP1.10)

Estimating Converter size for the project life time for the grid connected mode by considering seasonal variations

As like E-S2-36J, Estimate converter size for every month

BC_{NC} = Max { $BC_{NC\text{-}Jan}$, $BC_{NC\text{-}Feb}$,………………….,BC_{NCDec}}……………………………… (AP1.11)

Estimating surplus energy for a year for the grid connected mode by considering seasonal variations

Estimate surplus energy for every month's typical day using equation AP1.7 and

Total Surplus energy for an Year = $S_{TEE\text{-}Jan}$ * 31+ $S_{TEE\text{-}Feb}$ * 28 + $S_{TEE\text{-}Mar}$ * 31+ $S_{TEE\text{-}Apl}$ * 30+ $S_{TEE\text{-}May}$ * 31+ $S_{TEE\text{-}Jun}$ * 30+ $S_{TEE\text{-}Jul}$ * 31+ $S_{TEE\text{-}Aug}$ *31+ $S_{TEE\text{-}Sep}$ *30 + $S_{TEE\text{-}Oct}$ *31+ $S_{TEE\text{-}Nov}$ *30+ $S_{TEE\text{-}De}$*31……………………………………………………………… (AP1.12)

Reference

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Appendix 2

Load Profile Estimate

Appliances hourly On Time Estimation

ON time in minutes of an individual appliance/electrical outlet-in an hour

$(A_{oti}) = P_{shi} * F_{ds} * C_{ct}$……………………………………………………………………………… (AP2.1)

Energy consumption in kWh by an individual appliance/electrical outlets in an hour "i"

$E_{ah} = W_{Pi} * A_{oti} \ / (10^3 \text{ x } 60)$…………………………………………………………………… (AP2.2)

Monthly total power consumption by all appliances and electrical outlets

$= 30 \left(\sum_{i=1}^{n} \sum_{j=1}^{24} E_{ah} \right)$……………………………………………………………………… (AP2.3)

Where

P_{shi}	Starting probability of an individual appliance/electrical outlets in an hour
W_{Pi}	Nominal power rating of an individual appliance/electrical outlets in Watts
n	total number of electrical outlets and appliances included within a microgrid
F_{ds}	Daily average value of starting frequency
C_{ct}	Average time period of a cycle in minutes

Table AP2.1 details the method of hourly starting probability estimation for a refrigerator and Table AP2.2 details the method of monthly load estimation based on equation AP2.1 to AP2.3 for a washing machine.

Table AP2.1: *Hourly starting probability estimation*

Refrigerator daily starting frequency ($F_{ds)}$	40.5
If starts, then how long the fridge will run (C_{ct}) in minutes	14.4
Daily how many minutes the fridge will be On	=40.5x14.4 =583.2
Hourly starting probability	0.0417 [=1/24 (equal probability)]
Hourly On Time (A_{ot}) of Refrigerator in minutes	=583.2*0.0417 =24.32

Table AP2.2: Monthly energy consumption estimation for a washing machine

Time (hrs)	Wpi (Watts)	A_{oti} in minutes	Hourly kWh for the typical day	Monthly Washing machine kWh consumption
0	600 (750VA)	0.20	0.00201	6.70
1		0.11	0.00112	
2		0.00	0.00000	
3		0.00	0.00000	
4		0.00	0.00000	
5		0.00	0.00000	
6		0.00	0.00000	
7		0.00	0.00000	
8		0.16	0.00156	
9		0.45	0.00446	
10		1.03	0.01029	
11		1.57	0.01567	
12		1.61	0.01614	
13		1.61	0.01614	
14		1.64	0.01638	
15		1.64	0.01638	
16		1.64	0.01638	
17		1.66	0.01658	
18		1.66	0.01658	
19		1.73	0.01728	
20		1.73	0.01728	
21		1.66	0.01658	
22		1.37	0.01366	
23		0.87	0.00873	

Load curve scaling method

An average daily load profile of the microgrid based on the typical On-time of each and every appliances, daily average value of the appliance starting frequency, its hourly starting probability as discussed in equation AP2.1 to AP2.3 Once these daily load estimate is generated for each appliance, these are aggregated to get the monthly load estimate. This forms the base line data. To create the scaled data, each of the baseline data values are multiplied by a common factor that results in an annual average value equal to the value that is specified in Scaled Annual Average. Thus the load profile for every month is generated by following equation AP2.4 and sample calculations are shown in Table AP2.3 and AP2.4.

$$E_{ahsi} = E_{ahi} * F_T * F_S * F_R \quad \text{(AP2.4)}$$

Where

E_{ahsi} : Energy consumption by an individual appliance by considering seasonal changes in kWh at hour i

F_T : Trend de-rating factor

F_S : Seasonal de-rating factor

F_R : Noise de-rating factor

Table AP2.3: *details the method of load scaling method for this thesis.*

Month	**F_T**	**F_S**	**F_R**	**Total derating factor for Seasonal Variations**
January	1.05	1.2	1.02	1.29
February	1.1	1.2	1	1.32
March	1.17	1.2	1	1.40
April	1.21	1.2	1	1.45
May	1.19	1.2	1	1.43
June	1.01	1.2	1.05	1.27
July	0.91	1.2	1.03	1.12
August	0.98	1.2	1	1.18
September	0.94	1.2	1	1.13
October	0.93	1.2	1	1.12
November	0.97	1.2	1	1.16
December	0.99	1.2	1.05	1.25

Table AP2.4: *Scaled load estimation for the month of January.*

Month	Time	Derating Factor	Base Load (kWh)	Total Load (kWh)
JAN	12:00 PM	1.29	11.369	14.612
	1:00 AM	1.29	10.014	12.870
	2:00 AM	1.29	7.045	9.054
	3:00 AM	1.29	5.840	7.506
	4:00 AM	1.29	5.739	7.375
	5:00 AM	1.29	5.953	7.651
	6:00 AM	1.29	6.517	8.376
	7:00 AM	1.29	7.066	9.081
	8:00 AM	1.29	9.348	12.014
	9:00 AM	1.29	11.256	14.466
	10:00 AM	1.29	12.705	16.328
	11:00 AM	1.29	13.428	17.258
	12:00 PM	1.29	14.733	18.935
	1:00 PM	1.29	14.850	19.085
	2:00 PM	1.29	16.371	21.040
	3:00 PM	1.29	17.091	21.966
	4:00 PM	1.29	18.904	24.296
	5:00 PM	1.29	19.337	24.852
	6:00 PM	1.29	19.963	25.657
	7:00 PM	1.29	21.563	27.713
	8:00 PM	1.29	22.294	28.652
	9:00 PM	1.29	19.877	25.546
	10:00 PM	1.29	17.850	22.941
	11:00 PM	1.29	14.789	19.007

The BIM based electrical system modelling is to be complete with load identification code as shown in Fig.AP2.1 and hourly Aoti (ON time in minutes of an individual appliance) for every elementary electrical appliances/outlets and is to be added to BGMG by using load profile data adding section. BGMG will estimate load profile by following the flowchart given in Fig.AP2.2.

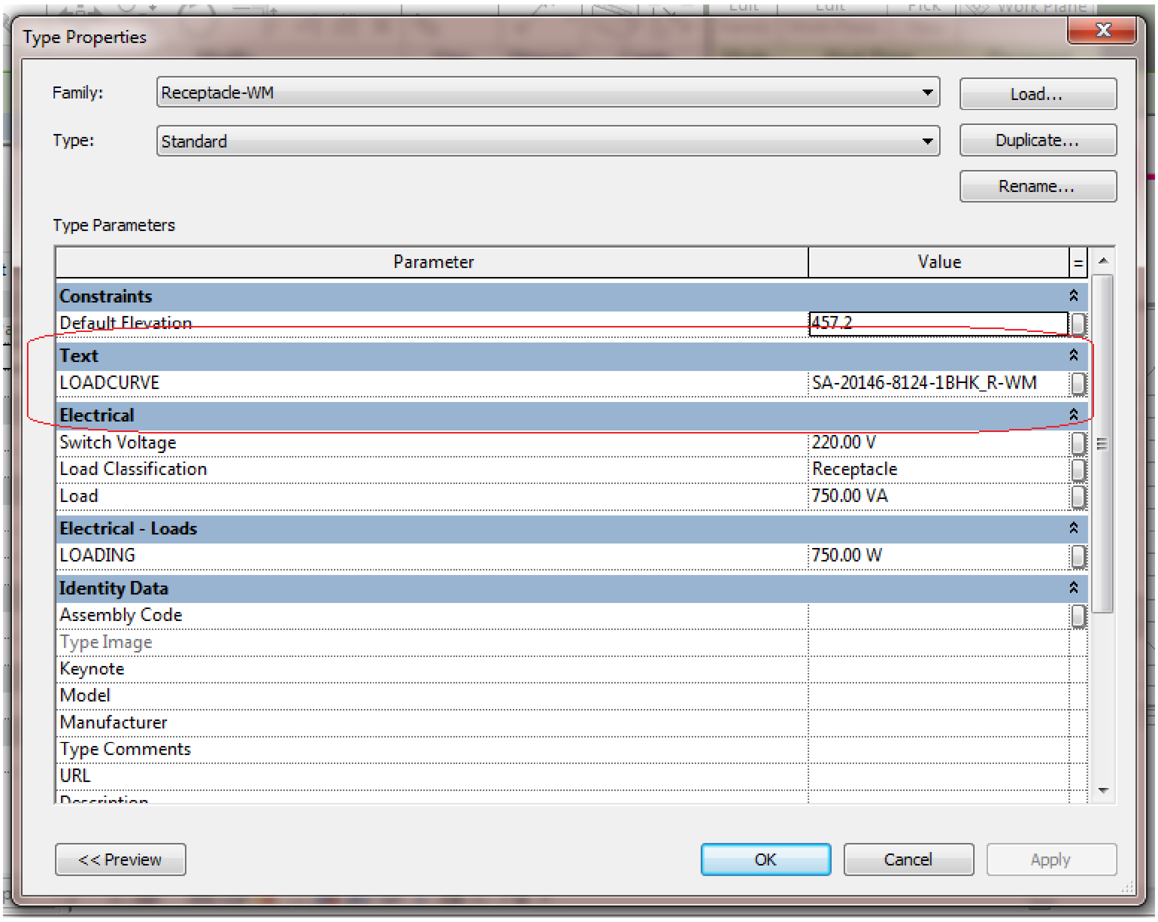

Fig.AP2.1: *Load profile code embedded in BIM family files as parameters.*

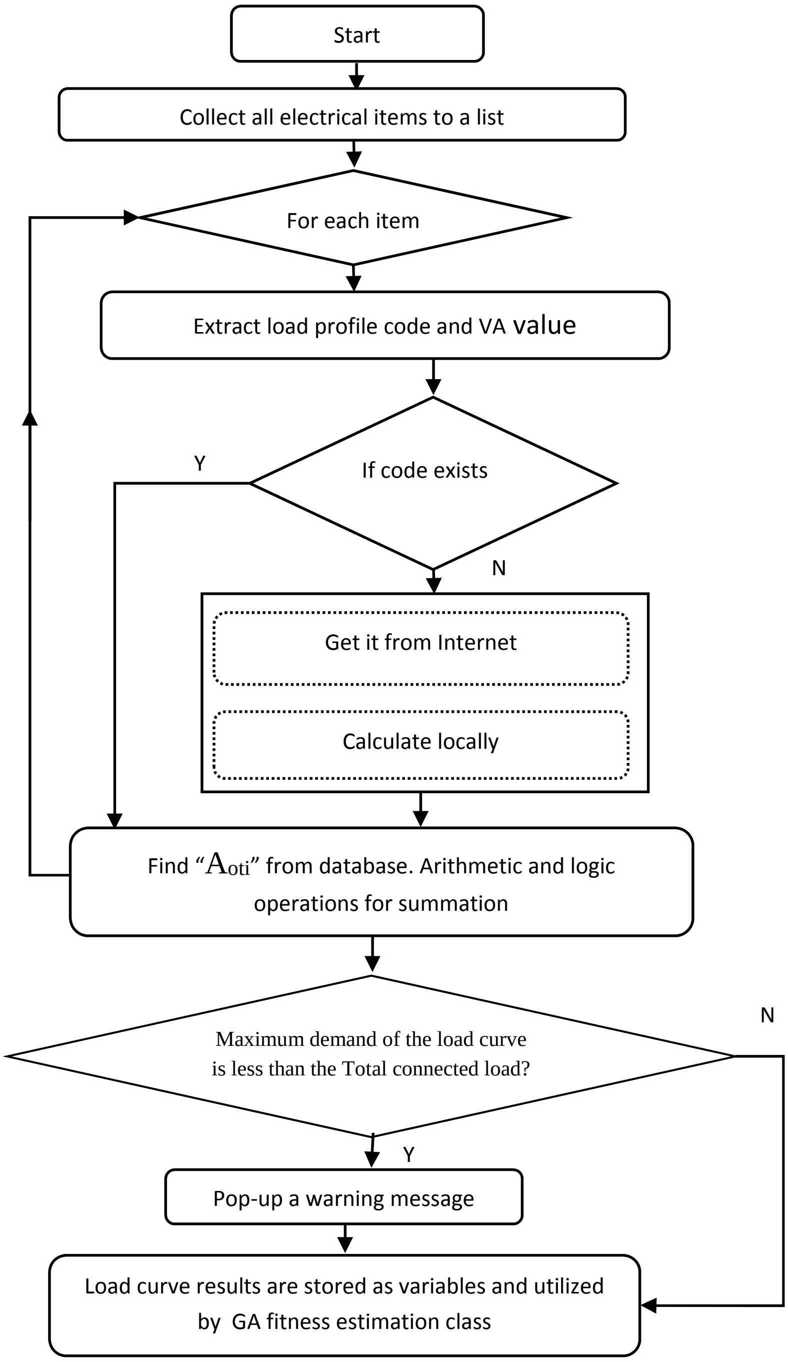

Figure AP2.2: Flowchart of load profile extraction.

Reference

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Appendix 3

Software and file format details

ArcGIS: ArcGIS is an application for GIS modelling. ArcGIS provides special tools for network modelling. ArcMap, ArcScene and ArcCatalog are the parts of the ArcGIS application. This work mainly uses ArcMap section of ArcGIS application.

Green Building Studio (GBS): One of the cloud-based building energy analysis tool is Autodesk's Green Building Studio (GBS) for building performance simulations, renewable energy potential estimation, carbon emission assessments and iterative optimization studies.

IFC: The Industry Foundation Classes (IFC) is the generalized object specification methodology for BIM modelling. The "buildingSMART" agency developed the specifications related to IFC. It is possible to convert Revit file to IFC file format.

Microsoft Visual Studio: A platform for developing apps and websites. By using .net based language codes are written to create novel tools.

Microsoft Excel: Microsoft Excel is an application included with M S Office. By using M S Excel based spreadsheets, electrical calculations such as VD and panel schedule can be conducted.

OmniClass: OmniClass is one of Work Breakdown Structure (WBS) used to classify objects in the construction industry. A thorough understanding of OmniClass is required to extract information from Revit based BIM modelling. Each and every object in Revit have an OmniClass parameter. Autodesk Revit is based on IFC format and supports OmniClass Work Breakdown Structure (WBS).

Revit: Autodesk's Revit is one of the foremost application for BIM and this research is mainly based on the Revit platform and its inbuilt and customized tools.

Appendix 4

GIS data integrating with BIM for site suitability assessment

Basic GIS data for site suitability modelling is gathered from agencies such as NREL. As described in chapter 4 by using ArcGIS GIS tools, Kerala State restriction is converted to MS excel based database format. Fig.AP4.1 is the screenshot of the protected regions of Kerala. Fig.AP4.2 is the screenshot of the combined river and lakes of Kerala. Fig.AP4.3 is the combined union raster of protected regions and water bodies of the Kerala state and in Fig.AP4.4, the administrative village boundaries of Kerala state is merged with union layer for conducting zonal statistics analysis. The entire GIS data processing and interfacing with BIM application is described in Fig.AP4.5.

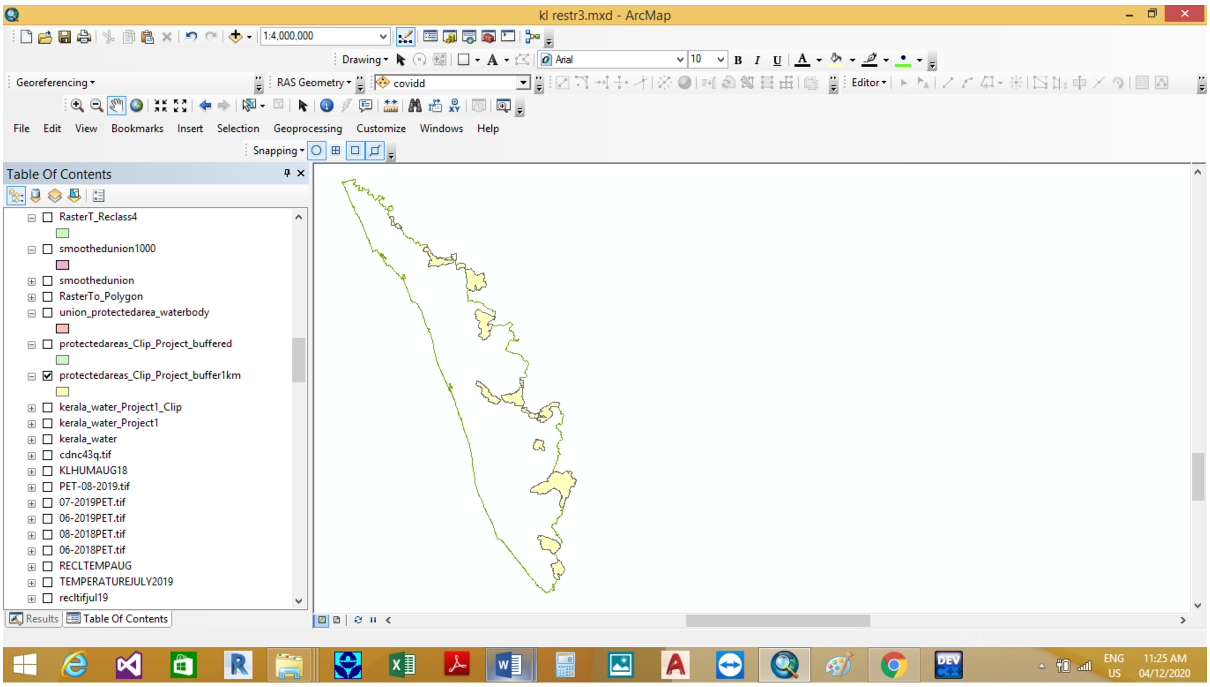

Fig. AP4.1: *Protected areas of Kerala state gathered from NREL*

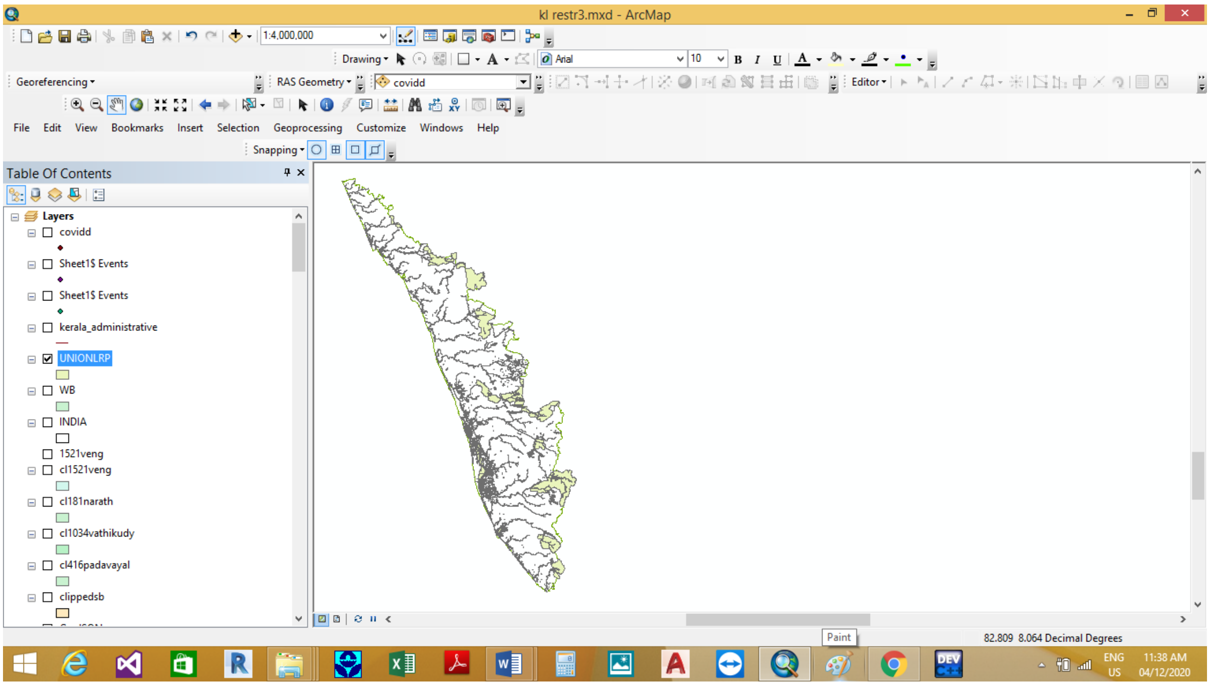

Fig.AP4.2: *Combined lakes and River layers of Kerala*

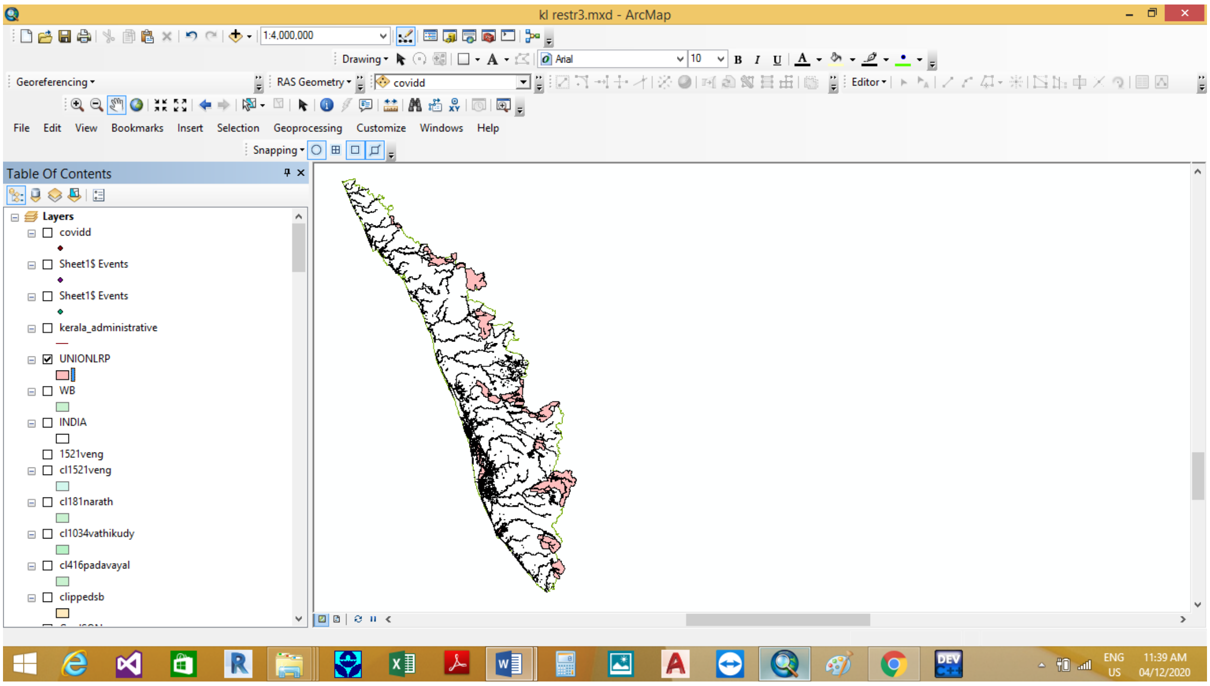

Fig.AP4.3: *Union layer of protected regions, lakes and River layers of Kerala*

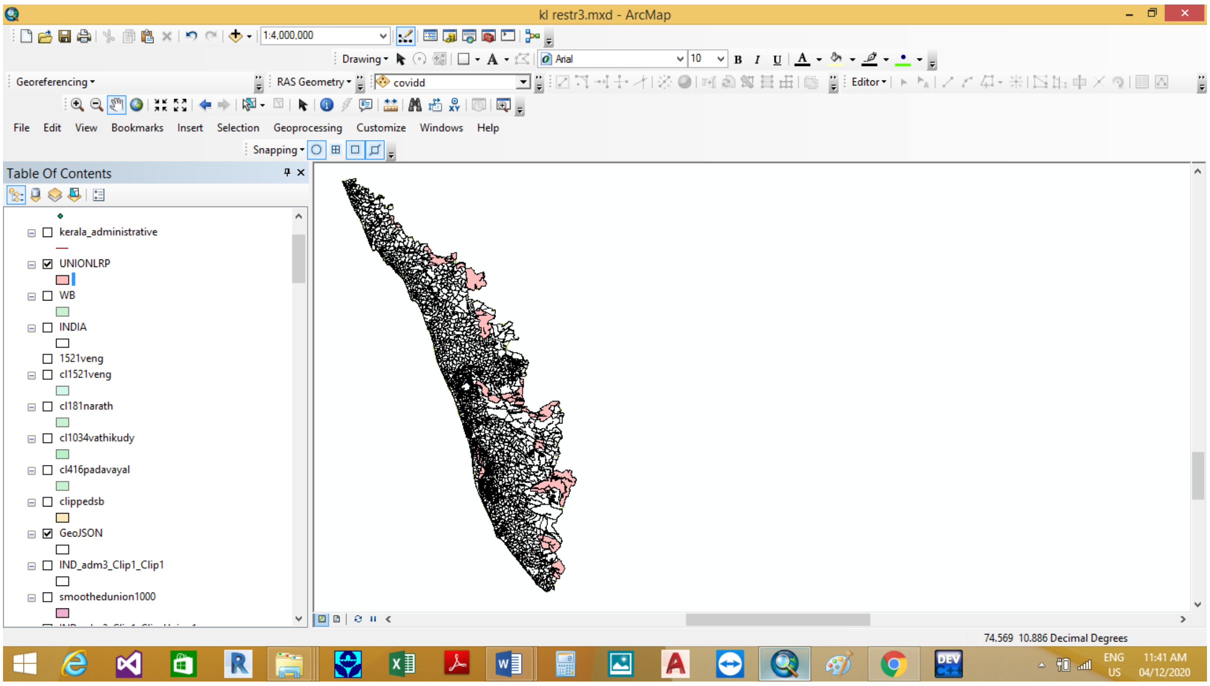

Fig.AP4.4: *Combined union layer of restrictions with Administrative villages*

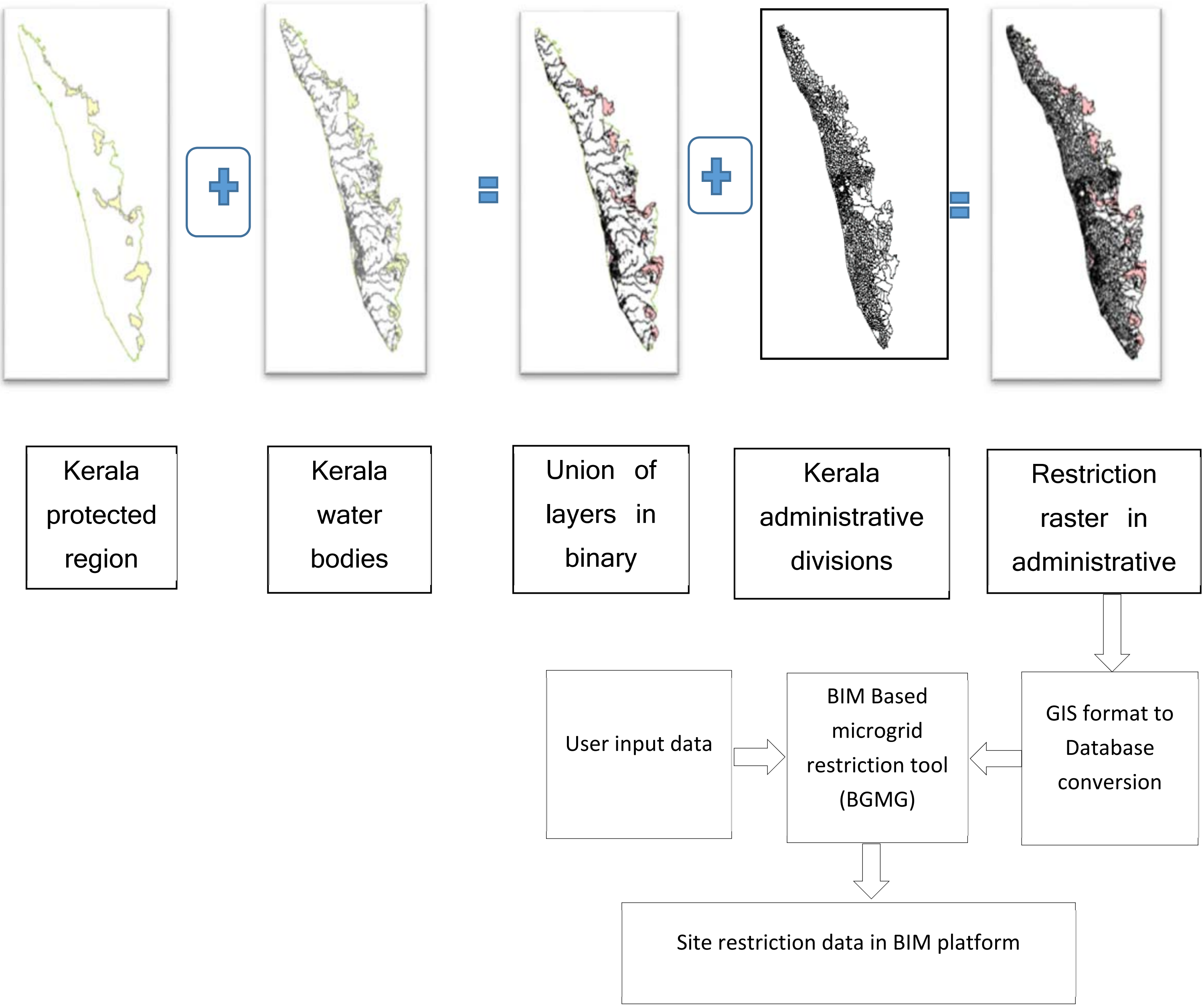

Fig.AP4.5: *GIS restriction data conversion to BIM platform*

GIS flood vulnerability raster for the state of Kerala is given in Fig.AP4.6. By processing this raster to point features by using ArcGIS's "Raster to Point features" conversion tool [1] and coordinates are added to points by using "Add XY Coordinates (Data Management) tool" [2]. The outcomes of the conversion process is given in Fig.AP4.7 and Fig.AP4.8. By following the methodology described in chapter 4, the flood data processing and interfacing is described in Fig.AP4.9.

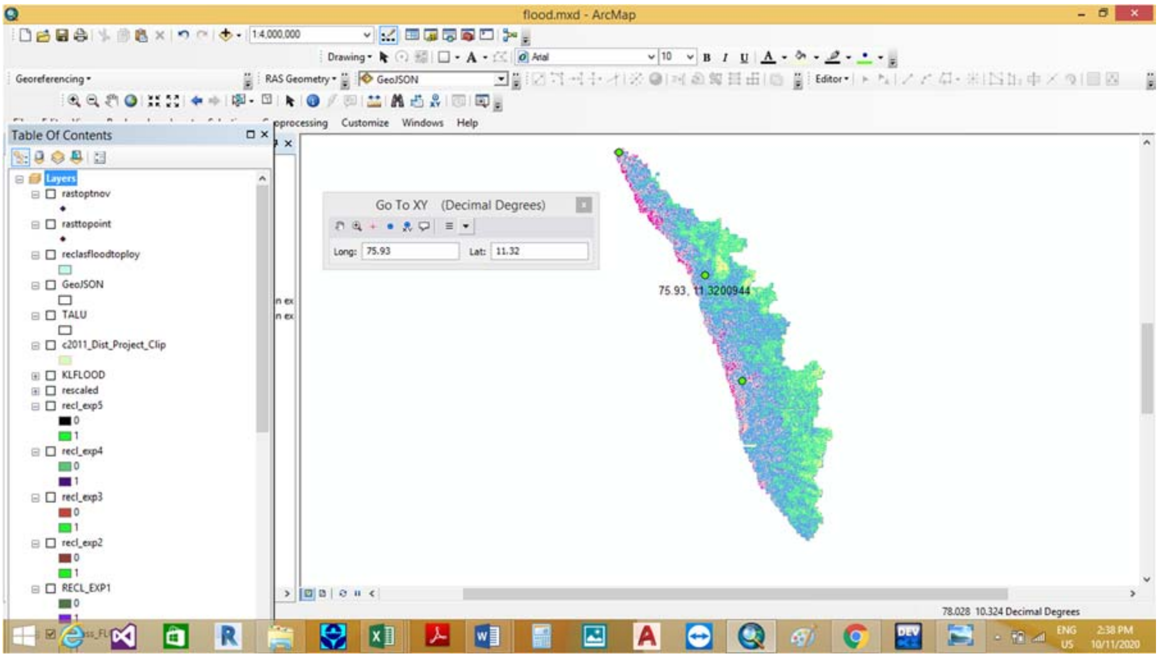

Fig.AP4.6: *Flood vulnerability map (refer Appendix-8)*

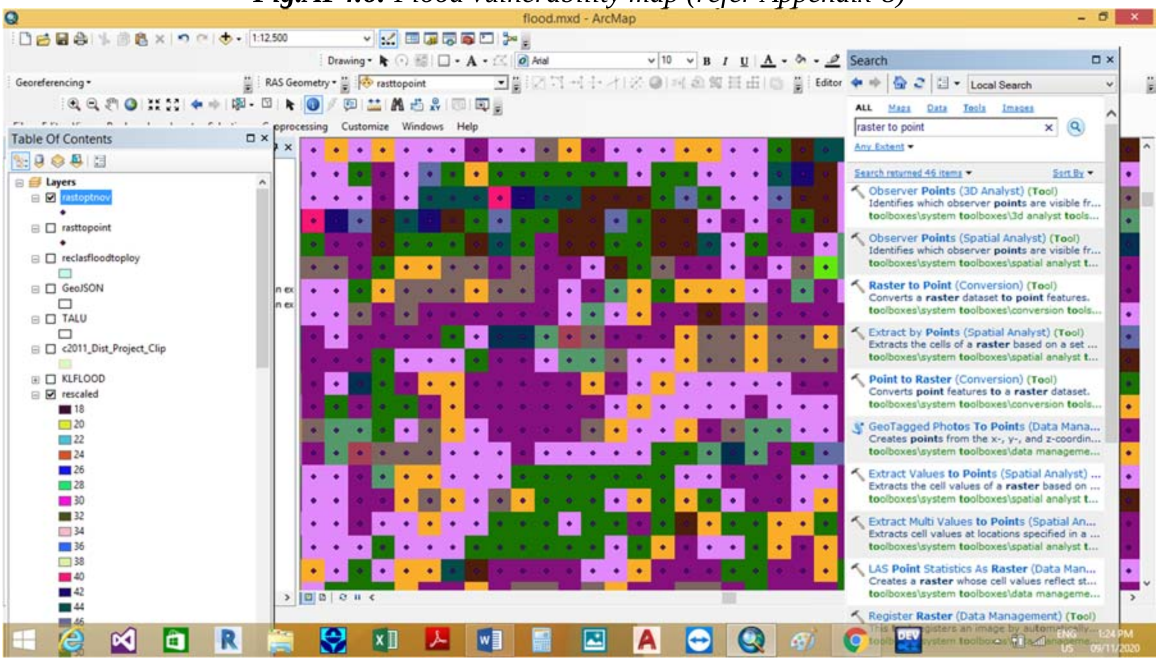

Fig.AP4.7: *Flood vulnerability raster to point features. Cell size of the raster is 10m*10m.*

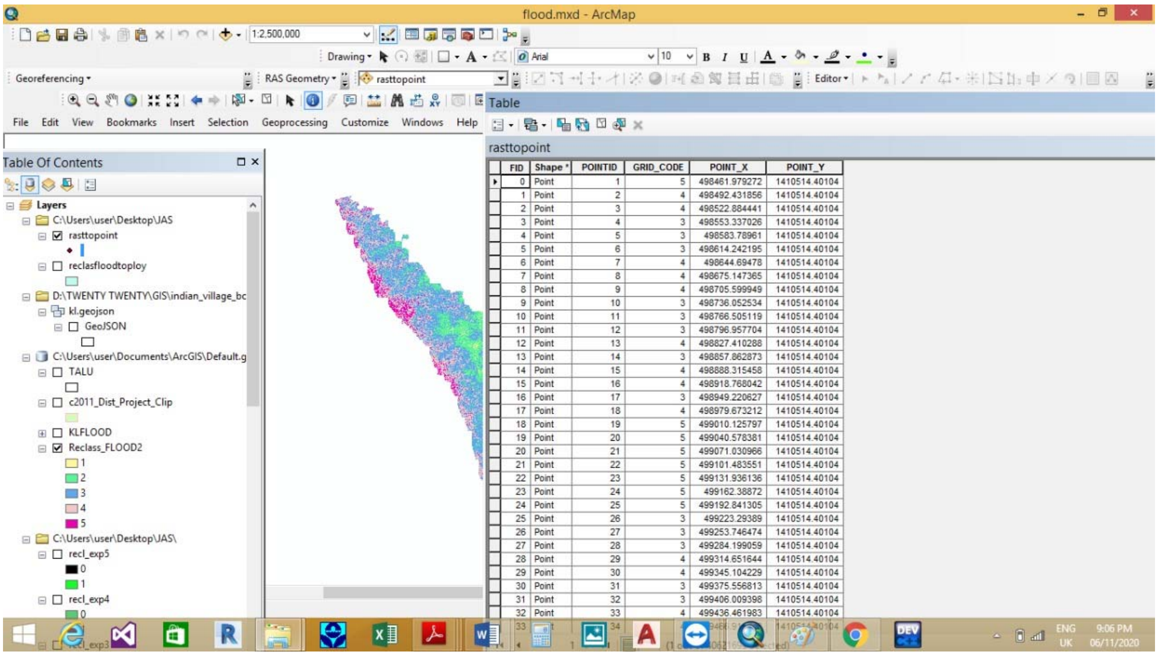

Fig.AP4.8: *the generated points' attribute table, the data will be exported to MS excel based database*

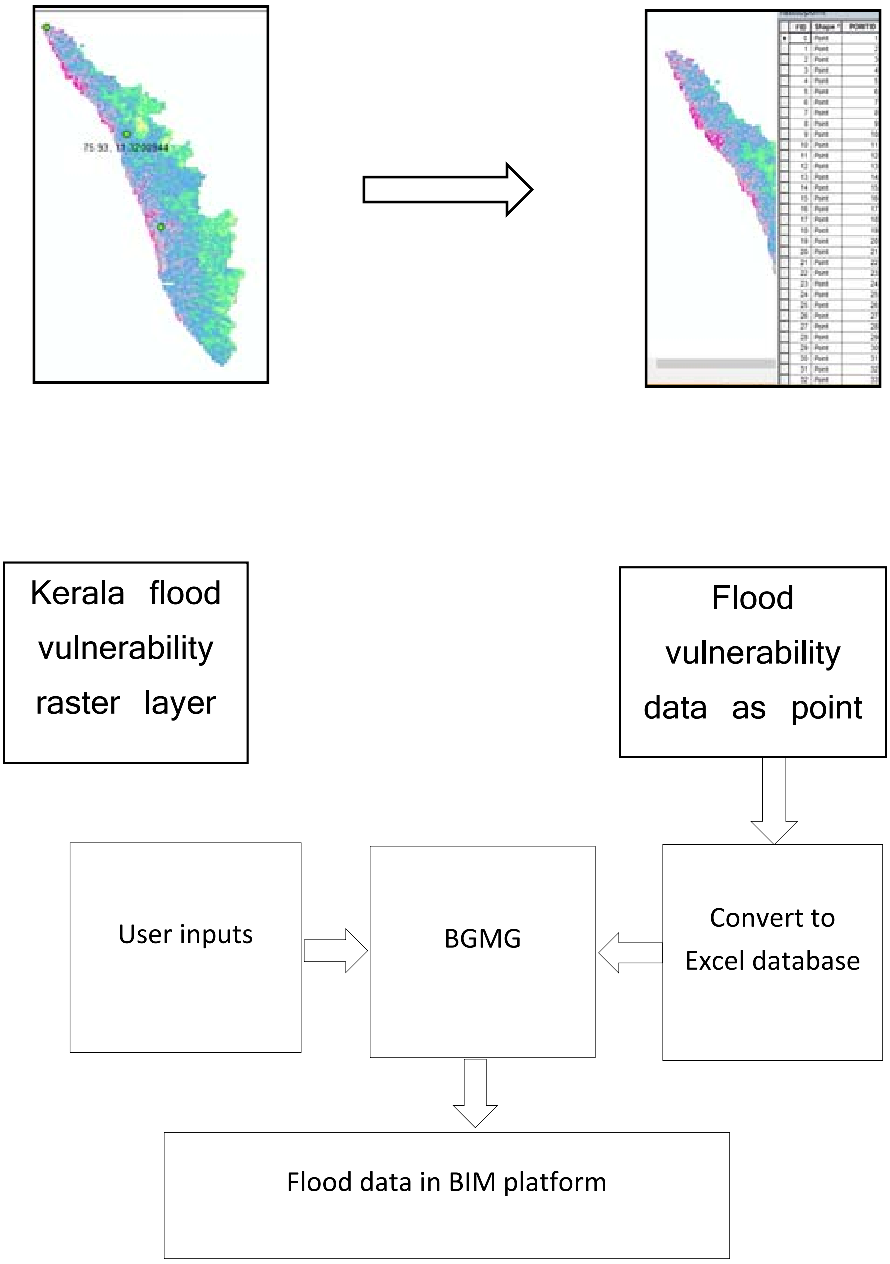

Fig.AP4.9: *GIS flood data conversion to BIM platform*

Reference

1. "Raster to Point—Help | ArcGIS for Desktop", *Desktop.arcgis.com*, 2020. [Online]. Available: https://desktop.arcgis.com/en/arcmap/10.3/tools/conversion-toolbox/raster-to-point.htm. *[Accessed: 14- Dec- 2020].*
2. *"Add XY Coordinates—Help | ArcGIS for Desktop", Desktop.arcgis.com, 2020. [Online]. Available: https://desktop.arcgis.com/en/arcmap/10.3/tools/data-management-toolbox/add-xy-coordinates.htm. [Accessed: 14- Dec- 2020].*

Appendix 5

Plan views of projects used to calculate the value of S_c

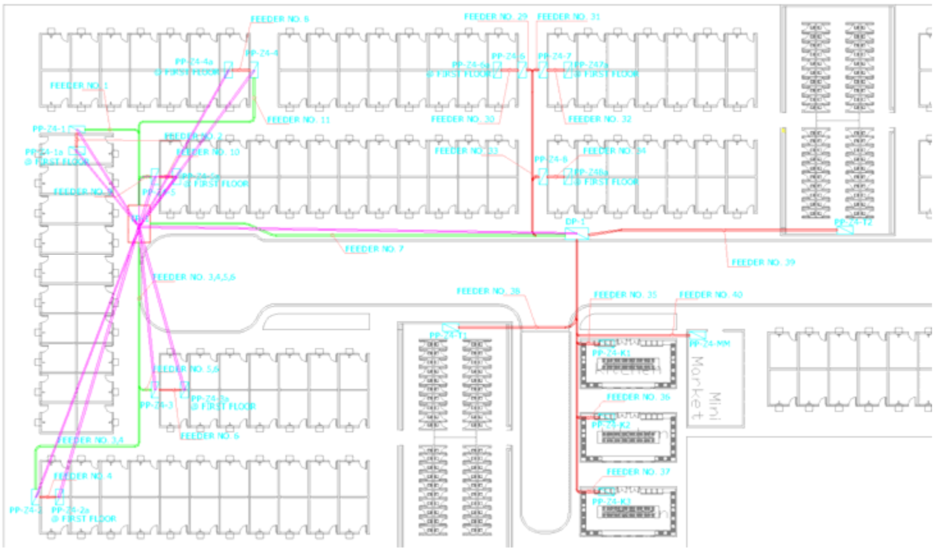

Fig. AP5.1: *Project 1*

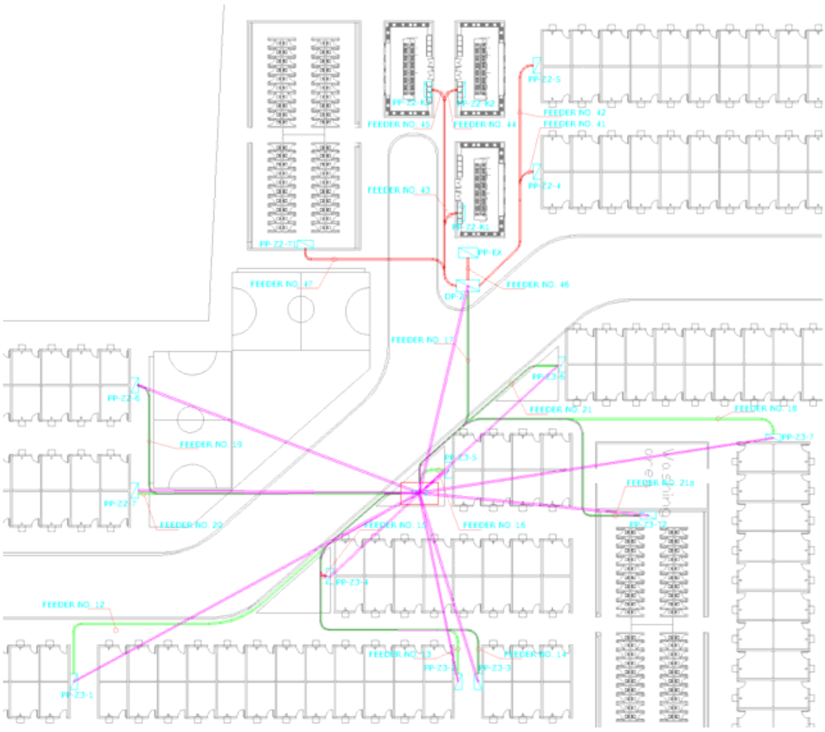

Fig. AP5.2: *Project 2*

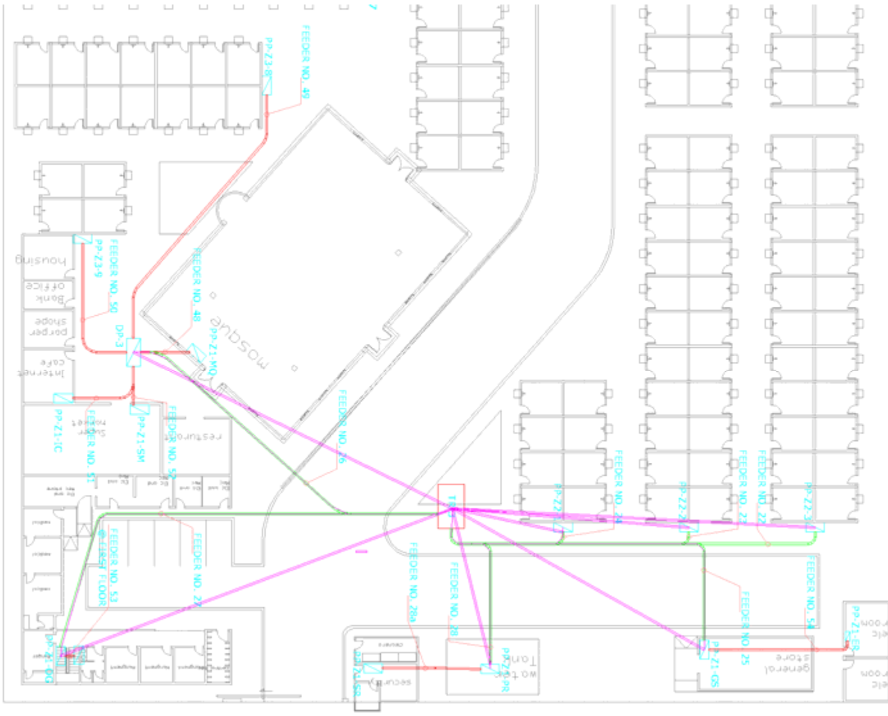

Fig.AP5.3: *Project 3*

Fig. AP5.4: *Project 4*

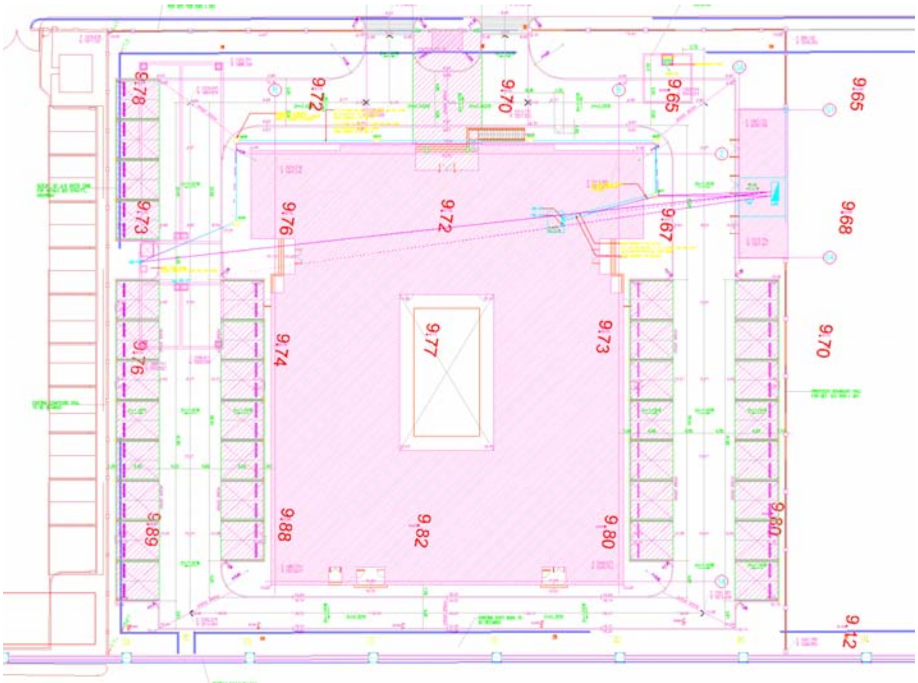

Fig. AP5.5: *Project 5*

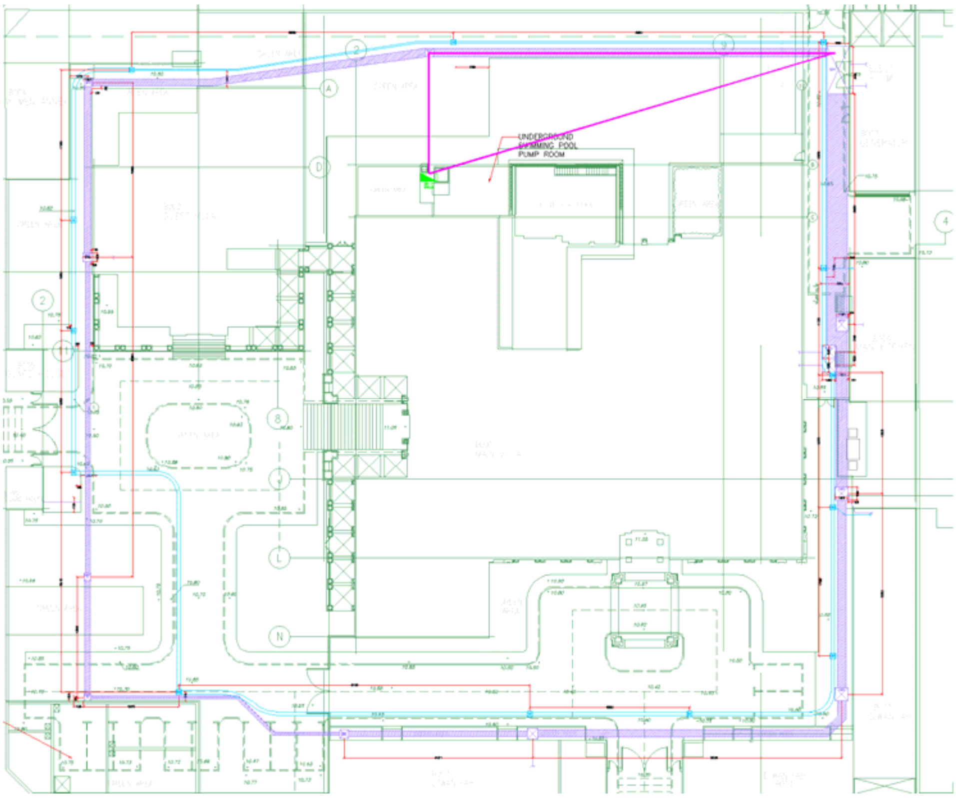

Fig. AP5.6: *Project 6*

As shown in Table AP.5.1, calculations are done according to formula 7.8 and 7.9 to get an average value for S_c.

Table AP.5.1: S_c estimation

T1

From	To	cable	actual length(m)	straight line length(m)	Cost ($)/m	act. Total.cabl.cost($)	straight. Total.cabl.cost($)
T1	PP Z4 1	4X50+25	20	14.7	34.93	698.67	513.52
T1	PP Z4 1a	4X25+16	22.7	12.7	21.33	484.27	270.93
T1	PP Z4 2	4X50+25	47	36.8	34.93	1641.87	1285.55
T1	PP Z4 2a	4X35+16	50	35.8	25.87	1293.33	926.03
T1	PP Z4 3	4X25+16	22.6	20.9	21.33	482.13	445.87
T1	PP Z4 3a	4X16+16	26.3	21.6	15.47	406.77	334.08
T1	DP 1	4X150+150	56	55.8	102.13	5719.47	5699.04
T1	PP Z4 4a	4X16+16	37.2	23	15.47	575.36	355.73
T1	PP Z4 5	4X50+25	8.34	6.7	34.93	291.34	234.05
T1	PP Z4 5a	4X35+16	10.9	8	25.87	281.95	206.93
T1	PP Z4 4	4X25+16	34	24.7	21.33	725.33	526.93
		Total	**335.04**	**260.7**		**12600.49**	**10798.67**
			L_{caT} / L_{csT}	**1.29**		C_{Ta} / C_{Ts}	**1.17**

T2

From	To	cable	actual length(m)	straight line length	Cost ($)/m	act. Total.cabl.cost($)	straight. Total.cabl.cost($)
T2	PP Z3 1	4X50+25	57.2	50.6	34.93	1998.19	1767.63
T2	PP Z3 2	4X50+25	48.4	24.7	34.93	1690.77	862.85
T2	PP Z3 3	4X10+10	50.1	25.4	11.47	574.48	291.25
T2	PP Z3 4	4X35+16	19	15.6	25.87	491.47	403.52
T2	PP Z3 5	4X10+10	6	4.7	11.47	68.80	53.89
T2	DP 2	4X240+120	30	27.47	167.47	5024.00	4600.31
T2	PP Z3 7	4X35+16	52.5	46	25.87	1358.00	1189.87
T2	PP Z2 6	4X35+16	49	38.7	25.87	1267.47	1001.04
T2	PP Z2 7	4X35+16	36	36	25.87	931.20	931.20
T2	PP Z3 6	4X70+35	26.66	24.3	48.80	1301.01	1185.84
T2	PP Z3 T2	4X10+10	45.1	29.5	11.47	517.15	338.27
		Total	**419.96**	**322.97**		**15222.53**	**12625.67**
			L_{caT} / L_{csT}	**1.30**		C_{Ta} / C_{Ts}	**1.21**

T3

From	To	cable	actual length(m)	straight line length	Cost ($)/m	act. Total.cabl.cost($)	straight. Total.cabl.cost($)
T3	PP Z2 3	4CX50+25	44	39.2	34.93	1537.066667	1369.386667
T3	PP Z2 2	4CX50+25	30.4	25.6	34.93	1061.973333	894.2933333
T3	PP Z2 1	4X10+10	16.7	12.2	11.47	191.4933333	139.8933333
T3	PP Z1 GS	4X10+10	41.8	31.2	11.47	479.3066667	357.76
T3	DP 3	4X240+120	41	38.47	167.47	6866.133333	6442.442667
T3	PP Z1 OG	4CX50+25	54	45.3	34.93	1886.4	1582.48
T3	PP Z1 PR	4X16+16	20.7	17.3	15.47	320.16	267.5733333

		Total	**248.6**	**209.27**		**12342.53**	**11053.83**
			L_{caT} / L_{csT}	**1.19**		C_{Ta} / C_{Ts}	**1.12**

T4

From	To	cable	actual length(m)	straight line length	Cost ($)	act. Total.cabl.cost($)	straight. Total.cabl.cost($)
T4	DP-1	5(4CX240+120)	61	48.5	772.32	47111.52	37457.52
			L_{caT} / L_{csT}	**1.26**		C_{Ta} / C_{Ts}	**1.26**

T5

From	To	cable	actual length(m)	straight line length	Cost ($)	act. Total.cabl.cost($)	straight. Total.cabl.cost($)
T5	DB-G1	3(4CX185+95)	27.72	25.6	363.84	10085.64	9314.30
T5	DB-G2	3(4CX185+95)	27.72	25.6	363.84	10085.64	9314.30
T5	LP-X	4X10+10	6	4	11.47	68.80	45.87
T5	DB-P	4X35+16	101	84	25.87	2612.53	2172.80
T5	SP	4X10+10	61	42	11.47	699.47	481.60
T5	DB-FP	4CX185+95	99	79	137.28	13590.72	10845.12
		Total	**322.44**	**260.2**		**37142.81**	**32173.99**
			L_{caT} / L_{csT}	**1.24**		C_{Ta} / C_{Ts}	**1.15**

T6

From	To	cable	actual length(m)	straight line length	Cost ($)/m	act. Total.cabl.cost($)	straight. Total.cabl.cost($)
T6	DB-3	4CX150+70	170	145	108	18360	15660
T6	DB-4	4CX150+70	237	172	108	25596	18576
T6	DB-5	4CX150+70	325	234	108	35100	25272
		Total	**732**	**551**		**79056**	**59508**
			L_{caT} / L_{csT}	**1.33**		C_{Ta} / C_{Ts}	**1.33**

T7

From	To	cable	actual length(m)	straight line length	Cost ($)/m	act. Total.cabl.cost($)	straight. Total.cabl.cost($)
T7	DB-1	4CX150+70	165	120	405	66825	48600
T7	DB-2	4CX150+70	112	80	405	45360	32400
T7	DB-A	4CX150+70	160	125	405	64800	50625
		Total	**437**	**325**		**176985**	
			L_{caT} / L_{csT}	**1.34**		C_{Ta} / C_{Ts}	

Where

C_c : Cost of cable in USD.

C_{Ta} : Total cost of all cables by actual length method in meters

C_{Ts} : Total cost of all cables by straight-line method in meters

L_{caT}: Total length of cable in according to actual site conditions

L_{csT}: Total length of cable in according to straight-line method

Average values estimated from Table.AP5.1 is given in Table AP5.2 and graphical representation is shown in Fig.AP5.1.

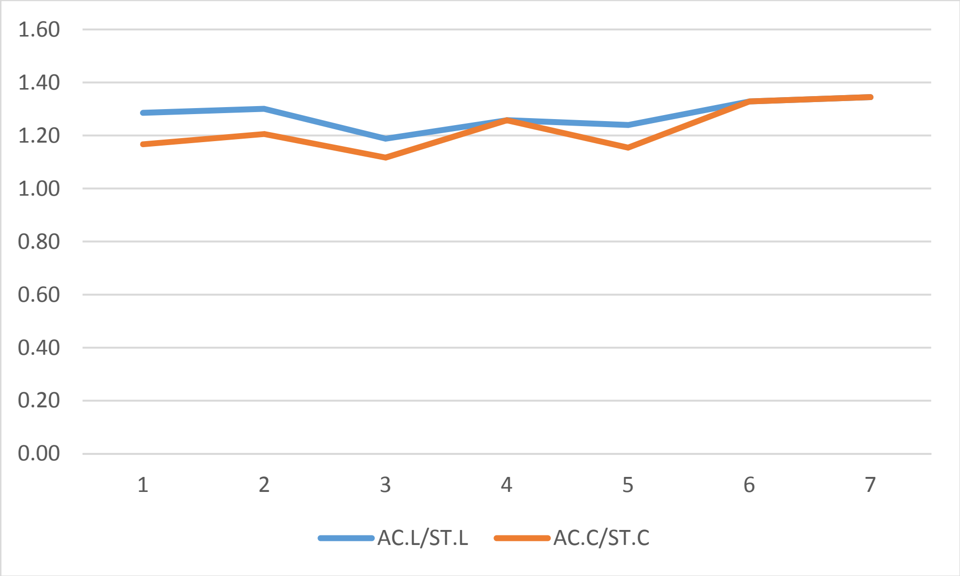

Fig. AP5.1: *Graphical representation of "L_{caT} / L_{csT}" and "C_{Ta} / C_{Ts}" for seven real projects*

Table AP6.2*: Average values of "L_{caT} / L_{csT}" and "C_{Ta} / C_{Ts}".*

SL.NO.	L_{caT} / L_{csT}	C_{Ta} / C_{Ts}
1	1.29	1.17
2	1.30	1.21
3	1.19	1.12
4	1.26	1.26
5	1.24	1.15
6	1.33	1.33
7	1.34	1.34
Average	**1.28**	**1.22**

So from the above calculations we can get a round figure as

$$L_{caT} = 1.28 * L_{csT}$$

$C_{Ta} = 1.22 * C_{Ts}$

$S_c = 1.22$

Conclusion : *Average value of* S_c is around 1.22 for the projects similar to the case study.

Author’s Profile and Details of Publications

Jasim Farooq is working as a senior technical office engineer at IBLEC, Saudi Arabia since 2008. He graduated from Kannur University in Electrical and Electronics. He has 14 years of experience in power system design and estimation, costing, CAD drafting and BIM modelling.

Publications

1. Jasim Farooq, Paawan Sharma, Sreerama Kumar R, “Applications of Building Information Modeling in Electrical Systems Design”, Journal of Engineering Science and Technology Review, Vol. 10, No.6, pp. 119-128, Dec. 2017.

2. Jasim Farooq, Rupendra Kumar Pachauri, Sreerama Kumar R, Paawan Sharma, “BIM-based Electrical Load Estimation from Architectural Building Models”, International Journal of Advanced Research in Dynamical and Control Systems, Issue-15, pp. 63-67, 2018.

3. Jasim Farooq, Paawan Sharma, Sreerama Kumar R, “A BIM-based Detailed Electrical Load Estimation, Costing and Code Checking”, International Journal of Electrical and Computer Engineering, Vol.8, No.5, pp. 3484-3495, Oct. 2018.

4. Jasim Farooq, Rupendra Kumar Pachauri, Sreerama Kumar R and Paawan Sharma, “An add-in Tool for BIM-based Electrical Load forecast for Multi-building Microgrid Design”, Book chapter in Proceedings of International Conference on Artificial Intelligence, Smart Grid and Smart City Applications, Chapter 6, ISBN: 978-3-030-24050-9, 2020.

5. Rahla Rabia M. P, Jasim Farooq, Integrated infrastructural design and management using BIM and GIS, My coordinate magazine, Volume X, Issue 11, pp 46-52, November 2014.

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