Power Grid Optimization

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***Abstract*—The provision of electricity to all villages in Assam is a critical task that requires careful planning and optimization. In collaboration with the Indian Institute of Technology Guwahati (IITG), the Assam Electricity Board has undertaken the responsibility of providing electricity to all villages in the region. The aim of this project is to determine the most cost-effective and efficient method of connecting all the villages to the electricity grid.**

The results of the optimization show that connecting villages through a chain of connections with other electrified villages is the most cost-effective method of electrifying all villages in Assam. The study also identifies the optimal locations for power plants and the minimum number of power plants required to electrify all villages. The findings of this project can be used as a roadmap for the Assam Electricity Board and other organizations tasked with providing electricity to rural communities in other parts of the country.

I. Introduction

Electricity is essential for rural areas for various reasons: (1) Economic Development: Electricity is vital for economic development in rural areas. It enables the use of modern technology, machinery and equipment and promotes the establishment of new businesses. Access to electricity increases productivity, creates job opportunities, and boosts economic growth. (2)Education: Access to electricity is crucial for education in rural areas. It enables students to use modern technology, computers, and other learning resources. It also improves the quality of education and enhances the learning environment, leading to better educational outcomes. (3) Healthcare: Electricity is critical for healthcare facilities in rural areas. It enables the operation of medical equipment, devices, and machinery, including refrigeration for vaccines, blood banks, and other medical supplies. Access to electricity is necessary for providing quality healthcare services in rural areas. (4) Agricultural Development: Agriculture is the backbone of the rural economy, and electricity is essential for its development. It enables the use of irrigation systems, mechanization of farming practices, and preservation of agricultural produce. Access to electricity is necessary for the growth and development of the agricultural sector in rural areas. (5) Quality of Life: Access to electricity improves the quality of life in rural areas. It provides lighting for homes, increases safety and security, and improves access to communication devices such as phones and radios. It also enables the use of appliances such as refrigerators, washing machines, and other modern conveniences, making life more comfortable and convenient. With this optimizing the cost-effective distribution of electricity is also essential. (1) Efficient use of resources: Optimization of electricity distribution helps to ensure that resources such as power generation capacity, transmission and distribution infrastructure, and human resources are used efficiently. This can lead to a reduction in waste and unnecessary costs, making the electricity system more sustainable. (2) Cost savings: Optimizing the distribution of electricity can help to reduce costs associated with electricity production and delivery. This can lead to lower prices for consumers and make electricity more accessible to people who might not otherwise be able to afford it. (3) Improved reliability: Optimization of electricity distribution can help to improve the reliability of the electricity supply. This can reduce the frequency and duration of power outages, which can have significant economic and social impacts, particularly in areas where electricity is critical for healthcare, education, and other essential services. (4) Better customer service: Optimization of electricity distribution can lead to better customer service. It can help utilities to respond more quickly and effectively to customer inquiries and complaints, improving customer satisfaction and loyalty. (5) Environmental benefits: Optimization of electricity distribution can also have environmental benefits. By reducing waste and increasing efficiency, it can help to reduce greenhouse gas emissions associated with electricity generation. In conclusion, optimizing the cost-effective distribution of electricity is crucial for achieving efficient use of resources, cost savings, improved reliability, better customer service, and environmental benefits. It can help to create a more sustainable and equitable electricity system that benefits all stakeholders.

The study is expected to contribute to the ongoing efforts to provide electricity to remote villages in India. The findings of the study will provide insights into the most cost-effective and efficient method of electrifying remote villages, which can be replicated in other regions facing similar challenges. Furthermore, the study will contribute to the ongoing research in the field of energy planning and policy-making, with a focus on improving access to electricity for all.

II. Problem Description

The Power grid optimization problem can be defined as follows. Given :

1) Location of villages
2) The number of houses in each village
3) average energy requirement of each house
4) plant installation cost for each village
5) the cost factor for transportation of electricity for each village
6) the maximum number of plants that can be installed
7) raw material required per unit electricity produced
8) Cost for transportation of raw material required by each village.

The objective is to provide electricity to each village either by building a power plant in that village, or by making a connection between that village and another one that already has a plant. So the village has electricity if it has a power plant in it or it is connected to a village which has electricity by a direct connection. In addition, there are several requirements that must be met as follows:

1) All villages must be electrified
2) A village must be directly connected to the power plant (source of electricity).
3) Each village must fulfill its electricity demand from one power plant.
4) Source of electricity of the village in which the power plant is to be built should be itself.
5) Each power plant has a capacity i.e. maximum amount of electricity it can produce.
6) A village must be supplied with electricity according to demand

III. Mathematical Model

The proposed formulation requires the following indices,sets, parameter and variables:

A. *Indices:*

$j \in$ index of villages
$k \in$ index of villages

B. *Sets:*

$x(j) \in$ x co-ordinate of village
$y(j) \in$ y co-ordinate of village

C. *Parameters:*

N Number of Villages
$HC(k)$ total number of houses in each village k
$IC(j)$ Cost of installing plant in village j
$RMTCost(j)$ Cost of transporting raw material to village j per unit raw material
$CF(j)$ Cost of transporting electricity per km for village j
$MaxPlants$ maximum number of plants that can be installed
$MinPlants$ the minimum number of plants to be installed
$TC(j,k)$ Cost of transporting electricity from village j to village k
$MaxProd$ Maximum energy produced by each plant
$Rawmat$ Raw material required to produce 1 unit of electricity
$HConsump$ Average energy consumed by each house

D. *Variables:*

OBJ continuous, Total cost of electrification;
$X(j)$ binary, whether or not the plant is to be installed in village j;
$Y(j,k)$ binary, whether or not electricity is transported from village j to k;

$Z(j,k)$ continuous, amount of electricity transported from village j to k;

$E(j)$ continuous, amount of electricity produced in plant at village j;

$R(j)$ continuous, amount of raw material required by the plant at village j;

E. ***Equations*** & ***Constraints***

On the basis of this notation, the mathematical model for the grid optimization problem involves the following constraints and equations:

Minimum Plants Constraint

This constraint expresses the requirement of minimum number of plants that needs to be installed for electrifying the villages, where X_j indicates whether the plant is being installed in village j or not.

$$\sum_j X_j \geq MinPlants \ \ \forall \ \ j \in N \tag{1}$$

Maximum Plants Constraint

This constraint expresses the upper limit of plants that we are allowed to install for electrifying all the villages, where X_j indicates whether the plant is being installed in village j or not.

$$\sum_j X_j \leq MaxPlants \ \ \forall \ \ j \in N \tag{2}$$

One village-One source-One plant Constraint

This constraint ensures that every village is getting electrified directly by the source village i.e. source village has a power plant built in it, and not from other village which is getting electrified from some source. Also, it ensures that village with power plant is the source of itself and hence minimizing transport cost of electricity. This constraint also ensures that energy requirement of each village is getting fulfilled by only one power source and each village is electrified.

$$\sum_j X_j Y_{j,k} = 1 \ \ \forall \ \ k \in N \tag{3}$$

Electricity Transported Constraint

This constraint ensures that electricity transported from village j to village k should be equal to the demand of the village k i.e. number of houses multiplied by the average energy required by each house also ensuring that village receives electricity only from the source to which it is connected.

$$Z_{j,k} = Y_{j,k} HC_k HConsump \ \ \forall \ \ k \in N \tag{4}$$

Total Electricity Received Constraint

This constraint ensures that the total electricity received by each village should be equal to the demand of village i.e. number of houses multiplied by the average energy required by each house.

$$\sum_j Z_{j,k} = HC_k HConsump \ \ \forall \ \ k \in N \tag{5}$$

Maximum Production Constraint

This constraint ensures that the total electricity produced and transported by each plant at village j should be less than the capacity of plant.

$$\sum_k Y_{j,k} HConsump HC_k \leq MaxProd \ \ \forall \ \ j \in N \tag{6}$$

Total Electricity Produced

This equation is used to calculate the total electricity produced by each village j.

$$E_j = \sum_k Z_{j,k} \ \ \forall \ \ j \in N \tag{7}$$

Total Raw Material Required

This equation is used to calculate the total raw material required by each village j to produce electricity as product of amount of electricity produced and raw material required to produce 1 unit of electricity.

$$R_j = Rawmat E_j \ \ \forall \ \ j \in N \tag{8}$$

Transportation Cost Calculation

This equation is used to calculate transportation cost of electricity from village j to village k. Village locations are considered as x and y co-ordinates on rectangular grid and motion is restricted in east,west,north and south directions only.Hence transportation cost can be calculated as product of distance of wiring between to villages and sum of their individual cost factors.

$$TC_{j,k} = (CF_j + CF_k)(abs(x_j - x_k)) + abs(y_j - y_k)) \ \ \forall \ \ j,k \in N \tag{9}$$

Objective Function Calculation

This equation is used to calculate total cost of electrification of all villages, which is objective function of and is to be minimised. This can be calculated as sum of costs of installing all plants (Eqn.10),cost of transporting of electricity from source j to village k if they are connected for all villages (Eqn.11) and cost of providing raw material to each source village based on plant's raw material demand(Eqn.12).

$$OBJ = \sum_j X_j IC_j + \sum_j \sum_k TC_{j,k} Y_{j,k} \quad (10)$$

$$+ \sum_j R_j RMTCost_j \ \forall \ j,k \in N \quad (11)$$

IV. Computational Example:

In this section, a power grid optimization problem is solved to demonstrate the effectiveness of the proposed approach. This example is implemented with GAMS 43.1.0 using GAMS studio 42 on a Windows 11 workstation and is solved with the non-linear solver DICOPT.

Example

In this example, a power grid optimization problem is solved which involves 60 villages that must be electrified. Each village has installation cost based on availability of land and other resources, cost factor, raw material transport cost based.on it's location.Each village has house count i.e. number of houses in village.Thus we have following data:

N = 60;
$MaxPlants$ = 5;
$MinPlants$ = 1; ensuring atleast 1 plant is built so that villages get electrified
$MaxProd$ = 1200;
$Rawmat$ = 0.5;
$HConsump$ = 0.3;

Other data are given in Table I. The transportation cost of electricity between two villages can be calculated in MATLAB using Equation 9.

TABLE I
SURVEY DATA ABOUT VILLAGES

Village	x	y	IC	HC	RMTCost	CF
1	84	21	43152	334	326	47
2	145	83	48929	283	242	48
3	1	139	45779	312	351	44
4	61	83	41840	228	213	41
5	30	10	47880	239	252	33
6	19	108	46120	360	361	39
7	38	133	40539	394	238	37
8	70	103	44202	262	328	34
9	80	189	46791	339	305	42
10	108	118	49186	376	385	36
11	84	181	40004	379	252	49
12	138	28	49768	217	213	49
13	41	28	43766	207	347	35
14	176	162	49738	234	355	32
15	6	80	46047	376	382	34
16	135	34	48289	219	387	40
17	84	186	45747	284	202	45
18	112	70	46281	392	247	34
19	29	151	42856	307	323	35
20	40	146	45868	339	390	47
21	161	177	47500	263	390	38
22	194	125	48583	337	311	42
23	63	151	47551	367	384	34
24	139	70	46981	203	328	32
25	176	54	48645	350	278	40
26	179	180	43227	398	297	40
27	18	86	46708	350	321	33
28	8	193	44509	256	310	43
29	34	133	43821	358	386	41
30	176	125	44108	220	384	43
31	20	23	44015	290	279	33
32	85	190	43174	382	393	45
33	192	90	46219	259	234	34
34	107	116	44302	257	225	40
35	139	82	49738	226	227	46
36	64	48	46778	203	301	30
37	138	181	41985	336	204	36
38	167	115	44267	242	390	48
39	4	1	43433	253	366	47
40	151	124	47977	298	203	41
41	198	66	48800	210	235	48
42	150	106	49039	315	266	49
43	57	178	46627	229	226	47
44	158	72	42702	318	362	47
45	21	182	42523	340	269	32
46	90	125	48549	220	388	43
47	182	4	45277	283	316	44
48	59	186	48022	339	376	42
49	58	139	45725	283	369	46
50	27	200	47332	210	381	30
51	4	35	45190	307	292	46
52	136	28	47709	333	309	45
53	43	187	45689	303	360	35
54	54	140	44657	389	257	35
55	99	14	43427	317	298	43
56	11	152	40682	381	320	37
57	115	151	43779	227	203	46
58	30	185	40796	227	319	39
59	118	143	49829	362	287	46
60	140	25	41816	279	362	50

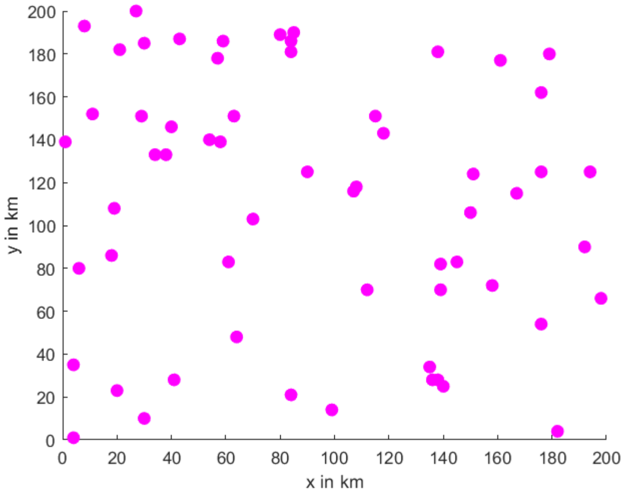
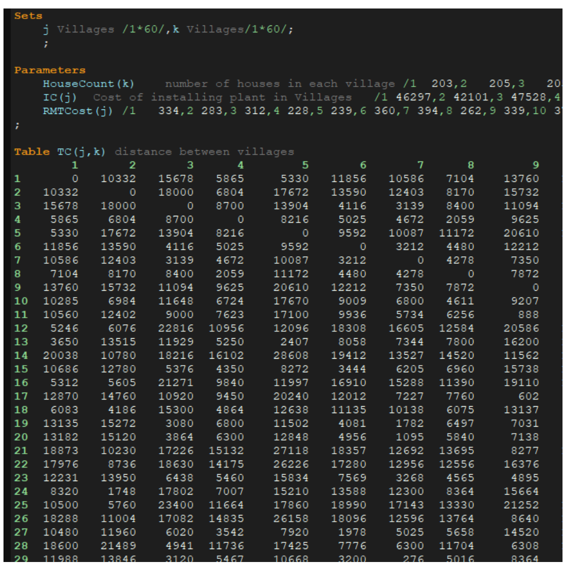


Fig. 1. Locations of Villages on grid

Solution

The GAMS (General Algebraic Modelling System) code for the example can be done as follows:

Fig.2 describes creation of sets j and k for village indices,



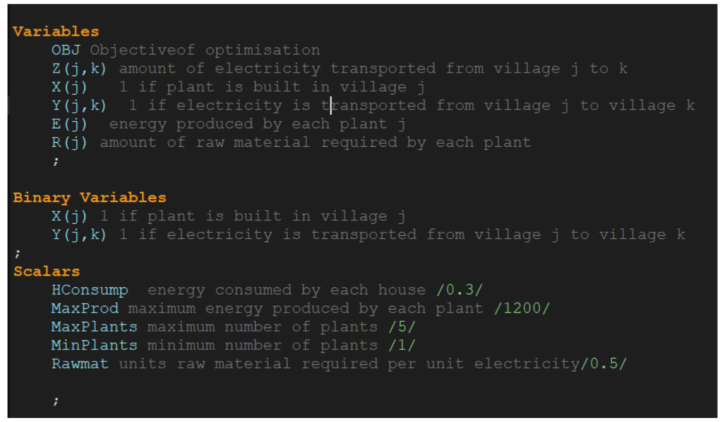
```
Sets
    j Villages /1*60/,k Villages/1*60/;
    ;

Parameters
    HouseCount(k)    number of houses in each village /1  203,2   205,3   20
    IC(j)  Cost of installing plant in Villages   /1 46297,2 42101,3 47528,4
    RMTCost(j) /1   334,2 283,3 312,4 228,5 239,6 360,7 394,8 262,9 339,10 3
;

Table TC(j,k) distance between villages
        1       2       3       4       5       6       7       8       9
1       0   10332   15678    5865    5330   11856   10586    7104   13760
2   10332       0   18000    6804   17672   13590   12403    8170   15732
3   15678   18000       0    8700   13904    4116    3139    8400   11094
4    5865    6804    8700       0    8216    5025    4672    2059    9625
5    5330   17672   13904    8216       0    9592   10087   11172   20610
6   11856   13590    4116    5025    9592       0    3212    4480   12212
7   10586   12403    3139    4672   10087    3212       0    4278    7350
8    7104    8170    8400    2059   11172    4480    4278       0    7872
9   13760   15732   11094    9625   20610   12212    7350    7872       0
10  10285    6984   11648    6724   17670    9009    6800    4611    9207
11  10560   12402    9000    7623   17100    9936    5734    6256     888
12   5246    6076   22816   10956   12096   18308   16605   12584   20586
13   3650   13515   11929    5250    2407    8058    7344    7800   16200
14  20038   10780   18216   16102   28608   19412   13527   14520   11562
15  10686   12780    5376    4350    8272    3444    6205    6960   15738
16   5312    5605   21271    9840   11997   16910   15288   11390   19110
17  12870   14760   10920    9450   20240   12012    7227    7760     602
18   6083    4186   15300    4864   12638   11135   10138    6075   13137
19  13135   15272    3080    6800   11502    4081    1782    6497    7031
20  13182   15120    3864    6300   12848    4956    1095    5840    7138
21  18873   10230   17226   15132   27118   18357   12692   13695    8277
22  17976    8736   18630   14175   26226   17280   12956   12556   16376
23  12231   13950    6438    5460   15834    7569    3268    4565    4895
24   8320    1748   17802    7007   15210   13588   12300    8364   15664
25  10500    5760   23400   11664   17860   18990   17143   13330   21252
26  18288   11004   17082   14835   26158   18096   12596   13764    8640
27  10480   11960    6020    3542    7920    1978    5025    5658   14520
28  18600   21489    4941   11736   17425    7776    6300   11704    6308
29  11988   13846    3120    5467   10668    3200     276    5016    8364
```

Fig. 2. Code Part 1

declaration of parameters IC_j,HC_k and $RMTCost_j$ along with their values.Table $TC_{j,k}$ is declared by calculating transportation cost using eqn. 9.



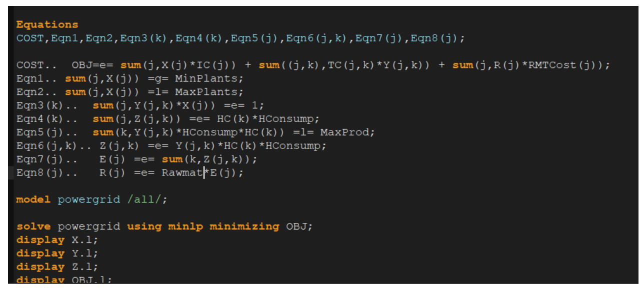
```
Variables
    OBJ Objectiveof optimisation
    Z(j,k) amount of electricity transported from village j to k
    X(j)   1 if plant is built in village j
    Y(j,k)  1 if electricity is transported from village j to village k
    E(j)  energy produced by each plant j
    R(j) amount of raw material required by each plant
    ;

Binary Variables
    X(j) 1 if plant is built in village j
    Y(j,k) 1 if electricity is transported from village j to village k
;
Scalars
    HConsump  energy consumed by each house /0.3/
    MaxProd maximum energy produced by each plant /1200/
    MaxPlants maximum number of plants /5/
    MinPlants minimum number of plants /1/
    Rawmat units raw material required per unit electricity/0.5/

    ;
```

Fig. 3. Code Part 2

Fig.3 describes declaration of variables,binary variables and scalars along with their given values.



```
Equations
COST,Eqn1,Eqn2,Eqn3(k),Eqn4(k),Eqn5(j),Eqn6(j,k),Eqn7(j),Eqn8(j);

COST..  OBJ=e= sum(j,X(j)*IC(j)) + sum((j,k),TC(j,k)*Y(j,k)) + sum(j,R(j)*RMTCost(j));
Eqn1.. sum(j,X(j)) =g= MinPlants;
Eqn2.. sum(j,X(j)) =l= MaxPlants;
Eqn3(k)..   sum(j,Y(j,k)*X(j)) =e= 1;
Eqn4(k)..   sum(j,Z(j,k)) =e= HC(k)*HConsump;
Eqn5(j)..   sum(k,Y(j,k)*HConsump*HC(k)) =l= MaxProd;
Eqn6(j,k).. Z(j,k) =e= Y(j,k)*HC(k)*HConsump;
Eqn7(j)..    E(j) =e= sum(k,Z(j,k));
Eqn8(j)..    R(j) =e= Rawmat*E(j);

model powergrid /all/;

solve powergrid using minlp minimizing OBJ;
display X.l;
display Y.l;
display Z.l;
display OBJ.l;
```

Fig. 4. Code Part 3

Fig.4 describes equations mentioned int mathematical model section and hence problem is solved using MINLP in GAMS. On running GAMS file we get output as indexes of villages where plants to be built and total cost of installation and connection. Villages where plants to be built are 6,7,9,13 and 16. Also connections to be made between villages can also be decided from output of vector Y_j.Total cost of electrification is obtained as objective of model.We get the following result:

TABLE II
SOURCE AND VILLAGES TO BE CONNECTED

Source	Village to be connected
6	3,6,27,28,45,56
7	10,19,20,22,23,28,30,34,40,4649,54,58,59
9	9,11,14,17,21,26,32,37,43,48,50,53,57
13	1,4,5,7,8,13,15,18,31,36,39,51,55
16	2,12,16,24,25,33,35,38,41,42,44,47,52,60

V. CONCLUSION

In conclusion, the power grid optimization model developed in GAMS has been successful in addressing the challenge of providing electricity to all villages in Assam in a cost-effective manner. The results obtained from the model provide a valuable insight into the most cost-effective method for electrifying villages in Assam. The model can be used by the Assam Electricity Board to make informed decisions and optimize their resources to provide electricity to all villages in the state. Overall, the power grid optimization model developed in this report highlights the potential of using mathematical modeling and optimization techniques to address complex problems in the energy sector. The results obtained demonstrate the effectiveness of the MILP model in GAMS for solving optimization problems and can be extended to other similar problems in the future.

VI. Further Improvements

Based on the power grid optimization model developed for providing electricity to all villages in Assam, there are several possible improvements that could be made:

Renewable energy sources: The model currently only considers traditional power sources, such as thermal or hydroelectric power. Incorporating renewable energy sources, such as solar or wind power, could provide a more sustainable and eco-friendly solution.

Incentivize electrification: Incentives could be provided to villagers and communities to encourage them to opt for electrification through a chain of connections, rather than building power plants in every village. This could help reduce costs and make the project more feasible.

Data refinement: The model relies heavily on accurate data inputs, such as the distances between villages and the cost of establishing connections. More accurate and comprehensive data could improve the accuracy and efficiency of the model.

VII. Acknowledgment

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