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Novel Distribution System Planning by Graph Theory Max-flow Min-Cut Algorithm with DG

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Abstract

Power system operation aims to meet the electricity demand at all the locations within power network as economically and reliably as possible. Conventional power system planning operation is based on centralized utility control. Optimal planning of DG for a distribution system is a crucial factor to achieve the benefits. DG may degrade the performance of the distribution system, if not planned properly. Therefore, in this paper, attempts have been made to develop some methodologies, which will be helpful for integrating DG into the existing electric power distribution systems and maximum power flow from source to destination with max-flow min-cut algorithm. The power flow should be not more than the capacity of the distribution line, hence max-flow min-cut theorem tells us that the value of flow and the capacity of the source to sink cut are both optimal in this network. Outflow from source node is equal to inflow in sink node indicates maximum flow in the network with minimum capacity of edges. The max-flow problem and min-cut problem can be formulated by Network optimization is a special type of linear programming model. This algorithm in implemented on IEEE-5 and IEEE-14 bus system using MATLAB graph theory function to validate the results.

Keywords: *Distribution system planning, Max-flow min-cut theorem, Maximum power flow*

I. INTRODUCTION

In optimization theory, the maximum flow problem is to find a feasible flow through a single source, single-sink flow. The maximum flow problem can be seen as a special case of more complex network flow problems, such as the circulation problem. The maximum value of an s-t flow is equal to the minimum capacity of an s-t cut in the network, as stated in the max-flow min-cut theorem. The max-flow min-cut theorem states that in a flow network, the maximum amount of flow passing from the source to the sink is equal to the minimum capacity which when removed in a specific way from the network causes the situation that no flow can pass from the source to the sink.

A. Network graph:

A network or graph consists of points, and lines connecting pairs of points. The points are called Nodes or vertices. The lines are called arcs. The arcs may have a direction on them, in which case they are called directed arcs. If an arc has no direction, it is often called an edge. If all the arcs in a network are directed, the network is a directed network. If all the arcs are undirected, the network is an undirected network. Two nodes may be connected by a series of arcs. A path is a sequence of distinct arcs (no nodes repeated) connecting the nodes. A directed path from node i to node j is a sequence of arcs, each of whose direction (if any) is towards j. An undirected path may have directed arcs pointed in either direction. A path that begins and ends at the same node is a cycle and may be either directed or undirected.

A network is connected if there exists an undirected path between any pair of nodes. A connected network without any cycle is called a tree, mainly because it looks like one. Another type of model again has a number on each arc, but now the number corresponds to a capacity. This limits the flow on the arc to be no more than that value that is weighted graph For instance, in a distribution system,

B. Theory:

Let N = (V,E) be a network (directed graph) with and being the source and the sink of respectively. The capacity of an edge is a mapping $c: E \rightarrow R+$, denoted by C_{uv} or $C(u,v)$. It represents the maximum amount of flow that can pass through an edge.

A flow is a mapping $f: E \rightarrow R+$, denoted by $\boldsymbol{f}_{uv}$ or $\boldsymbol{f}\,(u,v)$, subject to the following three constraints:

1) The flow along an edge $f(u,v) \leq c(u,v)$ otherwise the edge will overflow.

2) The flow along one direction say $f(u,v)=-f(v,u)$ which is the opposite flow direction.

3) Flow must be conserved across all vertices other than the source and sink, $\Sigma f(u,v) = 0$ for all $(u,v) \in V - \{S,T\}$.

Augmenting path and residual graph are two very important parameters of the maxflow Problem. An augmenting path is a simple path — a path that does not contain Cycles. Given a flow network $G(V,E)$, and a flow $f(u,v)$ on G, we define the residual graph R with respect to $f(u,v)$ as follows.

1) The node set v of R and G are same.

2) Each edge $e = (u,v)$ of R is with a capacity of $c(u,v) - f(u,v)$.

3) Each edge $e\_ = (v,u)$ is with a capacity $f(u,v)$.

Note that if the edges in the cut-set of C are removed, | f | = 0.

The max-flow problem and min-cut problem can be formulated as two primal-dual linear program.

C. Example:

The figure shows a network having a value of flow of 7. The vertex in source side and the vertices in sink side form the subsets S and T of an s-t cut, whose cut-set contains the dashed edges. Since the capacity of the s-t cut is 7, which is equal to the value of flow, the max-flow min-cut theorem tells us that the value of flow and the capacity of the s-t cut are both optimal in this network. Outflow from source node is equal to inflow in sink node indicates maximum flow in the network with minimum capacity of edges.

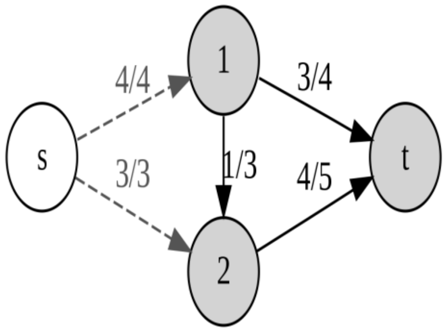


Fig.1: A network with the value of flow equal to the Capacity of an s-t cut

Network optimization is a special type of linear programming model. Network models have three Main advantages over linear programming:

1. They can be solved very quickly. This allows network models to be used in many applications (such as real-time decision making) for which linear programming would be inappropriate.

2. They have naturally integer solutions. By recognizing that a problem can be formulated as a network program, it is possible to solve special types of integer programs without resorting to the ineffective and time consuming integer programming algorithms.

3. They are instinctive. Network models provide a language for talking about problems that is much more instinctive than the variables, objective, and constraints" language of linear and integer programming.

The drawback of this method is that, network models cannot formulate the wide Range of models that linear and integer programs. However, they occur often enough that they form an important tool for real decision making. Associated with the maximum flow is a barrier, a set of arcs whose total capacity equals to the maximum flow and whose removal leaves no path from source to destination in the network. It is actually a significant result to show that the maximum flow equals the size of the minimum Barrier. The maximum flow problem, it considers own in networks with capacities. Like the shortest Path problem, it considers a cost for own through an arc. Like the transportation problem, it allows multiple sources and destinations. The objective is to minimize the total cost of sending the supply through the network to satisfy the demand.

Table-I: Bus data for IEEE-5 Bus system

Bus code p	Assumed bus voltages	Generation		Load	
		Mega watts	Mega VAR	Mega watts	Mega VAR
1	1.06 + j 0.0	0	0	0	0
2	1.0 + j0.0	40	30	20	10
3	1.0 + j0.0	0	0	45	15
4	1.0 + j0.0	0	0	40	5

5	1.0 + j0.0	0	0	60	10

Table-II: Megawatt limit for the branches in IEEE-5 bus system

Line	MW Limit (p.u)
1-2	0.8
1-3	0.3
2-3	0.2
2-4	0.2
2-5	0.6
3-4	0.1
4-5	0.1

II. IEEE-5 BUS SIMULATION

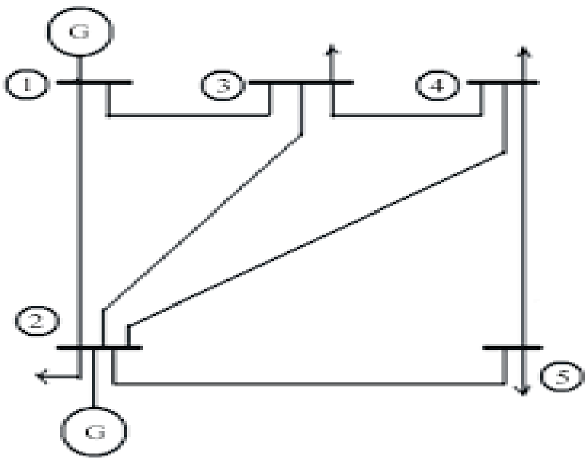


Fig.2: IEEE-5 bus system

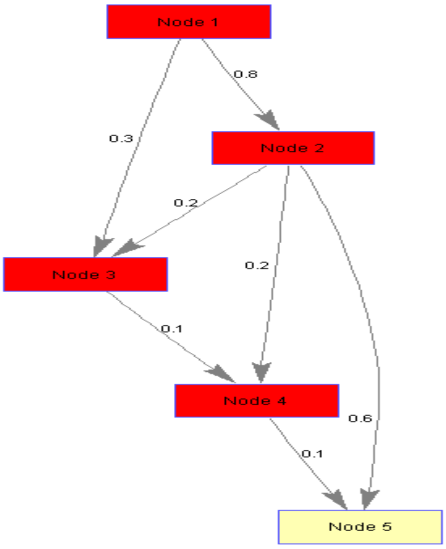


Fig.3: Maximum flow from Node1 to Node 5 simulated network.

```
Biograph object with 5 nodes and 7 edges.

cm =

   (1,2)        0.8000
   (1,3)        0.3000
   (2,3)        0.2000
   (2,4)        0.2000
   (3,4)        0.1000
   (2,5)        0.6000
   (4,5)        0.1000


M =

    0.7000


F =

   (1,2)        0.6000
   (1,3)        0.1000
   (3,4)        0.1000
   (2,5)        0.6000
   (4,5)        0.1000


K =

     1     1     1     1     0

Biograph object with 5 nodes and 7 edges.
```

Fig.4: Maximum flow from Node1 to Node 5 simulated results. Max-flow, Flow matrix and Cut path

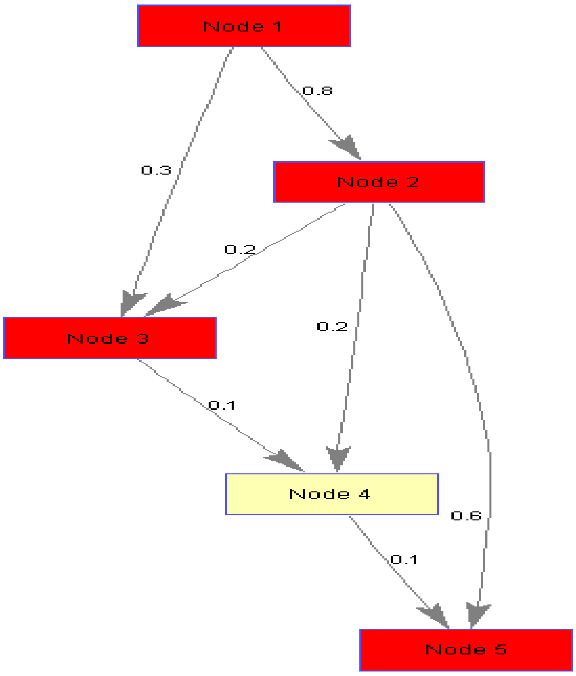
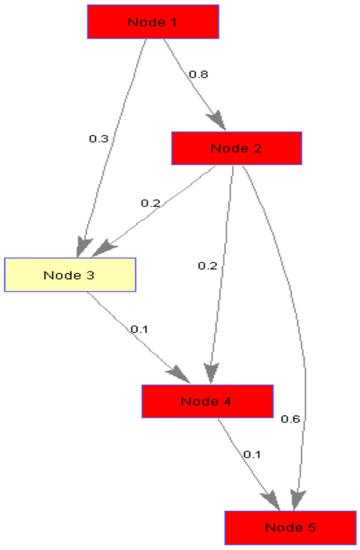


Fig.5: Maximum flow from Node1 to Node 4 simulated network.

```
M =

    0.3000


F =

   (1,2)        0.2000
   (1,3)        0.1000
   (2,4)        0.2000
   (3,4)        0.1000


K =

     1     1     1     0     1

Biograph object with 5 nodes and 7 edges.
```

Fig.6: Maximum flow from Node1 to Node 4 simulated results. Max-flow, Flow matrix and Cut path

M= MaxFlow, F= Flow Matrix, K= cut path




```
M =

    0.5000


F =

   (1,2)        0.2000
   (1,3)        0.3000
   (2,3)        0.2000


K =

     1     1     0     1     1

Biograph object with 5 nodes and 7 edges.
```

Fig.7: Maximum flow from Node1 to Node 3 simulated network and results

III. IEEE 5 BUS SIMULATION RESULTS

Table-III: Maximum flow simulation results

Lines	**Maximum flows**
1-5	0.7
1-4	0.3
1-3	0.5
2-5	0.7
…	…

IV. IEEE 14 BUS SYSTEMS SIMULATION

Table-IV IEEE 14 bus data

Line	Megawatts limits
1-2	0.6
2-3	0.7
2-4	0.8
1-5	0.5
2-5	0.4
3-4	0.3
4-5	0.2
5-6	0.5
4-7	0.4
7-8	0.2
4-9	0.2
7-9	0.2
9-10	0.2
6-11	0.3
6-12	0.2
6-13	0.2
9-14	0.2
10-11	0.2
12-13	0.2
13-14	0.2

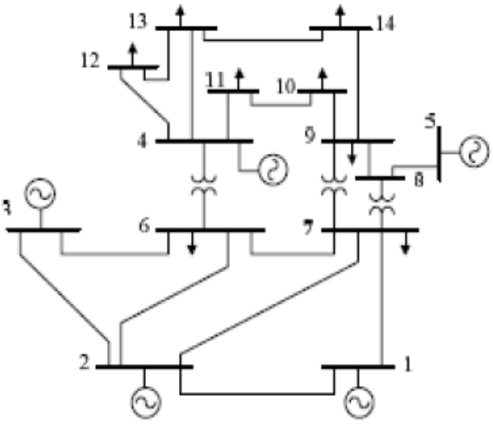


Fig.7: IEEE-14 Bus System

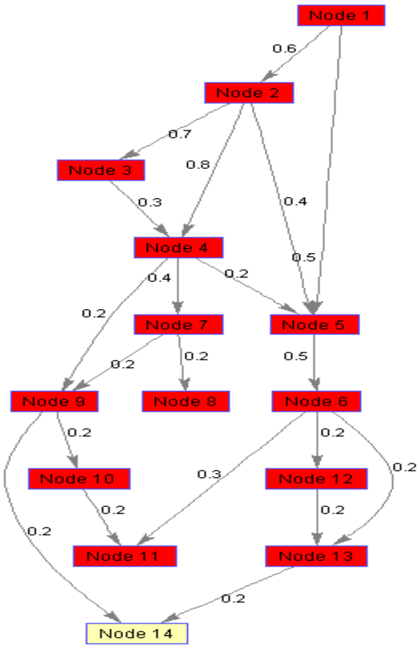


Fig.8: Maximum flow from Node1 to Node 14 simulated network

(1,2)	0.6000
(2,3)	0.7000
(2,4)	0.8000
(3,4)	0.3000
(1,5)	0.5000
(2,5)	0.4000
(4,5)	0.2000
(5,6)	0.5000
(4,7)	0.4000
(7,8)	0.2000
(4,9)	0.2000
(7,9)	0.2000
(9,10)	0.2000
(6,11)	0.3000
(10,11)	0.2000
(6,12)	0.2000
(6,13)	0.2000
(12,13)	0.2000
(9,14)	0.2000
(13,14)	0.2000

```
M =

    0.4000


F =

   (1,2)       0.2000
   (2,3)       0.2000
   (3,4)       0.2000
   (1,5)       0.2000
   (5,6)       0.2000
   (4,7)       0.2000
   (7,9)       0.2000
   (6,13)      0.2000
   (9,14)      0.2000
  (13,14)      0.2000


K =

     1     1     1     1     1     1     1     1     1     1     1     1     1     0

Biograph object with 14 nodes and 20 edges.
```

Fig.9: Maximum flow from Node 1 to Node 14 simulated Results Max-flow, Flow matrix and Cut path

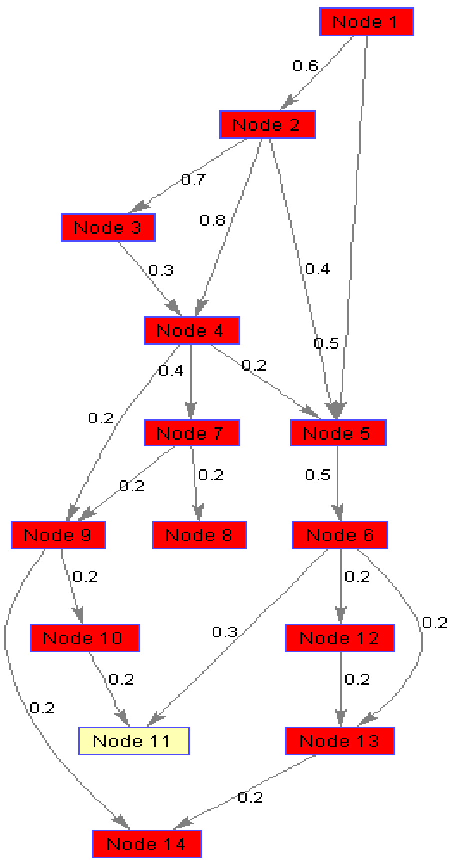


Fig.10: Maximum flow from Node1 to Node 11 simulated network

```
M =

    0.5000


F =

   (1,2)       0.2000
   (2,3)       0.1000
   (2,4)       0.1000
   (3,4)       0.1000
   (1,5)       0.3000
   (5,6)       0.3000
   (4,7)       0.2000
   (7,9)       0.2000
   (9,10)      0.2000
   (6,11)      0.3000
  (10,11)      0.2000


K =

     1     1     1     1     1     1     1     1     1     1     0     1     1     1
     1     1     1     1     1     1     1     1     1     0     0     1     1     1
```

Fig.11: Maximum flow from Node1 to Node 11 simulated Results Max-flow, Flow matrix and Cut path

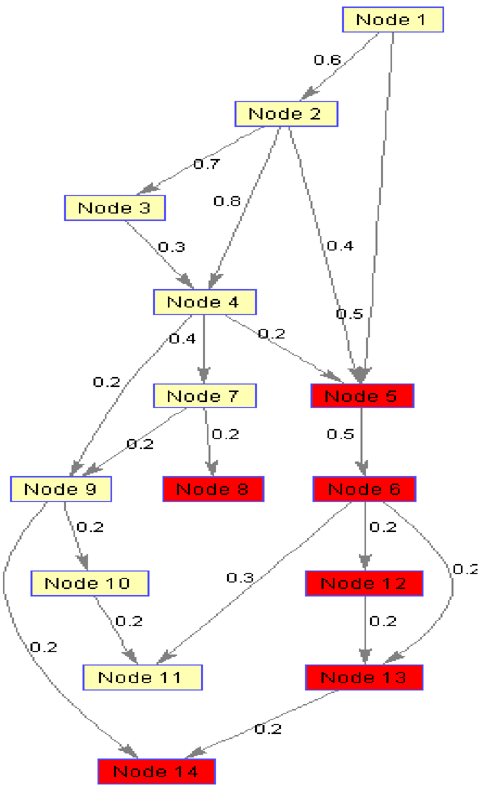


Fig.12: Maximum flow from Node 5 to Node 11 simulated network

```
M =

    0.3000


F =

   (5,6)       0.3000
   (6,11)      0.3000


K =

     0     0     0     0     1     1     0     1     0     0     0     1     1     1
     0     0     0     0     1     1     0     0     0     0     0     1     1     1

Biograph object with 14 nodes and 20 edges.
```

Fig.13: Maximum flow from Node 5 to Node 11 simulated Results Max-flow, Flow matrix and Cut path

V. IEEE 14 BUS SIMULATION RESULTS

Line	Maximum flow
1-14	0.4
1-11	0.5
1-8	0.2
2-8	0.2
2-11	0.5
5-14	0.2
5-11	0.3
…	…

CONCLUSION

This paper presents the use of Max-flow min-cut algorithm to find the maximum power flow in the distribution with DG. The power flow should be not more than the capacity of the distribution line, hence max-flow min-cut theorem tells us that the value of flow and the capacity of the source to sink cut are both optimal in this network. Outflow from source node is equal to inflow in sink node indicates maximum flow in the network with minimum capacity of edges. This is implemented on the IEEE-5 and 14 bus system and find that Max-flow, Flow matrix and cut path of the network.

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