Distribution Network Reconfiguration For Loss Reduction Using Ant Colony System Algorithm

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***Abstract* - In Electrical Power System, Network reconfiguration for loss reduction in distribution systems is very important way to save energy. But due to its nature it is inherently a difficult optimization problem. Distribution system reconfiguration for loss reduction is being applied using Ant Colony System Algorithm where in, the behavior of the real ants is developed into a series of steps which find most efficient in the network reconfiguration. Ants of the artificial colony are able to search for the successively shorter feasible routes by using information accumulated in the form of a pheromone trail deposited on the edges of their traveling path. In this work we make use of conventional distribution system load flow algorithm to check the constraints.**

Power flow constraints, the voltage deviation and the power transferred through the line should be met. A distribution network consisting of 14-bus system with three feeders, 19-branches and 11-load centers from Tamil Nadu Electricity Board (TNEB) is taken as case study. The results outstand positively forming an optimal network.

***Keywords* - Distribution Networks, Ant Colony System, Reconfiguration.**

I. Introduction

Network reconfiguration for loss reduction in distribution systems is a very important way to save energy. However, due to its nature it is inherently an optimization problem. Distribution systems are critical links between the utility and the customer, in which sectionalizing switches are used for both protection and configuration management. Recent studies indicate that up to 13% of the total power generation is wasted in the form of line losses at the distribution level [3]. Hence, it is of great benefit to investigate methods for network reconfiguration. The objective of network reconfiguration is to reduce power losses and improve the reliability of power supply by changing the status of existing sectionalizing switches and ties.

Distribution system reconfiguration for loss reduction was first proposed by Merlin et al [3] They employed a blend of optimization techniques and heuristics to determine the minimal- loss operating configuration. For the distribution system represented by a spanning tree structure at a specific load condition. Since then, many techniques have been proposed provides a survey of the state of the art in distribution system reconfiguration for system loss reduction.

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II. Ant System

The behavior of the ants has inspired the development of a new approach of optimization for any problem. Ants are the insects which has no eye sight by nature. But they communicate with other ants by secreting the chemical substance which are known as pheromones. This pheromone liberated by one ant is used as the guide for other ants of the colony. The pheromones have the property of evaporating after some period of time. The pheromone laid by ants is used as the main guide function for the ants. The ants are also tend to follow the path which has more pheromones [1].

The behavior of the ants with above nature is shown in fig1. Initially the ants move in the straight path AE for food collection. When an obstruct is placed in that straight line the ants have to take any one side to go to the nest. Let us assume the obstruct be HC. So the ants at the position B from A (i.e.) food source, to the nest E have to decide whether to turn right or left.

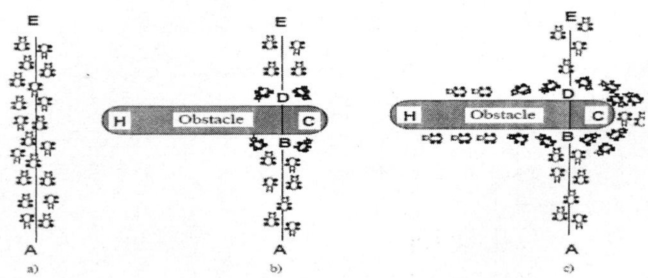

Fig.1. Behavior of Ants to find optimal path

Initially some ants will move to the right and some to the left, BH and BC respectively. But after some time the path BC will have more pheromones and all the ants will move in the path ABC. As the ants from B to reach D through C will reach quicker than that of the ants through H (i.e.) BHD. Hence ant at D from E will find pheromone a path DCBA and will go

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through it. Hence the magnitude of pheromone at that path will increase further. Similarly all ants will take that path.

Suppose the distance between DH and BH be 1 and the distance between CD and BC be 0.5. Also consider 30 ants from food source A and 30 ants from nest E as shown in fig2. At time t=0 there is no pheromone in both the path DH and DC and hence the ants are equally shared in each path (i.e.) 15 ants through DH and 15 ants through DC. Since the distance between DC and BC is 0.5 the 15 ants from B will reach D and vice versa at the time t=1 but ants through H will be on half the way. So the path DCB have a definite pheromone intensity and further ants will move in that way (i.e.) ants waiting at D and B will go through this way. As a result at time t=1, 20 ants will be moving from D to C and B to C and 10 ants from D and H and B and H as the intensity of the pheromone are by 30 and 10 ants.

The probability of selecting the path for any ant will be given as

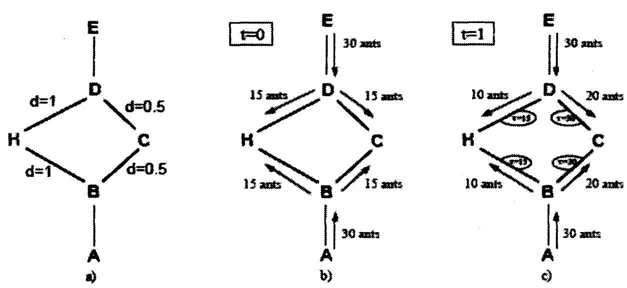

Fig 2 Principle of Ant System

$$P_k(i,j) = \frac{[\tau(i,j)]^{\alpha}\,[\eta(i,j)]^{\beta}}{\sum_{u \in \text{allowed}} [\tau(i,j)]^{\alpha}\,[\eta(i,j)]^{\beta}}$$

$\tau(i, j)$ shows the amount of pheromones in the path between points i and j

$\eta(i, j)$ is the factor indicates the relation of the objective function of any problem with the probability of that path.

The ant colony system is the advanced version of the Ant System(AS). This Ant Colony System (ACS) differs from ant system in the process of updating the pheromone in each path[2]. The Ant Colony System (ACS) which uses this local pheromone revision rule converges quickly compared with the Ant System (AS) algorithm. This is because the pheromone intensity is updated after every transition of the ants from one point to the other. As a result of this the ant was able to find the shortest path as it starts the search for next point itself. The optimal path will get a rapid increase in the pheromone intensity. The optimal path was found out quickly and the solution for the problem converges quickly.

The *local pheromone revision rule* is given by the formula

$$\tau(r,s) = (1-\rho)\,\tau(r,s) + \rho\,\tau_0\,;$$

where $\tau_0 =$ minimum pheromone level.

III. Problem Formulation

The main objective of a feeder reconfiguration is to find the network which is having economical losses during any undesirable condition that exist in the network.

Therefore the probability (P^k_{ij}) between node i and j depends on two functions intensity of the Pheromone $\hat{O}_{ij}$ and Heuristic function $\c{C}_{ij}$ which is taken as a function which is inversely proportional to the power loss ($Ploss_{ij}$) between node i and j

$$\eta_{ij} \;\; \alpha_1 / Ploss_{ij}$$

Therefore the probabilistic function is expressed as follows

$$P_{ij}^{k}(t) = \frac{[\tau_{ij}(t)]^{\alpha} * [\eta_{ij}]^{\beta}}{\sum_{k \in \text{allowed}} [\tau_{ik}(t)]^{\alpha} * [\eta_{ik}]^{\beta}} \quad \text{if } j \in \text{allowed}$$

$$= 0 \quad \text{otherwise}$$

IV. Constraints

i Operating voltage at each node must be in its safety range

$$V_i^{min} <= V_i <= V_i^{max}$$

ii) Power flow at each node must be kept in balance and power flow at each branch must be less than or equal to its maximum capacity

$$S_i <= S_i^{max}$$

iii) Load center (node) must not be isolated with out supply from any feeder.

V. Algorithm

Step 1 : Initialization. Set time, t=0; Cycles NC=0; Pheromone intensity in each branch is set initially to a constant value and also the change in pheromone intensity is set to zero $\tau_{ij}(0)=c;\ \Delta\tau_{ij}=0$

Step 2: Get the number of nodes. Place m ants on n nodes and store the starting node of each ant in the Tabu list (i.e) Tabu (1,m) for all m ants

Step 3: Calculate Power loss between two nodes i & j using the formula

$$\text{Ploss} = \sum_{j=1}^{N} \sum_{j=n_i}^{1} (r_{j-1,j}) [(P_j^2+Q_j^2) / (V_j^2)]$$

n_i = Number of nodes in the i^{th} feeder.
$r_{j-1,j}$ = Resistance in ohms.
P_j & Q_j = Power flow in the branches.
V_j = Voltage at the node j.
N = Number of feeders.

Step 4: Calculate the probability for the ants to move to the next node for all possible paths. The probability of transition of ants from node i to node j is given by

$$P_{ij}^k(t) = \frac{[\tau_{ij}(t)]^\alpha * [\eta_{ij}]^\beta}{\sum_{k \in \text{allowed}} [\tau_{ik}(t)]^\alpha * [\eta_{ik}]^\beta} \quad \text{if } j \in \text{allowed}$$

$$= 0 \quad \text{otherwise}$$

Table I: Network Data

Start bus	End bus	V p.u	R p.u	X p.u	P MW	Q MVAR
1	4	1	0.0055	0.028	121	73
4	3	1	0.0098	0.05	0	0
1	3	1	0.011	0.056	0	0
1	5	1	0.010	0.054	89	53
5	6	1	0.0062	0.032	120	72
6	7	1	0.019	0.097	86	52
7	8	1	0.019	0.079	94	56
7	9	1	0.019	0.101	67	40
9	10	1	0.009	0.046	94	56
10	11	1	0.0091	0.046	110	65
11	2	1	0.0084	0.043	0	0
2	12	1	0.0068	0.035	109	65
2	8	1	0.023	0.118	94	56
8	3	1	0.0132	0.067	0	0
6	12	1	0.014	0.072	109	65
12	13	1	0.007	0.037	120	72
13	3	1	0.007	0.036	0	0
3	14	1	0.0027	0.013	46	28
3	12	1	0.0039	0.02	109	65

Enter the node j which is the transition of the ant from node i in the second row of the Tabu list. (i.e.) in Tabu(2,k) Similarly, transition is made for all the nodes.

Step 5: The network combination is generated with the outage branches and the branches which has minimum probability such that the number of open switches are equal to the number of semi closed switches.

Step 6: Load flow is performed for the radial network generated in order to check the power flow constraints by Gauss-Seidel method. The voltage deviation is checked and the maximum power flow is also checked, given by the formula.

$$S_i < S_{max} \qquad (i=1,2,\ldots..n)$$
$$V_i^{min} <= V_i <= V_i^{max} \qquad (i=1,2,\ldots..n)$$

If the network satisfies the load flow constraints, then go to next step, otherwise go to step 5 and obtain the next combination.

Step 7: The pheromone intensity in each branch is updated using Global Pheromone Revision Rule.

$$\tau_{ij}(t+n) = \rho\ \tau_{ij}(t) + \Delta\tau_{ij}(t).$$
where, $$\Delta\tau_{ij} = \Delta\tau_{ij} + \Delta\tau_{ij}^k(t)\ ;$$

$$\Delta B\tau_{ij}^k(t) = Q / \text{Ploss}_{ij}$$
$$= 0 \quad \text{otherwise}$$

if (i,j) $\in$ tour described by tabu_k due to addition of pheromones by all the ants that takes that path.

The first term in the formula explains the effect of evaporation rate on the pheromone intensity and the second term explains change in pheromone intensity

Step 8: If the number of cycle is less than the maximum number of cycles ($NC < NC_{max}$).Clear the Tabu list, go to step 2 otherwise go to next step.

Step 9: Store the obtained optimal network that satisfies the radial and load flow condition.The optimal network is chosen by the ants depending on the probabilities for the branches.

Step 10: Calculate the total power loss for the obtained network and store the result corresponding to optimal network obtained.

V. Case Study

A real case of 230 kV Transmission line system is taken as a case study from Tamil Nadu Electricity Board (TNEB). The network is shown in the fig. It consists of 3-Generating Stations, 19-Tansmission Lines and 11-Sub-Stations (fig 3). The Transmission Network data are shown in the Table 1.

The Transmission lines are represented by S0,S1,S3......S18.Generating Stations are represented by 1,2,3 and Sub-Stations are represented by 4,5,6,....14. When any Transmission line fails to transmit the power to their corresponding Sub-Station due to some disturbances that occur in the power system, the load does not get satisfied in that Sub-Station. Under these circumstances the network has to be reconfigured with the objective of loss reduction.

Normally the status of the Transmission lines in the system is represented by a binary control parameter 0 or 1. If it is 1 it represents closed condition and if it is 0 it represents open condition. When a Transmission line supplying a particular Sub-Station gets opened due to any disturbances, it will cause the overloading the other Transmission lines supplying that particular Sub-Station.

The Transmission line feeding the corresponding Sub-Station (8) is considered to be opened due to some disturbances. Under this condition, it violates the power flow constraints in the other transmission lines feeding the sub – station (8). The reconfigured network using ACS algorithm with minimum loss which satisfies the constraints is shown in the table II.

Table II: Optimal Network Searched By ACS Algorithm :

System Status	Status of Sectionalizing Switches and Ties																			Power Loss (MW)
Original	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	
Network	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.464
Optimal Network	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	9.374
(case 1)	1	1	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	
Optimal Network	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	8.278
(case 2)	1	0	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	

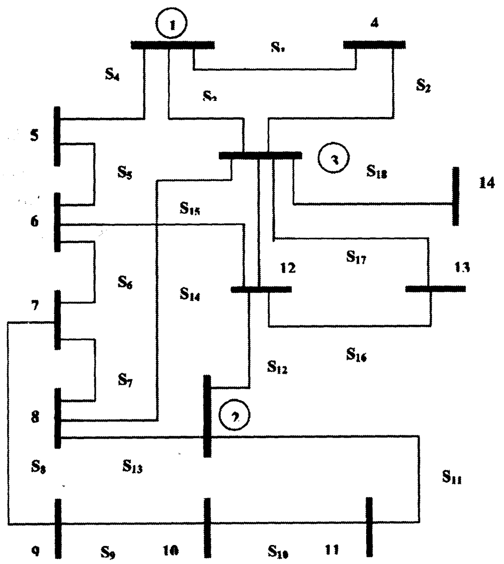

Fig.3. 14 –Bus , 19 – Branches TNEB System

VI. CONCLUSION

A new methodology, based upon the Ant Colony System (ACS) algorithm, is proposed for the reconfiguration of electric energy distribution systems. The methodology is very flexible and finds the optimal network with lower transmission losses while enforcing the technical constraints such as the transmission capabilities and the limits on voltage magnitudes.

The ACS methodology has the following characteristics like Positive feedback, Distributed computation, Greedy heuristic which makes the ACS algorithm to be the best suitable method for network reconfiguration. Since the algorithm involves a probability based search, the decision for the ants is made simple. Computer simulations are run for ACS algorithm which generates optimal network reliably.

Application of the algorithm to Case study consisting of 14 – bus transmission system with 3 –Generators and 11 sub - stations taken from Tamil- nadu Electricity Board (TNEB) shows better performance of the algorithm with significant reduction in the computational effort, as it searches for the optimal solution in the initial stage of the search process.

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