STATCOM Optimization Using Ant Colony Optimization Technique

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Abstract **- In recent practice, the use of flexible AC Transmission System (FACTS) devices has been proposed for enhancement of power grid protection and control in power system by improving the stability, reduction of losses, and reduction of generation cost and improves the loadability of the system. However, prohibitive cost is major stumbling block for utility company to install more than a few FACTS devices on any power grid.**

Low Environmental Impact technologies such as FACTS Devices and DC links provided solution to rapidly enhancing reliability and up-grading transmission capacity on a long term and cost effective basis. This paper presents an Ant Colony Optimization (ACO) algorithm to obtain optimum reactive power dispatch and it is applied to Static Variable Compensator (STATCOM) in order to minimize transmission loss, to improve voltage stability and voltage profile in the system. Ant colony optimization is a technique for optimization which was introduced in the early 1990's. Foraging behavior of ant colonies is exploited for the search of approximate solutions to discrete optimization problems. The proposed technique was tested using the standard IEEE 30-bus system and the results revealed that the proposed technique has the merit of achieving optimal solution in addressing the problem.

Keyword – Voltage profile, STATCOM, Ant Colony Optimization (ACO) Technique.

INTRODUCTION

Local Utility supply encountered enormous challenge to provide reliable and efficient electricity to residential, commercial and industrial users in the digital era. Lengthy delay to complete construction of transmission line, cost and regulatory uncertainty have resulted serious deficiency in power transmission capacity.

Increased in electric power consumption causes transmission line to be driven closed or beyond their transfer capabilities resulting the transmission line becomes overloaded and congested.

A recent concern about power quality has forced engineers to incorporate system voltage profile, transmission loss minimization in addition to economic criterion when designing transmission line. Power loss in transmission line causes loss of revenue due to increased generation capacity requirement. Transmission systems must be flexible to react to more diverse generation and load patterns.

For system voltage profile, magnitude of bus voltage is specified as voltage control bus and through observation, it is noted that the bus voltage magnitude is controlled by reactive power. Power system controller shall ensure that the Power delivered to consumers is satisfied and voltage at load bus is within specified value. Failure to maintain these requirements may cause equipment breakdowns or overheating. High load demand may lead to voltage collapse. The voltage collapses occur when the system load (P and Q) is increased beyond a certain limit. There are several techniques to control reactive power in the system and one of the methods is applying FACTs devices. The weakest bus of the system shall be identified as voltage stability of the system can be improved by introducing reactive power sources at those buses. Weakest bus of the system is defined as the bus (or substation) that is nearest to experiencing voltage collapse [1]. In emergency condition, load shedding can be applied at weak buses to bring back the system from voltage instability.

In power system, transmission losses is considered a major factor to be considered especially when it is required to transmit electrical energy over long distance or in case of low load density over vast area. The power loss generally represents 20% to 30% of total power generated [2]. The transmission losses in power system networks include line and cable losses, transformer losses and machines losses. Therefore, in a large interconnected network where power is transmitted over long distances with low load density area. Transmission losses increase operating cost of running of power system and it will determine how to operate generating plant. Equipment life span will be reduced because transmission loss is proportionate with thermal or heat generated.

Optimal reactive power dispatch (ORPD) is used to minimize total system transmission loss and improve voltage profile and it is required to determine the optimal values. There are several optimization techniques available to determine the optimal value such as linear and non-linear programming, random walk, quadratic programming and Tabu search. Several artificial intelligent based optimization techniques have been invented in this decade such as Evolutionary Programming (EP), Evolutionary Strategy (ES), Genetic Programming (GP) and Genetic Algorithm (GA) which it were based on the survivor of the fittest. Biological computing technique namely Artificial Immune system (AIS) was invented to solve complex optimization problems[2].

Ant colony optimization is inspired by ant behaviors which ants have indirect communication technique among themselves by means of chemical pheromone trails, which enables them to find short path between their nest and food sources. This kind of behaviors can be utilized to solve discrete optimization problem. ACO is one of most effective technique of swarm intelligence which the swarm intelligent is the design of intelligent multi agents system by taking into consideration collective behavior of social insects such as wasp, ant, flocks of birds or fish schools. ACO algorithm belongs to the class of metaheuristic which originates from Greek words. Meta means "beyond" and heuriskein means "to find". Real ants are capable of finding the shortest possible path from food source to their nest by exploiting pheromone, without using visual cues, as ant is blind. Real ant will deposit pheromone trails on the ground and it will follow pheromone that previously deposited by other ants. For Ant colony Optimization (ACO), a set of artificial ants cooperate in solving a problem by exchanging information via pheromone deposited into the graph. ACO algorithm aims to determine the optimal settings of voltage control variables, generator's outputs, voltages, and STATCOM.

This paper presents STATCOM Optimization Using Ant Colony Optimization Technique for minimizing transmission loss and voltage stability improvement. STATCOM is represented as an equivalent capacitive reactance installed on the transmission line. Results obtained from the experiments indicated that this technique is feasible for loss minimization and voltage stability improvement.

II. STATCOM

The emergence of FACTS devices and in particular gate turn-off (GTO) thyristor based STATCOMs has enabled such technology to be proposed as an alternatives to conventional static var compensators (SVC) using thyristor controlled reactor (TCR) and thyristor switched capacitor (TSC). A STATCOM is a voltage source converter (VSC) which uses power electronic switches to derive approximately sinusoidal output voltage from DC source [D]. The STATCOM is connected to the system via inductive impedance of low per unit value and has similar operating characteristic with synchronous compensator by controlling output voltage to be higher or lower than the system voltage. The STATCOM will draw either inductive or capacitive current from the system. A STATCOM has a natural tendency to compensate rapidly for any changes in system voltage due to its low stored energy. Unlike constant impedance device such as capacitor or inductor whose output will decrease with voltage, the STATCOM can continue generate maximum output current even at low voltage system. The advantage of STATCOM is it utilizes small area and easy to relocate as it size is relatively small. Fig.1 shows STATCOM model as a voltage source converter, which convert DC input voltage into AC output voltage at fundamental frequency in order to compensate the active and reactive power needed by the system [1]

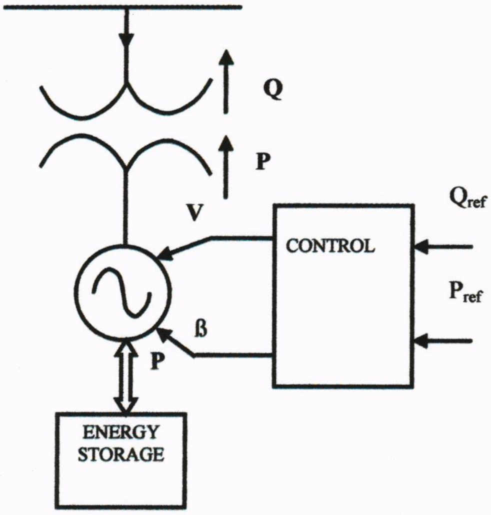

Fig. 1. Generalized Synchronous Voltage Source

Amplitude voltage (V) and phase angle (ß) are controlled by reference signal Q_{ref} and P_{ref} respectively. Varying the amplitude of output voltage can control the reactive power exchange between the inverter and the AC system. If the amplitude of the output voltage is increased above of AC system voltage, the inverter generates reactive power for the AC system. If the amplitude of the output voltage is decreased below that of the AC system, the inverter absorbs the reactive power. The reactive power exchanged is zero if the output voltage is equal.

Altering the phase angle between the inverter output and the AC system voltages will control the real power exchange between the inverter and the AC system. The inverter absorbs real power from AC system, if the inverter output voltage is made to lag the AC system voltage and conversely inverter supplies real power to the AC system if the inverter output is made to lead the corresponding AC voltage.

STATCOM *Architecture*

Basic Statcom consists of step down transformer with leakage reactance X_T, a three phase GTO voltage inverter (VSI) or alternatively known as Voltage Source converter (SVC) [3], and a dc side capacitor. The difference of AC Voltage across X_T produces reactive power exchange between the STATCOM and the power system at the point of interface. The role of STATCOM is to regulate the voltage and consequently to improve the voltage profile of interconnected power system. A secondary damping function can be added to the STATCOM to enhance power system dynamic stability.

The main function of STATCOM is to regulate bus voltage magnitude by dynamically absorbing or generating reactive power to the AC grid network. This reactive power transfer is done through the leakage reactance of the coupling transformer by using a secondary transformer voltage in phase with the primary voltage (network-side). This voltage is provided by voltage source PWM inverter and is always in quadrature to the STATCOM current. The STATCOM operation can be illustrated by the phasor diagram shown in Fig. 2. When the secondary voltage (V_S) is lower than the grid system bus voltage (V_B), the STATCOM acts like inductance absorbing reactive power from grid bus. When the secondary voltage (V_S) is higher than the grid system bus voltage (V_B), the STATCOM acts like capacitance generating reactive power to the grid bus.

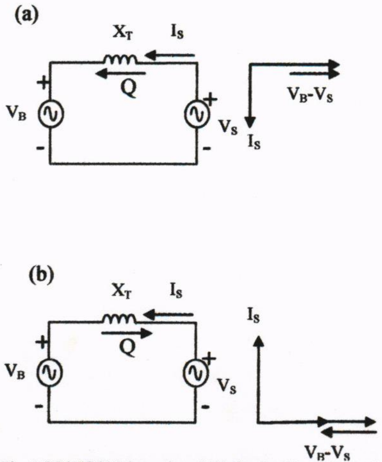

Fig. 2 STATCOM Operation: (a) Inductive Operation and (b) Capacitive Operation

The reactive power transfer is done through leakage reactance of the coupling transformer by using a secondary transformer voltage in phase with primary voltage. This primary voltage is provided by voltage source Pulse Width Modulator (PWM) inverter and it is always in quadrature to the STATCOM current. When the secondary voltage (V_S) is lower than the grid bus voltage system (V_B), the STAT|COM behave like inductance whereby it will be absorbing reactive power from the grid bus.

This is illustrated in figure 2(a). However, when the secondary voltage (V_S) is higher than bus voltage (V_B), the STATCOM will act like capacitor generating reactive power to the grid bus as illustrated in figure 2(b). The voltage source converter or inverter (VSC or VSI) which produces a square voltage waveform as it is switches the direct voltage source on and off is considered as building block of any FACTS devices including STATCOM. The capacitor is used to maintain dc voltage to the VSC, which itself will keep the capacitor charged to the required levels. The capacitor dc voltage can be increased or decreased to control the reactive power output of the devices which will consequently control the SVC voltage to be lead or lag.

When the VSC voltage leads the bus voltage, active power will be supplied to the system by the capacitor, reducing its voltage; on the other hand, when the VSC voltage lags the bus voltage, the capacitor is charged by consuming active power from the system [3]. In steady state operation and due to inverter losses, the bus voltage (V_B) always leads the inverter ac voltage by a very small angle to supply the required small active power losses. An inverter produces a square voltage waveform as it switches the direct voltage source on and off. The objective of VSI-converter is to produce a near sinusoidal ac voltage with minimal wave form distortion or excessive harmonic content.

III. ANT COLONY OPTIMIZATION

The field of "ant's algorithm" studies model was developed from the observation of real ants' behavior. This model was used for the design of novel algorithms for the solution of Optimal Reactive Power dispatch. The ACO methods belong to biologically inspired heuristics (meta-heuristic method) [4]

A. *Development of Algorithm for Ant Colony Optimization*

Ant Colony optimization (ACO) was first developed by Derigo *et al.* Concerning Ant System (AS) approach, the edge of given Travelling salesman problem (TSP), for each of $e_{i,j}$ is introduced into pheromone value $\tau_{i,j}$. The Task of each ant consists in the construction of feasible TSP solution.

The notion of task of ant changes from "choosing a path from the nest to the food sources" to "constructing a feasible solution to the tackled optimization problem".

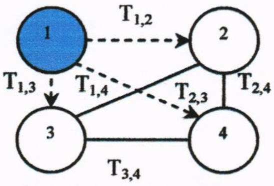

Fig. 3: First step of the solution construction

$$P(e_{1,j}) = \frac{T_{1,j}}{T_{1,2} + T_{1,3} + T_{1,4}} \qquad (1)$$

Where

T is the set of all pheromone values.

Step 1: Solution construction.

Fig. 3 illustrates the solution example for the construction of Travelling Salesman /problem (TSP) consisting of four (4) cities where: -

$$T_{(1,j)} = \frac{P(e_1+j)}{T_{2,3}+T_{2,4}} \qquad (2)$$

$$T_{(1,2)} = \frac{T_{(1,j)}}{P(e_1 \;,j)} - (T_{2,3} + T_{2,4}) \qquad (3)$$

$$T_{(1,3)} = \frac{T_{(1,j)}}{P(e_1 \;,j)} - (T_{1,2} + T_{1,4}) \qquad (4)$$

$$T_{(1,4)} = \frac{T_{(1,j)}}{P(e_1 \;,j)} - (T_{1,2} + T_{1,3}) \qquad (5)$$

The solution construction starts with random selection whereby node 1 is chosen as the start node. Fig. 3 shows the choice of first construction step which the current node of the ant is marked by blue colour.

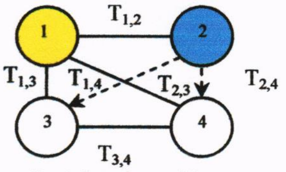

Fig. 4: Second step of the solution construction

$$P(e_{2,j}) = \frac{T_{2,j}}{T_{2,3} + T_{2,4}} \qquad (6)$$

Step 2: The already visited node is marked with yellow color and the current node is marked with blue color. The choice of traverse by ant is marked by dashed lines.

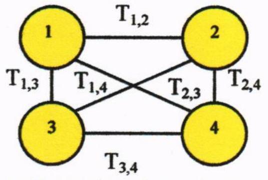

Fig. 5: The complete solution after the final construction step

Step 3: Final Construction Step.

Each ant constructs solution by one of the nodes of the TSP graph is randomly chosen as the start node. The ant moves in each construction steps from its current node to another node which if it has not yet visited.

When no unvisited node are left, the ant closes the tour by moving from her current node to the node which it started the solution construction. It can be proven that the ant foraging behavior can be transferred into an algorithm for discrete optimization.

Further illustrations of the ant behavior are given in the following section.

As illustrated in Fig. 6, let assume that ants want to travel from point A to point E. The following example shows how over time, the shortest paths are found through this self-reinforcing process.

In Fig. 6a), suppose that ants move between food source A to nest E on a straight line. Then, as shown in Fig. 6b), an obstacle suddenly appears and the path was cut-off. At position B, ants have to decide whether to turn left or right.

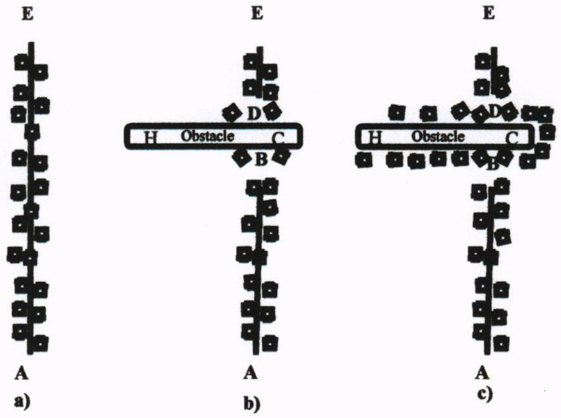

Fig. 6: Ant behavioral at different scenario

Under these circumstances, ants have to decide either to move left (BHD) or right (BCD). Due to shorter path of BCD than BHD, the first ant following path BCD will reach D before the first ant following path BHD. Due to shorter path, which consequently result on more intense of pheromone due to evaporation process, the right path will give information to other ants followers of a higher probability to turn right, as shown in Fig.6b). As explained earlier, the shorter path will collect larger amount of pheromone trail than the longer path. Therefore, more ants will be increasingly guided to move on the shorter path. Eventually, all ants will choose the shortest path in their movement and abandon other longer path.

As indicated in Fig.6c) deposited of pheromone is one of the most important factors for ants to find the shortest path. This factor, therefore, should be used to simulate the behavior of ants. Generally, the intensity of pheromone and the length of the path are used to simulate ant systems.

B. Ants' Path Searching Behavior

Starting from source node, each ant builds a solution to a problem by applying a step-by-step decision policy. At each node, local information stored on the node itself or on its outgoing arcs is read (sensed) by the ant and used in a stochastic way to decide which node to move next. At the beginning of the search process, a constant amount of pheromone is assigned to all the arcs. When located at a node *r* an ant *k* uses the pheromone trails, τ (*r*, *s*) to compute the probability of choosing *s* as next node.

$$P_{k(r,s)} = \left\{\frac{[\tau(r,s)].\eta(r,s)^{\beta}}{\sum_{u\varepsilon J_{k(r)}}[\tau(r,u)].[\eta(r,u)^{\beta}]}\right\} \ldots\ldots (7)$$

$$\{0, \text{otherwise}$$

Where $J_{k(r)}$ is the neighborhood of ant at node r. In ACO, the neighborhood of a node r contains all the nodes directly connected to node r, except for the predecessor of node r (i.e. the last node the ant visited before moving to r). In this way the ants avoids returning to the same node they visited immediately before node r. Only in case of $J_{k(r)}$, which corresponds to a dead end, node r's predecessor is included into $J_{k(r)}$. Note that this decision policy can easily lead to loops in the general paths.

Appling this policy, the ant will repeatedly move from node to node until it eventually reaches the destination node. The time that ant required to reach the destination node may vary due to differences among the ants' path because ant travelling on shorter path will reach their destination faster.

Path Retracing and Pheromone Update Upon reaching destination node, the ants switches from forward to backward mode and then repeat step by step the same step backward to the source node. During return travel to the source the *k*-th ant deposits an amount $\Delta\tau^k$ of pheromone on arcs it has visited. In particular, if ant k is in the backward mode and it traverses the arc (r,s), it changes the pheromone value τ(r , s) as follows: -

$$\tau\,(r,s) \leftarrow \tau(r,s) + \rho.\Delta\,\tau(r,s) + \Delta\tau k \qquad (8)$$

By this rule an ant using the arc connecting node r to node s increases the probability that forthcoming ants will use the same in the future.

C. Pheromone Trail Evaporation

Pheromone trail evaporation can be seen as an exploration mechanism that avoids quick convergence of all the ants toward a suboptimal path. In fact, the decrease in pheromone intensity favors the exploration of different paths during the whole search process. In real ant colonies, pheromone trails also evaporated, however, evaporation does not play important role in real ant's shortest finding. On the contrary, pheromone evaporation seems to be important in artificial ants is probably due to the fact that the optimization problems tackled by artificial ants are much more complex than those real ants can solve. Artificial pheromone evaporation plays the important function of bounding the maximum value achievable by pheromone trails. Evaporation decreases the speed of pheromone trails exponentially. The pheromone evaporation is interleaved with the pheromone deposit of the ants. After each ant k has moved to a next node according to ants' search behavior earlier, pheromone trail are evaporated. After all evaporation has been applied to all arcs, the amount of $\Delta\tau^k$ is added to the arcs. Iteration of ACO completes cycle involving ants' movement, pheromone evaporation, and pheromone deposit.

IV. METHODOLOGY

ACO algorithm that is used to solve combinatorial optimization problem includes initialization, state transition rule, local up-dating rule, fitness evaluation and global up-dating rule. The overall process of ACO algorithm is represented in the form of flow chart illustrated in Fig. 7: -

A. Initialization

ACO parameters have to be specified during initialization process. The difficulty encountered is that to determine appropriate choice of control parameters prior to applying ACO program. The choice of parameters has been obtained by trial and error. The parameters must be carefully selected to obtain better result in the development of ACO's program. Furthermore, every parameter requires to be set for limiting the search range in order to avoid large computing time. The following parameters need to be initialized for the purpose of ACO implementation.

n : no. of nodes
m : no. of ants
t_{max} : maximum iteration
d_{max} : max distance for every ants tour
β : Parameter, which determines the relative importance of pheromone versus distance ($\beta > 0$)
ρ : heuristically defined coefficient ($0 < \rho < 1$)
α :pheromone decay parameter ($0 < \alpha < 1$)
q_0 : parameter of algorithm ($0 \leq q_0 \leq 1$)
τ_0 : initial pheromone level. For matlab programming, τ_0 is set at one (1).

The maximum distance for every ant's tour (d_{max}) can be calculated by using the following formula;

$$dmax = \left[\sum_{i=1}^{n-1} di\right] \tag{9}$$

$$d_i = |r - \max(u)| \tag{10}$$

Where;
r : current node
u : unvisited nod
d_i : distance between two nodes

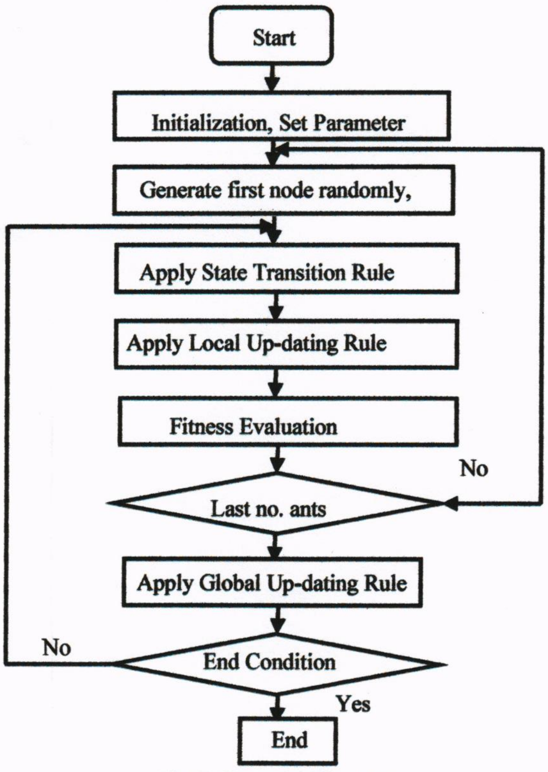

Fig. 7. Flow chart for ACO

Every node in the list is required to be set as the first node in order to determine d_{max}. The node in the list can only be selected once for every tour of ant. Each ant will select the next node which has higher distance from the current node. This process will repeat until the end node in the list.

B. Generate First Node

The first node will be selected by generating random number based on the uniform distribution, ranging from 1 to n where n is the number of node.

C. State Transition Rule

The state transition rule is the states whereby each ant decides the next node the ant to move to. A new state transition rule is called pseudo-random-proportioned is introduced for this Ant Colony optimization. The pseudo-random-proportional rule is a compromise between the pseudo-random state choice rule and the random-proportional action choice rule typically used in ant system. At each construction step, ant k applies a state transition rule in order to decide which node to be visited next. The ant k, which is currently positioned at current node (r), will move to the node (s) by applying the state transition rule given by: -

$$s = \left\{\frac{\arg max_{u\varepsilon}J_{k(r)\{[\tau(r,u)][\eta(r,u)^{\beta}]\}}}{S, otherwise\ (biased\ exploration)}\right\}$$

if $q \leq q_0$ (exploitation) …. (11)

Where:
q random number uniformly distributed in [0…..1]
S random variable selected according to the probability distribution given in below

*Note :- The above equation will determine the best path of $q \leq q_0$.

The state transition rule used by ACO is determined by the following probability equation;

The probability for an ant k at current node (r) to choose the next node (s) is calculated using the probability equation given by: -

$$P_{k(r,s)} = \left\{\frac{[\tau(r,s)].\eta(r,s)^{\beta}}{\sum_{u\varepsilon J_{k(r)}}[\tau(r,u)].[\eta(r,u)^{\beta}]}\right\} \tag{12}$$

{0, otherwise

*Note :- The above equation will determine the best path of $q \geq q_0$.

Where;
τ pheromone
$J_{k(r)}$ Set of nodes that remain to be visited by ant k positioned on node (to make the solution feasible)
η = $1/\delta$, is the inverse of the distance $\delta(r,s)$
r=ant positioned at current node

In equation (11) and (12) the pheromone on path $\tau(r,s)$ is multiplied by the heuristic value $\eta(r,s)$ in order to determine the selection of paths which are shorter and have a greater amount of pheromones. The parameter q_0 determines the relative importance of the exploitation versus exploration condition. An ant at node r (current node) shall choose the s (next node) to its next movement. This is randomly determine by the value of q where ($0 < q < 1$). If $q < q_0$ the best path will be determined based on equation 3.

Equation 12 will determine the best path (i.e in the exploration mode)If $q \geq q_0$.

The process to determine the next node (s) starts by calculating the probability of choosing the next node using equation (12). The value of q is generated randomly after the calculation of probability. If ($q \leq q_0$), node 4 was selected as next node (s) which has the highest probability (i.e in exploitation mode). On the other hand, if ($q \geq q_0$), the next node (s) will be selected randomly from the list of unvisited nodes (i.e in the exploration mode).

D. Local Up-dating Rule

Local up-dating rule is a process used to change the amount of pheromone to the visited paths during the construction of solution. The amount of pheromones can be updated based on the following equation;

$$\tau(r,s) \leftarrow (1-\rho)\,\tau(r,s) + \rho . \Delta\,\tau(r,s) \qquad (13)$$

where

ρ :heuristic defined coefficient ($0 < \rho < 1$)

$\Delta\,\tau(r,s) = \tau 0$

$\tau 0$: Initial Pheromone level on all edges.

$\tau(r,s)$: is the amount of pheromone on the edge (r,s)

ρ : is a parameter governing pheromone decay such that $0 < \rho < 1$.

The objective of local pheromone update rule is to make "the visited edge less and less attractive as they are visited by ants, indirectly favoring the exploration of not yet visited edges. As a result, and tend not to converge to a common path".

The local up-dating rule will shuttle the tours, so that the early nodes in one ant's tour may be explored later in other ant's tours. The amount of pheromone on visited paths becomes less desirable and therefore will be chosen with lower probability by the other ants in the remaining steps of an iteration of the algorithm. When the new value of τ value is lower, the probability to select the same node also becomes lower.

E. Fitness Evaluation

Fitness evaluation is performed after all ants have completed their tours. In this step, the control variable (x) is computed using the following equation: -

$$x = \frac{d}{d_{max}} X\, x_{max} \qquad (14)$$

Where ;

d : distance for every ants tour

x_{max} : maximum x

d_{max} : maximum distance for every ants tour

The value of variable x will be assigned for the fitness in the ACO algorithm.

The fitness evaluation is calculated by running a load flow program in which the objective function (voltage) needs to be maximized above the initial voltage (voltage set).

Voltage set is the minimum or initial voltages that can be obtained by running the load flow program using Newton-Raphson method.

F. Global Updating rule

Global updating rule is a processed used to update the amount of pheromones generated by the ants which has constructed the shortest tour from the beginning of the tour. There will be only one ant is allowed to update the amount of pheromone which determines the best fitness. The amount of pheromones is updated after all ants have completed their tours by applying equation (15) below: -

$$\tau(r,s) \leftarrow (1-\alpha)\,\tau(r,s) + \rho . \Delta\,\tau(r,s) \qquad (15)$$

$$\Delta(r,s) = \left\{ \frac{(L_{gb}), if\ (r,s) \varepsilon\ global-best-tour}{0\ otherwise} \right\} \qquad (16)$$

α : pheromone decay parameter ($0 < \alpha < 1$)

L_{gb} : Length of the globally best tour from the beginning of the tour.

In this case, the paths belong to the globally best tour (i.e. the best fitness) of current iteration will receive the reinforcement. For the next iteration, the first node of globally best tour in the first iteration will be selected as first node by each ant.

G. End Condition

The algorithm stops the iteration when a maximum number of iteration (t_{max}) has been performed. Every tour that was visited by ants shall be evaluated. If a better path is discovered in the process, it will be kept for next reference. The best path selected between all iteration engages the optimal scheduling solution. As a consequence, ants never converge to common path. This is observed experimentally, and it is desirable property. If ants explore different paths then there is higher probability that one of them will find an improving solution.

IV. RESULTS AND DISCUSSION

In this study, ACO is used to optimize the size or value of STATCOM for loss minimization or voltage stability improvement. Bus 12 is chosen as the loaded bus to emulate the heavy load situation. TABLE I tabulates the results for voltage maximization. Total loss is also monitored in this study. The result tabulated in TABLE I was obtained when the ACO parameter are set to the following values at the initialization process:

n=10, m=5, tmax=5, dmax=49, β=2, α=0.1, q0=0.6, ρ=0.6 and $\tau_{0=1.}$

TABLE 1

THE RESULTS BEFORE AND AFTER OPTIMAL STATCOM SETTING IDENTIFIED BY ACO IMPLEMENTATION

	Injected (Q_d) (MVAR)	Voltage		Total Losses	
		Before	After	Before	After
		Vp.u	Vp.u	(MW)	(MW)
Bus No 12	210	0.9305	1.0728	68.8112	69.9346
	220	0.9226	1.0840	73.4728	85.2925
	230	0.9140	1.0853	78.5169	89.0608
	240	0.9044	1.0771	84.0068	89.9121
	250	0.8938	1.0741	90.0297	93.0220
	260	0.8817	1.0661	96.7122	93.8248
	270	0.8677	1.0513	104.2517	94.8167

	280	0.8509	1.0351	112.9925	97.9815
	290	0.8295	1.0343	123.6591	103.2912
	300	0.7971	1.0208	138.5735	106.9110

TABLE 11
RESULT FOR PERCENTAGE INCREASE OF VOLTAGE

	Injected (Q_d) (MVAR)	Voltage		% Increase
		Before	After	
		Vp.u	Vp.u	
Bus No 12	210	0.9305	1.0728	15.29
	220	0.9226	1.0840	17.49
	230	0.9140	1.0853	18.74
	240	0.9044	1.0771	19.10
	250	0.8938	1.0741	20.17
	260	0.8817	1.0661	20.91
	270	0.8677	1.0513	21.16
	280	0.8509	1.0351	21.65
	290	0.8295	1.0343	24.69
	300	0.7971	1.0208	28.06

TABLE III
RESULT FOR PERCENTAGE DECREASE OF TOTAL LOSSESS

	Injected (Q_d)	Total Losses		% Increase
		Before	After	
	(MVAR)	(MW)	(MW)	
Bus No 12	210	68.8112	69.9346	-1.63
	220	73.4728	85.2925	-16.09
	230	78.5169	89.0608	-13.43
	240	84.0068	89.9121	-7.03
	250	90.0297	93.0220	-3.32
	260	96.7122	93.8248	2.99
	270	104.2517	94.8167	9.05
	280	112.9925	97.9815	13.28
	290	123.6591	103.2912	16.47
	300	138.5735	106.9110	22.85

TABLE 1V
STATCOM VALUE CHOSEN BY ACO at Q_d = 100MVar

Bus No	S1	S2	S3	S4	S5
12	1.1237	1.0589	1.6115	1.2649	1.6700

The results for voltage and total losses before ACO implementation can be obtained by running load flow program using Newton Raphson method. By using ACO technique, the STATCOM value will be optimized in order to increase the voltage profile and minimize the total losses in the system. The reduction in losses and increment of voltage profile at each condition at bus 12 are shown in TABLE I. On the other hand, the percentage of voltage

the transmission losses attributable to STATCOM is higher than the losses without STATCOM. However, for 260 MVAR and above, the transmission loss attributable to STATCOM is lower than without STATCOM. The values for STATCOM are given in TABLE IV i.e. S1, S2, S3, S4 and S5 are 1.1237, 1.0589, 1.6115, 1.2649 and 1.67 optimized by ACO. In TABLE II, it is observed that the bus voltage that the implementation of ACO has increased the voltage profile in the system. It is also observe that bus voltage reduces accordingly as Q_d is increased. For instance, at Q_d=300MVAR, the voltage is increased from 0.7971 to 1.0208p.u. This has increased 24.69 % of its original value as shown in TABLE II. Loss values at each loading conditioned were also monitored. However, the reduction is not experienced at each load variation. From TABLE I, it is observed that total losses reduce at only high loading which are at Q_d=260 Mvar onwards. From TABLE III, it is noted that the higher the loading condition, the lower the total transmission loss would be. ACO gives different results for every run. Therefore, the desired combinations of the STATCOM can be chosen accordingly. If better tour is discovered, it will give better results for voltage and total losses.

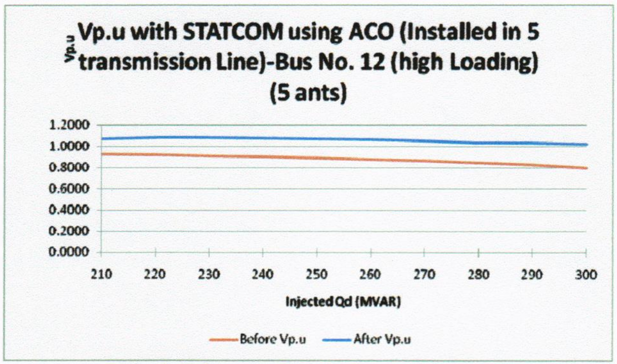

Fig. 8: Voltage Profile before and After ACO

Figure 8 illustrates the voltage profiles with and without ACO with respect to load variation. From the figure, it is observed that the voltage profile with the ACO implementation is higher than that before ACO implementation. These coherently imply the effectiveness of ACO in improving voltage profile of the system.

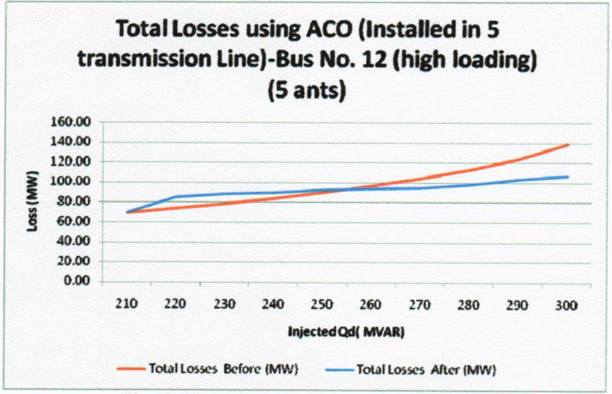

Fig. 9: Total Loss before and After ACO

Meanwhile, Fig. 9 illustrates the total losses with and without ACO implementation with respect to load variation.

have different maximum loadability since it depends on the capacity of the load. For example, from Fig. 8 and 9, the maximum loading condition for bus 12 is 300 MVar.

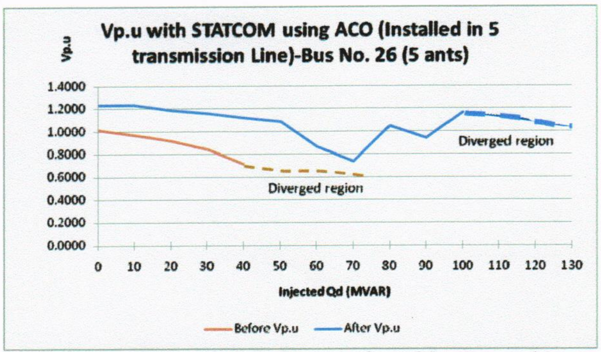

Fig. 10: Voltage profile before and After ACO at Bus no. 26

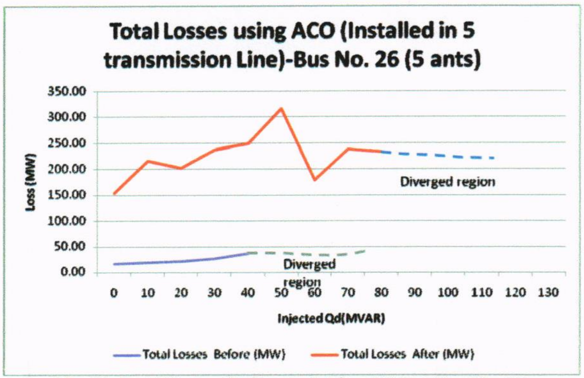

Fig. 11: Total Losses before and After ACO at Bus No. 26

Fig. 10 illustrates the simulation performed at bus 26 which is the weakest bust in 30 bus IEEE RTS [16]. Without STATCOM, the voltage profile will collapse when loaded at Q_d=40MVar. Fig. 11 illustrates that by installing the STATCOM, it is observed that it can be loaded up to 100MVar before the system collapse.

TABLE V

Result for five number of ants (busbar 12, at Q_d=100MVAR)

Node	S_1	S_2	S_3	S_4	S_5
5	Keep iterating continuously				
10	1.5926	1.0101	1.2577	1.6947	1.5854
15	2.8584	2.4735	2.9664	3.078	2.3274

TABLE VI

Result for ten (10)number of ants (busbar 12, at Q_d=100MVAR)

Node	S_1	S_2	S_3	S_4	S_5
5	Keep iterating continuously				
10	1.5246	1.0697	1.2369	1.4693	1.6091
15	2.8505	3.5856	2.4261	3.6742	2.3625

TABLE VII

Node	S_1	S_2	S_3	S_4	S_5
5	Keep iterating continuously				
10	1.3276	1.5024	1.1323	1.3181	1.6035
15	2.7878	3.9611	3.2896	3.7928	2.9645

TABLE V, VI and VII tabulate the effect of number of ants and nodes to loss and voltage. For instance, TABLE V tabulates the result for 5 ants, while TABLE VI and VII tabulate the result for 10 ants and 15 ants. These processes are conducted for 5 nodes, 10 nodes and 15 nodes.

V. CONCLUSION

This paper has presented the implementation of newly invented Ant Colony Optimization (ACO) technique for controlling voltage profile and loss minimization in power system. The proposed technique has been tested on the standard IEEE 30-bus RTS. Through the experiment, it has been observed that ACO approach has successfully determine the optimal values of STATCOM for solving the voltage and loss problems. It was found that for reducing the total losses, ACO technique can be implemented more effectively at high loading condition. The effect of number of ants for various numbers of nodes in performing the optimization problem was also investigated.

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VII. BIOGRAPHIES

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