[1]M. R. Kalil,
[2]I. Musirin MIEEE,
[3]M. M. Othman

Optimal Transformer Tap Changer Setting for Voltage Stability Improvement

IJPEAI
International Journal of Power, Energy and Artificial Intelligence

Abstract— This paper presents Ant Colony Optimization (ACO) technique for optimal transformer tap changer setting (OTTCS) in order to improve voltage stability condition along with transmission loss and voltage profile monitoring. ACO is a new cooperative agent's approach, which is inspired by the observation of the behaviours of real ant colonies on the topics of ant trial formation and foraging method. The set of cooperating agents called "ant" cooperate to find the optimal point of OTTCS. Comparative studies presented with respect to Evolutionary Programming (EP) and Artificial Immune System (AIS) had indicated the merit of the proposed technique. All of the algorithms are programmed on MATLAB applied to the IEEE 30-bus Reliability Test System (RTS).

Keywords – Ant colony optimization, evolutionary programming, artificial immune system, optimal transformer tap changer setting, voltage stability improvement

I. INTRODUCTION

Voltage stability has been considered as a major constraint on secure operation of electric power systems. The effective scheme to prevent voltage collapse incident requires power system researchers and engineers to develop new control strategies. The more stringent requirements have been imposed on electric utilities. This tendency has brought about sheer necessity of attaining system planning as well as system operations of higher security level and of greater sophistication [1]. The main factors influencing the adequacy of the level of reactive power support include the network loading level, the load-voltage behaviour, the action of on-load tap changing transformers, generator excitation control and the action of over-excitation limiters [2].

The operating environment has contributed to the growing importance of the problem associated with the static and dynamic assessment of power system. To a large extent this is also due to the fact that most of the major power system collapses are caused by problems related to the system's static, as well as dynamic responses. The static forms can be studied as parametric load flow problem and dynamic forms must be studied as the trajectory of a set of differential equations [3]. This study is concerned with static voltage stability which it seems to be sufficient for operational scheduling [1]. On the other hand, voltage stability often requires examination a lot of system states and many contingencies scenarios.

The generation of reactive power aims to increase the limit of power transfer between areas and control the voltage magnitude under both normal operation and contingencies. To support a large energy transfer, the system operators of the control areas must ensure a satisfactory voltage magnitude level throughout the system under both normal and emergency conditions, to prevent loss of load and keep system reliability at acceptable levels [4]. Reactive power plays an important role in supporting the real power transfer. This support becomes particularly important when an increasing number of transactions are utilizing the transmission system and voltages become a bottleneck in preventing additional power transfer [5].

Various techniques have been reported for voltage stability enhancement by transformer tap changer setting. D. Gao [6] proposed a novel thyristor assisted diverter switch for on load transformer tap changer which can eliminate excessive conduction losses and suppress the arcing in the diverter switch, which are inherent in traditional on load transformer tap changers. A static converter with power electronic for transformer tap changer is presented by P. Bauer *et al.* [7]. The static converter would replace the mechanical tap selector, in which one must be able to change the taps under the full operation of the transformer. B. Kasztenny *et al.* [8] used Fuzzy Logic Controller (FLC) for on load transformer tap changer. The proposed algorithm is optimized from the numerical point of view and proved to be implementable on contemporary Programmed Logic Controllers (PLCs). Bansilal *et al.* [9] developed an expert system for voltage corrections for base case and contingency using switchable shunt reactive compensation and transformer settings. The proposed expert system has been tested with simulated conditions of a few practical power systems. Transfomer tap changing by data classification using Artificial Neural Network (ANN) is proposed by M. F. Islam *et al.* [10]. It involved two algorithms, namely scaled conjugate gradient (SCG) and Bayesian regularization (BR) for training an ANN to control the automatic on-load tap changer of two transformers connected across the power network. M. Suzuki *et al.* [11] proposed fuzzy expert AVQC control system to investigate the mechanism of the inadequate motion of transformer's tap changer. In order to validate this method, simulations of tap changer behavior under various conditions are conducted. This study offer valuable practical information on the design of a coordinated voltage and reactive control system for a power network. This paper presents ACO based optimization technique for OTTCS. As efficient optimization techniques for solving combinatorial optimization problems by simulation, ACO is suitable for voltage stability improvement studies. Along with this, loss reduction, voltage profile, computation time and iteration numbers are the added criteria monitored in this study.

II. VOLTAGE STABILITY IMPROVEMENT

The purpose of optimal transformer tap changer setting (OTTCS) is to improve voltage stability condition and to minimize loss. The OTTCS is intended to modify the tap setting value of transformer in the test system. By an optimal adjustment, the transformer tap ratio is physically altered to effect a change in the secondary voltage with respect to the primary. To achieve this the transformer has its low tension winding 'tapped out', so that a switching mechanism referred to as a tap changer can switch more or less of the transformer winding into the circuit. This alters the ratio between the primary and secondary circuit therefore changing the voltage on the transformer output [12].

This study involves the development of ACO technique for OTTCS optimization problem. In order to solve OTTCS by taking transformer tap changer setting value as the variables in the test system. There are four transformers present in IEEE 30-bus RTS; therefore only four variables are required in this case. In the proposed technique, ACO is used to determine the optimum value for each variable in the test system. Voltage stability improvement has been chosen as the objective function which utilized a voltage stability index as the fitness in the problem formulation. A line-based voltage stability index termed as Fast Voltage Stability Index (*FVSI*) developed by I. Musirin [13] based on the quadratic equation of voltage at the receiving end of a 2 bus system was adopted as the fitness function. The general 2 bus system can be represented in Fig. 1.

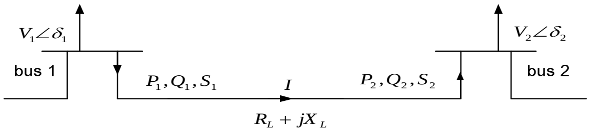

Fig. 1: 2 bus system

FVSI was used in the voltage stability analysis as an indicator of the voltage stability condition of the system. The voltage stability condition of all lines in power system could be assessed using this index which could predict the occurrence of voltage collapse in a system. The mathematical equation for *FVSI* [13] is given as follows:-

$$FVSI_{ij} = \frac{4{Z_{ij}}^2 Q_j}{{V_i}^2 X_{ij}} \qquad (1)$$

where:

Z_{ij} : line impedance
X_{ij} : line reactance
V_i : voltage at the sending end
Q_j : reactive power at the receiving end

The value of *FVSI* must be less than unity in order to maintain a stable system. Any line whose *FVSI* value exceeds unity indicates voltage instability has occurred on the corresponding line, which caused the reduction in voltage drop at the corresponding heavily loaded bus and overall system collapse.

III. ANT COLONY OPTIMIZATION (ACO)

Ant Colony Optimization (ACO) was introduced by Marco Dorigo as reported in [14 - 18]. These models were derived from the observation of real ants' behavior, and used as a source of inspiration for the design of novel algorithms for the solution of optimization and distributed control problem [18]. ACO algorithm is inspired by the behaviour of real ant colonies.

The described the behavior of real ant colonies can be used to solve combinatorial optimization problems in which artificial ants search the solution space by transiting from nodes to nodes. The artificial ants movement associated with their previous action stored in the memory with a specific data structure [19]. The pheromone consistencies of all paths are updated only after the ant has finished its tour from the first node to the last node. Every artificial ant has a constant amount of pheromone stored in it when the ant proceeds from the first node. The stored pheromone will be distributed evenly on the path after the artificial ants have finished their tour. Once the artificial ants have finished their tour, the amount of pheromone will be the highest on the optimal path. The pheromone of the routes decreases progressively through evaporation in order to avoid artificial ants stuck at the local optima solution [19]. The characteristic of an artificial ant is characterised through positive feedback, distributed computation and the use of constructive greedy heuristic [20]. Positive feedback accounts for rapid discovery of good solutions, distributed computation avoids premature convergence, while the greedy heuristic helps find acceptable solutions in early stages of the search process.

IV. ALGORITHM FOR OTTCS

ACO algorithm has been used in this study; involving initialization, state transition rule, fitness evaluation, local updating rule and global updating rule. In this study, there are some modifications performed on the ACO algorithm in order to make it suitable for the application in OTTCS. The algorithm was modified to solve the continuous optimization problems instead of graphical optimization problems in its original philosophy. The implementation of ACO technique for OTTCS is shown in Fig. 2. The procedural steps are given below:-

Step 1: Initialization; during the initialization process n, m, t_{max}, d_{max}, β, ρ, α and q_0 are specified. The parameters were set to the following values; $n = 9$, $m = 5$, $t_{max} = 3$, $d_{max} = 39$, $\beta = 5$, $\rho = 0.6$, $\alpha = 0.1$, $\tau_o = 0.1$ and $q_0 = 0.85$.

where:

n : no. of nodes
m : no. of ants
t_{max} : maximum iteration
d_{max} : maximum 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 the algorithm ($0 \leq q_0 \leq 1$)
τ_o : initial pheromone level

Every parameter requires to be set for the purpose of limiting the searching range in order to avoid large computation time.

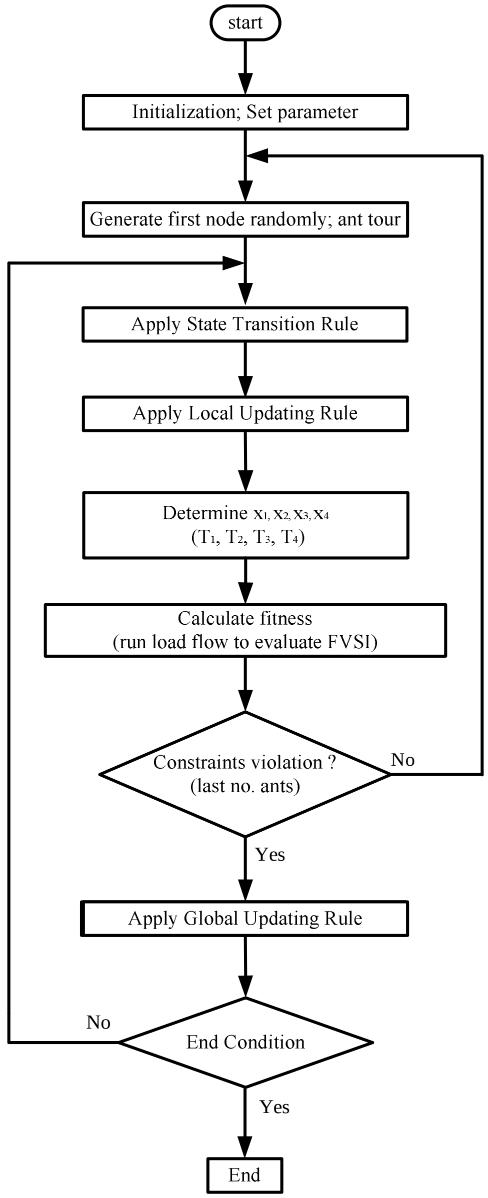

Fig. 2: Flow chart for OTTCS using ACO

d_{max} can be calculated using the following formula:

$$d_{\max} = \max\left[\sum_{i=1}^{n-1} d_i\right] \quad (2)$$

$$d_i = \left| r - \max(u) \right| \quad (3)$$

where:

r : current node
u : unvisited node
d_i : distance between two nodes

Step 2: Generate first node randomly; the first node will be selected by generating a random number according to a uniform distribution, ranging from 1 to *n*.

Step 3: Apply state transition rule; in this step the ant located at node *r* (current node) will choose the nodes *s* (next node) based on the following rule.

$$s = \begin{cases} \arg\max_{u\varepsilon\, J_{k(r)}} \left\{ [\tau(r,u)].[\eta(r,u)^{\beta}] \right\}, if\ \ q \le q_0\ (\exp loitation) \\ S,\ otherwise\,(biased\ \ \exp loration) \end{cases} \quad (4)$$

where:

q : random number uniformly distributed in [0…1]
S : random variable selected according to the probability distribution given in eq. (5)

The probability for an ant *k* at node *r* to choose the next node *s,* is calculated using the following equation.

$$P_k(r,s) = \begin{cases} \dfrac{[\tau(r,s)].[\eta(r,s)^{\beta}]}{\sum_{u\,\varepsilon\, J_{k(r)}} [\tau(r,u)].[\eta(r,u)^{\beta}]},\ if\ \ s\,\varepsilon\, J_{k(r)} \\ 0,\ otherwise \end{cases} \quad (5)$$

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/*d*, is the inverse of the distance *d(r,s)*.

Step 4: Apply local updating rule; while constructing a solution of transformer tap changer setting value search, ants visit edges and change their pheromone level by applying the local updating rule of eq. (6).

$$\tau(r,s) \longleftarrow (1-\rho)\,\tau(r,s) + \rho.\Delta\,\tau(r,s) \quad (6)$$

where:

ρ : heuristically defined coefficient ($0 < \rho < 1$)
$\Delta\,\tau(r,s) = \tau_o$

Step 5: Determine four variables (x_1, x_2, x_3, x_4) required to represent the transformer tap changer setting value for the transformers (T_1, T_2, T_3, and T_4).

Step 6: Fitness evaluation; it is performed after all ants have completed their tours. In this step, the control variable *x* is computed using the following equation:-

$$x = \frac{d}{d_{\max}} \times x_{\max} \quad (7)$$

where:

d : distance for every ants tour
$x_{\max}$: maximum *x*

The values of *x* will be assigned for the transformer tap changer setting value. The fitness is computed by performing ac load flow program. This program is called repeatedly into the ACO main program for the whole process. The AC load flow program was called into the ACO main program in order to calculate the *FVSI* value as the fitness. This *FVSI* value must satisfy some constraints violation where the *FVSI* value must be less than *FVSI_set* determined during the pre-OTTCS process.

Step 7: Apply global updating rule; to simplify the problem. This step is applied to edges belonging to the best ant tour which give the best fitness among all ants. The pheromone level is updated by applying the global updating rule in eq. (8).

$$\tau(r,s) \longleftarrow (1-\alpha)\,\tau(r,s) + \alpha.\Delta\,\tau(r,s) \qquad (8)$$

where:

$$\Delta(r,s) = \begin{cases} (L_{gb})^{-1}, \; if\ (r,s)\, \varepsilon\ global-best\ tour \\ 0, \; otherwise \end{cases}$$

L_{gb} : the length of the globally best tour from the beginning of the trial

Step 8: End condition; the algorithms stop the iteration when a maximum number of iterations have been performed; otherwise, repeat step 3. Every tour that has been visited by the ants should be evaluated. If a better path is discovered in the process, it will be kept for the next reference. The best path selected between all iterations engages the optimal scheduling solution to the OTTCS.

V. RESULTS AND DISCUSSION

OTTCS scheme was implemented in this study with the objective of improving voltage stability condition. OTTCS engine for ACO was developed in MATLAB with voltage stability improvement as objective function. Validation process was conducted on the IEEE 30-bus RTS. The single line diagram of IEEE 30-bus RTS is illustrated in Fig. 3. This system has 6 generator buses and 25 load buses with 41 interconnected lines. The results of this study were consequently compared with other techniques such as EP and AIS. The comparison is made in terms of voltage stability improvement, total loss reduction, voltage profile and computation time.

The results for OTTCS executed to the system for bus 29 loaded are tabulated in TABLE I, II and III. At every loading condition the result of *FVSI* value with the implementation of OTTCS (post) is lower than that before its implementation of OTTCS (pre). This means that the voltage stability improvement has been improved with the implementation of OTTCS using ACO, EP and AIS. On the other hand, the voltage profile is also improved and total losses are minimized. To demonstrate the above phenomenon, analysis at one of the loading conditions can be conducted. From TABLE I, at Q_{d29} = 38 MVAr; the values of *FVSI* at bus 29 identified by ACO technique is reduced from 0.9942 to 0.5690. It has also reduced the total loss in the system from 32.78 MW to 22.13 MW and at the same time voltage profile is improved from 0.5313 p.u. to 0.8780 p.u.. The tap setting for transformers 1 to 4 determined using ACO are 0.949, 1.092, 0.949 and 0.785. This is achieved within 13.06 seconds computation time in 3 iterations.

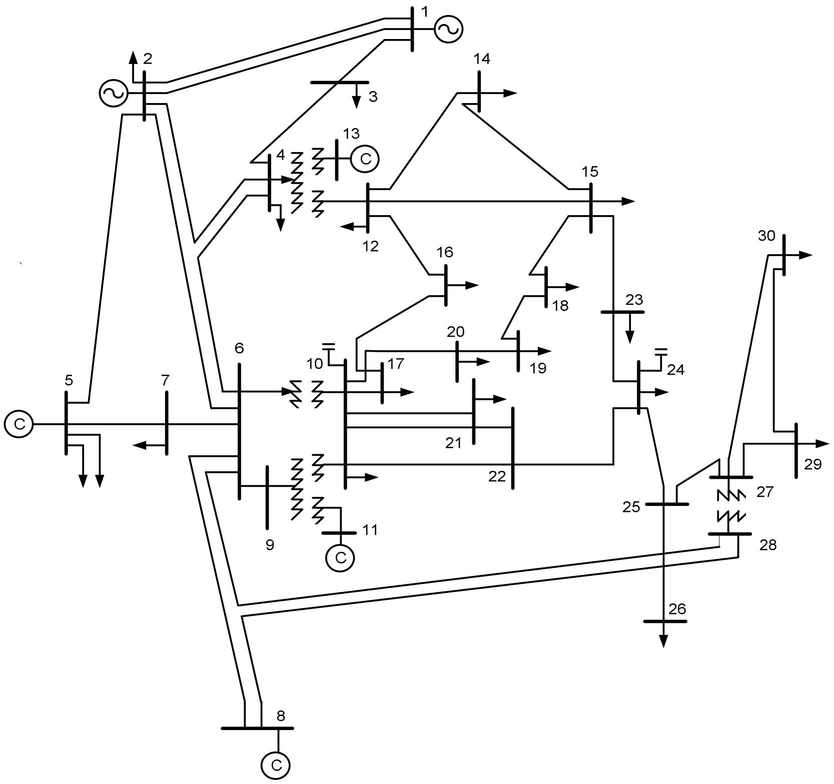

Fig. 3: Single line diagram for IEEE 30-bus RTS

TABLE I
OTTCS USING ACO WHEN BUS 29 LOADED

Loading Conditions (MVAr)	Analysis OTTCS	*FVSI*	Total loss (MW)	Iter. no.	Comp Time (sec)	T_1	T_2	T_3	T_4	V_m (p.u.)
$Q_{d29} = 10$	pre	0.2111	18.12							0.9436
	post	0.1595	17.92	3	41.33	1.031	1.031	0.949	0.908	0.9903
$Q_{d29} = 20$	pre	0.3573	19.39							0.8651
	post	0.2904	18.61	3	25.13	0.990	0.949	1.031	0.846	0.9825
$Q_{d29} = 30$	pre	0.5987	22.44							0.7524
	post	0.4499	20.69	3	14.91	0.887	1.072	1.072	0.785	0.9463
$Q_{d29} = 38$	pre	0.9942	32.78							0.5313
	post	0.5690	22.13	3	13.06	0.949	1.092	0.949	0.785	0.8780

TABLE II
OTTCS USING EP WITH BUS 29 LOADED

Loading Conditions (MVAr)	Analysis OTTCS	*FVSI*	Total loss (MW)	Iter. no.	Comp Time (sec)	T_1	T_2	T_3	T_4	V_m (p.u.)
$Q_{d29} = 10$	pre	0.2111	18.12							0.9436
	post	0.1615	17.82	6	747.90	1.053	0.965	0.995	0.914	0.9824
$Q_{d29} = 20$	pre	0.3573	19.39							0.8651
	post	0.2936	18.63	6	623.44	0.961	1.107	1.004	0.850	0.9723
$Q_{d29} = 30$	pre	0.5987	22.44							0.7524
	post	0.4300	21.10	6	215.97	1.164	1.179	1.047	0.786	0.9404
$Q_{d29} = 38$	pre	0.9942	32.78							0.5313
	post	0.6033	23.94	6	288.31	0.778	1.502	1.019	0.768	0.8422

TABLE III
OTTCS USING AIS WITH BUS 29 LOADED

Loading Conditions (MVAr)	Analysis OTTCS	*FVSI*	Total loss (MW)	Iter. no.	Comp Time (sec)	T_1	T_2	T_3	T_4	V_m (p.u.)
$Q_{d29} = 10$	pre	0.2111	18.12							0.9436
	post	0.1614	17.81	3	923.67	1.052	0.964	0.995	0.914	0.9825
$Q_{d29} = 20$	pre	0.3573	19.39							0.8651
	post	0.2935	18.63	3	638.83	0.961	1.107	1.003	0.850	0.9725
$Q_{d29} = 30$	pre	0.5987	22.44							0.7524
	post	0.4298	21.10	3	467.80	1.164	1.179	1.046	0.786	0.9407
$Q_{d29} = 38$	pre	0.9942	32.78							0.5313
	post	0.6048	23.94	3	647.58	0.777	1.502	1.019	0.768	0.8426

From TABLE II, at Q_{d29} = 38 MVAr; the values of *FVSI* at bus 29 identified by EP technique is reduced from 0.9942 to 0.6033. It has also reduced the total loss in the system from 32.78 MW to 23.94 MW and at the same time voltage profile is improved from 0.5313 p.u. to 0.8422 p.u.. The tap setting for transformers 1 to 4 determined using EP are 0.778, 1.502, 1.019 and 0.768. This is achieved within 288.31 seconds computation time in 6 iterations.

From TABLE III, at Q_{d29} = 38 MVAr; the values of *FVSI* at bus 29 identified by AIS technique is reduced from 0.9942 to 0.6048. It has also reduced the total loss in the system from 32.78 MW to 23.94 MW and at the same time voltage profile is improved from 0.5313 p.u. to 0.8426 p.u.. The tap setting for transformers 1 to 4 determined using AIS are 0.777, 1.502, 1.019 and 0.768. This is achieved within 647.58 seconds computation time in 3 iterations.

TABLE IV tabulates the results of OTTCS at Q_{d29} = 38 MVAr using all the three techniques (ACO, EP and AIS) when voltage stability is taken as the objective function. The reduction in *FVSI* is the lowest performed using ACO indicating the highest voltage stability improvement. It is observed that ACO managed to reduced from the *FVSI* value to 0.5690 from 0.9942.

TABLE IV: COMPARATIVE STUDIES OF OTTCS

Criteria	pre-OTTCS	post-OTTCS at Q_{d29} = 38MVAr		
		ACO	EP	AIS
FVSI	0.9942	0.5690	0.6033	0.6048
Total loss (MW)	32.78	22.13	23.94	23.94
Voltage (p.u.)	0.5313	0.8780	0.8422	0.8426
Comp. Time (sec)		13.06	288.31	647.58

From the same table, EP and AIS managed to reduce the *FVSI* value to 0.6033 and 0.6048 respectively. From the table, it is observed that ACO managed to reduce the transmission loss value to 22.13 MW while EP and AIS managed to reduce the transmission loss value to 23.94 MW.

The total loss reduction is not far difference among three techniques. This indicates that ACO is comparable with EP and AIS. ACO was also able to obtain the highest voltage profile improvement. It is observed that ACO managed to improve voltage profile value to 0.8780 p.u. while EP and AIS only managed to improve the voltage profile to 0.8422 p.u. and 0.8426 p.u. respectively; thus, highlighting ACO as the best technique for voltage improvement. ACO is also observed to be the fastest technique as compared to the other two techniques. ACO managed to converge to an optimal solution within 13.06 second, while EP and AIS consumed 288.31 second and 647.58 second respectively. From the results of comparative studies, it is observed that ACO has outperformed EP and AIS in all criteria concerning voltage stability improvement, loss minimization, voltage profile improvement and computation time. This reveals the superiority of ACO over the others.

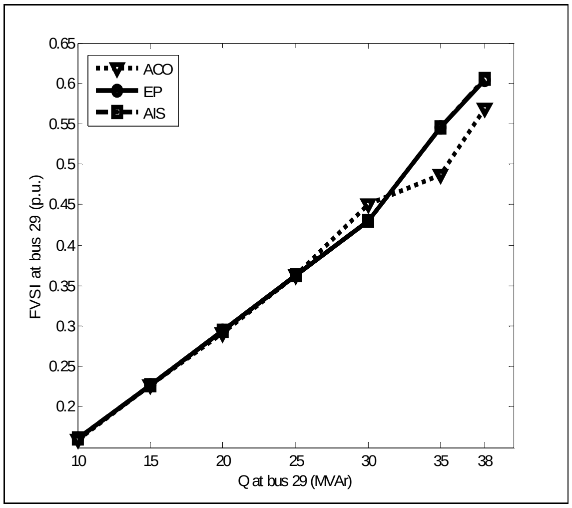

Fig. 4: *FVSI* profiles monitored with load varies at bus 29

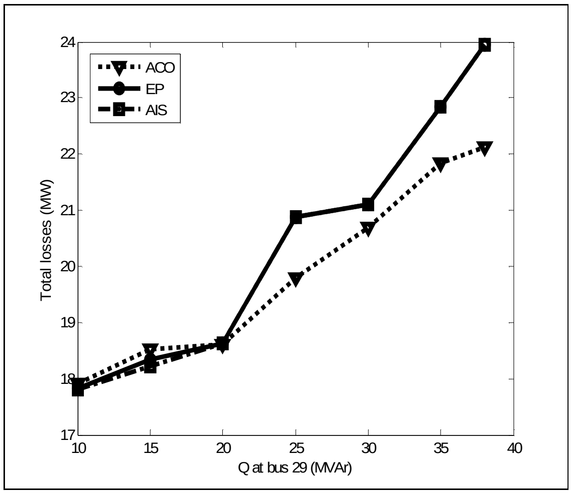

Fig. 5: Total losses profiles monitored with load varies at bus 29

The profiles for *FVSI*, loss and bus voltage in voltage stability improvement using ACO, EP and AIS are shown in Fig. 4, 5 and 6. In Fig. 4, it is observed that ACO is better than EP and AIS since the *FVSI* profile is lower indicating better voltage stability improvement particularly at high value of *Q*. On the Fig. 5 illustrates the transmission loss profile with OTTCS implemented using ACO, EP and AIS. From the figure, the ACO managed to reduce the largest transmission loss as compared to EP and AIS. On the other hand, in Fig. 6 the bus voltage is higher with the implementation of ACO as compared to EP and AIS. This reveals the strength of ACO in improving voltage profile. This has revealed the merit of ACO as compared to EP and AIS optimization techniques.

VI. CONCLUSION

ACO has been developed for voltage stability improvement in power system. The ACO algorithm for OTTCS was written in MATLAB and tested on the IEEE 30-bus RTS. The results of this study were consequently compared with other techniques such as EP and AIS. The implementation ACO for OTTCS was able to improve voltage stability condition by modify the tap setting value of transformer in the test system. Furthermore, the application of ACO for OTTCS has outperformed EP and AIS in terms of voltage stability improvement, loss minimization, voltage profile improvement and fast computation time. Minor modification of the developed ACO algorithm or engine could be the next step for solving more complex power system optimization problems.

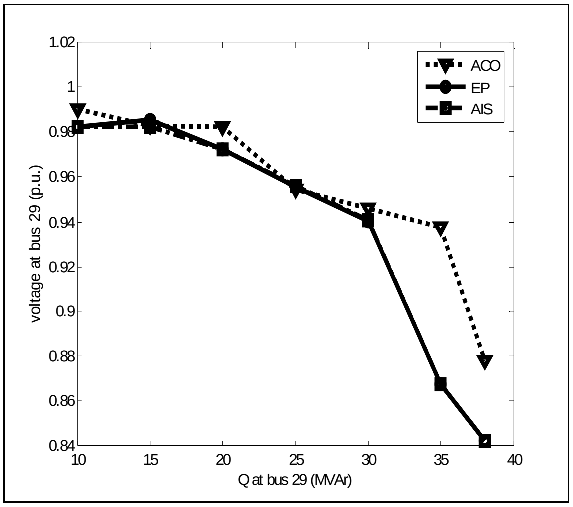

Fig. 6: Voltage profiles monitored with load varies at bus 29

VII. REFERENCES

[1] J. Kubokuwa, R. Inoue and H. Sasaki, "A Solution of Optimal Power Flow with Voltage Stability Constraints", *Proc International Conference of Power Systems Technology – PowerCon*, Vol. 2, 2000, pp. 625 - 630.

[2] C. J. Parker, I. F. Morrison and D. Sutanto, "Application of an Optimization Method for Determining the Reactive Margin from Voltage Collapse in Reactive Power Planning", *IEEE Transaction on Power Systems*, Vol. 11, No. 3, Aug. 1996, pp. 1473 - 1481.

[3] D. Thukaram, K. Parthasarathy, H. P. Khincha, N. Udupa and A. Bansilal, "Voltage Stability Improvement: Case Studies of Indian Power Network", *Electric Power Systems Research*, Vol. 44, No. 1, January 1998, pp. 35 – 44.

[4] Bansilal, D. Thukaram and K. Parthasarathy, "Optimal Reactive Power Dispatch Algorithm for Voltage Stability Improvement", *International Journal of Electrical Power and Energy Systems*, Vol. 18 No. 7 1996 pp. 461 – 468.

[5] J. W. Lamout and J. Fu, "Cost Analysis of Reactive Power Support", *IEEE Transaction on Power Systems*, Vol. 14, No. 3, Aug. 1999, pp. 890 - 917.

[6] D. Gao, "A Novel Thyristor Assisted Diverter Switch for On Load Transformer Tap Changer", *Transmission and Distribution Conference and Exhibition 2002: Asia Pacific. IEEE/PES Vol. 1*, 6 - 10 Oct. 2002, pp. 297 - 300.

[7] P. Bauer and S. W. H. de Haan, “Electronic Tap Changer For 500 kVA/10kV Distribution Transformers: Design, Experimental Results And Impacts In Distribution Networks” *Industry Applications Conference, 1998. Thirty-Third IAS Annual Meeting, The 1998 IEE Vol. 2,* 12 -15 Oct. 1998, pp. 1530 - 1537.

[8] B. Kasztenny, E. Rosolowski, J. Izykowski, M. M. Saha and B. Hillstrom, “Fuzzy Logic Controller for On-Load Transformer Tap Changer” *IEEE Transaction on Power Delivery,* Vol. 13, No. 1, Jan. 1998, pp. 164 - 170.

[9] Bansilal, D. Thukaram dan K. Parthasarathy, “An Expert System for Voltage Control in A Power System Network”, *Energy Management and Power Delivery, 1995. Proceedings of EMPD ’95., 1995 International Conference on Vol. 1,* 21 - 23 Nov. 1995, pp. 364 - 369.

[10] M. F. Islam, J. Kamruzzaman and G. Lu, “Transformer Tap Changing by Data Classification using Artificial Neural Network” *Power Systems Conference and Exposition, 2004. IEEE PES,* 10 - 13 Oct. 2004, pp. 1417 - 1422.

[11] M. Suzuki, T. Minakawa and K. Sato, “Coordinated AVQC Operations of EHV Transformer’s Tap Changer by Fuzzy Expert Control System”, *Power System Technology, 2002. Proccedings, PowerCon 2002, International Conference on Vol. 3,* 13 - 17 Oct. 2002, pp. 1679 - 1684.

[12] J. H. Harlow, “Transfomer Tap Changing Under Load: A review of Concepts and Standards”, *Proceedings 1993, 64th Annual Engineering Conference,* Kansas City, Missouri, pp. 305 - 310.

[13] I.Musirin, “Novel Computer Aided Technique for Voltage Stability Assessment and Improvement in Power System”, Ph.D. Thesis, Universiti Teknologi MARA, Malaysia, 2004.

[14] M. Dorigo, “Optimization, Learning and Natural Algorithms,” Ph.D Thesis, Dipartimento, Politecnico di Milano, Italy, 1992.

[15] M. Dorigo and G. Di Caro, “The Ant Colony Optimization Meta-Heuristic: in D. Corne, M. Dorigo, F. Glover, editors, *New Ideas in Optimization*, McGraw-Hill 1997, pp. 11 - 32.

[16] M. Dorigo, G. Di Caro and L. M. Gambardella, “Ant Algorithms for Discrete Optimization”, Artificial Life, Vol. 5, No. 2, 1999, pp. 137 - 172.

[17] M. Dorigo, V. Maniezzo and A. Colorni, “Ant System: Optimization by a colony of cooperating agents, *IEEE Transaction System Man. And Cybernatics, Part B: Cybernatic,* Vol. 26, No. 1, 1996, pp. 29 – 41.

[18] M. Dorigo, and T. Stutzle, “Ant Colony Optimization”, A Bradford Book, 2004.

[19] T. H. Ying, C. L. Chuang and C. C. Cheng, “Ant Colony Optimization for Best Path Planning”, *International Symposium on Communications and Information Technologies 2004 (ISCIT 2004),* Sapporo, Japan, 26 - 29 October 2004, pp. 109 - 113.

[20] M. Qoubutra, P. Premprayoon and P. Wardkein “Topological Communication Network Design Using Improved Ant Colony Optimization”, *The IASTED International Conference on Network and Communication Systems (NCS 2005),* Krabi, Thailand, 18 - 20 April 2005.

VIII. BIBLIOGRAPHIES

Mohd Rozely Kalil obtained Diploma in Electrical Engineering (Power) from Universiti Teknologi Malaysia in 1994, Bachelor in Electrical Engineering (Hons) from Universiti Teknologi MARA, Malaysia in 2000 and MSc in Electrical Engineering from Universiti Teknologi MARA, Malaysia in 2008. He has published more than 10 technical papers in the international conferences and journal. His research interest includes power system optimization, ant colony optimization (ACO) technique, Evolutionary Programming (EP), voltage stability studies, reactive power planning and loss minimization.

Dr. Ismail Musirin obtained Diploma of Electrical Power Engineering in 1987, Bachelor of Electrical Engineering (Hons) in 1990; both from Universiti Teknologi Malaysia, MSc in Pulsed Power Technology in 1992 from University of Strathclyde, United Kingdom and PhD in Electrical Engineering in 2005 from Universiti Teknologi MARA, Malaysia. He is currently an associate professor and the chair, Centre of Electrical Power Engineering Studies (CEPES) at the Faculty of Electrical Engineering, Universiti Teknologi MARA, Shah Alam, Malaysia. He His research interest includes power system stability, optimization techniques, distributed generator, biological computing, computational intelligence and artificial intelligence.

Dr. Muhammad Murtadha bin Othman received his B.Eng. (Hons) from Staffordshire University, England in 1998; M.Sc from Universiti Putra Malaysia in 2000 and Ph.D from Universiti Kebangsaan Malaysia in 2006. He currently lectures at the Universiti Teknologi MARA, Malaysia. His area of research interests are artificial intelligence, transfer capability assessment and reliability studies in a deregulated power system.