IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 11, Issue 2 Ver. I (Mar. – Apr. 2016), PP 54-65
www.iosrjournals.org

Optimal Placement of AVR in RDS Using Modified Cuckoo Search Algorithm

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Abstract : *Optimal Placement of Automatic Voltage Regulator (AVR) in distribution system with Modified Cuckoo search algorithm is proposed. The optimal Location of AVR's in distribution network has been achieved using the voltage stability index values at each node and the minimum total active power loss that is obtained for a particular location of the AVR at a node. The Tap-settings of the AVR has been descided based on the optimization of objective function subjected to constraints using Modified Cuckoo Search Algorithm. The proposed method has been tested on standard 15-node, 33-node and 69-node distribution systems and the results obtained are better than the existing methods.*
Keywords: *Automatic Voltage Regulators, Placement, Modified cuckoo search algorithm, Tap-settings*

I. Introduction

It is the utilities responsibility to keep the customer voltage within specified tolerances; voltage regulation is an important subject in electrical distribution engineering. One of the performance criteria for a distribution system and the quality of the provided service are the maintenance of satisfactory voltage levels at the customers' premises. However, most equipment and appliances operate satisfactorily over some 'reasonable' range of voltages; hence, certain tolerances are allowed at the customers' end. Thus, it is common practice among utilities to stay within preferred voltage levels and ranges of variations for satisfactory operation of apparatus as set by various standards [7]. One of the most important devices to be utilized for the voltage regulation is the AVRs which can be operated in manual or automatic mode. In the manual mode, the output voltage can be manually raised or lowered on the regulator's control board and it could be modelled as a constant ratio transformer in power flow algorithms. In the automatic mode, the regulator control mechanism adjusts the taps to assure that the voltage being monitored is within certain range. In distribution systems, voltages along the primary feeders are often controlled by voltage regulators. These regulators are generally auto-transformers with individual taps on their windings and must be incorporated into the load flow algorithms. Some distribution system power flow algorithms have been made to incorporate voltage regulator in manual or in automatic mode [5-9]. Although the Forward/ Backward sweep-based methods are mostly used for the load flow analysis of distribution systems, only a sweep-algorithm, given in [6], incorporated AVRs to the load flow analysis. In the study, AVRs are included into the forward voltage calculation of a particular forward/backward substitution method. However the authors did not model the automatic voltage regulators for the backward voltage calculation as it is not required for their particular algorithm. In distribution load flow analysis, there are number of power flow algorithms which has backward voltage calculation such as; Ratio-Flow method [2], Ladder Network theory [2, 6].

II. Problem Formulation

2.1 Optimization problem formulation with AVR

To formulate optimization problem with AVR, in this chapter, three objectives namely, savings, voltage deviation (Vdev) and section current index (SCI) are considered. The details are given as follows:

2.1.1 Maximization of Savings ($)

This objective is used to maximize the savings in a given system in the presence of AVR. The mathematical expression used to calculate the savings is given as follows:

Max (Savings) = $K_E \times P_{LR} \times 8760 \times L_{SF} - K_{VR} \times N(\alpha - \beta)$ (1)

Where,

P_{LR} The reduction in power loss due to installation of VR
= (power loss before installation of VR – Power loss after installation of VR)

K_E The cost of energy in Rs./kWh

L_{SF} is the Loss factor = 0.2 L_F + 0.8 L_F^2

Where,

L_F is the load factor

N is the number of VRs

K_{VR} is the cost of each VR

α is the rate of annual depreciation charges for VR
β is the cost of installation of VR.
KVA rating of the AVR is (rated voltage × % boost of booster × rated current) / 100

2.1.2 Minimization of Voltage deviation (V_{dev}) (p.u.)

It is necessary to main the voltage magnitude at the nodes within permissible limits to increase the security of the system. For this, it is necessary to minimize the voltage deviation at system nodes. The system voltage deviation can be calculated as

$$V_{dev} = \min\left(\sum_{j=2}^{nnode} (|V_j| - |V_{rated}|)^2)\right) \qquad (p.u) \qquad (2)$$

Where, V_j is the voltage magnitude at j[th] node and V_{rated} is the rated voltage considered to be 1.0 p.u. and 'nnode' is the total number of nodes in the system.

2.1.3 Minimization of Section current index (SCI)

Providing the active and reactive power near the loads may increase or decrease the current flow in some sections of the network, thus releasing more capacity or also place out of distribution line limits. The section current index (SCI) gives important information about the level of currents through the network. The section current index can be calculated when performing the power flow analysis before and after installation of capacitor banks as

$$\text{SCI} = \left[\min\left(\frac{\sum_{s=1}^{L} \frac{I_{sm} - I_{sas}}{\max(I_{sm}, I_{sas})}}{L}\right)\right] \qquad (3)$$

Where

I_{sm} is the mean of Line section current after placement of capacitor.

I_{sas} is the line section current after placement of Capacitor

L total number of line section
s is the line section

2.1.4 Selection of TAP settings

`The **tap** positions of voltage regulator is determined as follows
In general, the voltage regulator position at node 'j' can be calculated as

$$V_j^{new} = V_j^{old} \pm tap \times V_{rated} \qquad (4)$$

Where, V_j^{new} is the voltage at node 'j' after VR installation in p.u, V_j^{old} is the voltage at node 'j' before VR installation in p.u, V_{rated} is the rated voltage in p.u

tap is the tap position of VR in discrete steps, + for boosting of voltage and - for bucking of voltage
The tap position can be calculated by comparing voltage obtained before voltage regulator installation with lower and upper limits of voltage. The bus voltages are computed by load flows for each change in the tap settings of the voltage regulators, till all bus voltages are within the specified limits. Then obtain the net savings, with the above tap settings for voltage regulators.

2.1.5 Voltage stability index

The vector form of representation of voltage stability index is

$$\overline{VSI} = \overline{V}^4 - 4 \times \left[\overline{LPBB}^T \times \overline{X} - \overline{LQBB}^T \times \overline{R}\right]^2 - 4 \times \left[\overline{LPBB}^T \times \overline{R} + \overline{LQBB}^T \times \overline{X}\right]\overline{V}^2 \qquad (5)$$

Where, $\left[\overline{LPBB}\right]$ and $\left[\overline{LQBB}\right]$ are the vectors of total active and reactive load beyond a branch. $\overline{R}$ is the vector of branch resistance in p.u, also $\overline{LPBB}$, $\overline{LQBB}$ and $\overline{V}$ vector values are in p.u. The order of $\overline{LPBB}$ and $\overline{LQBB}$ are (nnode-1 × 1), The order of $\overline{V}$ is (nnode-1 × 1) and $\overline{R}$ and $\overline{X}$ are the branch resistance and reactance vectors and are of order (nbr × 1).

$\overline{VSI}$ = voltage stability index vector of nodes and is of order (nnode-1 × 1).

For stable operation of radial distribution networks, each element of the voltage stability index vector should be greater than or equal to zero i.e $\overline{VSI} \geq 0$.

By using this voltage stability index, one can measure the level of stability of radial distribution networks and there by appropriate action may be taken if the index indicates a poor level of stability.

2.1.6 Computation of voltage stability indices

Step-1: Read the system line and load data

Step-2: Run the load flow and compute the voltage stability index for each node by using eq.(6) with increasing load at every node of the system.

Step-3: Check the P-V curve to identify the nose-point, note the voltage stability index of the system.

Step-4: Arrange the list of nodes in ascending order of the VSI values.

Step-5: Locate the AVRs at the nodes according to priority list.

Step-6: End

2.1.7 Updating of voltages with AVR, for single feeder with sub-laterals

$$V_{k\_ratio} = \frac{V_k^{new}}{V_s^{new}} \tag{6}$$

$$V_k^{adjust} = V_{k\_ratio} \times V_s \tag{7}$$

Where, V_k^{new} is the voltage magnitude at the downstream nodes after AVR

V_s^{new} is the secondary voltage of the AVR transformer.

V_s is the standard voltage to be maintained at the transformer secondary.

The downstream nodes of the corresponding AVR's located in the system are identified using the NBIM matrix rows. Suppose if the AVR is located at node-6 in the 33-node system, the downstream nodes are the nonzero elements of the row-6 of the NBIM matrix. Using this row with only ones and zeros as its elements the updated voltage magnitudes calculated with eq. (6) and eq. (7).

III. Proposed Modified Cuckoo Search Algorithm (Mcsa)

3. Modified Cuckoo Search Algorithm (MCSA)

The cuckoo search algorithm, it is a new technique developed for solving continuous and non linear optimization problems. This algorithm was developed from the lifestyle of cuckoo bird family. The basic initiative for developing algorithm is special life style of cuckoo birds, characteristics in egg laying as well as breeding.

From the life style of cuckoo bird it is well known that cuckoo lays eggs in the host bird nest due to similarity between cuckoo and host bird eggs. Whenever cuckoo laid eggs in the host bird nest only some number of eggs will hatch up and turned into cuckoo chicks and remaining will be killed by host bird. The nest in which more number of cuckoo chicks will survive that nest will be the best nest in that area. The best habitat in any area with more number of egg survival rate gives best profit of that area.

In an optimization problem, the population can be formed as an array. In cuckoo optimization algorithm such an array is called habitat.

$$Habitat = [x_1,\ x_2,\ ....\ x_n] \tag{8}$$

The profit of habitat is estimated by evaluating profit function as,

$$profit = F[habitat] = F[x_1, x_2, ..., x_n] \tag{9}$$

It is the modified version of cuckoo search optimization method. Modified cuckoo search method is developed by combining GA with actual cuckoo search process by which it is observed that such method yields to better performance. Sequential steps for Modified cuckoo search algorithm are given as follows.

3.1.1 Initialization

Initial population of control variable is randomly generated by using,

$$x_{ab} = x_b^{\min} + rand(0,1) \times (x_b^{\max} - x_b^{\min}) \tag{10}$$

Where, $a = 1, 2, \ldots, n$, $b = 1, 2, \ldots, m$

$n =$ Number of nests, $m =$ Number of control variables

$x_b^{\min}$ *and* $x_b^{\max}$ are min. and max. limits of b^{th} control variable $rand$ $(0,1)$ is the random number generated between [0,1]

3.1.2 Levy flights

Levy flight is the search process of population of solution from the randomly generated initial population. After performing the levy flight cuckoo chooses the host nest position randomly to lay egg is given in Eqn. (8) and (10). for i^{th} cuckoo, latest solutions are generated using,

$$x_i^{(t+1)} = x_i^{(t)} + s_{ab} \times \alpha \oplus Levy(\lambda) \tag{11}$$

Where, α random number between [-1,1], $\oplus$ is entry wise multiplication

$s_{ab} > 0$, it is the step size, based on this only new solution is generated. step size can be calculated as

$$s_{ab} = x_{ab}^t - x_{fb}^t \tag{12}$$

Where $a, f = 1, 2, \ldots\ldots, n$; $b = 1, 2, \ldots, m$ and

$$Levy(\lambda) = \left| \frac{\Gamma(1+\lambda) \times \sin\left(\frac{\pi \times \lambda}{2}\right)}{\Gamma\left(\frac{1+\lambda}{2}\right) \times \lambda \times 2^{\left(\frac{\lambda-1}{2}\right)}} \right|^{1/\lambda} \quad ; 1 < \lambda \leq 3 \tag{13}$$

Levy walk of population will generate new solution around the best solution. Population vector is modified using levy flight equation x_{ab}^{t+1} i.e, belongs to a^{th} nest and b^{th} control variable. Here old value x_{ab} is updated with respect to f^{th} neighborhood's nest, using Eqn. (8) is used to select host nest position and the egg laid by cuckoo is evaluated.

3.1.3 Crossover

Recently an efficient operator crossover has been designed for searching process [17].

$$x_{ab}^{new} = (1-\lambda) \times x_{1b}^{ref} + \lambda \times x_{ab}^{old} \tag{14}$$

Where λ is the random number between [0, 1]

Modified value x_{ab} is obtained by crossover of old value and its reference value. After crossover check the control variable limits for all the population. If upper limit is violated set to the maximum value, lower limit is violated set to the minimum value and if it is within the limit keep as such.

3.1.4 Selection

For this work sorting and ranking process is used. By comparing initial generation function vector and new function vector after performing crossover operator. Now modified function vector is obtained for new population, the minimum function value will be memorized. Now the function vectors sort by ascending order in which function values are ranked from minimum to maximum value. Then first rank function value and its corresponding population value are treated as best, and best population vector is given to the next generation.

3.1.5 Stopping criteria

Whenever the number of current generations equals to the maximum number of generations specified then final solution is obtained.

3.2 Computational procedure for optimal placement of AVR's

Step-1: Read the system line and load data.
Step-2: Run the load flow to get initial values of the voltage profile of the system.
Step-3: Locate the AVR's according to the procedure given in the Section.IV.
Step-4: Calculate the secondary voltage of the AVR transformer using eq.(4).
Step-5: Update the downstream voltages of nodes from the node where AVR is placed, using eq.(6) and eq.(7).
Step-6: Repeat the procedure for all the AVR's placed in the system.
Step-7: Calculate the AVR tap-setting values by optimizing the objective functions mentioned in section.2.1, using MCSA.
Step-8: Print the AVR Tap values and the voltage profile of the system.

IV. Results And Analysis

Example-1

To illustrate the proposed methodology, 15-node RDS is considered. To identify the effect of AVR on system performance, the descending ordered VSI values at the system nodes are tabulated in Table.1. From this table, it is identified that, the top three least VSI valued nodes are 2, 4 and 8. Among these nodes, to identify the optimum number of locations, the total power losses are optimized in the presence of AVR. The optimized TPL values are tabulated in Table.2. From this table, it is observed that, minimum TPL value is obtained, if the AVRs are placed at nodes 2 and 4 when compared to the other locations. From this, the further analysis is performed by placing the AVRs in these locations.

Table.1 Voltage Stability Index values at nodes of 15-node RDS

S. No	Node No	VSI value
1	2	0.933709
2	3	0.966428
3	8	0.974529
4	11	0.984597
5	6	0.985729
6	4	0.986762
7	12	0.990569
8	15	0.990935
9	10	0.991478
10	14	0.991554
11	7	0.994695
12	13	0.995193
13	5	0.996363
14	9	0.99838

Table.2 Optimum AVR locations of 15-node RDS

S. No	Locations	TPL value, Kw
1	2	37.1842
2	2, 4	33.9814
3	2, 4, 8	35.4169

The detailed summary of the test results for AVR placement are tabulated in Table.3. From this table, it is observed that, 25.1281 kW losses are reduced with AVRs when compared to without AVRs. It is also observed that, minimum voltage magnitude is obtained at node 8 because of lack of reactive support at this node.

Table.3 Summary of test results for AVR placement of 15-node RDS

Description		With AVR
AVR locations		2, 4
AVR Tap settings		+9, +3
TPL, kW	Without device	59.1095
	With AVR	33.9814
Loss reduction, kW		25.1281
Min voltage (p.u)		0.9725
Min voltage node		8

To show the effect of AVRs, the voltage values and power losses for without and with AVRs are tabulated in Tables 4 and 5 respectively. The variations of these parameters are shown in Figs 1 and 2.

Table.4 Voltage values with AVRs of 15-node RDS

Node No	Voltage magnitude (p.u.)	
	Without AVRs	With AVRs
1	1	1
2	0.9589	1.0012
3	0.9386	0.9807
4	0.9298	0.9727
5	0.9294	0.9723
6	0.9454	0.9726
7	0.9451	0.9724
8	0.9444	0.9717
9	0.9501	0.9827
10	0.9494	0.9825
11	0.9285	0.9814
12	0.9226	0.9757
13	0.9221	0.9753
14	0.929	0.9718
15	0.9289	0.9718

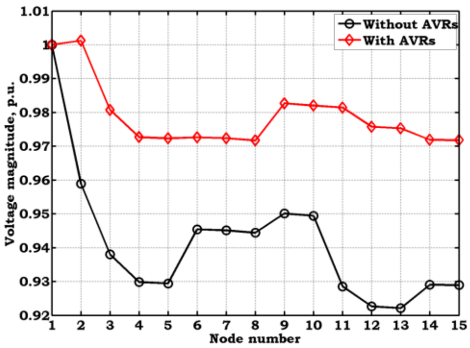

Fig.1 Variation of voltage values with AVRs of 15-node RDS

Table.5 Power losses with AVRs of 15-node RDS

Branch No	Sending Node	Receiving Node	P_{loss} (kW)	
			Without AVRs	With AVRs
1	1	2	13.8534	8.6918
2	2	3	12.3239	8.1207
3	3	4	7.66717	6.2927
4	4	5	0.87805	0.7241
5	2	9	3.26244	2.3124
6	9	10	1.11135	0.7941
7	2	6	4.26231	1.4375
8	6	7	0.61918	0.5131
9	6	8	2.07978	0.1853
10	3	11	5.16603	1.9726
11	11	12	2.54681	1.9654
12	12	13	1.01236	0.7871
13	4	14	1.43841	1.1934
14	4	15	2.8884	2.3982
Total losses (kW)			**59.1096**	**37.389**

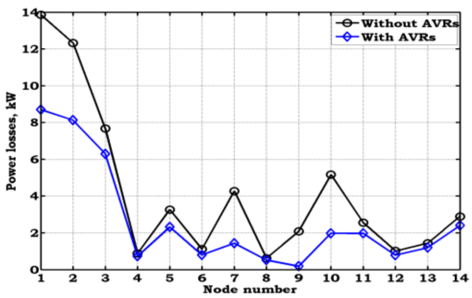

Fig.2 Variation of power losses with AVRs of 15-node RDS

From the Tables 4 and 5, it is identified that, the proposed method with AVRs yields better results when compared to the without AVRs. The single objective optimized results with savings, voltage deviation (Vdev) and section current index (SCI) as objectives for with and without AVRs using the developed MCSA is tabulated in Table.6. From this table, it is identified that, with AVR maximum benefit in terms of savings, Vdev and SCI values is obtained when compared to without AVR. It is also identified that, minimization/maximization of value of one of the objectives maximizes/minimizes the value of the other objectives. Hence, it is necessary to solve multi objective optimization problem to get compromised solution among the objectives.

Table.6 Single objective optimized results with AVRs of 15-node RDS

Control Parameters	**Without AVR**	**With AVR**		
		Savings ($)	**Voltage deviation (Vdev) (p.u.)**	**Section current Index (SCI)**
TAP_{AVR2}, Kw	-	+6	+10	+8
TAP_{AVR4}, Kw	-	+8	+8	+9
KP, ($)	-	5384.615	7692.308	6923.077
KF, ($)	-	298.5897	376.4349	1980.622
KE, ($)	-	11184.77	12362.11	10596.1
KC, ($)	-	8806.431	12580.62	11951.58
Savings, ($)	-	8061.542	7850.239	7548.21
Vdev, p.u.	0.08784	0.012456	0.01021	0.01346
SCI value	0.6252	0.5878	0.5947	0.60149
TPL, kW	59.5954	40.5614	38.5661	41.0649

When the voltage deviation is the objective function, the total active power losses are less when compared to other objective (i.e savings and SCI) with the Tap sizes being +10 for 2nd node voltage regulator and +8 for the 4th node voltage regulator. There is no much improvements in the section current index for all the three objectives, because the Automatic voltage regulator improved the voltage deviations, so, the total active power losses are more, also the saving in energy losses are less. But the benefits due to reduced demand and the benefits due to released feeder capacity are more with the improved voltage deviations. As the number of taps is more the cost of AVR is more, so, the net savings are less.

When the savings is the objective function, the total active power losses are moderate when compared to other objective (i.e SCI and voltage deviation) with the Tap sizes being +6 for 2nd node voltage regulator and +8 for the 4th node voltage regulator. There is no much improvements in the section current index for all the three objectives, because the Automatic voltage regulator improved the voltage deviations, so, the total active power losses are more, also the saving in energy losses are less. But the benefits due to reduced demand and the benefits due to released feeder capacity are more with the improved voltage deviations. As the number of taps is more the cost of AVR is moderate, so, the net savings are more.

When the section current index is the objective function, the total active power losses are less when compared to other objective (i.e savings and voltage deviation) with the Tap sizes being +8 for 2nd node voltage regulator and +9 for the 4th node voltage regulator. But the benefits due to reduced demand and the benefits due to released feeder capacity are more with the improved voltage deviations. As the number of taps is more the cost of AVR is moderate, so, the net savings are more.

For 15-node system it is observed from the voltage profile of the system for base case load that the voltages from node-3 to node-15 are below the tolerance voltage of the system i.e 0.95 p.u. Also by finding the voltage stability indices for all the nodes the best location for AVR has been found to be at node-2 and node-4.

As the 15-node system has a total active and reactive power loads of 1226 kW and 1251 kVAr, the number of Tap connections needed for the AVR to improve the voltage profile of the system are 18 Taps, with each tap boosting a voltage by 0.625%, the voltage profile of the system has been improved with the voltage deviation of the system being 0.01021, with the objective of minimization of voltage deviation. Even with the objectives of maximization of savings and minimization of section current index, the voltage deviation of the system is less for AVR than with the DG and the capacitors placed in the system independently. The improvement in voltage magnitudes results in the benefits in the release demand, released feeder capacity and moderate benefits in the annual energy loss savings of the system for all the considered objective functions. The net savings of the system are more as compared to the capacitors placement, because of the AVR directly improves the voltage magnitudes of the system by adjusting the number of Tap's in the booster transformer.

Example-2:

To illustrate the proposed methodology, 33-node RDS is considered. To identify the effect of AVR on system performance, the descending ordered VSI values at the system nodes are tabulated in Table.7. From this table, it is identified that, the top three highest VSI valued nodes are 24, 5 and 7. Among these nodes, to identify the optimum number of locations, the total power losses are optimized in the presence of AVR. The optimized

TPL values are tabulated in Table.8. From this table, it is observed that, minimum TPL value is obtained, if the AVRs are placed at nodes 24 and 5 when compared to the other locations. From this, the further analysis is performed by placing the AVRs in these locations.

Table.7 Voltage Stability Index values at nodes of 33-node RDS

S.No	Bus number	Voltage stabily index		S.No	Bus number	Voltage
1	24	0.996486353		17	19	0.999772486
2	5	0.998908236		18	22	0.999776659
3	28	0.999515344		19	29	0.999790383
4	23	0.999584814		20	6	0.999793256
5	27	0.999324986		21	1	0.999819751
6	2	0.999149197		22	26	0.999848695
7	8	0.999630139		23	13	0.999867032
8	7	0.999712453		24	16	0.999881355
9	4	0.999560352		25	25	0.999886004
10	9	0.999657335		26	11	0.999911738
11	17	0.999395043		27	14	0.999917236
12	12	0.999641048		28	15	0.999919871
13	21	0.999310278		29	31	0.999946199
14	3	0.999554245		30	10	0.999949335
15	32	0.999716229		31	20	0.999955207
16	30	0.999755407		32	18	0.999966368

Table.8 Optimum AVR locations of 33-node RDS

S. No	Locations	TPL value, kW
1	24	186.235
2	24, 5	172.536
3	24, 5, 7	182.456

The detailed summary of the test results for AVR placement are tabulated in Table.9. From this table, it is observed that, 40.95 kW losses are reduced with AVRs when compared to without AVRs. It is also observed that, minimum voltage magnitude is obtained at node 18 because of lack of reactive support at this node.

Table.9 Summary of test results for AVR placement of 33-node RDS

Description		With AVR
AVR locations		24, 5
AVR Tap settings		+10, +8
TPL, kW	Without device	213.564
	With AVR	172.614
Loss reduction, kW		40.95
Min voltage (p.u)		0.9825
Min voltage node		18

To show the effect of AVRs, the voltage values and power losses for without and with AVRs are tabulated in Tables 10 and 11 respectively. The variations of these parameters are shown in Figs 3 and 4.

Table.10 Voltage values with AVRs of 33-node RDS

Node No	Voltage magnitude (p.u.)	
	Without AVRs	With AVRs
1	1	1
2	0.996343	0.996343
3	0.978468	0.978468
4	0.968194	0.968194
5	0.957914	1.012104
6	0.933113	1.030218
7	0.92957	1.026306
8	0.924662	1.020887
9	0.918259	1.013818
10	0.91236	1.007305
11	0.911482	1.006336
12	0.909945	1.004639
13	0.903715	0.99776
14	0.901388	0.995191

15	0.899944	0.993597
16	0.898554	0.992063
17	0.896493	0.989787
18	0.895879	0.989227
19	0.995791	0.995791
20	0.99222	0.99222
21	0.991514	0.991514
22	0.990858	0.990876
23	0.974885	0.974885
24	0.968143	1.002165
25	0.964832	0.998932
26	0.929677	1.026425
27	0.925041	1.021305
28	0.905594	0.999835
29	0.891347	0.984106
30	0.884081	0.976084
31	0.879716	0.971264
32	0.878806	0.970259
33	0.878465	0.969991

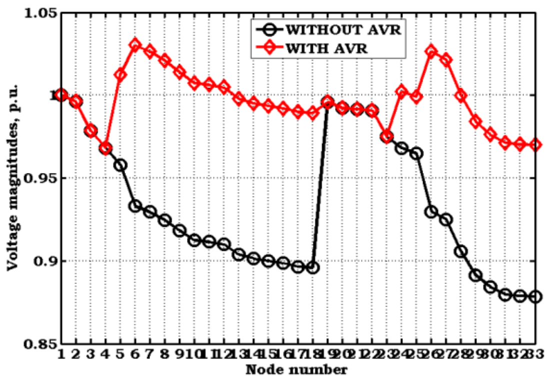

Fig.3 Variation of voltage values with AVRs of 33-node RDS

Table.11 Power losses with AVRs of 33-node RDS

Branch No	**Sending Node**	**Receiving Node**	**P_{loss} (kW)**	
			Without AVRs	**With AVRs**
1	1	2	2.20623	1.786291
2	2	3	11.2456	9.10509
3	3	4	11.3873	9.21979
4	4	5	14.1231	11.43486
5	5	6	20.5389	16.62946
6	6	7	10.9847	8.89388
7	7	8	9.83256	7.96098
8	8	9	8.35870	6.76766
9	9	10	8.25392	6.68283
10	10	11	7.54865	6.11180
11	11	12	7.10265	5.75070
12	12	13	6.75004	5.46521
13	13	14	5.9890	4.84907
14	14	15	4.24278	3.43519
15	15	16	3.34032	2.704510
16	16	17	2.428565	1.966300
17	17	18	1.461061	1.182955
18	2	19	0.234171	0.189598
19	19	20	0.330187	0.267338
20	20	21	0.23889	0.193420
21	21	22	0.127579	0.103295
22	3	23	3.689666	2.987357

23	23	24	4.276965	3.46286
24	24	25	2.377458	1.92492
25	6	26	9.77841	7.91714
26	26	27	9.76177	7.90366
27	27	28	11.12596	9.00819
28	28	29	11.73584	9.50199
29	29	30	10.61977	8.59836
30	30	31	6.96394	5.63839
31	31	32	4.522531	3.66169
32	32	33	1.01850	0.82463
TOTAL ACTIVE POWER LOSS			**212.59**	**172.13**

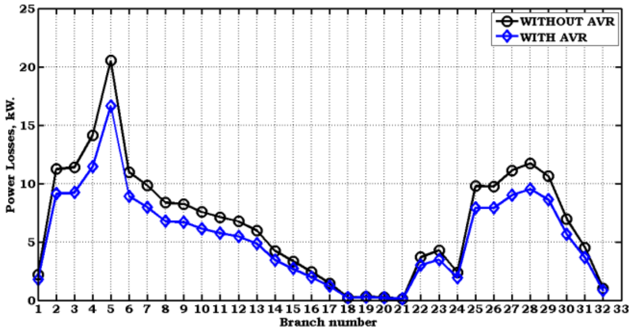

Fig.4 Variation of power losses with AVRs of 33-node RDS

From the Tables 10 and 11, it is identified that, the proposed method with AVRs yields better results when compared to the without AVRs. The single objective optimized results with savings, voltage deviation (Vdev) and section current index (SCI) as objectives for with and without AVRs using the developed MCSA is tabulated in Table.12. From this table, it is identified that, with AVR maximum benefit in terms of savings, Vdev and SCI values is obtained when compared to without AVR. It is also identified that, minimization/maximization of value of one of the objectives maximizes/minimizes the value of the other objectives. Hence, it is necessary to solve multi objective optimization problem to get compromised solution among the objectives.

Table.12 Single objective optimized results with AVRs of 33-node RDS

Control Parameters	**Without DG**	**With AVR**		
		Savings ($)	**Voltage deviation (Vdev) (p.u.)**	**Section current Index (SCI)**
TAP_{AVR24}	-	+13	+11	+13
TAP_{AVR5}	-	+8	+12	+10
KP, ($)	-	4615.385	5384.615	4615.385
KF, ($)	-	439.6814	417.5256	492.1657
KE, ($)	-	22822.36	22822.36	23365.75
KC, ($)	-	13209.65	14467.71	14467.71
Savings, $	-	14667.78	14156.79	14005.59
Vdev, p.u.	0.08674	0.02381	0.02031	0.02634
SCI value	0.6834	0.6534	0.6675	0.6245
TPL, kW	213.495	169.284	163.644	166.618

When the voltage deviation is the objective function, the total active power losses are less when compared to other objective (i.e savings and voltage deviation) with the Tap sizes being +11 for 24^{th} node voltage regulator and +12 for the 5^{th} node voltage regulator. There is no much improvements in the section current index for all the three objectives, because the Automatic voltage regulator improved the voltage deviations, so, the total active power losses are more, also the saving in energy losses are less. But the benefits due to reduced demand and the benefits due to released feeder capacity are more with the improved voltage deviations. As the number of taps is more the cost of AVR is more, so, the net savings are less.

When the savings is the objective function, the total active power losses are moderate when compared to other objective (i.e SCI and voltahe deviation) with the Tap sizes being +13 for 24^{th} node voltage regulator and +8 for the 5^{th} node voltage regulator. There is no much improvements in the section current index for all the three objectives, because the Automatic voltage regulator improved the voltage deviations, so, the total active power losses are more, also the saving in energy losses are less. But the benefits due to reduced demand and the benefits due to released feeder capacity are more with the improved voltage deviations. As the number of taps is more the cost of AVR is moderate, so, the net savings are more.

When the section current index is the objective function, the total active power losses are less when compared to other objective (i.e savings and voltage deviation) with the Tap sizes being +13 for 24th node voltage regulator and +10 for the 5th node voltage regulator. But the benefits due to reduced demand and the benefits due to released feeder capacity are more with the improved voltage deviations. As the number of taps is more the cost of AVR is moderate, so, the net savings are more.

The 33-node system has a total active and reactive power load of 3715 kW and 2674 kVAr, the voltages from node-5 to node-18 and node-25 to node-33, have voltage magnitudes less than tolerance of 0.95 p.u, the voltage stability indices indicate that the optimal locations of AVR's are at node-24, 5, 7 with minimum total active power loss as objective function. As the voltage deviations of most of the nodes are more for 33-node are below 0.95 p.u. The Tap settings needed for improving the voltage profile of the system are more for 33-node system than the 15-node system. The voltage deviation has been improved to 0.08674 from 0.02031. The benefits due to released demand, released feeder capacity and the benefits due to energy loss savings are more when compared to 15-node system; also the net savings of the system are more for 33-node system with more investment in the size of AVR as compared to the 15-node system. The percentage loss reduction is less for 33-node system as compared to the 15-node system.

Table.13 Single objective optimized results with AVRs of 69-node RDS

Control Parameters	**Without AVR**	**With AVR**		
		Savings ($)	**Voltage deviation**	**Section current**
TAP_{AVR57}	-	+14	+12	+14
TAP_{AVR6}	-	+15	+15	+11
KP, ($)	-	8192.308	4346.154	3884.615
KF, ($)	-	1491.8377	1094.8524	1415.2316
KE, ($)	-	24452.53	27169.48	25539.31
KC, ($)	-	18241.89	16983.83	15725.77
Savings, $	-	15894.78	15626.65	15113.39
Vdev, p.u.	0.08674	0.02181	0.01931	0.02434
SCI value	0.6776	0.6534	0.6675	0.6245
TPL, kW	225.659	180.226	174.694	178.165

As the 69-node distribution system is having long feeders with more loads at 11th, 12th, 49th, 50th, and the 61st load is having 33% of the overall load of the system, so, the number of tap settings needed for AVR's are more for 69-node system than the 33-node and the 15-node systems.

As the AVR sizes are more the net savings of the system are more, with more benefits in the released demand, released feeder capacity and the benefits due to the annual energy loss savings of the system. The benefits in the reduced feeder capacity are more for the case with objective function as minimization of section current index, than with savings and voltage deviations as objective functions. The energy loss savings are less for SCI as the objective, moderate for savings as objective and more for voltage deviation as the objective function. The cost of AVRs are more for savings as objective, moderate for voltage deviation as objective and less for SCI as objective function.

V. Conclusion

A novel method for the optimal location of AVR in distribution system has been proposed, where the voltage stability indices and the minimum total active power losses are taken into consideration. The tap-settings of the AVR has been determined by optimizing the objective function subjected to constraints using modified cuckoo search algorithm. The row of nodes beyond branch incidence matrix is used for updating of the downstream node voltages of the AVR. The row number corresponds to the AVR node number, is used for updating of voltages on the secondary side of the AVR. The proposed method has been tested on three standard 15-node, 33-node and 69-node distribution systems, it has been observed that the proposed method is superior to the existing method. Here the authors have considered the objective functions which includes the technical and Economical benefits, so that the results obtained are very useful for system planner/operator.

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