Optimal Distribution System Reconfiguration Using Qualified Binary Particle Swarm Optimization Algorithm

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***Abstract*—Distribution System Reconfiguration (DSR) is a complex action that changes the topology of distribution system by altering the status of its switches to afford radial construction with lower losses and confirm operating limits. In this paper, a comparison is made between two power flow methods, Direct Backward Forward Sweep Method (DBFSM) and Newton Raphson Method (NRM) to perform optimal DSR. Qualified Binary Particle Swarm Optimization (QBPSO) algorithm is used to obtain optimal DSR. Two standard networks (IEEE-16 bus, and IEEE-33 bus) are used to explain comparisons between two load flow methods. The using of DBFSM led to a significant influences in the minimizing of power losses and achieve more improvement in the voltage profile for both 16 bus and 33 bus RDS. The tabulated results and figures show that the DBFSM is more fast and robust than NRM. Also comparisons with literature works are made.**

***Index Terms*—Distribution System Reconfiguration, Radial Distribution System, DBFSM, QBPSO, Power Loss Minimization.**

I. INTRODUCTION

Electrical power systems are frequently labeled for interconnection of generation, transmission, and distribution systems. Distribution systems hold a very considerable place in the power systems because they represent the main point of link between bulk power systems and consumers. Usually, features of distribution systems are radial and power flow is in one direction. In distribution system, higher losses are found as a result of low voltage compared to transmission system. Copper losses are prevailing in distribution systems [1].Power losses in distribution systems may be severe and may passively impact the economics of electric power distribution systems. Then, it is benefit to search for reduction of losses using techniques such as DSR. The radial description is commonly used in distribution systems, whereas transmission systems can be either in loop or radial configurations [2]. DSR is a significant tool in distribution system for the objective of computerization process. With loads predictive system and faraway controlling system, system structure can be real-time modified, by changing open/closed case of some normally open and normally closed switches, to decrease power losses, equity overloads, enhance power system reliability and raise the power system capacity of distribution systems [3]. Lately, new optimization methods have been applied to RDS by many authors to reinforce the results and provide optimal system structure [4]-[8]. The load-flow study of radial distribution network is of major interest for effective planning in a load power transfer.

In this paper, DSR technique is studied using DBFSM and NRM, while QBPSO algorithm is proposed to obtain optimal structure. Systems with distinct topologies are executed to estimate the convergence action of the proposed technique and comparisons with other works are made.

II. METHODOLOGY

A. DBFSM LOAD FLOW

Classical power flow methods such as the NRM are insufficient and may diverge due to the different system characteristics of power distribution systems such as radial and high Resistance/Reactance (R/X) ratio [9]. Therefore, other techniques such as DBFSM are developed for power distribution systems.

The main steps of this load flow method will be summarized as follows [10]:

1) Read line, and bus data for the system.
2) Obtain the per-unit values for the line, and bus data.
3) Calculate Bus Injected-Branch Current (BIBC) array, and Branch Current-Bus Voltage (BCBV) array which calculate as follow:

$$[BCBV]= [BIBC]* \text{dig}\,(Z_{branch}) \tag{1}$$

where [BIBC] is a triangular matrix contains values either 0 or 1 corresponding to Kirchhoff's Current Low (KCL), dig (Z_{branch}) is diagonal matrix of branches impedance.

4) Define initial voltage for each bus as 1 p. u. with zero voltage angle.
5) Perform backward sweep step, first calculating bus current I_i using "Eq. 2" using complex load power S_i and bus voltage V_i values.

$$I_i= \left[\frac{S_i}{V_i}\right]^* \tag{2}$$

Then calculate branch current I_l by using "Eq. 3" which must be within current constraint.

$$I_l=[BIBC]*I_i \tag{3}$$

6) Perform forward sweep step by calculate voltage deviations (V_{div}) for each bus, then determine voltage drop (V_{drop}) across each branch which used to update voltage magnitude for each bus (j) using "Eqs. (4 - 6) ".

$$V_{div}=[BCBV]*[BIBC] \tag{4}$$

$$V_{drop}= V_{div}*I_i \tag{5}$$

$$V_j=V_i- V_{drop} \tag{6}$$

7) This process (backward and forward sweep steps) is repeated until tolerance value is achieved or maximum iteration number is reached. If these criteria achieved, go to next step, else return to step 5.

$$\Delta V_i^{iter}=|V_i^{iter}-V_i^{iter-1}| < \epsilon \tag{7}$$

where iter is iteration number, and ϵ is error value which equals 10^{-6}.

8) Determine real power loss for each branch, reactive power losses for each branch, total real power losses, and total reactive power losses using "Eqs. (8-11)".

$$P_{lossl}=I_l^2*R_l*10^5 \text{ kW} \tag{8}$$

$$Q_{lossl}=I_l^2*X_l*10^5 \text{ kVAr} \tag{9}$$

$$P_{losst}=\sum_{l=1}^{N_{br}} P_{lossl} \text{ kW} \tag{10}$$

$$Q_{losst}=\sum_{l=1}^{N_{br}} Q_{lossl} \text{ kVAr} \tag{11}$$

where P_{losst} is total real power losses, N_{br} is number of branches, R_l is a resistance of branch l, X_l is a reactance of branch l, and I_l is current flow in branch l.

B. Objective function and constraints

The objective functions and constraints of RDS are described as follows:

1) *Objective function:* The objective of DSR in this study is to reduce real power losses in order to reduce the cost of supplying the electrical power demanded by the loads, while specifying RDS constraints. Its mathematical formula can be presented as:

$$\text{Objective Function} = \text{loss reduction} + \text{saving maximizing} \tag{12}$$

where loss reduction problem can be represented by [11]:

$$P_{loss}=P_{losst}+C_{vv}* L_v+C_{cv}* L_i \tag{13}$$

where L_v, and L_i are retribution specifications for buses voltage and branches current respectively, which are equal 0 when bus voltage and branch current constraints are achieved. C_{vv}, and C_{cv} are constraints of voltage violation, and current violation respectively which can be calculated by "Eqs. (14-15)".

$$C_{vv} =\sum_{i=1}^{N_b} ((V_i<V_{min}) \text{ or } (V_i>V_{max}))^2 \tag{14}$$

$$C_{cv} =\sum_{l=1}^{N_{br}} ((I_l>I_{max}))^2 \tag{15}$$

where i, and N_b are bus number, and number of buses respectively; V_{min}, and V_{max} are minimum and maximum allowable bus voltage limits respectively; l , N_{br} and I_{max} are branch number, number of branches, and maximum allowable branch current respectively.

Saving maximizing problem depends on difference between cost of base power losses and cost of power losses after applying DSR technique considering cost coefficient equals to 0.06 $/kWH [12].

2) *Constraints:*

- *Radial structure*

  This condition used to check whether all loads are covered, which can be determined by calculation of determinant of bus incidence matrix [A] as follows:

$$[A] = \begin{cases} -1 \text{ or } 1 & \text{system is radial} \\ 0 & \text{system is not radial} \end{cases} \tag{16}$$

- Bus voltage limits:

$$|V_{min}|\le|V_j|\le|V_{max}| \tag{17}$$

where standard minimum voltage used is 0.95 p. u. and maximum voltage is 1.05 p. u. (i.e. 1±5%)

- Branch current limits:

It represents thermal coefficient for each branch that can be written as below:

$$|I_l|\le|I_{max}| \tag{18}$$

- Power balance constraint:

$$P_{sub}=P_d+P_{losst} \tag{19}$$

where P_{sub} is substation power, P_d is demand power.

III - APPLICATION of QBPSO algorithm to DSR PROBLEM

In this section, the mathematical model of QBPSO algorithm is explained in detail. Also, this section provides the implementation procedure of this algorithm to DSR technique.

A. QBPSO

In search space with dimension of (d) which have number of particles of range (20-40), the velocity and position for particle (p) can be updated using information of previous iteration by the following equations [13]:

$$v_{pd}^{iter+1}= w^{iter} *v_{pd}^{iter}+ c_1*r_1* \left(pbst_{pd}^{iter}- x_{pd}^{iter}\right) +c_2*r_2*(gbst_d^{iter}- x_{pd}^{iter}) \tag{20}$$

$$x_{pd}^{iter+1}= x_{pd}^{iter}+v_{pd}^{iter+1} \tag{21}$$

where v_p, x_p, $pbst_p$ are velocity , position , and best position of particle p respectively; $gbst_d$ is global best position ; c_1 & c_2 are acceleration factors(its rate: 1.5-2.5); r_1 and r_2 are random numbers between 0 &1. w is inertia weight which calculated by :

$$w^{iter}=\frac{w_{max}-w_{min}}{max.iter}*iter \tag{22}$$

where w_{max} , and w_{min} are maximum and minimum inertia weight values respectively, while max.iter is maximum number of iterations which equals 300.

To enable this algorithm to search in discrete space, velocity and position values for each particle need to restricted to (0 or 1), then, the following transfer function T.f can be used as:

$$T.f\,(V_p^{iter+1}) = \frac{1}{1+e^{-V_{pd}^{(iter+1)}}} \qquad (23)$$

Then, by using this function, the "Eq. 21" will be changed to:

$$x_{pd}^{iter+1} = \begin{cases} 1 & \text{if } r < T.f(V_p^{iter+1}) \\ 0 & \text{else} \end{cases} \qquad (24)$$

The optimal values for algorithm parameters used in this study for two systems are tabulated in Table I.

TABLE I. PARAMETERS OF QBPSO ALGORITHM.

Parameter	Value
Number of particles (population)	30
Maximum inertia weight	0.9
Minimum inertia weight	0.4
c_1 & c_2	2.0

B. Implementation of QBPSO for DSR

The proposed algorithm is implimented to find the optimal topology that reduces the real power losses with enhance the voltage profile.The switches of RDS here specified as discrete values, where 0 means switch is open, and 1 means switch is close.The flowchart of this algorithm to DSR problem is shown in Fig. 1.

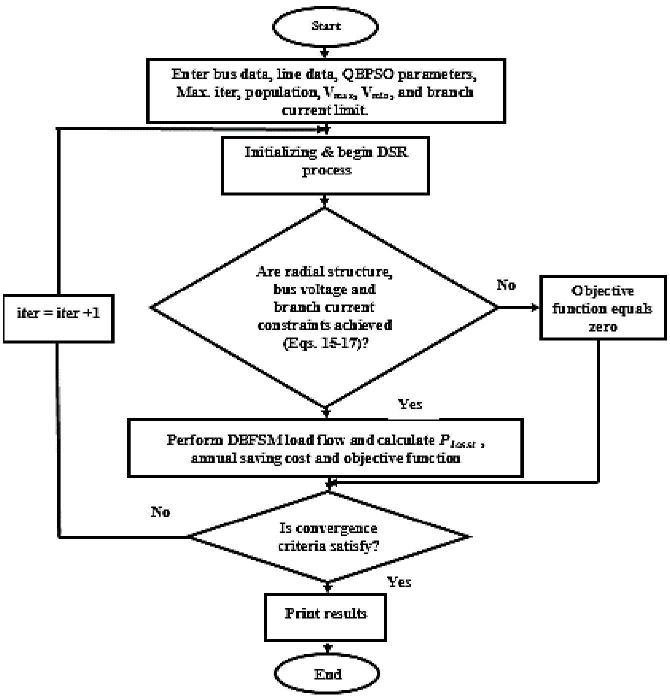

Fig.1. QBPSO algorithm for optimal DSR.

IV. RESULTS AND DISCUSSIONS

In order to explain the effectiveness and efficiency of QBPSO algorithm for DSR technique, it is tested on two standard systems, IEEE-16 and 33 buses. The results are compared with that obtained by other literature works. The QBPSO algorithm based technique was programmed by MATLAB language 2018a. The line data and bus data are taken from [14].

A. Case study one: IEEE-16 bus

The single line layout of this network in base case, with DSR using DBFSM, and with DSR using NRM are shown in Figs. 2, 3, and 4 respectively .The standard system, 23 kV, 100 MVA, in base case contains 3 feeders, 16 bus (3 slack buses, and 13 load buses), 16 branches, 13 closed sectionalizing switches (S_1-S_{13}), and 3 opened tie switches (S_{14}-S_{16}). The system Load is 28.7 MW [15]. Voltage profile for different cases is shown in Fig. 5. Losses, minimum bus voltage, open tie-switches no., and percentage loss reduction for three cases are tabulated in Table II.

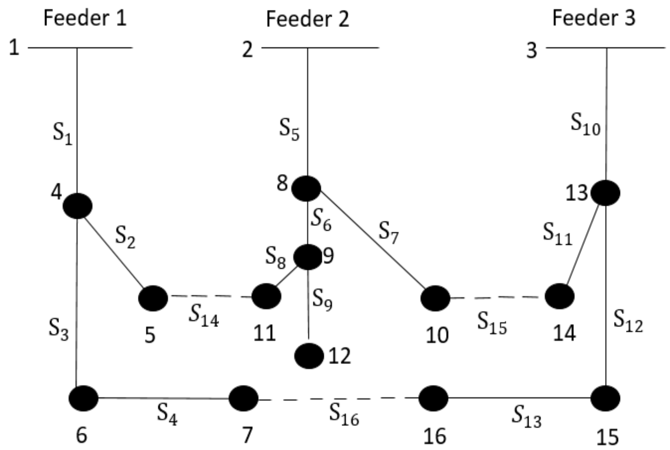

Fig. 2. IEEE-16 bus topology in Base case.

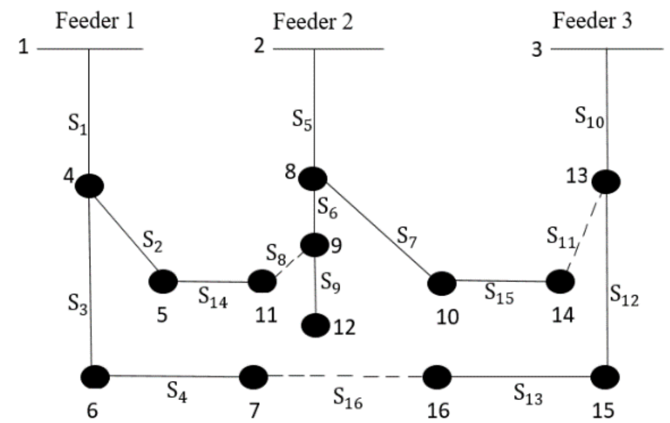

Fig. 3. IEEE-16 bus topology with DNR technique using DBFSM.

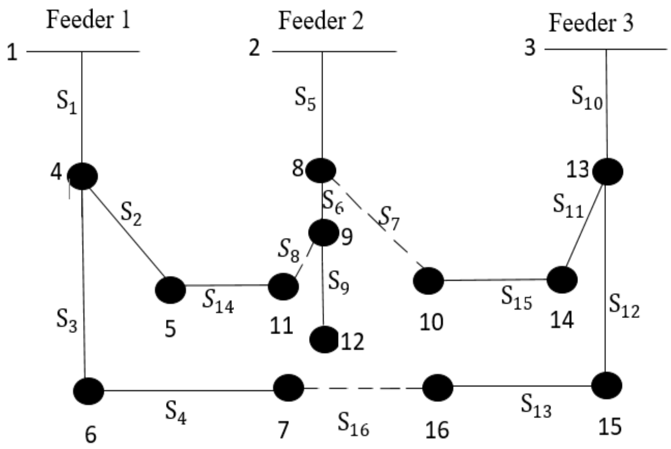

Fig. 4. IEEE-16bus topology with DNR technique using NRM.

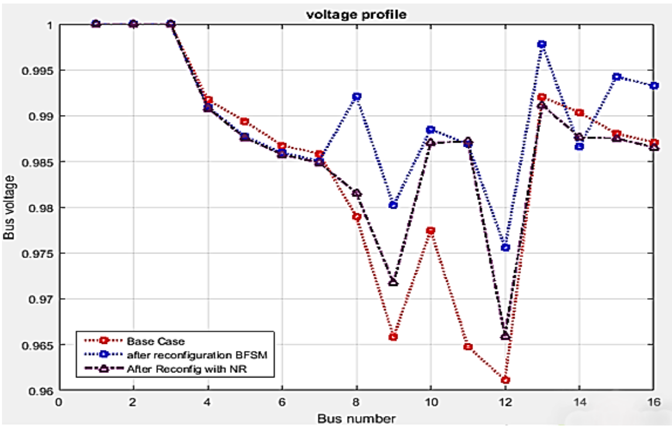

Fig. 5. IEEE-16 bus voltage profile after DSR technique using DBFSM &NRM.

From Fig. 5, it is clear that the voltage profile of 16 bus RDS resulting from using the DBFSM is better than this resulting from using the NRM for the reconfigured network, also it is explained in Table II as a Min. V value.

Table II. COMPARISONS BETWEEN NRM & DBFSM FOR DSR IN IEEE-16 bus.

Load flow method	Losses (kW)	Min. V (p. u.)	Open Tie switches no.	% loss reduction
Base case	511.452	0.96113	14, 15, 16	-
Reconfiguration with NRM	453.492	0.96591	7 , 8 , 16	11.3323
Reconfiguration with DBFSM	251.226	0.97561	8, 16, 11	50.8797

The effectiveness of QBPSO for DSR of case study one is better than literature works such as, Hybrid Big Bang-Big Crunch (HBB-BC), Novel Genetic Algorithm (NGA), Plant Growth Simulation Algorithm (PGSA), Modified Culture Algorithm (MCA), and Heuristic Branch Exchange (HBE) as presented in Table III.

TABLE III. COMPARISONS WITH OTHER ALGORITHMS FOR IEEE-16 BUS RDS.

Algorithm	**Literature works**					**Proposed algorithm**
	HBB-BC [16]	**NGA [17]**	**PGSA [11]**	**MCA [10]**	**HBE [18]**	**QBPSO**
Losses (kW)	485	466.1	466.13	462.977	466.102	251.2266
Min. V (p. u.)	0.969	-	0.9716	0.97158	0.9732	0.97561
Open Tie switch no.	7, 8, 16	7, 8, 16	8, 7, 16	7, 8, 16	7, 8, 16	8, 11, 16
% Reduction	5.171	8.85	8.859	8.9856	8.86	50.8797

B. Case study two: IEEE-33bus

The standard system, 12.66 kV, 100 MVA, in base case contains 1 feeder, 33 bus, 37 branches, 32 closed sectionalizing switches (S_1-S_{32}), and 5 opened tie switches (S_{33}-S_{37}). The system Load is 3715 kW and 2300 kVAr [15]. The single line layout of this system in base case, with DSR using NRM , and with DSR using DBFSM are shown in Figs 6, 7, and 8 respectively. Voltage profile for different cases is shown in Fig. 9. Losses, minimum bus voltage, Open tie-switches no., and percentage loss reduction for three cases are tabulated in Table IV.

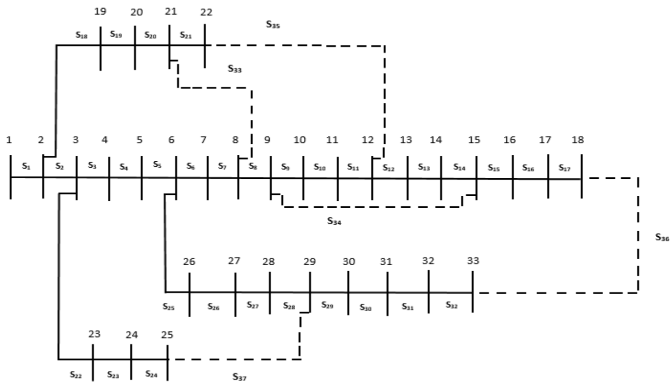

Fig. 6. IEEE-33 bus topology in base case.

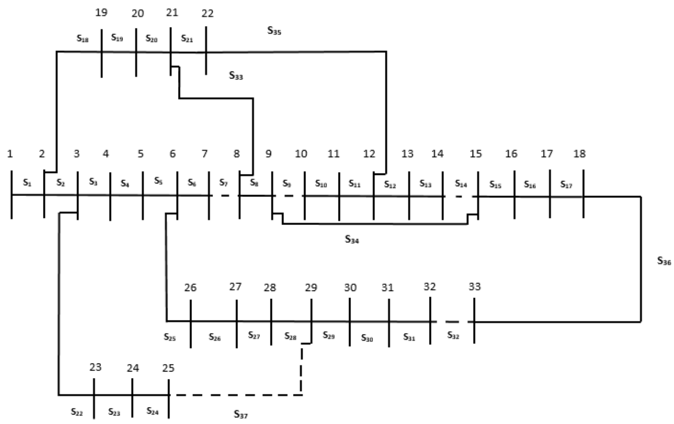

Fig. 7. IEEE-33 bus topology with DSR technique using NRM.

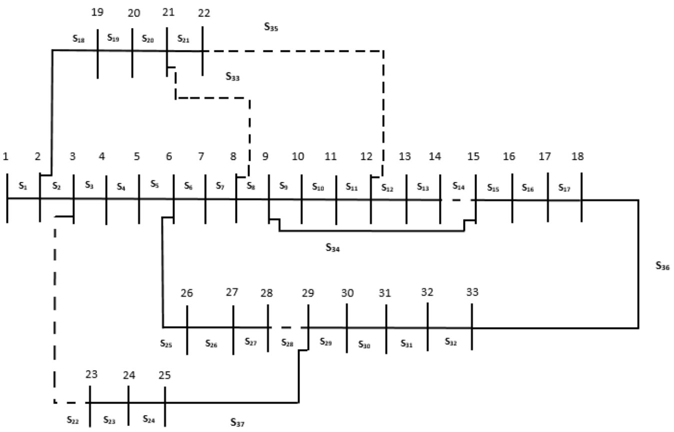

Fig. 8. IEEE-33 bus topology with DSR technique using DBFSM.

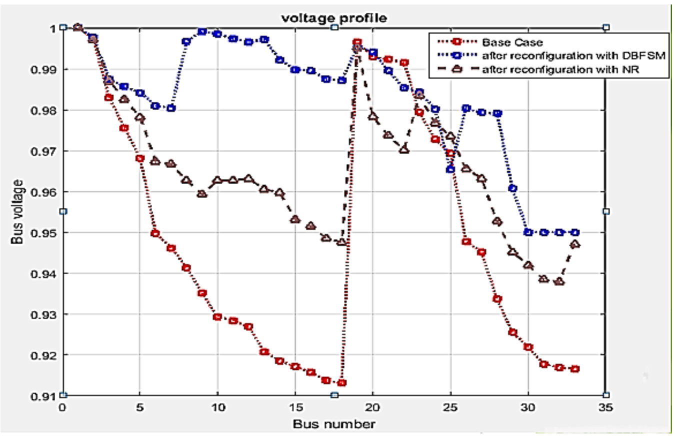

Fig. 9. IEEE-33 bus voltage profile after DSR technique using DBFSM &NRM.

From Fig.9, it is clear that the voltage profile of 33 bus RDS resulting from using the DBFSM is better than this resulting from using the NRM for the reconfigured network, also it is explained in Table IV as a Min. V value.

TABLE IV. COMPARISONS BETWEEN NRM & DBFSM FOR DSR IN IEEE-33 BUS.

Load flow method	Loss (kW)	Min. V (p. u.)	Open tie-switch no.	% loss reduction
Base case	202.677	0.91306	33, 44, 35, 36, 37	-
Reconfiguration with NRM	139.569	0.93781	7, 9, 14, 32, 37	31.1465
Reconfiguration with DBFSM	120.848	0.95	28, 22, 33, 14, 35	40.3805

Also, the reported results for the case study are compared with previous works such as, Gravitational Search Algorithm (GSA), Bacterial Foraging Optimization Algorithm (BFOA), Hierarchical Encoded Particle Swarm Optimization (HEPSO), Improved Genetic Algorithm (IGA), and Hyper Cube - Ant Colony Optimization (HC-ACO) Algorithm as explained in Table V.

TABLE V. COMPARISONS WITH OTHER ALGORITHMS FOR IEEE-33 BUS RDS.

Algorithm	Literature work					Proposed Algorithm
	GSA [19]	BFOA [20]	HEPSO [21]	IGA [22]	HC-ACO [23]	QBPSO
Losses (kW)	134.61	135.67	139.44	132.0	139.5	120.848
Min. V (p. u.)	0.9604	0.9406	-	0.96	0.9378	0.95
Open tie switch no.	7, 14, 28, 9, 32	7, 9, 14, 32, 37	7, 14, 9, 32, 37	13, 7, 15, 27, 10	7, 14, 9, 32, 37	28, 22, 33, 14, 35
% Reduction	33.49	33.07	31.22	34.8	31.18	40.3805

From above tables and graphs, it has been released that a notable reduction in real power losses after DSR, voltage profile improvement, and saving cost maximizing when using DBFSM. Also from computation time side, it proves the fastness when compared with NRM as explained in Table VI for two case studies.

TABLE VI. COMPUTATION TIME FOR DIFFERENT LOAD FLOW METHODS.

Load flow method	System	Time (sec.)
NRM	IEEE 16 bus	360.9373
	IEEE 33 bus	574.0139
DBFSM	IEEE 16 bus	153.7506
	IEEE 33 bus	266.8143

V. CONCLUSIONS

DSR approach is used to enhance voltage profile of RDS and reduce its losses. This technique needs a strong load flow method and fast optimization algorithm. A DBFSM provide this facility due to its efficiency and speed when compared with conventional load flow methods such as NRM. In addition, QBPSO algorithm shows its robustness and provides better results than other literature works. Also, it confirms all required constraints for RDS and can satisfy a huge reduction for both real power losses and cost for energy losses. The amounts of percentage loss reduction are 50.8797 % and 40.3805 % for 16 bus and 33 bus RDS respectively. The minimum voltage constraint (0.95 p. u.) has been satisfied in this present work while in several of literature works has been not ensured. In addition, the implementation time of the DBFSM is lesser than NRM for both case studies. The intelligent algorithm used provides an optimal solution and better results compared with others algorithms used in literature.

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