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Coordinated and Optimal Voltage Control in Active Distribution Networks using Fuzzy Logic and Backtracking Search Algorithm

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ABSTRACT

With progressively increasing distributed generation (DGs) connections, the transfer of power has been transformed into an active distribution system in the distribution network and it is no more unidirectional. The relationship between the DGs in distribution channels has created the distribution service providers with a bidirectional power flow obstacle. A tolerable voltage level of the system is the key technical hurdle for an active distribution network. These voltage regulation schemes can be divided into decentralized and centralized voltage controls. There are three voltage control methods implemented and compared in this paper to test the effectiveness and limitations of the control methods by performing simulations using the DigSilent Power Factory software. Throughout this study, the three decentralized voltage control strategies are assembled using fuzzy logic by taking into account load bus voltages and DG power as inputs and voltage control behaviors as outputs. The coordinated and optimal voltage control methods are implemented on the IEEE 13 bus and 69 bus test systems. From the results obtained, the voltage deviations in both the test systems tested has shown that the BSA technique has resulted in lower voltage deviation compared to using PSO.

Key words : Decentralized Voltage Control, Coordinated Voltage Control, Fuzzy Logic, Optimization, Active Distribution Network

1. INTRODUCTION

The evolving utility climate will keep demanding financial and market forces so that the power system will run more optimally and cost-effective with regard to generation, transmission and distribution and hence it requires a more secure and efficient operation of electricity networks which is crucial to advancement in technology [1]. Substantial distributed generation penetration varying from energy sources, rising demand flexibility, and modernization of transport represent major challenges to current and long term electricity distribution networks. The gradual development of DG penetration results in power supply and stability disruption, which raises greater concern to the network providers [2]. Traditional distributors require an appropriate protection to support the interchange of power which could be a problem when translating from the conventional passive power network to the current active power network [3]. Due to the involvement of DGs, the bidirectional power dissipation in a distribution network has developed a much more vibrant and active framework called active distribution networks. The active distribution network is interpreted as a structure that integrates control and communication innovations, enabling distribution network companies to maintain and host the latest distribution network.

One of the international organizations dealing with the underlying problems of active distribution networks stated that the configuration as well as the regulation with boosted operational efficiency for power supply are the vital features of the active distribution networks. On the other hand, the weaknesses include maintenance issues, lack of experience and the need for upgrading the existing communication structure to improve the overall system performance [4].

The phenomenon of voltage rise is one of the core problems in a distribution network associated to DGs. A generator is highly probable to be operated at a greater voltage in order to export power, compared to the other endpoints where it is driven. It happens when the DGs have an active capacity that exceeds the instant grid load and is not essential if the active power of the generators is less or equal to that of that grid load [5]. As the potential difference increases at the Point Common Coupling (PCC), the voltage along the grid decreases and leads to the reverse of power flow and a cause severe damage to the existing machinery.

A wide range of voltage control methods effectively exist on an active distribution network, and it can be segregated into centralized control and decentralized control [6]. Decentralized control system may be more practicable than centralized control system due to the geographically fragmented existence of power system and lack of communication system [7]. Coordinated control defines commands based on network data that involves data exchange and communication among system modules and devices. Alternatively, decentralized control perform preventive actions, with constrained communication with other devices and thus, increases the productivity. For example, on-load tap changer (OLTC), power factor control (PFC), static Var compensators, STATCOM as well as capacitor banks are considered as decentralized voltage regulation approaches. Many such strategies have been cultivated to augment intelligent decentralized voltage measures using the local operation of network devices and these artificial intelligent based control methods include the use of artificial neural network (ANN), evolutionary programming, Tabu search, multi-agent system and fuzzy logic.

Researchers are exploring and putting further efforts to improve the efficiency of voltage in the system by automating and optimizing their control actions that can be achieved by applying intelligent and heuristics optimization techniques. In spite of the success rate in using Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) for finding optimal solutions to solving the subject of voltage control, development is essential in order to get improved heuristic optimization techniques to overcome the limitations of GA and PSO. GAs are numerical methods of search based on genetic and evolutionary principles [8]. GA have problems in identifying the fitness function as well as in finding the global optimum and it gives slow convergence [9]. This makes the optimization process using GA more time consuming and less precise in finding the optimal solution. On the other hand, PSO has also suffers from partial optimism which causes less precise regulation of its speed and direction. Hence, improved versions of heuristics optimization techniques are explored so as to obtain more accurate and fast solutions to the problems encountered in administering the voltage variation issues in active distribution systems. This paper discusses various decentralized methods of voltage control techniques. Another method is by using fuzzy logic to evaluate the performance and drawbacks of the decentralized methods by simulating the load bus voltages and DG power as input and voltage control actions as output. Finally, to obtain the optimal settings in solving the voltage control issues, two optimization methods of PSO and BSA were utilized to obtain the optimal solutions in terms of minimizing losses and voltage deviations.

2. MATERIALS AND METHOD

By using the DigSilent Power Factory Software, IEEE 13 bus test system was modelled and simulated. Distributed generator models are added to the test system and simulations are run while the settings of the DG power factor and the OLTC were controlled. It must also be assured that the amount of generation of voltage at the load bus must not exceed the permissible limits. In addition to this, three separate control schemes have been implemented, comprising power factor control, OLTC and generation curtailment by using fuzzy logic. Fuzzy logic has been used to combine the three different control mechanisms by incorporating voltage and DG power into consideration as inputs, creating controlled outputs in desired settings.

To achieve an optimal coordinated voltage control, two different heuristic optimization techniques, namely BSA and PSO has been developed and compared. by utilizing the minimization of power loss and the voltage fluctuation as optimization algorithm, the optimal settings for power factor, OLTC and amount of generation to be suppressed were determined. The MATPOWER power flow software is integrated with the optimization codes in MATLAB to evaluate the featured function. The performance of the BSA and PSO techniques are tested and compared on the IEEE 13 bus test system and the 69 bus radial distribution systems. PSO has been chosen and compared with the BSA due to its established capability in performing optimization in various fields particularly in power systems. The optimum setup for the coordinated voltage control strategies as well as the parameters of power loss and voltage deviation have been compared so as to evaluate the effectiveness of the BSA in achieving the optimized solution. Figure 1 illustrates the effect of connecting a DG to a simple two bus distribution system.

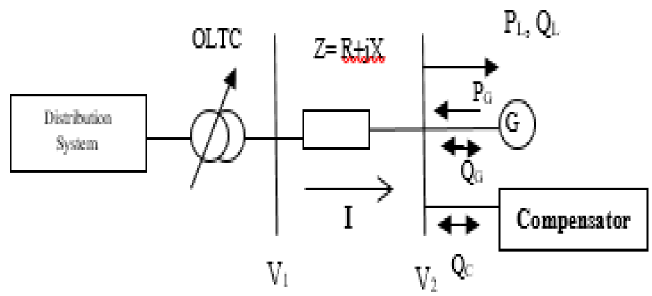

Figure 1: A simplified circuit for a distribution system connected with a DG

A generator will probably function at a larger voltage compared to voltages at other nodes when outsourcing power. V_2 is notated as the voltage at the connection point of the generator will be higher than the sending end voltage, V_1. Hence, using equations (1) and (2), the voltage difference ΔV can be represented by:

$$\Delta V \approx \frac{RP + XQ}{V_1} \quad (1)$$

$$\Delta V \approx RP + XQ \quad (2)$$

$$\Delta V = V_2 - V_1 \approx \frac{RP + XQ}{V_2} \quad (3)$$

where V_1 is the bus 1 voltage and V_2 is the voltage at the point of DG connection, R and X are the line resistance and reactance, respectively.

Consider the fact that,

$$P = (P_G - P_L) \tag{4}$$

And,

$$Q = (\pm Q_C - Q_L \pm Q_G) \tag{5}$$

where P_G and P_L are the active powers at the generator and load, respectively and Q_G, Q_L and Q_C are the reactive powers of the generator, load and compensator, respectively.
Substituting (4) and (5) into (3), we get,

$$\Delta V = V_2 - V_1 \approx R(P_G - P_L) + X(\pm Q_C - Q_L \pm Q_G) \tag{6}$$

Rewriting (6),

$$V_2 \approx V_1 + R(P_G - P_L) + X(\pm Q_C - Q_L \pm Q_G) \tag{7}$$

The relationship between the voltage at bus 2 as shown in Figure 1 and the number of distributed generation that can be connected and also the effect of the alternative control actions for controlling voltage rise can be qualitatively analyzed by using Equation (7) [10].

2.1 Decentralized Voltage Control Methods

Decentralized or distributed voltage control uses data stored in a specific bus regardless of voltage, where calculation, optimization and communication methods are typically limited. The 13 bus test system's single-line diagram includes two DGs type of synchronous generator and inverter at bus 634 and 680. The OLTC is located in between buses 633 and 634. Simulations were carried out to evaluate the effect of both components on the voltage profile at the load buses. Figure 2 shows the one-line diagram of the IEEE 13 bus test system.

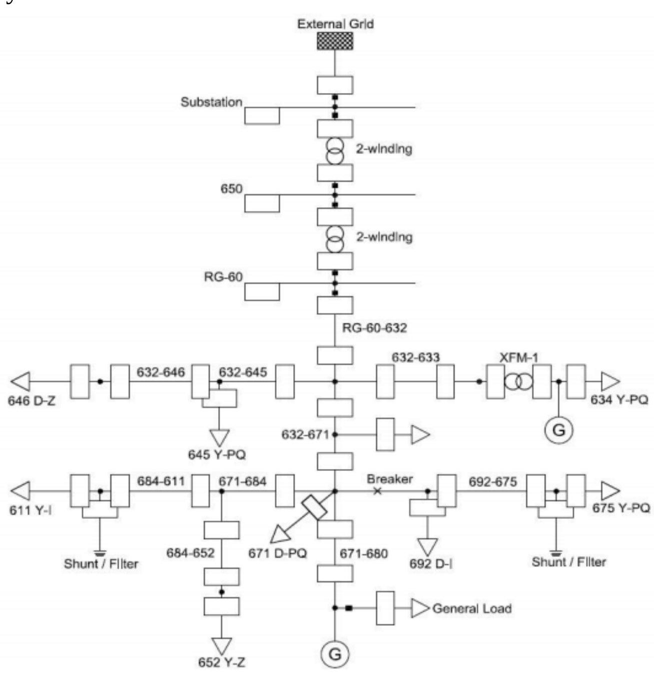

Figure 2: The IEEE 13 bus test system

Firstly, in Power Factor Control (PFC) method, the ratio of real power to reactive power is maintained constantly; real power has proportional variation to reactive power in case of any fluctuation occurs. By any chance, if the reactive power can compensate the system's unstable voltage produced by the real power, thus, the voltage level will be within its statutory limits. When there is a rise in voltage, power factor in the leading mode is needed at which the DG is connected. DG in leading operation mode, imports reactive power and this leads to a reduced voltage level at the load buses and vice versa. Conversely, high voltage values are recorded for load buses when a DG exports reactive power in lagging mode.

Next, OLTC transformer governs and maintains the voltage supplied to the customers within their legislative limits. The transformer's basic operation relies on the change of ratio between the primary and secondary windings. A typical medium to low voltage distribution transformer has six taps and is able to lower or raise the secondary voltage by 2.5% at each step.

Voltage increase can also be alleviated by reducing DG 's active power output but seldom will a DG owner find it helpful to slow down any of their production, which may lead to financial losses when a voltage level is surpassed. The easiest way for enforcing generation restrictions is by disconnecting the requisite series of generators when the voltage exceeds its limits. Generation curtailment may be implemented if all voltage control methods have been exhausted. This however avoids voltage variations which can lead to reverse flow of power from DG and to a reduction in load in the event that voltages fall below its lower statutory limit.

2.2 Fuzzy Logic for Coordinated Voltage Control in Active Distribution Systems

Fuzzy uses the spectrum of logical values from 0 (false) to 1 (true). Fuzzy systems are simple to enforce because of the application of rules based on fuzzy linguistic concepts derived from human intuition and relying on the understanding of experts [11]. It functions such that the input and output data are adequate linguistic variables and decisions are made based on the defined rules. The implemented parameters in this fuzzy logic control system are two inputs (active power from generator and voltage from load buses) and three outputs are the implemented parameters in the fuzzy logic control system proposed in [12].

2.3 Heuristics Optimization Techniques for Optimal Coordinated Voltage Control

Particle Swarm Optimization (PSO) and an evolutionary algorithm called the Backtracking Search Algorithm (BSA), are regarded as the optimization techniques. To minimize the total losses and voltage variation in the network, a multi-target feature is devised. To solve the multi-objective optimization problem, the MATPOWER dependent load flow algorithm is incorporated into MATLAB.

PSO is considered as a popular technique used to solve the complex optimization problems in power systems. It is a population-based optimization technique inspired by nature like a bird flock. Including inertia "w" in the algorithm, PSO enhances the control performance [13]. It is an approach focused on the demographic in which the particles keep moving around the problem state space under a number of constraints like a particle's ability to adopt its best results and its potential to move to the best current outcome among adjacent particles [14]. In general, the PSO algorithm consists of three major steps:

i) Generate the position and velocity of the initial particle
ii) Determine each particle's fitness value, and
iii) Adjust all particles' speed and position [15]. The particle travels through a random-scale dimensional search space and updates the speed and position

PSO is suitable for wide range of application in science and engineering and it also has simple calculation compared to the other optimization techniques but PSO concerns the accuracy of its solution in which it depends on the initial conditions and parameter values selected. The implementation procedures in PSO are described as shown in

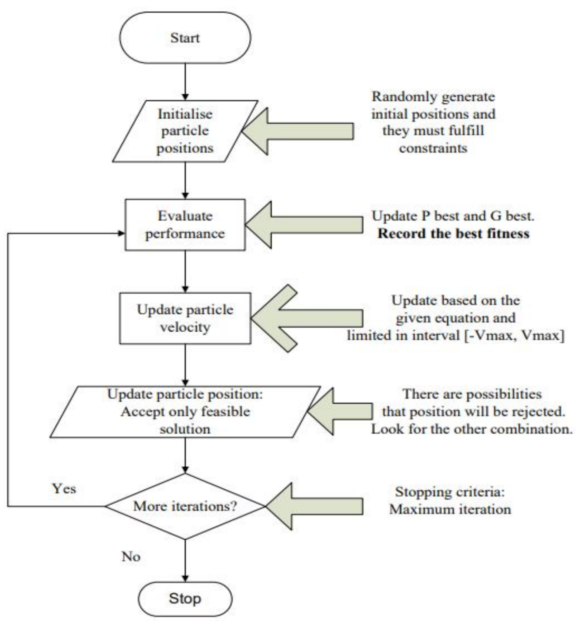

Figure 3 [16].

Figure 3: The implementation procedures of PSO algorithm

BSA was first discovered in 1848 and later was redesigned by Pinar Civicioglu (2013) as the Evolutionary Algorithm (EA) to overcome numerical problem rapidly [17]. The EAs are famous stochastic genetic algorithm that are broadly used in the resolution of numbers that are non-linear, non-differentiable and complex. Swarming intelligence and genetic evolution are the most commonly used techniques of EA optimisation. By sorting their functions through preceding guidelines, BSA can be clarified as [18]:

i) Initialization
ii) Selection-I
iii) Mutation
iv) Crossover
v) Selection-II.

Figure 4 depicts the flowchart of BSA, which is implemented in the optimization process to determine the optimal parameters for coordinated voltage control and to minimize the losses and voltage deviation.

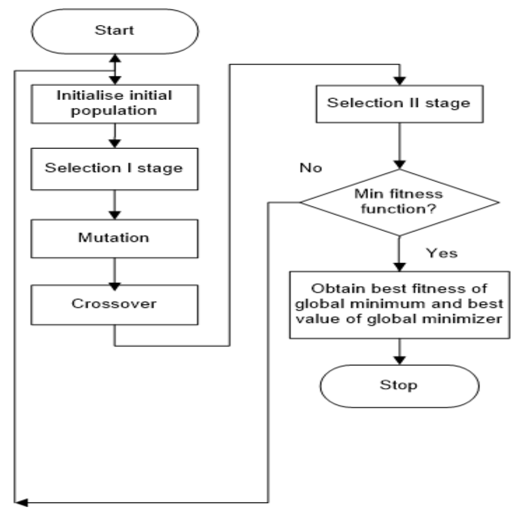

Figure 4: Flowchart of the BSA optimization technique

The application of both methods was built through MATLAB software to address the problems of optimal change, with minimum overall power loss and voltage variance being the objective functions. The fitness function of the power loss and voltage deviation are calculated from the MATPOWER Newton-Raphson load flow program where the load flow is integrated with the optimization coding in the MATLAB software package.

3. RESULTS AND DISCUSSION

A reconstructed IEEE 13 bus test system and 69 bus radial distribution test system were simulated to obtain an equilibrium system. For the 13 bus system, the loads were balanced (spot load) with total of 945.3 kW and 873.2 kVar. As for the 69 bus test system, the total load is of 3.8 MW and 2.69 MVar. The MVA base for both test systems is 100 MVA and voltage ranges from 0.9 p.u to 1.05 p.u.

Firstly, three different power factor configurations have been used by using the PFC approach to compare the performance of each voltage control system. The simulation considers three various power factor settings:

(i) 0.85 leading and lagging
(ii) 0.90 leading and lagging
(iii) 0.95 leading and lagging

The effect of the output indicates that the DG at the lagging power factor causes voltage to increase at the loading buses while the DG is operating at leading power factor (absorbing Q) results in low voltage. This observation was also made by other researchers in which the issue of voltage rise can be mitigated by driving the DG at the leading power factor [19].

Secondly, the OLTC control method was tested on the test system. Two different tap changer settings were taken into account in this simulation [20]:

i) Maximum tap setting of 1.02 and minimum tap setting of 0.90.
ii) Maximum tap setting of 1.05 and minimum tap setting of 0.90.

Both the designated settings enable the voltage to be regulated within its permissible limit on the load buses.

Diverse factors, including voltage limit, network sensitivity, operating response, DG efficiency and load features, are needed to reduce the amount of generation to curtail. The last option to activate is the generation curtailment strategy if all other voltage control processes are completed. Using 3MW DG as the case study, generation amounts are reduced by two separate generation numbers, namely 30% and 40%. A 30% amount of generation curtailed from the 3MW generation resulted in 2.1MW generation left but the voltage magnitude at bus 1 and bus 2 has exceeded its permissible voltage value of 1.05 p.u. On the other hand, an amount of 40% of generation from the 3MW resulted in 1.8MW generation left in total and the voltage profile of the test system is maintained within permissible limits of 0.95 p.u to 1.05 p.u. All the case studies discussed above is summarized in the graph as show in Figure 5. Figure 5 shows the voltage profiles of the operating DGs with different decentralized voltage control methods.

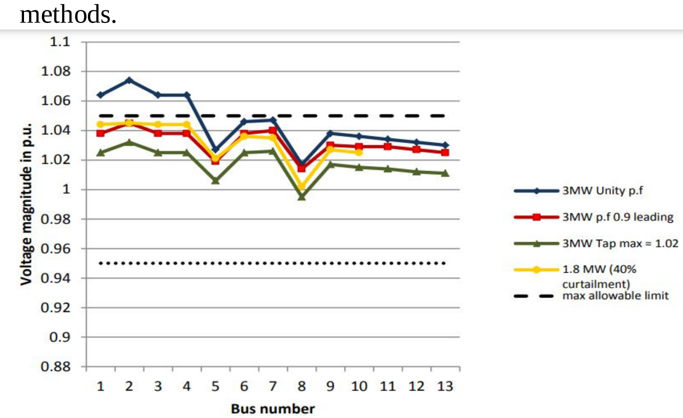

Figure 5 Comparison of the voltage profile in the distribution system connected with DGs using different voltage control methods

The aim of the fuzzy logical coordination method of voltage control is to synchronize the three decentralized voltage control methods in order that voltage profiles on load buses can be controlled within its acceptable boundaries. The configurations of the three modes of voltage control are presumed as outputs and the voltage values captured on load buses are the inputs to the fuzzy logic controllers. Figure 6 depicts the inputs and outputs captured from the fuzzy logic coordinated voltage control system which utilizes two inputs and three outputs.

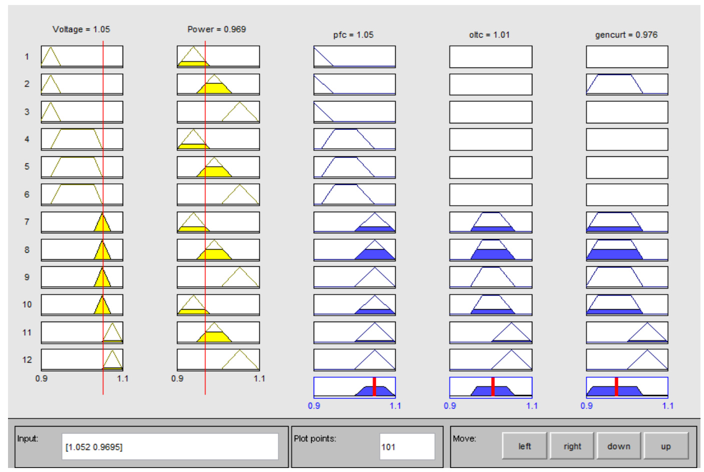

Figure 6: Rule viewer of the fuzzy logic control system output.

From Figure 6, the sample of input voltage tested is 1.052 while the input power is 0.9695. Observing the rule viewer, the output of PFC = 1.05, OLTC = 1.01 and gencurt = 0.976. Hence, it is proven that the control method's outputs fall within the designated power factor level of 1.05. Moreover, fuzzy logic is able to mitigate the challenge of voltage fluctuations within the approved limits. To justify this statement, Figure 7 shows the voltage profile at bus 675 at which initially the value recorded has surpass the range of 1.05 for a period of hour 1 until hour 7. By introducing fuzzy logic based coordinated voltage control, the profile value has decreased to a restriction of 1.01 p.u to 1.022 p.u.

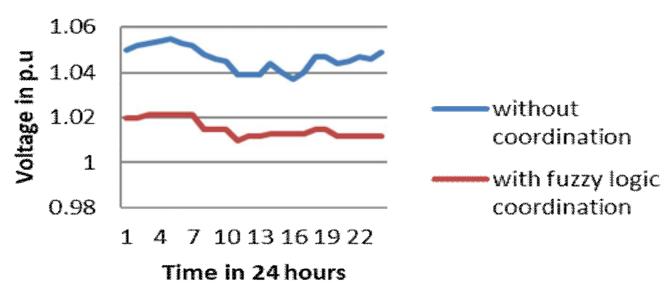

Figure 7: Voltage profile at bus 675 with and without coordinated voltage control

In terms of optimization, four simulation cases with two DG generators vary with total generation capacities of 1MW, 2MW and 3MW are induced in this project. The goal of this study is to reduce the system's power loss and voltage deviation. Following 30 simulation runs, the optimal optimization of the BSA and PSO methods is accomplished. Various presumptions were made in terms of the effects of DG installation on the distribution system's power loss and the voltage deviation as indicated below:

i) The system's number of DGs are 2.
ii) At a time, only a single unit of DG is installed at the selected bus.
iii) The DG installed bus is considered as a power and voltage controlled bus.
iv) The system at base case does not have any DG connection so as to ensure that there is no effect on the voltage profile and losses in the system caused by any DG connection.

The discrepancy or boundaries for the control factors like the power factor (PF), tap configuration and the amount of output to be reduced are defined as follows:

(i) $0.85 \leq PF \leq 0.95$
(ii) $0.98 \leq$ tap setting ≤ 1.03
(iii) $0 \leq$ % of MW generation curtailed ≤ 40

The results revealed that in contrast with PSO techniques, BSA has the least fitness benefit and speedier convergence. The basic power loss is 0.146 MW whereas the average voltage difference for the base case is 0.014 V. The system's overall performance is reduced by a power loss and a voltage deviation with optimal DG parameter configuration. The base case is for 100% loading conditions; the 0.8 base case represents the 80% loading conditions whereas the 0.6 base case represents the 60% loading conditions.

Table 1 represents the voltage deviation and power losses values recorded under different loading conditions using PSO and BSA techniques for the 13 bus test system. From the results that have been obtained for the three case studies, the voltage deviation values recorded are insignificant and have small deviation values from the base case studies. From the 3MW case study, the values of voltage deviation are 0.0018V, 0.0020V and 0.0029V and this shows that the deviation values are small for the different loading conditions. With the load supplied lower, and since lower load is translated to lower current, the resultant of the power loss is also lower with the lower loading conditions.

Table 1: Voltage deviation and power losses using PSO and BSA with different loading conditions for the 13 bus test system

Case study			PSO	BSA
1MW	Base case	Voltage deviation (V)	0.0017	0.0016
		Losses (MW)	0.0446	0.0430
	0.8 base case	Voltage deviation (V)	0.0018	0.0018
		Losses (MW)	0.0426	0.0426
	0.6 base case	Voltage deviation (V)	0.0021	0.0024
		Losses (MW)	0.0350	0.0355
2MW	Base case	Voltage deviation (V)	0.0015	0.0007
		Losses (MW)	0.0491	0.0543
	0.8 base case	Voltage deviation (V)	0.0017	0.0015
		Losses (MW)	0.0487	0.0502
	0.6 base case	Voltage deviation (V)	0.0027	0.0030
		Losses (MW)	0.0368	0.0387
3MW	Base case	Voltage deviation (V)	0.0018	0.0006
		Losses (MW)	0.0681	0.0684
	0.8 base case	Voltage deviation (V)	0.0020	0.0017
		Losses (MW)	0.0585	0.0595
	0.6 base case	Voltage deviation (V)	0.0029	0.0026
		Losses (MW)	0.0541	0.0551

Another test system which was considered in the implementation of the optimization techniques of BSA and PSO is the 69 bus radial distribution test system. The same methods of finding the optimal solutions as carried out for the 13 bus test system is applied in this 69 bus distribution test system optimization problem. The spot loads with a total load of 3.8MW and 2.69MVAr. The only supply source is the substation at bus 1 (slack bus) with steady voltage. The findings show that BSA offers improved fitness and higher rate of convergence. Figure 8 shows the 69 bus radial distribution system.

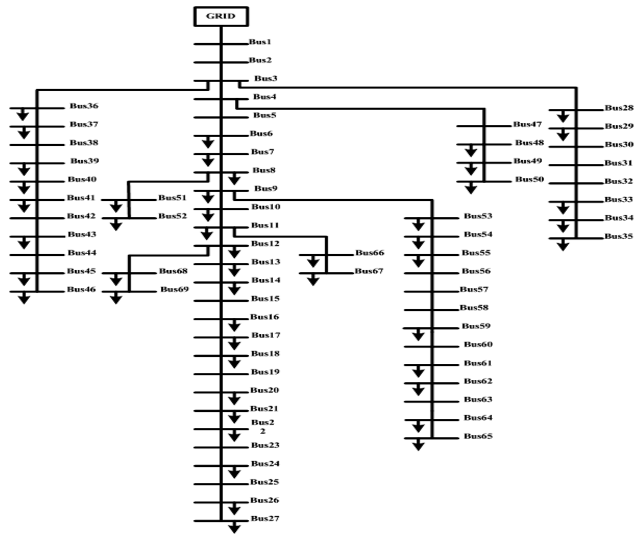

Figure 8: 69 bus radial distribution test system

Table 2: Voltage deviation and power losses using PSO and BSA using different loading conditions for the 69 bus test system

Case study			PSO	BSA
1MW	Base case	Voltage deviation (V)	0.0019	0.0005
		Losses (MW)	0.0430	0.0429
	0.8 base case	Voltage deviation (V)	0.0051	0.0046
		Losses (MW)	0.0189	0.0188
	0.6 base case	Voltage deviation (V)	0.0086	0.0077
		Losses (MW)	0.0119	0.0148
2MW	Base case	Voltage deviation (V)	0.0182	0.0179
		Losses (MW)	0.0401	0.0389
	0.8 base case	Voltage deviation (V)	0.0212	0.0208
		Losses (MW)	0.0387	0.0352
	0.6 base case	Voltage deviation (V)	0.0233	0.0252
		Losses (MW)	0.0355	0.0332
3MW	Base case	Voltage deviation (V)	0.0249	0.0244
		Losses (MW)	0.0799	0.0785
	0.8 base case	Voltage deviation (V)	0.0239	0.0232
		Losses (MW)	0.0648	0.0652
	0.6 base case	Voltage deviation (V)	0.0230	0.0228
		Losses (MW)	0.0633	0.0622

Table 2 represents the voltage deviation and power losses values recorded under different loading conditions using PSO and BSA techniques for the 69 bus test system. From the results that have been obtained for the three case studies, the voltage deviation values recorded are insignificant and have small deviation values from the base case studies. The base case is for 100% loading conditions; the 0.8 base case represents the 80% loading conditions whereas the 0.6 base case represents the 60% loading conditions. From the 1MW case study using the PSO technique, the values of voltage deviation are 0.0019V, 0.0051V and 0.0086V and this shows that the deviation values are small for the different loading conditions. With the load supplied lower, and since lower load is translated to lower current, the resultant of the power loss is also lower with the lower loading conditions as shown in the table. The optimal power factor settings of the DGs recorded using BSA are nearly 0.90 for all the three case studies. This finding is correlated with the settings of 0.90 as used by most distribution network operators in different countries, including Tenaga Nasional Berhad in Malaysia.

Table 3: Comparisons between the methods of PFC, OLTC, generation curtailment, coordinated fuzzy logic, PSO and BSA in terms of voltage deviation and losses

Method used	Settings	Voltage deviation (V)	Losses (MW)
Base case		0.014	0.146
	0.95 lead	0.0412	0.07944
PFC	0.90 lead	0.0253	0.07461
	0.85 lead	0.0269	0.07581
OLTC	Tap_{max} = 1.05	0.0263	0.07595
	Tap_{max} = 1.02	0.0242	0.07281
Generation curtailment	40%	0.0641	0.010416
Fuzzy logic coordination		0.0023	0.06935
PSO		0.0018	0.0681
BSA		0.0006	0.0684

From Table 3, it can be seen that the voltage deviation shows a decreasing trend from using the decentralized methods until the optimization methods were implemented. For examples, using PFC method of 0.95 leading gives a voltage deviation of 0.0412V and using PFC with 0.90 leading settings gives a value of voltage deviation of 0.0253 V. Using the method of OLTC control, with settings of Tapmax = 1.05, voltage deviation value is 0.0263V while the settings of Tapmax = 1.02 yields a value of 0.0242 V. Using generation curtailment method with 40% curtailment, the voltage deviation value recorded is the highest with 0.0641V. With fuzzy logic coordinated control, the voltage deviation value recorded is lower with 0.0023 V compared to the decentralised methods.

The voltage deviation value is the smallest using the optimization techniques of PSO and BSA with PSO giving 0.0018V and BSA recorded a value of 0.0006V. In terms of power losses, the losses recorded are bigger when using the decentralized methods compared to using the coordinated or optimization methods. The power losses recorded are the smallest when using the optimization techniques of PSO and BSA with PSO recorded a value of 0.0681MW and BSA giving a value of 0.0684MW. From the results shown it can be concluded that the voltage deviation and power losses recorded are lower and have been improved with the implementation of the coordinated control and optimization techniques compared to using decentralized voltage control methods.

Hence, from both the test systems results, the following points can be summarized:

i) In comparison with PSO technology, the BSA technology performs best in terms of fitness functions in reducing power loss and voltage variation.
ii) BSA and PSO are accurate in determining the optimum setup for the three coordinated PFC voltage techniques, tap setting and amount of generation to be whittled down.
iii) Once the optimal settings of the coordinated voltage control methods are determined, the power loss curtailment and voltage deviation can be acquired.
iv) The voltage profiles are improved and able to be maintained within its allowable limits with the DGs installed in the test systems with the optimal settings of the coordinated voltage control methods.

4. CONCLUSION

Overall, various voltage control tools were explored, implemented in order to supply voltage in a distribution system connected to DGs, by using intelligent techniques. Finally, all the research objectives outlined were achieved and the findings shown are satisfactory. In order to determine its efficiency in mitigating the voltage increase problem in a DG distribution network, the decentralized control methods using PFC, OLTC and generation curtailment have been compared and assessed. The proposed fuzzy logic control applied for coordinating the three decentralized control methods; PFC, OLTC control and generation curtailment is found to be effective in controlling the voltage in a distribution system with DGs. The proposed BSA applied for determining optimal settings of PFC, OLTC and generation curtailment is found to be an effective and accurate optimization technique compared to PSO.

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