A Novel Reconfiguration Mixed with Distributed Generation Planning via Considering Voltage Stability Margin

M. H. Hemmatpour [i *]; M. Mohammadian[ii] and M. Rashidinejad[iii]

ABSTRACT

In recent years, in Iran and other countries the power systems are going to move toward creating a competition structure for selling and buying electrical energy. These changes and the numerous advantages of *DGs* have made more incentives to use these kinds of generators than before. Therefore, it is necessary to study all aspects of *DGs*, such as size selection and optimal placement and impact of them on *Distribution System (DS)* reconfiguration. So, the problem of optimum reconfiguration and optimal location of *DGs (DGs Planning)* in *DS* is a task which must be solved in an optimal manner. This paper presents a novel approach for optimum reconfiguration and optimal location of *DGs* in distribution networks based on a hieratical two-stage optimization problem to improve power system voltage stability margin and reduce active power losses. Hence, a toolbox has been developed to recognize loadability limit of distribution power systems based on Lagrangian optimization method. Finally, the simulations are carried out on 33, 69 bus IEEE distribution systems and demonstrate the validity of the proposed method.

KEYWORDS

Distribution System (*DS*), Distributed Generations (*DGs*), Graph Theory (*GT*), Harmony Search (*HS*), Hierarchical Optimization, Loadability limit, Matroid Theory, Reconfiguration, Voltage Stability (*VS*)

1. INTRODUCTION

With the development of national economy and the improvement of people's life, load demands in *DS* especially in industrial area are sharply increasing and the operation conditions of *DS* are more and more close to the system boundaries. *DS* experience distinct change from a low to high load levels every day. Under certain critical loading conditions, the distribution systems may experience voltage collapse. Hence, voltage stability is considered to be one of the keen interests of industry and research sectors around the world.

Voltage stability is the ability of a system to maintain voltage and closely associates with power delivering capability. The voltage instability phenomena, which can occur in distribution systems, may not be new to power system practicing engineers and researchers. The decline of voltage stability level is one of the important factors which restrict the increase of load served by distribution companies. Hence, it is necessary to consider voltage stability constraints for planning and operation of *DS*.

Also, there are two types of switches used in primary distribution systems; sectionalize switches (normally closed) and tie-switches (normally open). They are designed for both protection and configuration management in the system. There are many technical benefits of employing reconfiguration in existing *DS*, such as improvement line losses, economic, reliability indicators, voltage control issue, load balancing which investigated in previous literatures.

Until yet, many studies have been done on reconfiguration scenarios to reach the optimum conditions in distribution systems. In this field, *GCPSO* and graph theory is used to improvement voltage profile and loss [1]. Also, using Genetic Algorithm based on the Matroid theory is suggested in [2]. Many reconfiguration methods based on heuristics optimization, artificial intelligence methods and evolution programming can be found in the literature, too. Sensitivity and heuristics

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method based on loss minimization is used by Viswanasha et al. [3]. Saffer et.al presented a new combined method for optimal reconfiguration using a multi-objective function with fuzzy variable [4]. This method considered both load balancing and loss reduction in the feeders as objective function. The authors in [5] used *DSTATCOM* allocation to mitigate losses and improve voltage profile via reconfiguration in *DS*. Furthermore, *DS* reconfiguration has a potential to improve the system voltage stability too. M.A. Kashem et al. [6] presented the relationship between voltage stability and loss minimization. It can be shown that voltage stability is maximized when power losses are minimized in the networks. In [7], a new method for optimal reconfiguration was suggested for radial distribution systems. Then, the several performance criteria were considered for optimal network reconfiguration, in which, maximizing loadability is an important one. Owing to the discrete nature of the solution space, a fuzzy adaptation of the evolutionary programming algorithm for optimal reconfiguration of radial distribution systems to maximize loadability is proposed in this reference. In [8], the authors reported a reconfiguration algorithm based on Tabu search for maximizing the security margin to voltage collapse. M. Arun et al. [9] presented a new reconfiguration algorithm that enhances voltage stability and improves the voltage profile besides minimizing losses. A fuzzy genetic algorithm was reported by N.C. Sahoo et al. This algorithm is used for reconfiguration of radial distribution systems to improve the voltage stability security margin for a specific set of loads [10]. J. Olamaei et al. [11] presented a new approach to distribution system reconfiguration at the distribution networks considering *DGs*. The main objective of this paper is to minimize the deviation of the bus voltage, the number of switching operations and the total cost of the active power generated by *DGs*. Ant colony algorithm is used to aim the minimum power loss and increment load balance factor of radial distribution networks with *DGs* [12]. In [13], a tabu search algorithm is applied to search for the on/off patterns of the sectionalizing switches and tie switches to obtain the minimum total power loss, whereas the dispatch schedule of the distributed generators which gives the minimum total cost of generation is solved by an optimal power flow.

In this paper, a novel method for solving *DS* reconfiguration problem and *DGs* size selection and placement is suggested. The proposed method establishes a tradeoff between security index (voltage stability security margin) and power losses simultaneously for reconfiguration problem as a multi-objective nonlinear optimization problem. This method uses the new voltage stability index for *DS* voltage stability analysis, P_{sys} (Maximum Loadability limit), which is maximum loading of *DS* under the feasibility of power flow equations. The proposed method used *HSA* to solve the mentioned optimization problem as the first layer of optimization search. *HSA* has emerged as a useful tool for engineering optimization which has been used in complex optimization problems.

In the second layer of hierarchical optimization method and, respectively, to each feasible reconfiguration pattern, the voltage stability index is calculated based on non-linear optimization. The analysis process is performed using a steady state voltage stability index, *Psys*, which is maximum loading under the feasibility of power flow equations [14]-[19]. Hence, a toolbox has been developed to assess the power system voltage stability margin based on Lagrangian method.

The IEEE-33 and IEEE-69 bus *DS* test systems are used to illustrate the performance of the proposed methodology and the results were compared with other studies, too.

2. Problem Formulation

Several aspects might be taken into consideration when defining the objective function of the network reconfiguration problem with *DGs*. The objects which were considered in this study, for finding optimal reconfiguration of *DS* via optimum allocation of *DGs* are minimizing total active power losses, maximizing loadability limit, and minimizing the investment costs.

One of the most common adopted refers to the minimization of power losses, but the maximization of the voltage stability security margin is also mentioned in this study. The objectives of this optimization problem are maximizing static voltage stability, minimizing the *DS* active losses, and minimizing the investment costs. These objectives are discussed as follows:

A. Minimize the active power losses

One of the major potential benefits offered by reconfiguration and *DGs* location is the reduction in electrical line losses. The utility is forced to pass the cost of electrical line losses to all customers in terms of higher energy cost. With the inclusion of reconfiguration, line loss in the distribution system can be reduced. The proposed index for a bus is defined as follow:

$$P_{loss} = \sum_{l=1}^{b} R_l B_l^2 = \sum_{i,j=1,2,\ldots NB} [V_i^2 + V_j^2 - 2\, V_i V_j \cos(\delta_i - \delta_j)]\; Y_{ij} \cos\varphi_{ij} \qquad (1)$$

where b is the number of branches, R_l is the resistance of line l, B_l is the current passing through line l, NB is the number of buses, V_i, δ_i are the voltage magnitude and voltage angle of node i and, Y_{ij}, φ_{ij} are the magnitude and angle of the ***i-j*** line admittance. To aim active power losses in *DS*, it is necessary to calculate voltage magnitude and voltage angle of each node. For this calculation, a load flow model is presented. This model is based on graph theory and used graph topology of system.

The relationship between the bus current injection and branch currents (*BIBC* matrix) is obtained by applying Kirchoff's current law (*KCL*) to the distribution network. However, in the reconfiguration process the network structure is continuously changing and the load flow algorithm generates the corresponding down-stream nodes' vectors necessary for dynamic generation of BIBC's matrices securing radiality of the network and correct current flow direction. The load flow algorithm follows changes in system structure by creating directed graph for the distribution network in each switching-iteration [20]. For effective explain, a 6-bus *DS* is suggested. This *DS* is shown in Fig. 1. The relationship between the bus current injections and branch current can be expressed as:

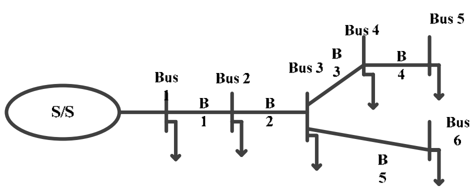

Figure 1: Test system.

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \tag{2}$$

This equation can be showing in form as:

$$[B] = [BIBC][I] \tag{3}$$

The relationship between branch currents and voltage bus can be explained as:

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{45} & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{36} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} \tag{4}$$

The general format is:

$$[\Delta V] = [BCBV][B] \tag{5}$$

By combination of 3 and 5, the relationship between bus current injection and bus and bus voltage can be shown as:

$$[\Delta V] = [BCBV][BIBC][I] = [DLF][I] \tag{6}$$

For gain to power flow converge, the algorithm repeat by Fig. 2. At this step, voltage magnitude and voltage angle of each node are detected. So, active power losses are calculated by equation (1).

B. Maximizing Loadability limit index

Loadability limit is a new index to determine static voltage stability of *DS* [16]. System loadability can be evaluated by means of non-linear optimization which it tries to maximize system loading under the constraint of power flow equations. For this purpose, the problem can be formulated as follows [15]-[19]:

$$Min \quad : -P_{sys}$$
$$s.t \quad : \begin{cases} P_{Gi} - P_{Di} - f_i(v,\delta) = 0 \\ Q_{Gi} - Q_{Di} - g_i(v,\delta) = 0 \end{cases} \tag{7}$$

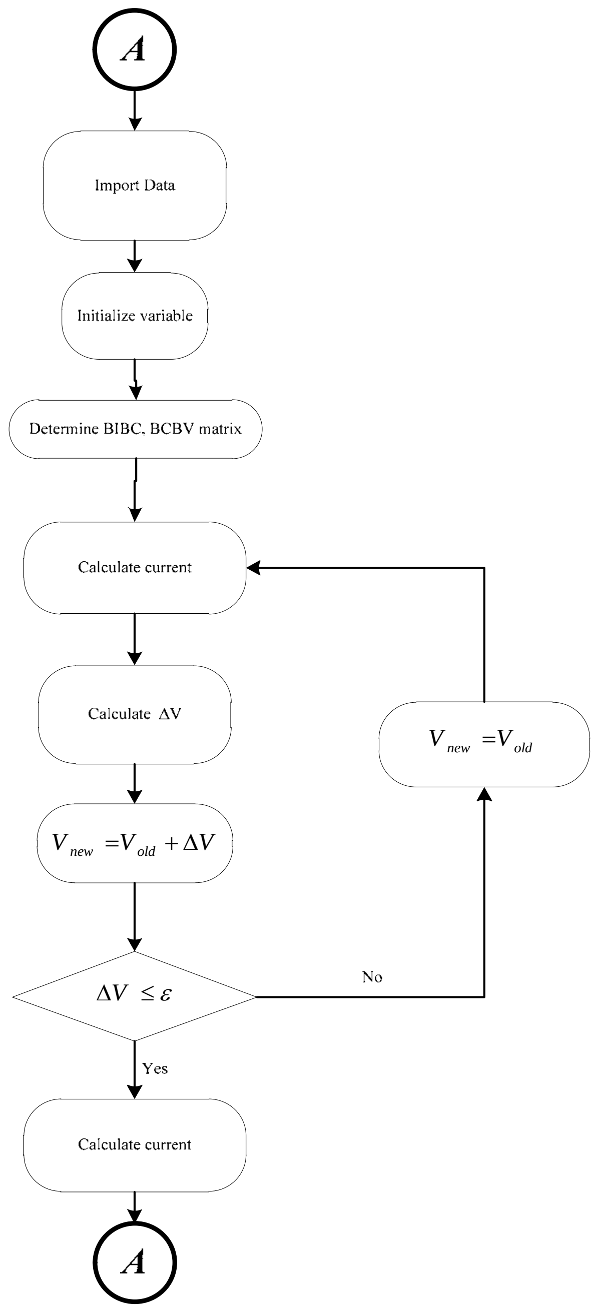

Figure 2: Flow chart of loss calculation.

where P_{sys} is the system total active load, P_{Gi} and Q_{Gi} represent vectors of active and reactive generation (*DGs* and sub-transmission system), P_{Di} and Q_{Di} represent vectors of active and reactive load f_i and g_i are active and reactive power flow equations, respectively.

The main constraint for voltage stability is feasibility of power flow solution, therefore, the above equation tries to find maximum loading under the feasibility of power flow equation which corresponds to system Loadability limit. This nonlinear problem can be solved by the Lagrange method. For this purpose, the non-constrained Lagrange function can be constructed as follows:

$$\begin{aligned} L = -P_{sys} + [\lambda]^T [P_G - P_D - f(V,\delta)] + \\ [\gamma]^T [Q_G - Q_D - g(V,\delta)] \end{aligned} \tag{8}$$

In this optimization problem, the increase pattern of loads at buses is one of the main factors, which dominates the Loadability limit. So, in order to include their effects, it can be modeled as follows [16]:

$$\begin{aligned} P_{Di} &= \left[P_{Di}^{(0)} + \beta_i Pf_i\,(P_{sys} - P_{sys}^{(0)})\right]\left(\frac{V_i}{V_i^{(0)}}\right)^{kpvi} \\ Q_{Di} &= \left[Q_{Di}^{(0)} + \beta_i Qf_i\,(P_{sys} - P_{sys}^{(0)})\right]\left(\frac{V_i}{V_i^{(0)}}\right)^{kqvi} \end{aligned} \tag{9}$$

Hence, the Lagrange equation can be finalized as follows:

$$\begin{aligned} L: &-\sum_{i=2}^{NB}\left[P_{Di}^{(0)} + \beta_i Pf_i(P_{sys} - P_{sys}^{(0)})\right]\left(\frac{V_i}{V_i^{(0)}}\right)^{kpvi} + \\ &\sum_{i=2}^{NB}\lambda_i\left\{\alpha_i P_{sys} - \left[P_{Di}^{(0)} + \beta_i Pf_i(P_{sys} - P_{sys}^{(0)})\right]\left(\frac{V_i}{V_i^{(0)}}\right)^{kpvi} - f_i(v,\delta)\right\} + \\ &\sum_{i=2}^{NB}\gamma_i\left\{Q_{Gi} - \left[Q_{Di}^{(0)} + \beta_i Qf_i(P_{sys} - P_{sys}^{(0)})\right]\left(\frac{V_i}{V_i^{(0)}}\right)^{kqvi} - g_i(v,\delta)\right\} \end{aligned} \tag{10}$$

where $P_{Di}^{(0)}$ and $Q_{Di}^{(0)}$ are the primary values of active and reactive load powers, α_i is generation contribution of each bus, β_i is generation and load contributions for each buses, Pf_i and Qf_i are load factor coefficients, $V_i^{(0)}$ is the primary value of bus voltage magnitude, V_i is the value of bus voltage, kpv_i and kqv_i are load active and reactive powers, $P_{sys}^{(0)}$ is the total primary active load of system and P_{sys} is the total active load of system.

To solve Lagrange equation, the Newton-Raphson method is employed. For this purpose, the first derivatives of Lagrange equation are calculated as follows:

$$\begin{aligned} F_X &= \frac{\partial L}{\partial X} = 0 \\ X &= [V, \delta, \lambda, \gamma, P_{sys}] \end{aligned} \tag{11}$$

,

For example, F_{λ_i} can be derived as:

$$\begin{aligned} F_{\lambda_i} &= \alpha_i P_{Sys} - \left[P_{Di}^{(0)} + \beta_i Pf_i(P_{Sys} - P_{Sys}^{(0)})\right] \\ &- V_i\sum_{m=1}^{nb} Y_{im} V_m \cos(\delta_i - \delta_m - \varphi_{im}) = 0 \end{aligned} \tag{12}$$

where *nb* is the system bus numbers. Other equations also derived with same manner. Then, factors of every equation is calculated that contains ΔV, $\Delta\delta$, $\Delta\lambda$, $\Delta\gamma$ and ΔP_{Sys} by derivative of equation (10) with these factors, for example, the other equations can be derived as:

$$\begin{aligned} \frac{\partial F_{\lambda j}}{\partial X}\Delta X = &\left\{-\alpha_j + \beta_j Pf_j\right\}\Delta P_{Sys} + \\ &\left\{\begin{array}{l} V_j Y_{jj}\cos(\varphi_{jj}) + \\ \sum\limits_{m=1}^{NB} Y_{jm} V_m \cos(\delta_j - \delta_m - \varphi_{jm}) \end{array}\right\}\Delta V_j + \\ &\left\{V_j \sum_{\substack{i=2 \\ i\neq j}}^{NB} Y_{ji}\cos(\delta_j - \delta_i - \varphi_{ji})\Delta V_i\right\} - \\ &\left\{V_j \sum_{\substack{m=1 \\ m\neq j}}^{NB} Y_{jm} V_m \sin(\delta_j - \delta_m - \varphi_{jm})\right\}\Delta\delta_j + \\ &\left\{V_j \sum_{\substack{i=2 \\ i\neq j}}^{NB} Y_{ji} V_i \sin(\delta_j - \delta_i - \varphi_{ji})\Delta\delta_i\right\} \end{aligned} \tag{13}$$

In this study, factors of every equation are calculated which contains ΔV, $\Delta\delta$, $\Delta\lambda$, $\Delta\gamma$ and ΔP_{sys} .By derivative of each equation (11) with these factors, following objective matrix would be earned:

$$\begin{bmatrix} F_V^{(0)} \\ F_\delta^{(0)} \\ F_\lambda^{(0)} \\ F_\gamma^{(0)} \\ F_{P_{Sys}}^{(0)} \end{bmatrix} = \begin{bmatrix} F_{VV} & F_{V\delta} & F_{V\lambda} & F_{V\gamma} & F_{VP_{Sys}} \\ F_{\delta V} & F_{\delta\delta} & F_{\delta\lambda} & F_{\delta\gamma} & F_{\delta P_{Sys}} \\ F_{\lambda V} & F_{\lambda\delta} & F_{\lambda\lambda} & F_{\lambda\gamma} & F_{\lambda P_{Sys}} \\ F_{\gamma V} & F_{\gamma\delta} & F_{\gamma\lambda} & F_{\gamma\gamma} & F_{\gamma P_{Sys}} \\ F_{P_{Sys}V} & F_{P_{Sys}\delta} & F_{P_{Sys}\lambda} & F_{P_{Sys}\gamma} & F_{P_{Sys}P_{Sys}} \end{bmatrix} . \begin{bmatrix} \Delta V \\ \Delta\delta \\ \Delta\lambda \\ \Delta\gamma \\ \Delta P_{Sys} \end{bmatrix} \tag{14}$$

The proposed method is implemented using *MATLAB* platform and *FORTRAN 95*. The flowchart of this proposed method is given in Fig.3.

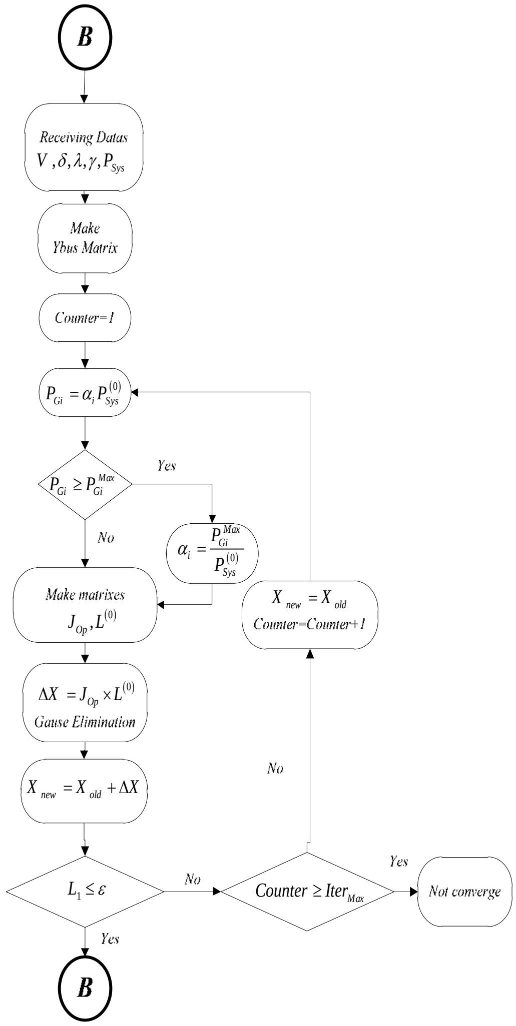

Figure 3: Flow chart of loadability limit index calculation.

C. Minimizing the investment costs

The *DG* (Wind Turbine) costs in installed are given as 3700 $/KWatt [21]. In this study, the size selection of *DGs* is contiguous between 0 and 60 kW based on heuristic algorithm. The five DGs are size selection and allocation in 33 and 69-bus *DS*.

The flowchart for finding optimal reconfiguration of *DS* is shown in Fig. 4. Based on the above discussions, the formulation of objective function is considered as follows.

$$Minimize\ \text{Fitness}=w_1 * C\hat{o}st + w_2 * \hat{P}_{loss} + w_3 * \frac{1}{\hat{P}_{sys}}$$

$$C\hat{o}st = \frac{\sum_{j=1}^{5} Cost_{DG}(j)}{Cost^{base}} \qquad (15)$$

$$\hat{P}_{loss} = \frac{P_{loss}}{P_{loss}^{base}}$$

$$\hat{P}_{sys} = \frac{P_{sys}}{P_{sys}^{base}}$$

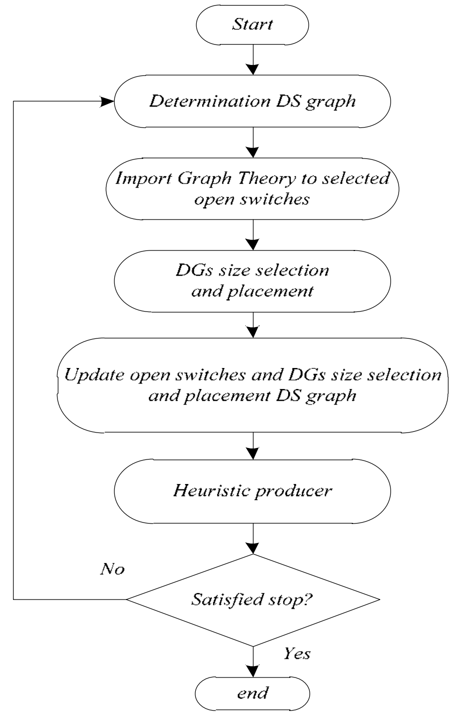

Figure 4: Proposed method flowchart.

where P_{Sys}, $P_{Sys\text{-}base}$ are total active load and the total active load of network without reconfiguration and *DGs* placement of *DS*, and P_{loss}, $P_{loss\text{-}base}$ are total active power loss and primary value of active load.

The multi-objective function and the constraints are used to find optimum configuration of distribution system and *DGs* placement and size selection with proposed objective function within the Harmony search Algorithm and Particle Swarm Algorithm which presented in following sections.

3. Harmony Search Algorithm

A. Brief survey

Harmony search algorithm was derived from the natural phenomena of musician's behavior when they collectively play their musical instruments (population members) to come up with a pleasing harmony (global optimal solution). This state is determined by an aesthetic standard (fitness function). The *HS* algorithm, is simple in concept, few parameters, and easy in implementation, has been successfully applied to various benchmarking, and real-world problems like traveling salesman [21].

Despite the passage of more than a decade, this algorithm still has noted many researchers. The debut of the PSO algorithm looks place in 2001 by Geem, Kim and Longathan [23]. Sinem Kulluk et al. addressed the application of Self-adaptive Global Best Harmony Search algorithm for the supervised training of feed-forward neural networks. A structure suitable to data representation of neural networks is adapted to Self-adaptive Global Best Harmony Search algorithm [24]. In [25] presented a self-adaptive global best harmony search algorithm for solving continuous optimization problems. In the proposed SGHS algorithm, a new improvisation scheme is developed so that the good information captured in the current global best solution can be well utilized to generate new harmonies [25]. The authors in [26] focused on the optimal scheduling of the generators to reduce the fuel consumption in the oil rig platform by using HSA. V. Ravikumar Pandi et.al presented a hybrid harmony search algorithm with swarm intelligence to solve the dynamic economic load dispatch problem [27]. To maximize the degree of customers' satisfaction, benefit third-party-logistics providers and minimize transport costs simultaneously, fourth-party logistics needs to design an optimal route from a supply node to a demand node.

In [28], the mathematical model of the point to point single task path optimization in fourth-party logistic with soft time window is set up. To solve the model, harmony search is suggested. The authors in [29] presents a comparison of post outage bus voltage magnitudes calculated by two meta-heuristic approaches; namely differential evolution and harmony search methods. Harrou et al. combines the universal generating function *UGF* with harmony search meta-heuristic optimization method to solve a preventive maintenance problem for series parallel system [30].

A. Definition

The *HSA* optimization technique consists of several steps. Fig.5 introduces the main flowchart of proposed algorithm. Fig.5 also shows the *HSA* procedure for solving reconfiguration problem.

Flowcharts are explained in detail. In each step, related constraints are taken into account while finally the objective function associated with all constraints is minimized via *HSA*.

The *HSA* search algorithm is applied to solve the feeder configuration problem using the following steps:

Step1: Initialize the optimization problem and algorithm parameters

These parameters are harmony memory size (HMS), harmony memory considering rate (HMCR), pitch adjusting rate (PAR), number of improvisation (NI), and harmony memory (*HM*).

Step 2: Initialize the HM

The format of the solution vector in HM matrix is given in Fig.6. This HMS consisted of reconfiguration (suggested open switches with matroid and graph theory (explained in the next paragraph)) with 5 size selection and 5 DGs allocation in DS.

In this step, the part of switch selection of HM matrix is filled with spanning tree theory. Spanning tree is a theory that has been explained by Kruskal [31]. It will be taken a base of Matroid to be a spanning tree of G. The following is a definition of a spanning tree. If G be a graph with n vertices, a spanning tree is a connected sub-graph that uses all vertices of G that has n-1 edges. Introduction to Graph Theory, explains the exchange axiom for spanning trees. Let M and N be spanning trees of a connected graph G.

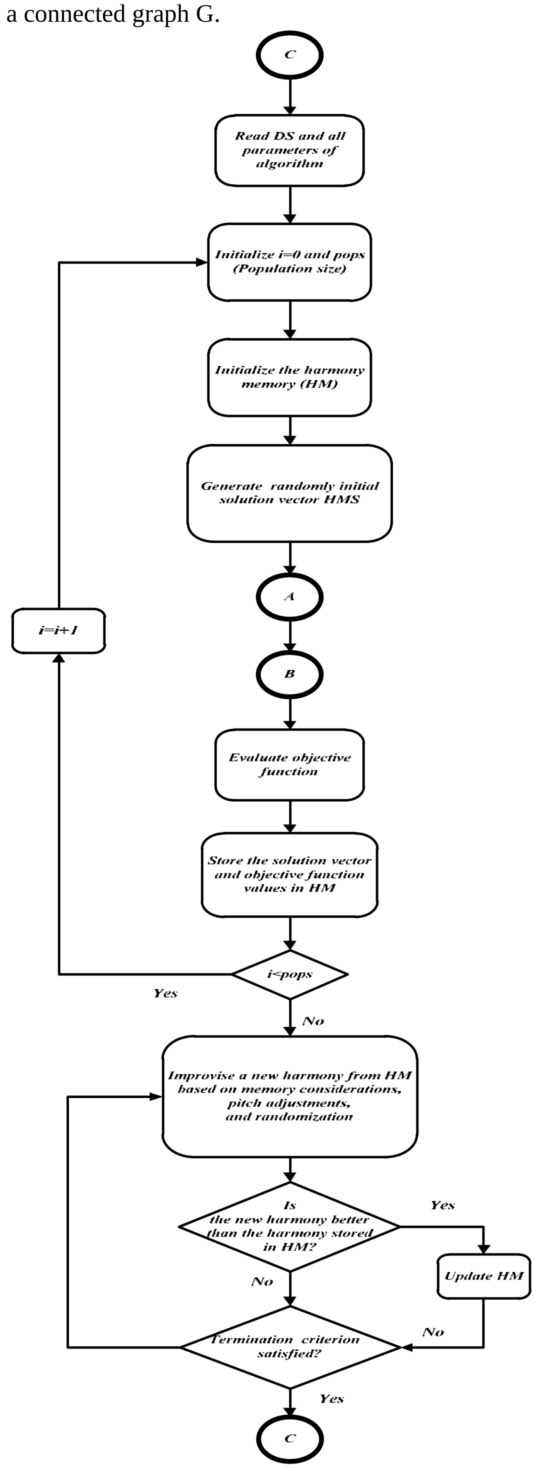

Figure 5: Flow chart of Harmony Search Algorithm (*HSA*).

Switch Statues						DGs information										Fitness value
						DGs place					DGs size					
		....														

Figure 6: Format of the solution vector.

(i) If e is any edge of M, show that there exists an edge f of N such that the graph $(T_1-\{e\})\bigcup\{f\}$ (obtained from M on replacing e by f) is also a spanning tree.

(ii) Deduce that M can be 'transformed' into N by replacing the edges of *M* one at a time by edges of *N* in such a way that a spanning tree is obtained at each stage.

Because the spanning trees of a graph can be taken to be the bases of a Matroid, it can be concluded that the bases of a Matroid have the same number of elements, and by the definition of a spanning tree has n-1 elements (if there are n vertices).

Suppose M and N are two spanning trees of the graph G, and $a \in M$, $a \notin N$ then $b \in N$. Also, $N-a+b$ is a spanning tree in the graph. To understand better, two spanning trees are shown in Fig. 7. One edge that replaces in a=6 in M order to form another spanning tree can be found. Edge b can be selected in the loop formed by $N \cup a$. In Fig. 8, this loop is formed by $N \cup a$ the branches 4, 5, 6, and 7. Only the edges 5 and 7 can replace the edge 6 in. Finally, the edge 5 is chosen to replace the edge 6 in, and a new spanning tree is obtained (see the resulting tree in Fig. (7)).

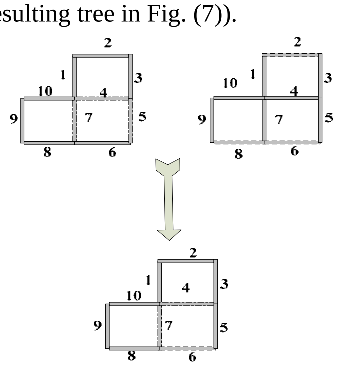

Figure 7: Branch exchange between two spanning trees.

Step 3: Improvise a new harmony: a New Harmony vector $x_i' = \{x_1', x_2', ..., x_N'\}$ is generated using three rules: memory considering, pitch adjustment, and random selection. In the two last rules, is used Matroid theory to form New Harmony vector. General algorithm of this step is:

For each $i \in [1, N]$ do

If $rand < HMCR$

Then $x_i' \in \{x_i^1, x_i^2, ..., x_i^{HMS}\}$

Else if $rand < PAR$

Then $x_i' = x_i' \pm rand(bw)$ and bw is a switch selection via Matroid theory.

Step 4: Update harmony memory: if the New Harmony vector has better fitness function that the worst harmony in the HM, the replaces the worst harmony in HM.

Step 5: Check stopping criterion: terminate when the stopping criterion has been met.

PSO algorithm is applying to verify the result of HSA .The typical PSO algorithm is described in detail in [32]. The flowchart of PSO algorithm is shown by Fig. 8.

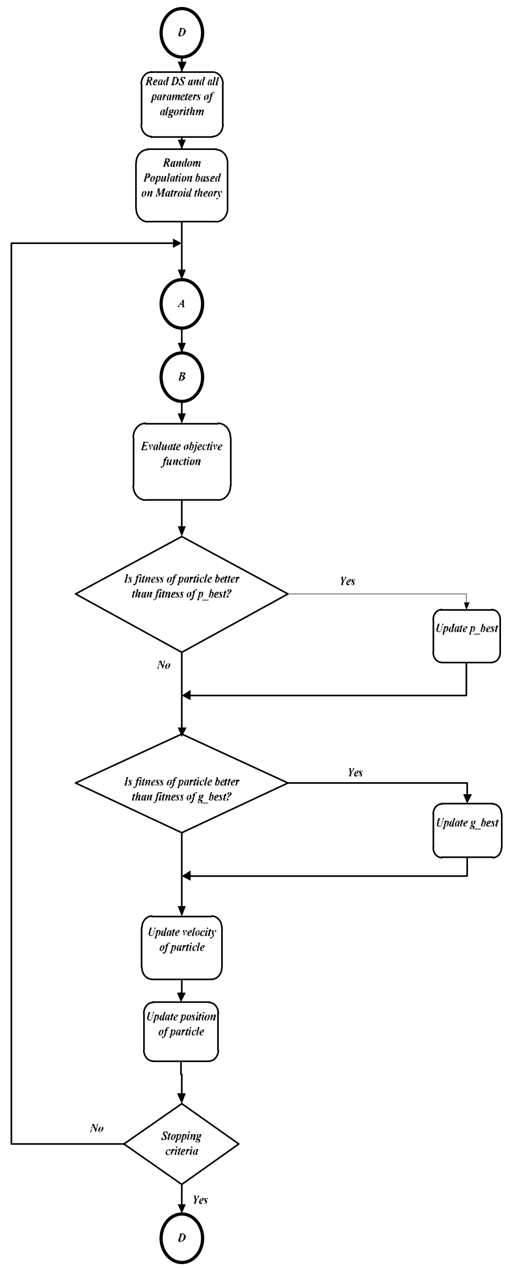

Figure 8: Flow chart of PSO.

4. APPLICATION OF MATROID THEORY TO HSA AND PSO

Matroid theory was initially developed by Whitney [33]. The Matroid theory abstracts the important characteristic of matrix and graph theories. A definition and detail is given in [33].

A Matroid *M* consists of a non-empty finite set *E* and a non-empty collection *B* of subsets of *E*, called bases, satisfying the following properties:

(i): no base properly contains another base;

(ii): if B_1 and B_2 are bases and if $\{e\}$ is any element of B_1, then there is an element of B_2 such that $(B_1 - \{e\}) \bigcup \{f\}$ is also a base.

ii is known as the exchange property. This property states that if an element is removed from B_1, then there exists an element in B_2, such that a new base, B_3 is formed when that element is added to B_1. The property *ii* can be used to show that every base in a Matroid has the same number of elements.

Matroid theory had been used to define *bw* in *HSA* and updating swarm in *PSO*. For reconfiguration problem, this operation means one of several edges is exchange between two spanning tree for a *DS* graph.

Let us consider a graph with the vertices set and the edge set. The co-cycle is composed by all branches that connect the isolated nodes (loads) to the rest of graph (electric network) [34].

To better determine the manner, we continue with an example. In Fig.9, if the switch number 7 must be opened, so the switches 8 or 9 or 10 must be opened, to eliminate cycle. Here, switch 8 is randomly chosen. We used Matroid theory to keep the *DS* topology in radial form during optimization process.

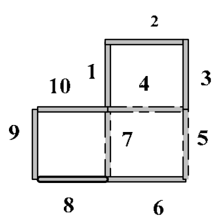

Figure 9: New based on the Matroid approach.

5. RESULT AND DISCUSSION

The proposed methodology is implemented on standard IEEE 33- and 69-bus *DS*. The single line diagram of these systems is shown in Figures (10), (11).

For the study system IEEE 33- and 69-bus DS, the goal of the optimization is to find the best generation of the optimization and to find the best generation for these bus systems. The *HMS* is selected to be 20. *HMCR* and evaluation number are set to 0.9 and 100, respectively, in *HSA*. The *PAR* increase linearly from 0.44 and 0.99. Each harmony in the population is evaluated using equation (15) searching for harmony associated with min fitness.

The parameter in *PSO* must be tuned. These parameters control the impact of the previous velocities on the current velocity where, based on the reference 1, c_1 and c_2 are set to 1.4, w decrease linearly from 0.9 to 0.1.

To find the minimum fitness, the *HSA* and *PSO* are run for 50 independent runs under different random seeds.

A. Case study 1. IEEE 33-bus test system

This distribution network consists of 33 buses and 5 tie lines. The normally open switches are 33, 34, 35, 36, and 37 represented by the dotted lines and normally closed switches 1 to 32 are represented by the solid lines as shown in Fig. 10. For this base case, the total loads at feeder head-section are 3932.9450kW and 2448.2604 kVAr. The base network losses are 210.9931. The results of running *HSA* and *PSO* for different terms of objective function and results are derived as Tables 1 and 2.

In this paper, 3 objects are considered in fitness function for reconfiguration which is considering Matroid theory. This causes that all feasible patterns for switching status to be considered in this study. Hence, switching statuses via Matroid and graph theory affected finding optimum reconfiguration.

The results for initial condition (without reconfiguration) are showing in Column 2 of Tables 1 and 2. The results for improving voltage stability security index as objective function are derived as Column 3 of Tables 1 and 2. Five fixed *DGs* placement and size of them with switches status are given in Tables 1 and 2. These results show improvement in voltage stability margin (loadability limit) with these obtained switching statuses for reconfiguration and these size selection and allocation of *DGs*.

Column 4 of Tables 1 and 2 is presented results for reduction power losses as objective function. (6, 14, 16, 19, 25) are candidate allocation of *DGs* with maximum size. Also, variable load patterns have variable optimum configuration.

This result emphasizes the usefulness and robustness of mixing Matroid and graph theory via heuristic algorithm for reconfiguration.

Trade of between objectives (security improvement, loss reduction and investment cost reduction) is another objective for reconfiguration in *DS* which are derived as Column 5 of Tables 1 and 2. For aiming to this objective function, $w_1 = 0.5, w_2 = w_3 = 0.25$ is assumed. Five (6, 11, 23, 24, 28)-*DGs* placement with (60, 60, 60, 60, 60) kW size selections and (5, 8, 13, 26, 31) opened switches are obtained in this case for improving voltage stability index, reducing power losses and minimizing *DGs* installation cost.

B. Case study 2: IEEE 69-bus test system

The developed methodology is demonstrated by a radial distribution system with 69 buses, 7 laterals and 5 tie-lines, as shown in Fig.11. For this base case, the total loads at feeder head- section are 3801.5kW and 2694.6kVAr. The base network losses are 20.89. The results of running *HSA* and *PSO* for different terms of objective function and results are derived as Tables 3, 4. From the result of this case study, it can be seen from the 69-bus test system that mixing Matroid and graph theory with heuristic algorithm for reconfiguration and location of *DGs* and size selection has the effects of loss reduction improvement over feeders in this particular case, and the configuration structures of optimum network with proposed reconfiguration and location of *DGs* and size selection are different from those without reconfiguration. In This Tables *HSA* and *PSO* have improvement in voltage stability and power losses.

6. CONCLUSION

In this study reliable and efficient methods are using heuristic technique for reconfiguration and *DGs* planning. On the other hand, a new approach to select best harmony with *HSA* & *PSO* has been presented, where objective function in *HSA* & *PSO* has been comprised power loss and voltage stability and this yields a wide search area.

The proposed method has been successfully applied to a standard IEEE 33- and 69-bus *DS*. The results also can offer the usefulness of the proposed method which can be considered as a practical technique. The results have shown that the *PM* has the following merits in both reconfiguration problems and *DGs* planning with considering variable objectives: efficient searching ability, robustness in result.

TABLE I
EXECUTING PROGRAM UNDER IEEE 33BUS VIA *HSA*

Results \ Objective Function	Initial condition	Max. P_{Sys}	Min. P_{Loss}	P_{Sys} P_{Loss} Cost
Switch Status	33,34,35,36,37	4,7, 9, 14, 32	6, 11, 14, 28 ,30	5,8,13,۲۶,31
DG place(DG size(kw))	---	9(60),13(60),17(60), 24(60), 32(60)	6(60), 14(60), 16(60),19(60),25(60)	6(37.32), 11(24.64),23(40.96) ,24(29.04),28(36.73)
P_{Sys} (MW)	15.19	30.97	28.69	29.30
P_{Sys} growth in compare with initial condition (%)	---	103.88	88.87	92.89
P_{Loss}(KW)	210.99	175.11	44.28	59.74
P_{Loss} reduction (%)	---	17.01	79.13	71.69
Cost(M$)	---	1.11	1.11	0.624

TABLE II
EXECUTING PROGRAM UNDER IEEE 33BUS VIA *PSO*

Results \ Objective Function	Initial condition	Max. P_{Sys}	Min. P_{Loss}	P_{Sys} P_{Loss} Cost
Switch Status	33,34,35,36,37	7,11,14, 36, 28	6, 11, 14, 28 ,30	5,8,13,۲۶,31
DG place(DG size(kw))	---	2(60) ,8(60), 16(60),17(60), 18(60)	6(60), 14(60), 16(60),19(60),25(60)	6(37.32), 11(24.64),23(40.96) ,24(29.04),28(36.73)
P_{Sys} (MW)	15.19	30.29	28.69	29.30
P_{Sys} growth in compare with initial condition (%)	---	99.41	88.87	92.89
P_{Loss}(KW)	210.99	154.65	44.28	59.74
P_{Loss} reduction (%)	---	26.70	79.13	71.69
Cost(M$)	---	1.11	1.11	0.624

TABLE III

EXECUTING PROGRAM UNDER IEEE 69BUS VIA *HSA*

Objective Function / Results	Initial condition	Max. P_{Sys}	Min. P_{Loss}	P_{Sys} P_{Loss} Cost
Switch Status	69, 70, 71, 72, 73	20, 41,46, 55, 61	16, 55, 62, 69,71	19, 42, 44, 58, 62
DG place(DG size(kw))	---	23(60), 50(60), 56(60), 60(60), 64(60)	20(60), 32(60), 37(60),47(60),48(60)	4(22.13), 6(32.55), 26(35.79), 17(29.40), 51(36.37)
P_{Sys} (MW)	12.66	22.34	21.17	21.43
P_{Sys} growth in compare with initial condition (%)	---	76.46	67.22	69.27
P_{Loss}(KW)	20.89	10.72	7.64	8.85
P_{Loss} reduction (%)	---	48.68	63.43	57.64
Cost(M$)	---	1.11	1.11	0.577

TABLE IV

EXECUTING PROGRAM UNDER IEEE 69BUS VIA PSO

Objective Function / Results	Initial condition	Max. P_{Sys}	Min. P_{Loss}	P_{Sys} P_{Loss} Cost
Switch Status	69, 70, 71, 72, 73	18, 41,44, 57, 61	16, 55, 62, 69,71	19, 42, 44, 58, 62
DG place(DG size(kw))	---	28(60), 45(60), 52(60), 60(60), 64(60)	20(60), 32(60), 37(60),47(60),48(60)	4(22.13), 6(32.55), 26(35.79), 17(29.40), 51(36.37)
P_{Sys} (MW)	12.66	21.92	21.17	21.43
P_{Sys} growth in compare with initial condition (%)	---	73.14	67.22	69.27
P_{Loss}(KW)	20.89	9.55	7.64	8.85
P_{Loss} reduction (%)	---	54.28	63.43	57.64
Cost(M$)	---	1.11	1.11	0.577

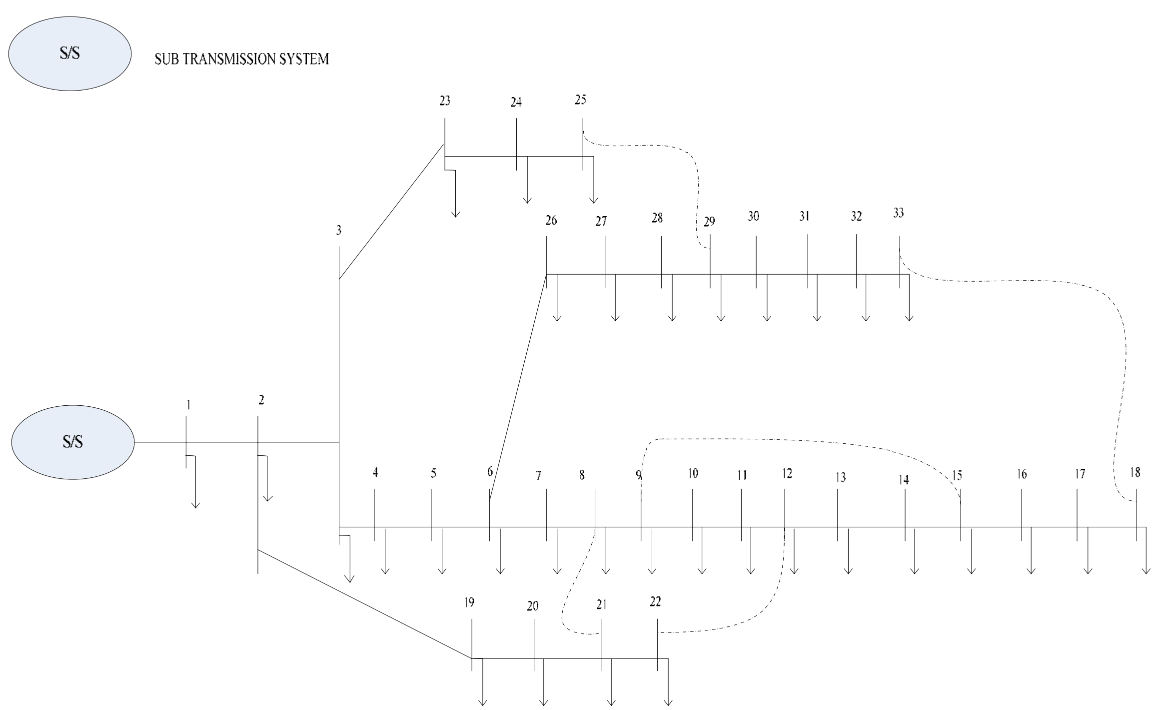

Figure 10: IEEE 33bus test system.

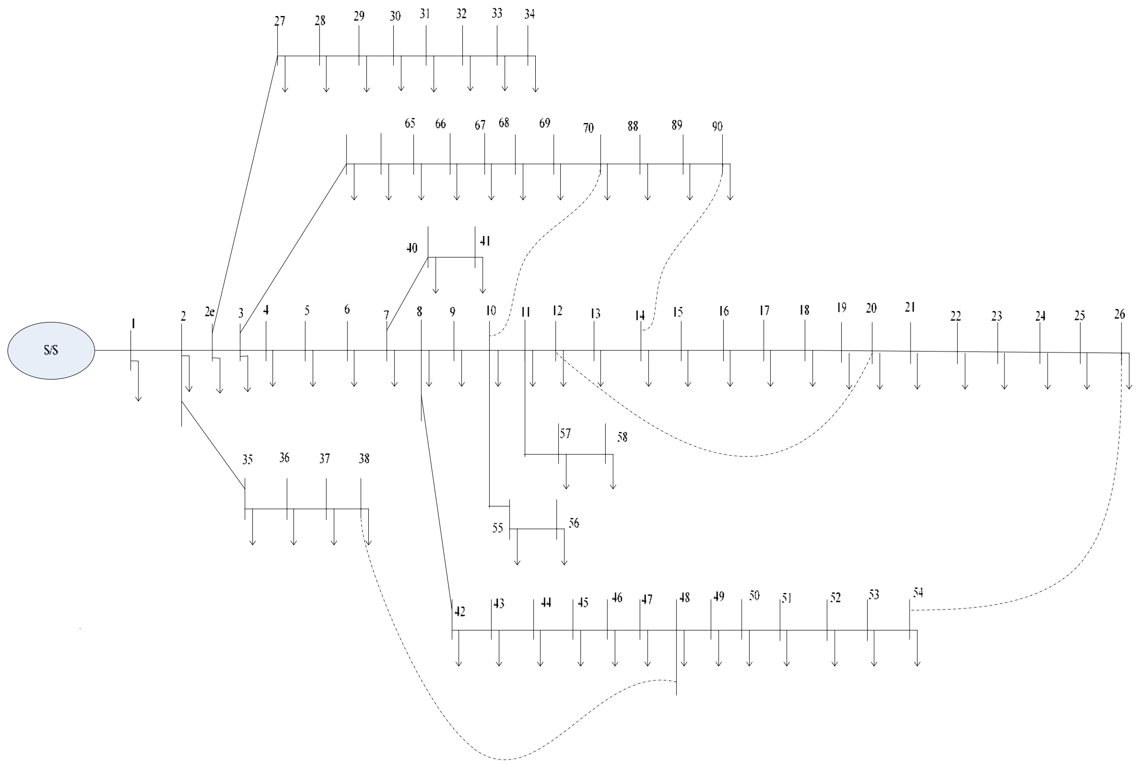

Figure 11: IEEE 69bus test system.

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