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(RESEARCH ARTICLE)

Voltage profile improvement and power loss minimization of new haven injection substation for optimal placement of DG using harmony search algorithm optimization technique

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Abstract

The main importance of a power grid is to transfer electrical energy from the production to the consumption, while maintaining an acceptable reliability and voltage quality for all customers. The role of electrical power distributions to have centralized plants distributing electricity through Distributed Generation (DG) which reduces the Power Loss on transmission and distribution station and also improve voltage profile by optimization. This research work analyzes New Haven injection substation for optimal placement of DG generation based on wind power renewable energy source to the Distribution network and voltage stability using Harmony Search Algorithm. The model developed was simulated using MATLAB/SIMULINK software. The work applied new improved Harmony Search Algorithm for integration of renewable energy generation in the distribution network with positive impact on the operation of the voltage stability between 0.95 to 1.05p.u and reactive power distribution improvement through minimization of line losses. The total power system Loss without and with DG are 338.712KW and 307.9KW. Also, the voltage profiles of the sixteen faulty buses are stabilized for efficient performance of substation. Hence, the percentage of power system improvement is 27.23%. Therefore from the results, there is reduction of power Loss when DG is applied and optimised in the power system.

Keywords: Harmony Search Algorithm; Distributed Generation; Power Flow; Injection Substation

1. Introduction

Adequate and efficient supply of electricity is an important facilitator for sustainable development in our modern time. While Nigeria is reported to suffer from severe fall/shortages in electric power, the condition of some of its recent constitutional units can be verified. It is deduced that a good amount of power loss and low voltages profile is associated in power system network, particularly, in the primary and secondary distribution system of electric power supply. The radial configuration of network distribution is often deployed and adopted with a very long distance of feeder line and several loads connected, referred to as T-offs. The challenges of distribution feeder performance and efficiency, inadequate power distribution from the grid, are poor power factor from load end, inadequate use of undersize conductors, feeder transformer overload, poor energy management systems, power rationing at the secondary distributions (11KV), unexpected faults, inadequate real and reactive power distribution from the grid to the end users, unmitigated acts of vandalism[1]. With the above-mentioned challenges and the need to restructure the distribution network safely with adequate power supply to avoid load rationing, power voltage margin, etc. gave birth to the idea of this research[2].

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As necessity is the main invention, so the important to maintain a reliable and safe power system is the main driving force for the design of power system. Power system security is the ability to maintain the flow of electricity from the generators to consumers. Disturbances can be small or large, localized or widespread, but ultimately the design of the power system must achieve an adequate level of security.

To obtain a system that sustains power flow during inevitable disturbances, it is necessary to meticulously design the system even though this may be expensive [3].

Ultimately the design should meet an appropriate level of security in order to ensure proper power flow in a power system, it is of paramount importance to make an effective and efficient power system design and plan. An efficient power system is one that is able to meets the consumers demand and with a high degree of reliability [4][5]. Major outages occur when there is a huge failure in the power system. Major blackouts are usually caused by successive failures of power system components which subsequently lead to failure of the transmission system or generation unit. Problems may arise in a power system as a result of inappropriate power flow on lines; voltage limits violation, short circuit of transmission lines, earth faults, and over-current[6][7].

The whole process can be the beginning of cascading when it spreads uncontrollably in the power system. For economic reasons, most power systems operate at the minimum level required for it to be stable. This increases the chance of turning from a local to a wider failure when such faults are not quickly detected and cleared, they could become cascaded over the power system which may eventually have a devastating effect on the system components, and huge economic disadvantage to both the energy providers and energy consumers. Therefore, it is reasonable to operate power systems within their stability range [8].

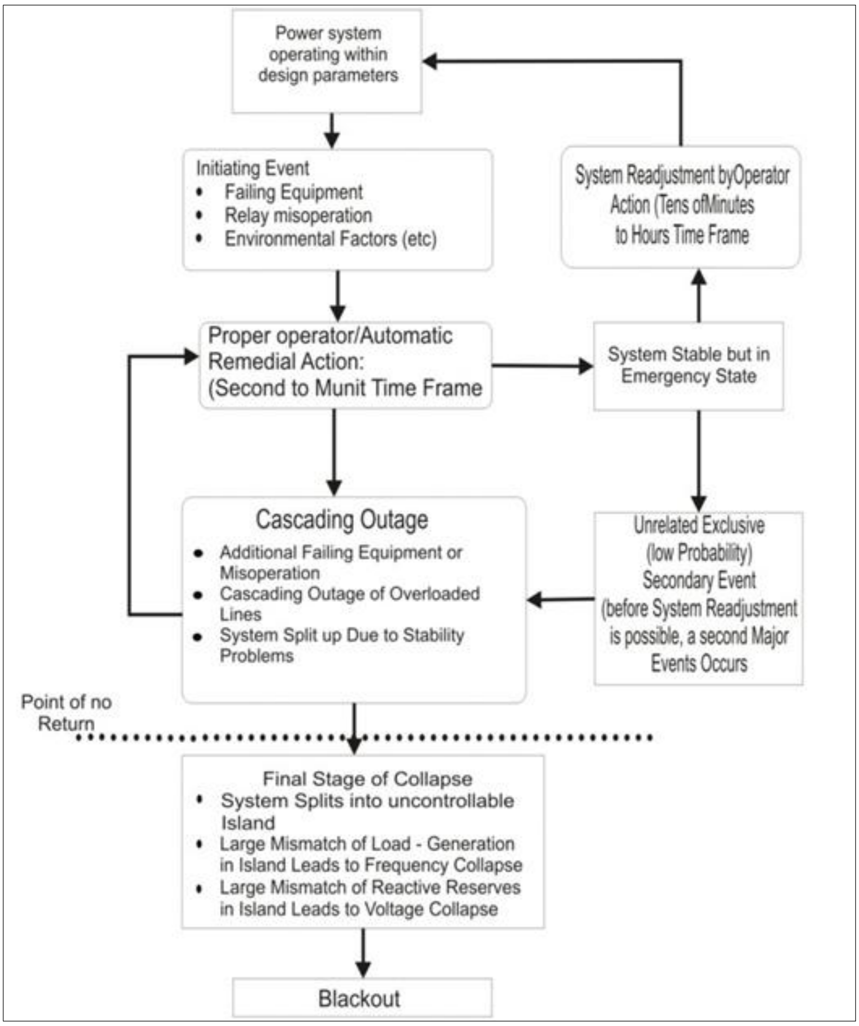

Figure 1 Blackout structure [9]

Figure 1 shows the inter-relationship between the events and the system as blackout unfolds. The correlation between various events and system blackout are shown in figure 1. It could be seen that a system component failure is most times the beginning of a major outage. Failure of a component arises as a result of aging, inappropriate use, or environmental factors such as transients caused by lightning or any other natural disaster. Power systems are designed to have an optimal security level in order to handle faults as some faults are capable of pushing the system into unstable conditions while others do not have a big effect [9].

These alternative sources of energy however have their peculiar characteristics which majorly depend on their means of conversion in order to synchronise with the energy utility at the distribution end. Electrical energy converters are majorly classified into three: synchronous generators, asynchronous (induction) generators, and static (or electronic) inverters.

There are various definitions describing Distributed Generation (DG) both in literature and in practice. Some of these definitions appear ambiguous and sometimes contradicting when compared with other definitions. Examples of terms used in defining DG include embedded, decentralized and dispersed generation[10].

Nevertheless, DG may be defined based on different parameters like voltage profile, unit connection, the type of prime-mover, state of generation dispatch and maximum power rating [10].

Author [10] evaluated this fact and concluded that DG is an electrical energy source which may be integrated with the distribution network or connected at the meter site of the customer. In this definition of DG, the rating of the generating source is not taken into consideration, as maximum rating is often determined by the nature of the local distribution network, for example, the voltage level. Again, this definition has no specification of the technologies used because diverse forms of technologies may be applied.

The definition of DG according to Ackermann appears basically generic as there was no scope of the size of the DG as well as its location. The synchronous and asynchronous generators are driven by wind turbines, hydro-turbines, steam turbines, combustion turbines or electric motors. The electronic inverters are often supplied with dc power by direct current (DC) storage sources (such as batteries), DC sources e.g. fuel cells, or an alternating current generating source with a converter (e.g. variable speed drive or wind turbine). There is a difference in response of these machines due to the varying mechanical and electrical compositions, and different time constants of the regulator by which the machines are operated.

According to reference [11], distributed generation DG may be defined as “the generation of electricity by facilities that are sufficiently smaller than the central generating plants so as to allow interconnection at nearly any point in a power system.” This definition emphasises the size of DG and compares it with that of the conventional generating plants. Reference [12] offered a comparatively more precise definition of DG and it was defined with regards to size, location and type. Author [12] defined DG as “all generation units with a maximum capacity of 50 MW to 100MW, that are usually connected to the distribution network and that are neither centrally planned nor dispatched.”

According to author [13], DG may be defined as “a small source of electric power generation or storage (typically ranging from less than a kW to tens of MW), which is not a part of a large central power system and is located close to the load. The definitions provided by the authors encompass the storage facilities. Also, Author[14], defined DG in a way that included the cost implication. DG was defined as “relatively small generation units of 30 MW or less that are sited at or near customer sites to meet specific customer needs in order to support economic operation of the distribution grid or both.”

2. Material and method

The New haven injection substation is one of several injection substations is a 330/132/33kv substation located in New Haven North Nigeria, Enugu State, Nigeria. The step-in voltage of the substation is 330kv and step-out voltage is 33kv. The substation capacity is 150MVA.

The methods to be applied for analysis for this research are load flow-based techniques using MATLAB load flow technique. This involve modeling the feeder (network) configurations, run load flow for the base case, identifying the bus voltage margins, power flow and losses at branches, integration of OSGs or DGs at the optimal locations of the feeder buses, making list of voltage margins and power losses from the results obtained. The operational algorithm is applied for optimal placement of DG units which includes include determination of the base case load flow, analysis of voltage profile and power loss rate or level without the DG, examining of voltage profile and power loss with OSG unit at each bus, and finally with sizable OSG units at the optimal location(s).

Equations (3) to (7) is used to model the power flow equations in the substation, while equations (10) to (12) is used to analyzed power loss reduction and performance assessment of the substation with the installation of DG units, and finally equation (13) and (14) is used to decide the optimal locations to mount the DGs on the distribution system. This research paper used Matlab/Simulink power-lab environment to analyze and design. The DG system used is wind energy. The advantages of wind energy are that it is a clean power source, and the cheapest technology compared to other types of renewable energies.

The overall efficiency of the Wind is between 20-40% of the distributed generation and its power rating varies between 0.3 to 7 MW in order to avoid waste in the system.

Wind turbine mechanical output power= 1.4MW

Base power of electrical generator=1.6MVA

Base wind speed=12m/s

Maximum power at wind speed =0.73p.u

Base rotational speed=1.2p.u

2.1. Power Flow Equations in a Distribution System

From the single line diagram shown in figure 1, the power flows in a distribution system are derived and computed as follows:

$$P_{k+1} = P_k - P_{Loss,k} - P_{LK+1} = P_k - \frac{R_k}{|V_k|^2}\{P_k^2 + (Q_k + Y_k|V_k|^2)^2\} - P_{LK+1} \dots\dots\dots\dots \ (1)$$

$$Q_{k+1} = Q_k - Q_{Loss,k} - Q_{LK+1}$$

$$= Q_k - \frac{X_k}{|V_k|^2}\{P_k^2 + (Q_k + Y_{k1}|V_k|^2)^2\} - Y_{k1}|V_k|^2 - Y_{k2}|V_{k+1}|^2 - Q_{LK+1} \dots\dots\dots\dots\dots\dots \ (2)$$

$$|V_{k+1}|^2 = |V_k|^2 + \frac{R_k^2 + X_k^2}{|V_k|^2}(P_k^2 + Q_k'^2) - 2(R_k P_k + X_k Q_k)$$

$$= |V_k|^2 + \frac{R_k^2 + X_k^2}{|V_k|^2}(P_k^2 + (Q_k + Y_k|V_k|^2)^2) - 2\big(R_k P_k + X_k(Q_k + Y_k|V_k|^2)\big) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . (3)$$

The power loss in the line section connecting buses *k* and *k+1* may be computed as:

$$P_{Loss}(k, k+1) = R_k . \frac{(P_k^2 + Q_k^2)}{|V_k|^2} \dots\dots\dots\dots\dots\dots \ (4)$$

The total power loss of the feeder $P_{T,Loss}$ may then be determined by summing up the losses of all line sections of the feeder, which is given as

$$P_{T,Loss} = \sum_{k=1}^{n}(k, k+1) \dots\dots\dots\dots\dots\dots\dots . (5)$$

Equations (3) to (7) represents the power flow expressions, and this is applied to the New Haven substation, but this time with the DG to analyze the efficiency of the systems proposed performance.

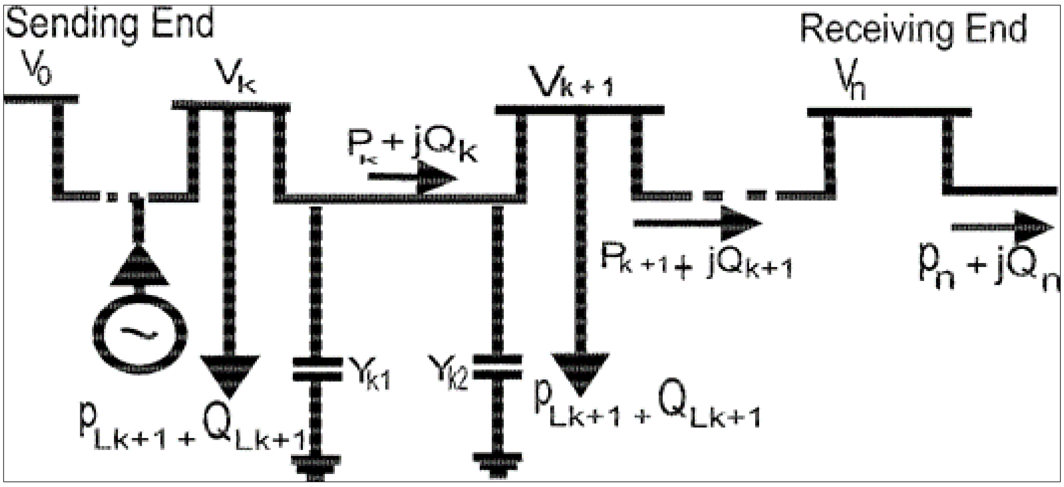

Figure 2 Single line diagram of a main feeder

2.2. Optimization of Harmony Search Algorithm

The HSA is based on the natural musical process which searches for a perfect state of harmony. The HS algorithm does not require initial values for the decision variables and uses a stochastic random search[15]. In general, the algorithm works as follows. As shown in figure 3;

- Step1: initialize the problem and algorithm parameter.
- Step2: initialize the harmony memory
- Step3: improve a new harmony
- Step4: update the harmony memory
- Step5: check the stopping criterion

2.2.1. Step1: Define the objective function and decision variables. Input the system parameters and the boundaries of the decision variables.

The optimization problem can be defined as

Minimize*(x)*

$$\text{Subject to} x_{iL} \le x_i \le x_{iu} \quad (i = 1,2,3 \ldots .N)$$

Where x_{iL} and $x_{iu}$are the lower and upper bounds for decision variables. The HS algorithm parameters are specified in this step. They are the harmony memory size(HMS) or the number of solution vectors in harmony memory, the harmony memory considering rate (HMCR), the distance bandwidth(BW), the Pitch Adjusting Rate (PAR), and the number of improvisations(K) or stopping criterion, where K is the same as the total number of function evaluations.

2.2.2. Step2.Initialize the Harmony Memory (HM). The harmony memory is a memory location where all the solution vectors (sets of decision variables) are stored. The initial harmony memory is randomly generated in the region

$$x_i^j = x_{iL} + rand() \times (x_{iu} - xiL)$$

Where rand () is a random number from the uniform distribution of (0,1)

2.2.3. Step 3. Improvise a new harmony from the harmony memory. Generating a new harmony x^{new}

Is called improvisation, which is based on 3 rules: memory consideration, pitch adjustment, and random selection.

First of all, a uniform random number r is generated in the range [0,1].$x_i^{new} = x_i^{new} \pm r \times bw$ Harmony, the worst harmony in the HM will be replaced with x^{new} and become a new member of the HM.

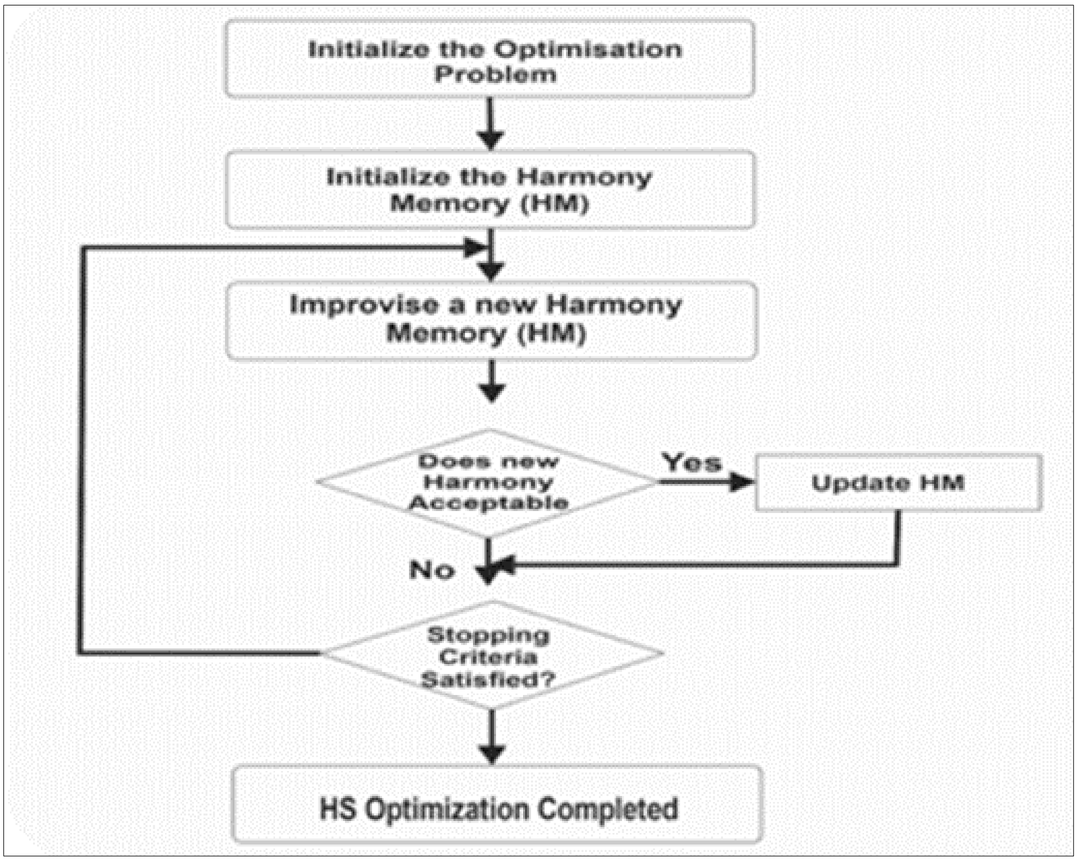

Figure 3 Flow Chat of Harmony Search

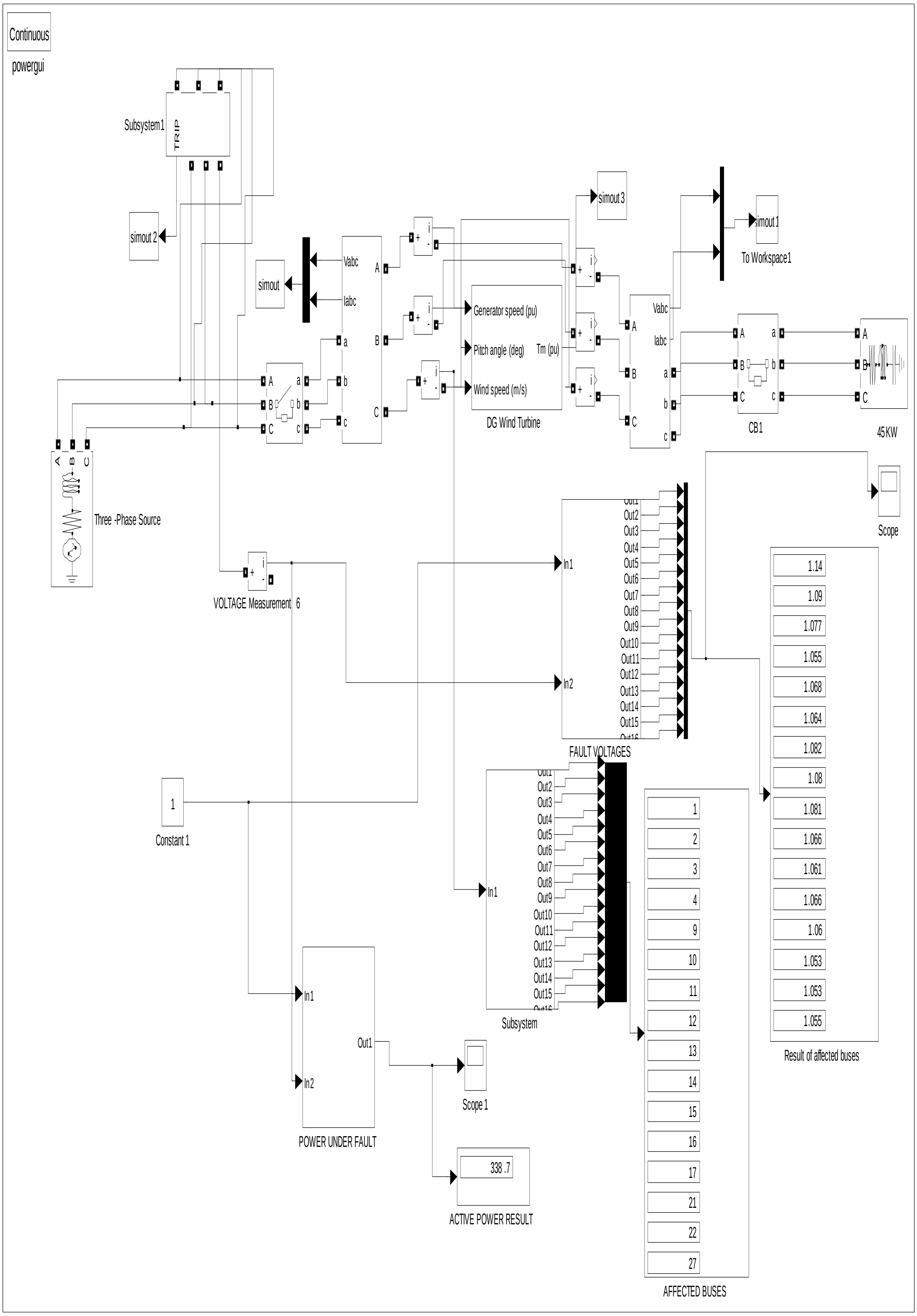

Figure 4 SIMULINK Model of injection substation without DG

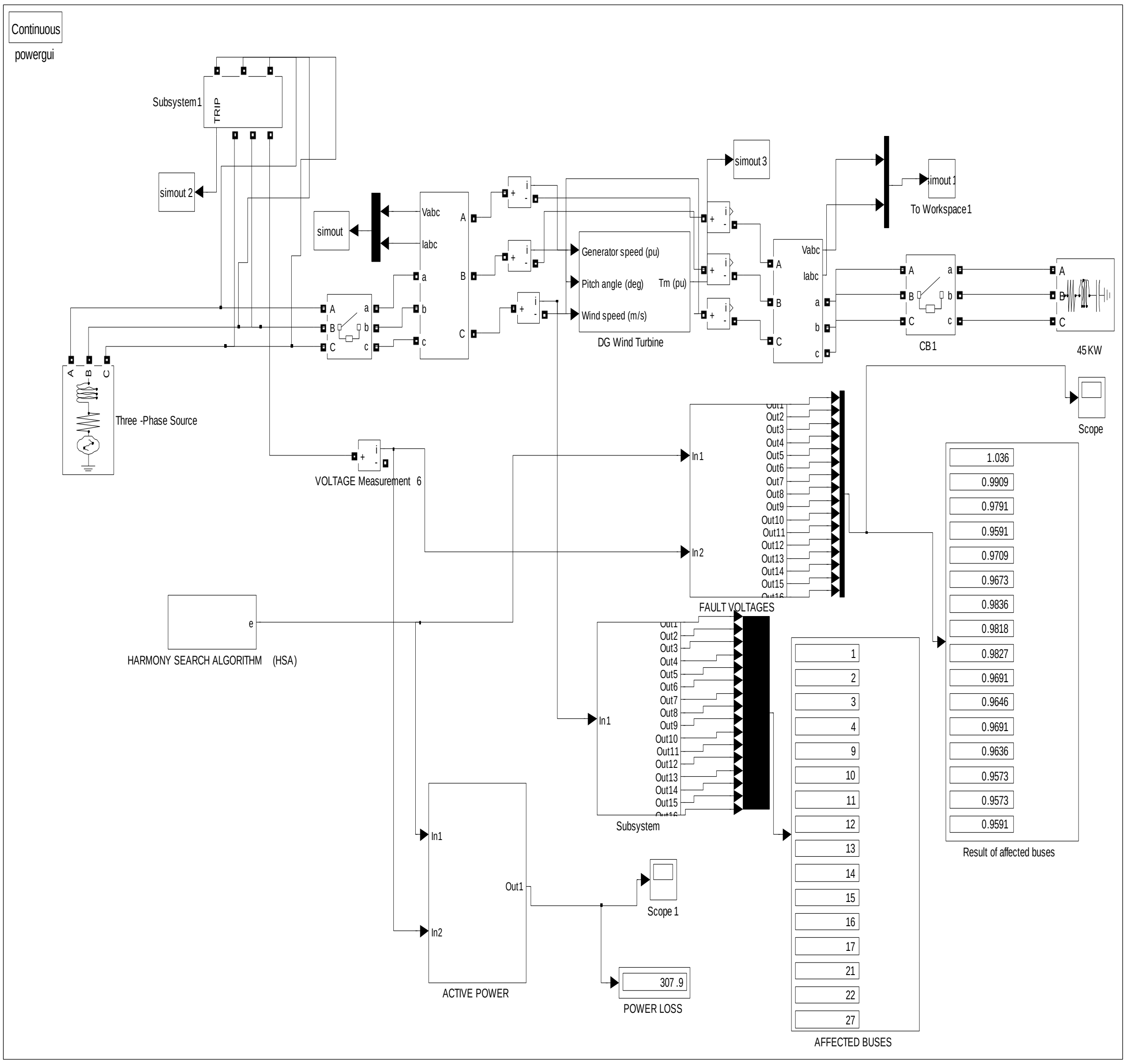

Figure 5 SIMULINK Model of injection substation with DG

3. Results and discussion

In order to study the system, the power flow method chosen has been the Newton Raphson. The effectiveness of the Newton Raphson method to achieve feasible iterative solutions is dependent upon the selection of suitable initial values for all the state variables involved in the study. The power flow solution is normally started with voltage magnitudes of 1pu at all PQ buses. The slack and PV and PVT buses are given their specified values, which remain constant throughout the iterative solution if no generator reactive power limits are violated. The initial voltage phase angles are selected to be 0 at all buses.

The empirical data in table 1 obtained from Substation was used to run the load flow of Newton Raphson in order to determine the faulty buses that did not fall within the range of 0.95 to 1.05 per unit volts**.**

Table 1 Load flow Analysis Result of substation

BUS No	BUS Code	Voltage (p.u.)	Voltage Angle (deg)	PGEN (KW)	QGEN (KVAR)	PLOAD (KW)	QLOAD (KVAR)
BUS_1	1	1.140	0.00	188.712	78.269	0.0	0
BUS_2	2	1.09	-3.182	40	-8.868	21.7	12.7
BUS_3	0	1.077	-3.730	60	0	2.4	1.2
BUS_4	0	1.055	-5.598	0	0	7.6	1.6
BUS_5	2	1.050	-10.055	0	31.029	94.2	19
BUS_6	0	1.044	-7.283	0	0	0	0
BUS_7	0	1.044	-8.154	50	0	42.800	10.9
BUS_8	2	1.030	-7.786	0	-2.592	30.00	30
BUS_9	0	1.068	-11.622	0	0	0	0
BUS_10	0	1.064	-12.646	0	0	5.80	2
BUS_11	2	1.082	-13.994	0	7.548	23.00	0
BUS_12	0	1.080	-11.402	0	0	11.200	7.5
BUS_13	2	1.081	-11.402	0	0.392	0	0
BUS_14	0	1.066	-12.309	0	0	6.2	1.6
BUS_15	0	1.061	-12.445	0	0	8.2	2.5
BUS_16	0	1.066	-12.185	0	0	3.5	1.8
BUS_17	0	1.060	-12.705	0	0	9.00	5.8
BUS_18	0	1.050	-13.181	0	0	3.20	0.9
BUS_19	0	1.047	-13.437	0	0	9.50	3.4
BUS_20	0	1.050	-13.294	0	0	2.2	0.7
BUS_21	0	1.053	-13.023	0	0	17.5	11.2
BUS_22	0	1.053	-12.994	0	0	0	0
BUS_23	0	1.050	-12.888	0	0	3.2	1.6
BUS_24	0	1.045	-13.150	0	0	8.7	6.7
BUS_25	0	1.046	-12.515	0	0	0	0
BUS_26	0	1.029	-12.912	0	0	3.5	2.3
BUS_27	0	1.055	-11.873	0	0	0	0
BUS_28	0	1.040	-7.909	0	0	0	0
BUS_29	0	1.036	-13.029	0	0	2.4	0.9
BUS_30	0	1.024	-13.858	0	0	10.6	1.9
				338.712	105.778	236.400	126.200

The table 1 shows the result of power flow analysis of substation in Enugu State. The analysis was done using MATLAB 2015 software in order to determine the faulty buses in the system. Therefore, from the result shown in the table1 the faulty buses are bus1, bus2, bus3, bus4, bus9, bus10, bus11, bus12, bus13, bus14, bus15, bus16, bus17, bus21, bus22 and bus27. The table 2 indicate the faulty buses that did not fall between the voltage magnitude of 0.95 to 1.05 p.u.

Table 2 Faulty Buses of Substation

BUS No	BUS Code	Voltage (p.u.)	Voltage Angle (deg)	PGEN (KW)	QGEN (KVAR)	PLOAD (KW)	QLOAD (KVAR)
BUS_1	1	1.140	0.00	188.712	78.269	0.0	0
BUS_2	2	1.09	-3.182	40	-8.868	21.7	12.7
BUS_3	0	1.077	-3.730	60	0	2.4	1.2
BUS_4	0	1.055	-5.598	0	0	7.6	1.6
BUS_9	0	1.068	-11.622	0	0	0	0
BUS_10	0	1.064	-12.646	0	0	5.80	2
BUS_11	2	1.082	-13.994	0	7.548	23.00	0
BUS_12	0	1.080	-11.402	0	0	11.200	7.5
BUS_13	2	1.081	-11.402	0	0.392	0	0
BUS_14	0	1.066	-12.309	0	0	6.2	1.6
BUS_15	0	1.061	-12.445	0	0	8.2	2.5
BUS_16	0	1.066	-12.185	0	0	3.5	1.8
BUS_17	0	1.060	-12.705	0	0	9.00	5.8
BUS_21	0	1.053	-13.023	0	0	17.5	11.2
BUS_22	0	1.053	-12.994	0	0	0	0
BUS_27	0	1.055	-11.873	0	0	0	0

Table 3 Comparison of voltage profile with and without DG

BUS No	VOLTAGE PROFILE WITH DG(P.U)	VOLTAGE PROFILE WITHOUT DG(P.U)
BUS_1	1.036	1.140
BUS_2	0.9909	1.09
BUS_3	0.9791	1.077
BUS_4	0.9909	1.055
BUS_9	0.9673	1.068
BUS_10	0.9836	1.064
BUS_11	0.9836	1.082
BUS_12	0.9818	1.080
BUS_13	0.9827	1.081
BUS_14	0.9691	1.066
BUS_15	0.9646	1.061
BUS_16	0.9691	1.066
BUS_17	0.9636	1.060
BUS_21	0.9573	1.053
BUS_22	0.9573	1.053
BUS_27	0.9591	1.055

The result in table 3 shows the faulty and corrected sixteen buses. The faulty buses are bus1, bus2, bus3, bus4, bus9, bus10, bus11, bus12, bus13, bus14, bus15, bus16, bus17, bus21, bus22 and bus27 and the voltage profile without DG are 1.14p.u, 1.09p.u,1.077p.u, 1.055p.u, 1.068p.u, 1.064p.u, 1.082p.u, 1.08p.u, 1.081p.u, 1.066p.u, 1.061p.u, 1.066p.u, 1.06p.u, 1.053p.u, 1.053p.u and 1.055p.u also with DG in the network the voltage profile are 1.036p.u, 0.9909p.u, 0.9791p.u, 0.9591p.u, 0.9709p.u, 0.9673p.u, 0.9836p.u, 0.9818p.u, 0.9827p.u, 0.9691p.u, 0.9646p.u, 0.9691p.u, 0.9636p.u, 0.9573p.u, 0.9573p.u and 0.9591p.u respectively. Figure6 shows that the voltage stabilizes when the DG is incorporated into the network.

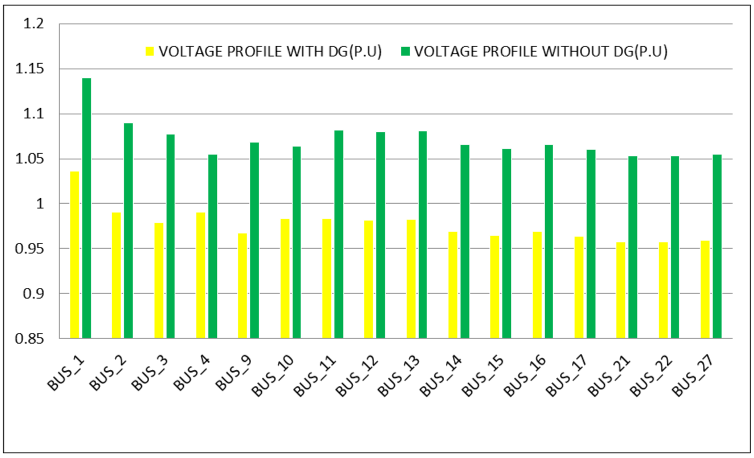

Figure 6 Voltage profile with and without DG

Table 4 The comparison of Active power loss with and without DG

Time(s)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Power Loss without DG	0	460	300	350	280	338.712	338.712	338.712	338.712	338.712	338.712
Power Loss wit DG	0	420	280	320	305	307.9	307.9	307.9	307.9	307.9	307.9

Table 4 shows the comparison of Active power loss with and without DG. The total active power loss without DG and with DG is 338.712KW and 307.9KW respectively at 10 seconds.

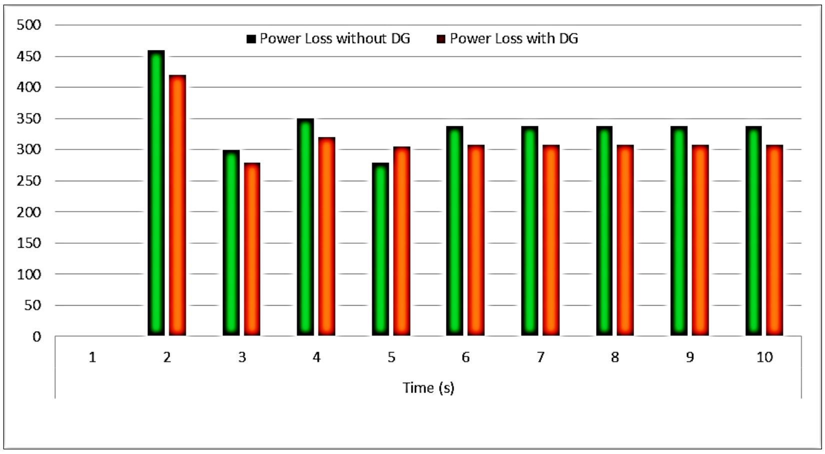

Figure 7 Power Loss with and without DG

Figure 7 shows that when the DG is incorporated the active power loss reduced by 30.812KW. This insinuate that the active power loss reduced by 27.23% when DG is incorporated through Harmony Search Algorithm. The DG system helps in reduction of power loss, over voltage and stabilizes the network. Therefore high quality power supply is distributed to the consumers with minimal load loss

4. Conclusion

The need to address the problem of incessant power failure or system collapse, system instability and insecurity of power systems disturbances in the Nigeria grid system led to this research work. To get a good grasp of the subject matter existing literatures were reviewed. The exact dynamic model of New Haven injection substation was able to analyze with wind energy system using new improved Harmony Search Algorithm. This research work applied new improved Harmony Search Algorithm for integration of renewable energy generation in the distribution network with positive impact on the operation of the voltage stability between 0.95 to 1.05p.u and reactive power distribution improvement through minimization of line losses. The result shows that the sixteen faulty buses were corrected which insinuates the power loss reduction of 27.23%. Therefore, from the results, the network can operate optimally without being over-flogged, reduced the cost of maintenance and also stabilize the voltage of New Haven substation network.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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