International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Optimal Load Shedding of Iraqi Power System using Frequency and Voltage Sensitivities Method

Afaneen Anwer and Mizher Nazar*

Department of Electrical Engineering, University of Technology, Baghdad, Iraq

Received 12 Dec 2018, Accepted 12 Feb 2019, Available online 13 Feb 2019, **Vol.9, No.1 (Jan/Feb 2019)**

Abstract

Load shedding scheme is implemented as a safety net to prevent system collapse after subjected to a disturbance and to maintain the stability of power system. The load shedding algorithm based on the frequency and voltage sensitivities was presented in this paper. The rate of frequency change is using to determine the total amount of load shedding, and the corresponding quantity of load shedding at each bus is determine based on voltage sensitivity that calculated for each bus. The proposed algorithm was applied on the Iraqi Power System, the results showed that the proposed load shedding scheme is accurate with minimum load shedding. The analysis was applied with or without taking into account the importance of some loads. It was obvious that the total amount of load and the values of the frequency and voltage levels are the same in the two cases but there was a new amount of load shedding from the buses.

Keywords: *Load Shedding; Rate of Frequency Change; Voltage Sensitivities; Importance of Load; Iraqi Power System.*

1. Introduction

The main objective of the power systems is to supply electricity to its customers. When a disturbance occurred, the frequency and the voltage of the system will be in instability state and if the disturbance extended, it will lead to the system collapse. Therefore, the need regaining original value of the parameters or re-establish a new stability point as quickly as possible is very important in order to minimize the system collapse. When all the existing controls cannot to sustain the stability of power system, load shedding schemes is applied in emergency situations to maintain the power system stability or to restore the system to steady state (P. Ajay-D-Vimal Raj, 2010). Many researchers focused on the load shedding because of its importance. (P. Ajay-D-Vimal Raj *et al*. 2010), Presented a load shedding strategy with optimal location and optimal amount of load to be shed using L-Indicator index with a modified new technique. (Vladimir V. Terzija, 2006), presented a procedure for protecting electrical power systems from the frequency collapse and the dynamic instability of the system. The Newton-type method calculates the frequency and the rate of frequency change, while the magnitude of the disturbance is determined by using generator swing equation. (L.D. Arya *et al*. 2012), proposed a methodology to optimize the load curtailments necessary to restore the equilibrium of operating point by accounting stability inequality constraints using sensitivity of proximity indicator of load flow Jacobian with respect to load. (Ardiaty Arief. 2014), proposed an advanced under voltage load shedding using the trajectory sensitivity analysis to enhancement the voltage stability. This trajectory sensitivity was calculated at each bus to select the most proper location of load shedding. (Norazliani Md Sapari *et al*. 2014), proposed a load shedding scheme depending on the frequency and voltage stability. The rate of the frequency change is used to determine the amount of imbalance power. And used the voltage stability index to determine the load shedding priority. (Suja Theresa James *et al*. 2016), proposed a method for using fast voltage stability index, these voltage stability indices can be used to determine whether a system is close to collapse or not.

This paper present a method for determining the amount of the load shedding using the rate of frequency change and using the voltage sensitivities to calculate the corresponding amount of load shedding from each bus to avoid risk of system instability.

2. Load frequency control (LFC):

The frequency is a common factor throughout the system. It is dependent on the balance of active power. The active power change at any point of the system is reflected throughout the system by the change of the frequency (P. Kundur. 1994).

*Corresponding author's ORCID ID: 0000-0002-9927-9018
DOI: https://doi.org/10.14741/ijcet/v.9.1.14

The two main objectives of the (LFC) are to maintain the frequency of the system and output corresponding power (MW) in the interconnected system, and to control in the power change in tie line between the control areas. In the interconnected power system, the areas are connected throughout the tie lines. The control area are supplied in each area and they allow the power flow through the tie lines among the areas. Thus, the (LFC) of the interconnected multi area power system generally combines the proper control system by which the frequencies of the areas could back to its predefined value or very nearer to its predefined value when a sudden change in load occurs (Niranjan Behera.2013).

The value of (R) is determines the steady-state speed in competition with load characteristic of the generating unit. The value of (R) is referred to the speed drop or speed regulation and it is expressed as:

$$R = \frac{\Delta f}{\Delta Pg} \quad (1)$$

If two or more generators with drooping governor characteristics are connected to a power system, the speed regulation can be expressed as (P.Kundur, 1994):

$$R_i = \frac{\Delta f_i}{\Delta Pgi} \quad (2)$$

From equation (2), the frequency deviation (Δf) is equal to:

$$\Delta f_i = R_i * \Delta P_{gi} \quad (3)$$

and

$$\Delta P_{gi} = P_{gi.0} - P_{gi} \quad (4)$$

Where the Δf_i is the different of the frequency of each generator caused by the disturbance, R_i the speed drop of each generator, ΔP_{gi} is the generated power difference caused by the disturbance, $P_{gi.0}$ is the power generated before the disturbance, P_{gi} is the power generated after the disturbance.

The deviation in the frequency of the equivalent inertial center (Δf_{coi}) can be obtained by the weighted sum of the frequency deviations caused by the individual generators:

$$\Delta f_{coi} = \frac{\sum_{i=1}^{n}(H_i \,\Delta f_i)}{\sum_{i=1}^{n} H_i} \quad (5)$$

By inserting (5) into equation (3), the frequency of the system was calculated as show:

$$freq. = f_N \mp \Delta fcoi \quad (6)$$

Where the f_N the rated frequency in Hz, H_i is the inertia constant in (sec).

3. Analysis of system frequency response

3.1 Analysis of the swing equation

The swing balance equation of single generator can be expressed as follows (Zhichao Zhang, *et al.*, 2014):

$$\frac{2H_i}{f_N}\frac{d\Delta f_i}{dt} = \Delta P_i \quad (7)$$

Where the H_i is the constant inertia in (sec), f_N is the nominal system frequency in Hz, ΔP_i is the imbalanced system power in per unit.

The swing equation for multi generators can be obtained by adding (n) differential generators swing equations as the following:

$$\Delta P = \sum_{i=1}^{n} \Delta P_i = \frac{2\sum_{i=1}^{n} H_i}{f_n}\frac{d\Delta f_{coi}}{dt} \quad (8)$$

Where Δf_{coi} is the COI of the system frequency, which can obtained by:

$$\Delta f_{coi} = \frac{\sum_{i=1}^{n}(H_i \,\Delta f_i)}{\sum_{i=1}^{n} H_i} \quad (9)$$

Where $d\Delta f_{coi}/dt$ is the rate of frequency change.

In the initial moment of the disturbance in the system, the swing equation for the equivalent system will be as follow:

$$\frac{d\Delta f_{coi}}{dt} = \frac{f_N}{2\,H_{eq}}(\Delta P_M - \Delta P_L) = \frac{f_N}{2\,H_{eq}}\Delta P \quad (10)$$

ΔP_M is the change of the mechanical power in per unit and ΔP_L is the change of the electrical power in per unit.

In addition, ΔP is defined in per unit based on S_{eq} of the system as shown below:

$$\Delta P = \frac{P_{def}}{\sum_{i=1}^{n} S_i} = \frac{P_{def}}{S_{eq}} \quad (11)$$

Where S_{eq} is the total apparent power of the generators in the system in (volt-ampere) and P_{def} is the power deficits in MW.

Considering equation (9) and equation (11), P_{def} in MW can be written as:

$$P_{def} = \frac{2\,H_{eq}\,\text{Seq}}{f_N}\frac{d\Delta f_{coi}}{dt} \quad (12)$$

Therefore, the measured value P_{def} from Equation (12) include the changes of the load, the mathematically load model as follows:

$$\begin{cases} P_L = \sum_{i=1}^{m} P_{L0.i}\left(\frac{V_i}{V_{0.i}}\right)^{\alpha_i}\left[1 + K_P\left(\frac{\Delta f}{f_0}\right)\right] \\ Q_L = \sum_{i=1}^{m} Q_{L0.i}\left(\frac{V_i}{V_{0.i}}\right)^{\beta_i}\left[1 + K_Q\left(\frac{\Delta f}{f_0}\right)\right] \end{cases} \quad (13)$$

Where P_L is the active load power in the system and Q_L is the reactive load power in the system. $P_{L0.i}$ is the active power of the the i^{th} load bus before the disturbance and $Q_{L0.i}$ is the reactive power of the the i^{th} load bus before the disturbance. V_i is the i^{th} load bus voltages, $V_{0.i}$ is the i^{th} load bus voltages before the disturbance. And (m) the number of load bus in the system, α_i and β_i is the factors showing the active power and reactive power dependence on load bus voltage deviations. In addition, the factors of load frequency dependence are K_P and K_Q .

3.2 The measurement analysis of the rate of frequency change

After the system is subjected to a disturbance, the effecting main factors include; the active mechanical power of the turbine before the disturbance P_{m0}, pre-disturbance active power load of the system P_{L0}, the speed drop R. Neglecting the frequency dependence of the load, figure (1) shows the important variables for determine the active power deficit in the system through the frequency gradient (U. Rudez *et al.* 2011).

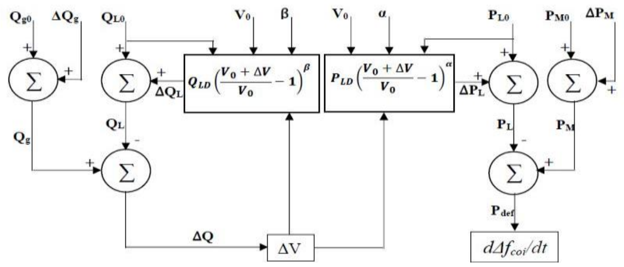

Fig.1 Viable relation determining the rate of frequency change

According to the analysis of Figure (1), the output of this analysis is the rate of the frequency change $d\Delta f_{coi}/dt$, and it is a main part for determining the total amount of requires load to be shed. Neglecting other system losses, P_{def} can be written as (U. Rudez *et al.* 2011):

$$P_{def} = P_M - P_L \quad (14)$$

Inserting the load characteristics equation (13) into equation (14), the amount of the load to be shed in MW can be written as:

$$P_M - P_{L0} = P_M - \sum_{i=1}^{m} P_{L0.i}$$
$$= P_{def} + \sum_{i=1}^{m} P_{L0.i}\left[\left(\frac{V_i}{V_{0.i}}\right)^{\alpha_i} - 1\right] \quad (15)$$

By considering the equation (12) and equation (15) the rate of frequency change is dependence on the initial loading of the system and voltage deviations, therefore the $d\Delta f_{coi}/dt$ can be written as (U. Rudez *et al.* 2011):

$$\frac{d\Delta f_{coi}}{dt} = \Delta f_1 + \Delta f_2 \quad (16)$$

Where: $\Delta f_1 = \frac{f_N}{2\,H_{eq}\,S_{eq}}\,(P_M - P_L)$

And

$$\Delta f_2 = -\frac{f_N}{2\,H_{eq}\,S_{eq}}\sum_{i=1}^{m} P_{L0.i}\left[\left(\frac{V_i}{V_{0.i}}\right)^{\alpha_i} - 1\right]$$

The equation (16) above shows the ($d\Delta f_{coi}/dt$) that consist of two main part which is (Δf_1 and Δf_2), the first part (Δf_1) is to determine the rate of the frequency change when the system consist of constant active power and reactive power.

The second part, determines the influence of the load change to $d\Delta f_{coi}/dt$ because of the change of the loads voltages. As shown in the analysis above and in figure (1), if the values of ($\alpha_i = 0$, β_i=0), then Δf_2 can be ignored. It evident that the value of the Δf_2 is dependent on the initial load of the system P_{L0} and the changes of the voltages ΔV. When Δf_2 compared to Δf_1 is become bigger, Δf_2 must be considered (U. Rudez *et al.* 2011).

4. Voltage stability

Voltage stability is the ability of the system to sustain the voltages of all the buses after the system is subjected to a disturbance at any bus of the system. When the system subject to a disturbance or the load demand is increased, this will lead to a continuous drop in system voltage, and then the system enters to the voltage instability state. If at least one bus of the system in unstable state, the system is unstable, the magnitude of the bus voltage will be decreased as the injection of reactive power at the same bus is increased. It implies that, the voltage stable when the V-Q sensitivity is positive for all bus of the system. And if one of the V-Q sensitivity in the system is negative, then the system voltage is unstable.

Voltage collapse is the term used for the voltage instability conditions. It is the process, by which, the sequence of events following voltage instability leads to abnormally low voltages or even a black out in a large part of the system. Voltage collapses usually occur on power system, which are heavily loaded or faulted or have shortage of reactive power (P. Kundur, 1994).

The load shedding is an active countermeasure against voltage collapse. In general, a load shedding scheme is designed to shed an exact amount of load from one or more locations within a power system after finite amount of time upon detecting the onset of voltage collapse. The two main areas for consideration in a load shedding scheme are summarized as:

4.1 Determining the amount of load shedding

Determining the power deficiency of the system accurately that is very important for load shedding strategy. As for the difference between the generation power and the load demand, the spinning reserve power P_{SR} in the system must be considered, by equation (15) the load power that needed to be adjusted can be obtained, namely P_{shed} is the total load to be removed from the system as follow (Zhichao Zhang, *et al.*,2014):

$$P_{Shed} = P_{SR} + P_{def} + \sum_{i=1}^{m} P_{L0.i} \left[\left(\frac{V_i}{V_{0.i}}\right)^{\alpha_i} - 1 \right] \quad (17)$$

P_{shed} is the most important parameters since they represent the input variables of the system disturbance. By inserting equation (12) into equation (17), the relationship between P_{shed} and $d\Delta f_{coi}/dt$ as follow (Zhichao Zhang, *et al.*, 2014):

$$P_{Shed} = \frac{2\, H_{eq}\, \text{Seq}}{f_N} \frac{d\Delta f_{coi}}{dt} + P_{SR} + \sum_{i=1}^{m} P_{L0.i} \left[\left(\frac{V_i}{V_{0.i}}\right)^{\alpha_i} - 1 \right] \quad (18)$$

Calculate the accurate power deficiency in the power system which is namely of P_{shed} is represented by equation (18).

4.2 Determining the amount of load shedding from each bus

After total amount of P_{shed} is identified, the corresponding quantity of load shedding from each bus must be determine. The bus voltages change reflect the information whether the reactive power distribution is balanced in the system (Zhichao Zhang, *et al.*, 2014).

The V-Q sensitivity at a bus represents the slope of the Q-V curve at the given operating point. With the decrease of the sensitivity, the stability of the system will increased (P.Kundur, 1994). The V-Q sensitivity is reflect the relation between the voltages and the reactive power of the system.

In the system, the equations for active power, reactive power and voltage sensitivities are (Huy Anh Quyen, 2013):

$$P_i = \sum_{j=1}^{n} |V_i V_j Y_{ij}| \cos(\delta_i - \delta_j - \theta_{ij}) \quad (19)$$

$$Q_i = \sum_{j=1}^{n} |V_i V_j Y_{ij}| \sin(\delta_i - \delta_j - \theta_{ij}) \quad (20)$$

$$\frac{dQ_i}{dV_i} = 2|V_{ii}Y_{ii}|\cos(\theta_{ii}) + \sum_{\substack{j=1 \\ i\neq j}}^{n} |V_j Y_{ij}| \sin(\delta_i - \delta_j - \theta_{ij}) \quad (21)$$

$$\frac{dV_i}{dQ_i} = \frac{1}{\frac{dQ_i}{dV_i}} = \frac{1}{2|V_{ii}Y_{ii}|\cos(\theta_{ii}) + \sum_{\substack{j=1 \\ i\neq j}}^{n} |V_j Y_{ij}| \sin(\delta_i - \delta_j - \theta_{ij})} \quad (22)$$

The quantity of the load shedding from each bus can be calculated using:

$$P_{Shed,i} = \frac{\frac{dV_i}{dQ_i}}{\sum_{i=1}^{m} \frac{dV_i}{dQ_i}} P_{Shed} \quad (23)$$

Where: P_i, Q_i are the powers incoming to the i^{th} bus; V_i, V_j are the voltages at the i^{th} and j^{th} bus; Y_{ij} is the impedance matrix; δ_{ij} is the difference of the phase angle of the voltage at the i^{th} bus and j^{th} bus, θ_{ij} phase angle of line ij.

Depending on load bus voltage sensitivity (dV_i/dQ_i), equation (23) express the quantity of load to be shed from each bus, $P_{shed,\,i}$.

5. Procedure for load shedding program

The structure of the optimal load shedding program is summarized below:

Step 1: Read input data (initial voltages, voltage angle, active and reactive power of load bus and generation power).
Step 2: Run the load flow program and calculate the bus voltages of the system.
Step 3: Calculate the frequency of the system according to eq. (6).
Step 4: If the voltage is below (0.95 P.U) or/and the system frequency is below (49.5 Hz), then go to step 5, else No Load Shedding and print results and go to step 11.
Step 5: Calculate the optimal amount of load (active and reactive) to be shed according to eq. (18).
Step 6: Check if there is any load that is very important.
Step 7: Determine the optimal amount of load (active and reactive) to be shed from each bus has a load according to eq. (23).
Step 8: Print results (the voltages (V_{LS}) and the frequency (F_{LS})) after load shedding.
Step 9: If the voltages after load shedding (V_{LS}) is below (0.95 P.U) or/and the system frequency after load shedding (F_{LS}) is below (49.5Hz), return to step 5, else go to step 10.
Step 10: Print results.
Step 11: End.

The flowchart of the load shedding program is presented in Figure (2).

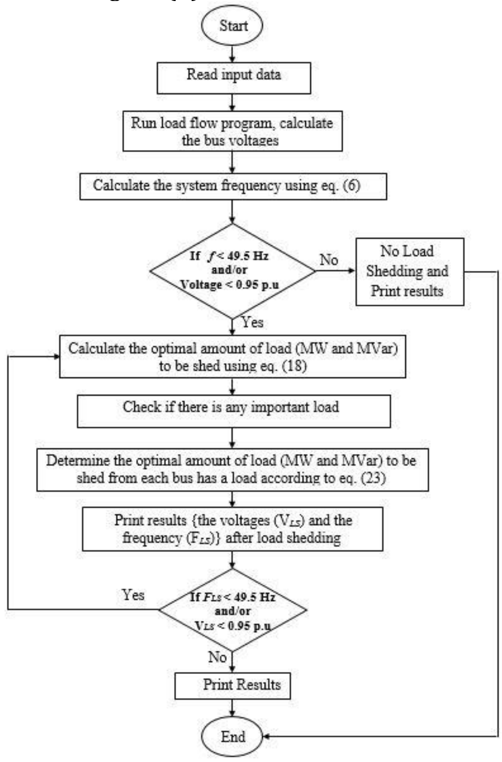

Fig.2 Flowchart algorithm load shedding based on frequency and voltage sensitivities

6. Application of the proposed algorithm on Iraqi power system

In this paper the proposed load shedding algorithm was applied on Iraqi power system, the transmission level in the Iraqi electrical network consists of 400 kV network and 132 kV network. This work is limited to the 400 kV network with its buses and transmission lines. The Iraqi Super grid (400 KV) has 33 buses, 18 as generation buses and 15 as load buses. For load flow solution the station (KUTP) at bus-19 is selected as a slack bus. Figure (3) shows the one line diagram of this network. Bus data, line data and generator data are tabulated in **appendix A**. the total system power is (10851.43 MW) and (3269.67 MVar) in normal situation and the nominal frequency is 50 Hz. All network data are expressed in per-unit referred to a common base voltage of 400 KV. Every generator has 3% of its capacity as a power reserve capacity. Assume that α = 2, and β = 2.

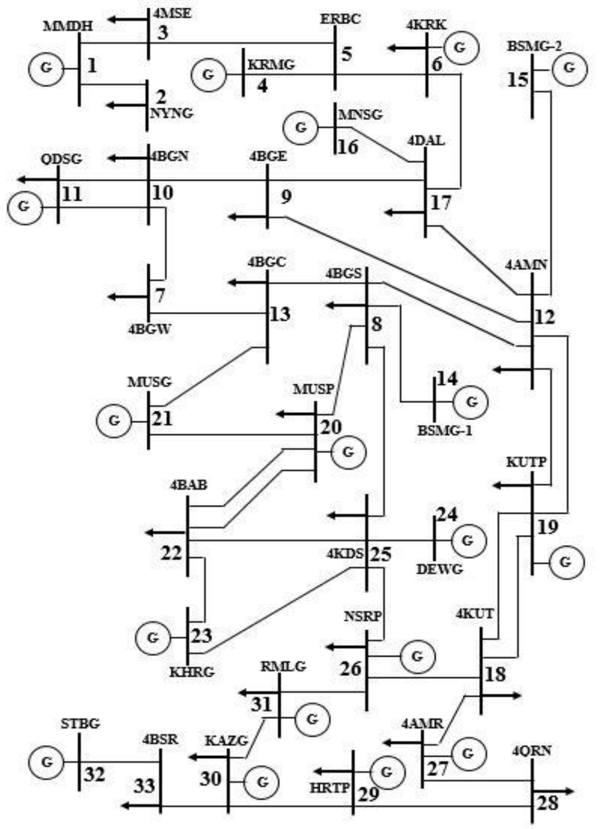

Fig.3 One line diagram of 400kV Iraqi power network

In this work, the occurrence of single contingency is considered. Different cases were applied with or without taking into account the importance of load, the analysis of the load shedding was applied as shown:

- **Case 1:** ***separation of generator from the system***

Generator BSNG-1 at bus-14 having (980 MW) and (284.9 MVar) was removed from the system. The frequency was dropped to (47.85 Hz). The total amount of load shedding was (729.21 MW) and (259.3 MVar). Table (1) shows the value of dV/dQ and the corresponding quantity of load shedding from each bus which having load despite being (generation or load) bus. The frequency of the system after shedding the load was (49.513 Hz).

Table 1 The results of tripping generator BSMG-1

Bus number	Bus name	dV_i/dQ_i	$P_{shed,i}$ (MW)	$Q_{shed,i}$ (MVar)
2	NYNG	0.0025	34.543	12.283
3	4MSE	0.0036	50.491	17.954
6	4KRK	0.0012	17.426	6.197
7	4BGW	0.0021	30.002	10.669
8	4BGS	0.0009	11.902	4.232
9	4BGE	0.0009	12.378	4.402
10	4BGN	0.0005	6.406	2.278
11	QDSG	0.0008	11.021	3.919
12	4AMN	0.0007	9.283	3.301
13	4BGC	0.0018	25.791	9.171
17	4DAL	0.0019	26.919	9.572
18	4KUT	0.0027	38.428	13.665
19	KUTP	0.0018	25.488	9.063
20	MUSP	0.0007	10.39	3.695
22	4BAB	0.0014	19.4	6.899
25	4KDS	0.0015	20.864	7.419
26	NSRP	0.0066	92.118	32.757
27	4AMR	0.0042	58.337	20.744
28	4QRN	0.0037	51.857	18.44
29	HRTP	0.0039	55.164	19.616
30	KAZG	0.0022	30.7	10.917
31	RMLG	0.0058	80.717	28.702
33	4BSR	0.0007	9.587	3.409

The variation of the bus voltages are showing in figure (4).

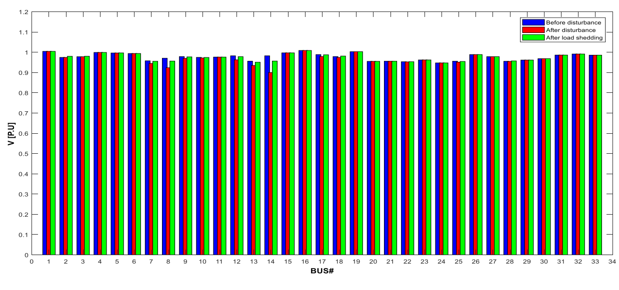

Fig.4 The change of bus voltages

In a special case when taking the importance of the load into account, assume the load at the bus-6 (4KRK) and bus-29 (HRTP) are very important; the total amount of load shedding is the same (729.21 MW) and (259.3 MVar). The load of this bus (4KRK) and bus (HRTP) were assumed to be constant. Table (2) shows the value of dV/dQ and the amount of load shedding from each bus. The frequency after load shedding was (49.513 Hz).

Table 2 The results of tripping generator BSMG-1 with taking the load of bus (4KRK) and bus (HRTP) are the important load

Bus number	Bus name	dV_i/dQ_i	$P_{shed,i}$ (MW)	$Q_{shed,i}$ (MVar)
2	NYNG	0.0025	38.362	13.641
3	4MSE	0.0036	56.072	19.939
6	4KRK	**0.0**	**0.0**	**0.0**
7	4BGW	0.0021	33.319	11.848
8	4BGS	0.0009	13.218	4.7
9	4BGE	0.0009	13.747	4.888
10	4BGN	0.0005	7.114	2.53
11	QDSG	0.0008	12.239	4.352
12	4AMN	0.0007	10.309	3.666
13	4BGC	0.0018	28.643	10.185
17	4DAL	0.0019	29.894	10.63
18	4KUT	0.0027	42.677	15.176
19	KUTP	0.0018	28.306	10.065
20	MUSP	0.0007	11.539	4.103
22	4BAB	0.0014	21.545	7.661
25	4KDS	0.0015	23.17	8.239
26	NSRP	0.0066	102.302	36.378
27	4AMR	0.0042	64.786	23.038
28	4QRN	0.0037	57.59	20.479
29	HRTP	**0.0**	**0.0**	**0.0**
30	KAZG	0.0022	34.094	12.124
31	RMLG	0.0058	89.64	31.875
33	4BSR	0.0007	10.647	3.786

The bus voltages changes are showing in the figure (5).

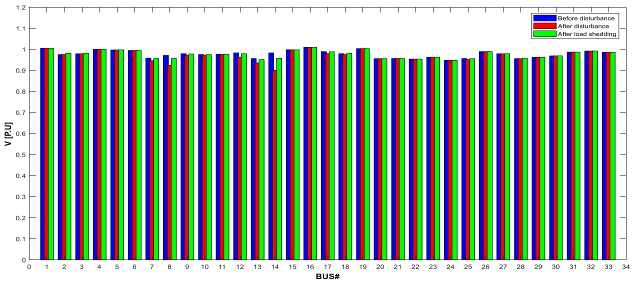

Fig. 5 The change of bus voltages

- **Case 2:** ***Separation of a transmission line***

The Transmission line 4BGC-MUSG (13-21) which is loaded with (319.6 MW) and (-50.42 MVar) was separated, the frequency was dropped to (49.48 Hz). The amount of load shedding should be (207.52 MW) and (64.92 MVar). Table (3) shows the values of dV/dQ and the amount of load shedding from each (generation or load) bus. The frequency after shedding the load was (49.5 Hz).

Table 3 The results of tripping transmission line (4BGC-MUSG)

Bus number	Bus name	dV_i/dQ_i	$P_{shed,i}$ (MW)	$Q_{shed,i}$ (MVar)
2	NYNG	0.0025	9.604	3.004
3	4MSE	0.0036	14.038	4.391
6	4KRK	0.0012	4.803	1.502
7	4BGW	0.0022	8.399	2.628
8	4BGS	0.0007	2.841	0.889
9	4BGE	0.0009	3.623	1.134
10	4BGN	0.0005	1.862	0.583
11	QDSG	0.0008	3.065	0.959
12	4AMN	0.0008	3.284	1.027
13	4BGC	0.0031	11.922	3.73
17	4DAL	0.002	7.793	2.438
18	4KUT	0.0024	9.44	2.953
19	KUTP	0.002	7.765	2.429
20	MUSP	0.0007	2.686	0.84
22	4BAB	0.0015	5.664	1.772
25	4KDS	0.0015	5.733	1.793
26	NSRP	0.0061	23.746	7.428
27	4AMR	0.0049	18.984	5.939
28	4QRN	0.0037	14.545	4.55
29	HRTP	0.0036	14.092	4.408
30	KAZG	0.0022	8.476	2.651
31	RMLG	0.0058	22.493	7.036
33	4BSR	0.0007	2.665	0.834

The voltages of the buses (before disturbance, after disturbance and after shedding the load) are show in the figure (6).

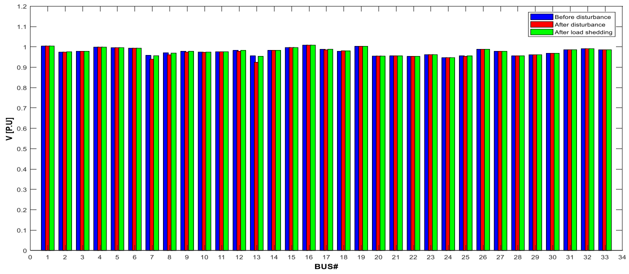

Fig. 6 The variation of the bus voltages

When taking the load at the bus-2 (NYNG) and bus-9 (4BGE) are very important, the total amount of load shedding is the same (207.52 MW) and (64.92 MVar). Table (4) shows the value of dV/dQ and the total load to be shed for each bus. The frequency after load shedding was (49.5 Hz).

Table 4 The results of tripping transmission line with (NYNG and 4BGE) as important load

Bus number	Bus name	dV_i/dQ_i	$P_{shed,i}$ (MW)	$Q_{shed,i}$ (MVar)
2	NYNG	**0.0**	**0.0**	**0.0**
3	4MSE	0.0036	14.994	4.69
6	4KRK	0.0012	5.13	1.605
7	4BGW	0.0022	8.971	2.806
8	4BGS	0.0007	3.034	0.949
9	4BGE	**0.0**	**0.0**	**0.0**
10	4BGN	0.0005	1.989	0.622
11	QDSG	0.0008	3.274	1.024
12	4AMN	0.0008	3.507	1.097
13	4BGC	0.0031	12.734	3.983
17	4DAL	0.002	8.324	2.604
18	4KUT	0.0024	10.083	3.154
19	KUTP	0.002	8.293	2.594
20	MUSP	0.0007	2.868	0.897
22	4BAB	0.0015	6.05	1.893
25	4KDS	0.0015	6.123	1.916
26	NSRP	0.0061	25.363	7.934
27	4AMR	0.0049	20.276	6.343
28	4QRN	0.0037	15.535	4.86
29	HRTP	0.0036	15.052	4.708
30	KAZG	0.0022	9.053	2.832
31	RMLG	0.0058	24.024	7.515
33	4BSR	0.0007	2.847	0.891

Figure (7) shown the change of the bus voltages

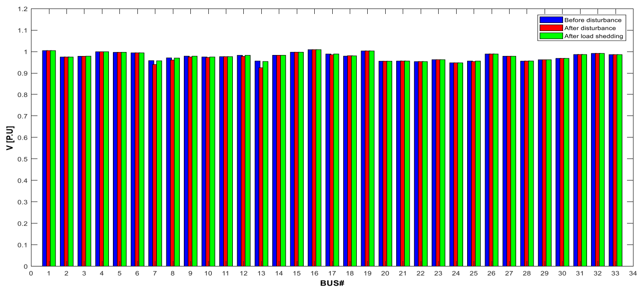

Fig. 7 The results of the bus voltages

Conclusions

Load shedding schemes are used in relieve system overload and correct the declining system frequency. This paper is focused on a load shedding scheme which corrects the system frequency and improves the voltage profile throughout any system. The total amount of load shedding was calculated by using the rate of frequency change, while the corresponding quantity of load to be shed from each bus was determined using voltage sensitivity. The voltage sensitivities formula enhanced the stability of the system by reducing the losses. The proposed load shedding was applied to the Iraqi Network, it was very effective in terms of frequency, and voltage improvement with the minimum amount of load shedding after the system was subjected a disturbance. When the important of loads were taken into account. It was very clear from the obtained results that the total amount of the shaded load, the system frequency and the busses voltages are almost the same values in both cases (with and without taking into account the important of the loads), but the amount of the shedding load from each bus having a load was different (larger).

References

P. Ajay-D-Vimal Raj and M. Sudhakaran, (2010), Optimum Load Shedding in Power System Strategies with Voltage Stability Indicators, *Engineering*, Vol. 2, No. 1.

Vladimir V. Terzija, (2006), Adaptive Underfrequency Load Shedding Based on the Magnitude of the Disturbance Estimation*, IEEE transactions on power systems*, Vol. 21, No. 3.

L.D. Arya, et al., (2012), Optimum load shedding based on sensitivity to enhance static voltage stability using DE, *Swarm and Evolutionary Computation*,Vol 6, P.P. 25-38.

Ardiaty Arief, (2014), Under Voltage Load Shedding Using Trajectory Sensitivity Analysis Considering dynamic Loads, *Universal Journal of Electrical and Electronic Engineering,*Vol. 2, No.3, P.P. 118-123.

Norazliani Md Sapari, (2017), Load shedding scheme based on frequency and voltage stability for an islanding operation of a distribution network connected to mini-hydro generation, *Turkish Journal of Electrical Engineering & Computer Sciences*, Vol. 25, PP. 1852-1863.

Suja Theresa James and Ancy Sara Varghese, (2016), Optimum Load Sheding Algorithm Based on Voltage Stability Index , *International Journal of Innovative Research in Technology (IJIRT)*, Vol. 3, Issue 3.

P. Kundur, (1994), Power System Stability and Control, *McGraw-Hill,Inc*.

Niranjan Behera, (2013), Load Frequency Control of Power System, *M.Sc Thesis, National Institute of Technology*, Odisha, India.

Zhichao Zhang, et al., (2014), Study on Emergency Load Shedding Based on Frequency and Voltage Stability , *International Journal of Control and Automation*, Vol.7, No. 2, PP. 119-130.

U. Rudez and R. Mihalic, (2011), Analysis of Under Frequency Load Shedding Using a Frequency Gradient, *IEEE Transactions on Power Delivery*, Vol. 26, No. 4, PP. 29-34.

Huy Anh Quyen, (2013), Optimal Load Shedding Based on Frequency, Voltage Sensitivities and AHP Algorithm, *Recent Advances In Electrical Engineering And Related Sciences(AETA)*, PP. 75-84.

Appendix A

Iraqi Super Grid Data (400 kV)

Table A.1 Bus data of Iraqi power system

Bus No.	Bus Name	Bus type	Voltage mag.(p.u)	Voltage angle	Load MW	Load MVar	Generation MW	Generation MVar
1	MMDH	PV	1.0044	0.0	0.0	0.0	240.0	0.0
2	NYNG	PQ	1.00	0.0	198.2	115.1	0.0	0.0
3	4MSE	PQ	1.00	0.0	403.2	273.0	0.0	0.0
4	KRMG	PV	0.9991	0.0	0.0	0.0	360.0	0.0
5	ERBC	PQ	1.00	0.0	0.0	0.0	0.0	0.0
6	4KRK	PV	0.9939	0.0	537.2	184.0	304.4	0.0
7	4BGW	PQ	1.00	0.0	571.8	115.1	0.0	0.0
8	4BGS	PQ	1.00	0.0	517.6	173.9	0.0	0.0
9	4BGE	PQ	1.00	0.0	303.4	-1.9	0.0	0.0
10	4BGN	PQ	1.00	0.0	674.2	77.0	0.0	0.0
11	QDSG	PV	0.9763	0.0	235.4	133.8	690.7	0.0
12	4AMN	PQ	1.00	0.0	647.1	243.9	0.0	0.0
13	4BGC	PQ	1.00	0.0	581.2	113.1	0.0	0.0
14	BSMG-1	PV	0.9825	0.0	0.0	0.0	980.0	0.0
15	BSMG-2	PV	0.9970	0.0	0.0	0.0	490.0	0.0
16	MNSG	PV	1.0088	0.0	0.0	0.0	325.0	0.0

17	4DAL	PQ	1.00	0.0	121.9	19.8	0.0	0.0
18	4KUT	PQ	1.00	0.0	526.0	401.8	0.0	0.0
19	KUTP	Slack	1.0028	0.0	631.7	199.3	–	–
20	MUSP	PV	0.9551	0.0	517.2	258.0	800.0	0.0
21	MUSG	PV	0.9558	0.0	0.0	0.0	166.3	0.0
22	4BAB	PQ	1.00	0.0	563.3	157.3	0.0	0.0
23	KHRG	PV	0.9621	0.0	0.0	0.0	746.0	0.0
24	DEWG	PV	0.9474	0.0	0.0	0.0	345.8	0.0
25	4KDS	PQ	1.00	0.0	408.5	84.0	0.0	0.0
26	NSRP	PV	0.9286	0.0	565.9	618.4	524.2	0.0
27	4AMR	PV	0.9783	0.0	317.0	66.8	345.8	0.0
28	4QRN	PQ	1.00	0.0	316.3	189.2	0.0	0.0
29	HRTP	PV	0.9616	0.0	339.6	156.6	116.5	0.0
30	KAZG	PV	0.9682	0.0	758.7	477.9	224.0	0.0
31	RMLG	PV	0.9862	0.0	383.4	187.9	980.4	0.0
32	STBG	PV	0.9914	0.0	0.0	0.0	769.0	0.0
33	4BSR	PQ	1.00	0.0	656.2	249.4	0.0	0.0

Table A.2 Line data of Iraqi power system

From Bus	Bus Name	To Bus	Bus Name	Line R (p.u)	Line X (p.u)	Charging B (p.u)
1	MMDH	2	NYNG	0.003142	0.028565	0.846365
1	MMDH	3	4MSE	0.002015	0.018321	0.542841
3	4MSE	5	ERBC	0.001409	0.012805	0.379405
4	KRMG	5	ERBC	0.000271	0.002462	0.072963
5	ERBC	6	4KRK	0.002449	0.022261	0.659581
6	4KRK	17	4DAL	0.004018	0.036387	1.080845
7	4BGW	10	4BGN	0.000932	0.008471	0.250991
7	4BGW	13	4BGC	0.000854	0.007167	0.219669
8	4BGS	12	4AMN	0.000966	0.008786	0.26033
8	4BGS	13	4BGC	0.001236	0.010125	0.313493
8	4BGS	14	BSMG-1	0.000365	0.002989	0.092544
8	4BGS	20	MUSP	0.00122	0.01015	0.31897
8	4BGS	25	4KDS	0.00308	0.02795	0.82827
9	4BGE	10	4BGN	0.00029	0.00262	0.07763
9	4BGE	12	4AMN	0.000779	0.006633	0.201972
9	4NGE	17	4DAL	0.000919	0.008192	0.24473
10	4BGN	11	QDSG	0.000185	0.001513	0.04685
10	4BGN	11	QDSG	0.000185	0.001513	0.04685
12	4AMN	15	BSMG-2	0.000775	0.006351	0.196656
12	4AMN	17	4DAL	0.001553	0.013464	0.406894
12	4AMN	19	KUTP	0.002338	0.020124	0.60997
12	4AMN	19	KUTP	0.002338	0.020124	0.60997
13	4BGC	21	MUSG	0.002307	0.019847	0.608338
16	MNSG	17	4DAL	0.002508	0.020548	0.63624
18	4KUT	19	KUTP	0.001728	0.01542	0.460381
18	4KUT	19	KUTP	0.001728	0.01542	0.460381
18	4KUT	26	NSRP	0.00432	0.03928	1.1639
18	4KUT	27	4AMR	0.00479	0.04354	1.28998
20	MUSP	21	MUSG	0.000125	0.001043	0.032791
20	MUSP	22	4BAB	0.00081	0.00673	0.21165
20	MUSP	22	4BAB	0.00081	0.00673	0.21165
22	4BAB	23	KHRG	0.000898	0.00736	0.22789
22	4BAB	25	4KDS	0.00233	0.01935	0.60812
23	KHRG	25	4KDS	0.002062	0.016897	0.523197
24	DEWG	25	4KDS	0.000604	0.00495	0.153276
25	4KDS	26	NSRP	0.00383	0.03485	1.03256
26	NSRP	31	RMLG	0.00346	0.031232	0.929646
27	4AMR	28	4QRN	0.00169	0.015366	0.455286
28	4QRN	29	HRTP	0.00122	0.011091	0.328623
29	HRTP	30	KAZG	0.00118	0.01076	0.3187
30	KAZG	31	RMLG	0.001488	0.013305	0.398479
30	KAZG	33	4BSR	0.000563	0.005122	0.151762
33	4BSR	32	STBG	0.000103	0.000841	0.026028

Table A.3 Machines data

Unit name	Bus number	Capacity of generating MW	moment of inertia H (sec)	The Speed drop Ra
MMDH	1	240	14.1	0.05
KRMG	4	360	10.281	0.05
4KRK	6	304.4	12	0.04
QDSG	11	690.7	55.5	0.04
BSMG-1	14	980	24	0.05
BSMG-2	15	490	12	0.05
MNSG	16	325	12	0.04
KUTP	19	2443.33	48	0.04
MUSP	20	800	20	0.05
MUSG	21	166.3	3	0.05
KHRG	23	746	54	0.04
DEWG	24	345.8	24	0.04
NSRP	26	524.2	38	0.05
4AMR	27	345.8	24	0.05
HRTP	29	116.5	9.5	0.04
KAZG	30	758.7	10	0.04
RMLG	31	980.4	24	0.04
STBG	32	769	48	0.04

Power Flow and Initial Values for Iraqi power system

Buses:	33
Lines:	43
Generators:	18
Loads:	15
Number of Iterations:	4

Table A.4 Power flow results of the Iraqi power system (400 KV)

Bus No.	Bus mane	Voltage mag.(p.u)	Angle Degree	Load MW	Load MVar	Generation MW	Generation MVar
1	MMDH	1.004	-16.302	0.0	0.0	240	158.7
2	NYNG	0.975	-19.48	198.2	115.1	0.0	0.0
3	4MSE	0.978	-16.568	403.2	273.0	0.0	0.0
4	KRMG	0.999	-13.409	0.0	0.0	360	67.564
5	ERBC	0.996	-13.908	0.0	0.0	0.0	0.0
6	4KRK	0.994	-13.817	537.2	184.0	304.4	139.445
7	4BGW	0.957	-12.11	571.8	115.1	0.0	0.0
8	4BGS	0.97	-7.006	517.6	173.9	0.0	0.0
9	4BGE	0.978	-9.481	303.4	-1.9	0.0	0.0
10	4BGN	0.975	-10.37	674.2	77.0	0.0	0.0
11	QDSG	0.976	-10.172	235.4	133.8	690.7	292.584
12	4AMN	0.982	-6.731	647.1	243.9	0.0	0.0
13	4BGC	0.955	-10.636	581.2	113.1	0.0	0.0
14	BSMG-1	0.983	-5.312	0.0	0.0	980	301.79
15	BSMG-2	0.997	-4.994	0.0	0.0	490	177.702
16	MNSG	1.009	-4.884	0.0	0.0	325	39.811
17	4DAL	0.988	-8.621	121.9	19.8	0.0	0.0
18	4KUT	0.969	-4.129	526.0	401.8	0.0	0.0
19	KUTP	1.003	0.0	631.7	199.3	2443.333	576.245
20	MUSP	0.955	-6.512	517.2	258.0	800	41.958
21	MUSG	0.956	-6.619	0.0	0.0	166.3	30.753
22	4BAB	0.953	-6.645	563.3	157.3	0.0	0.0
23	KHRG	0.962	-4.336	0.0	0.0	746	74.427
24	DEWG	0.947	-5.654	0.0	0.0	345.8	-99.796
25	4KDS	0.95	-6.779	408.5	84.0	0.0	0.0
26	NSRP	0.929	-8.417	565.9	618.4	524.2	203.982
27	4AMR	0.978	-10.35	317.0	66.8	345.8	162.472
28	4QRN	0.956	-12.659	316.3	189.2	0.0	0.0
29	HRTP	0.962	-12.284	339.6	156.6	116.5	135.474
30	KAZG	0.968	-11.102	758.7	477.9	224	112.369
31	RMLG	0.986	-7.105	383.4	187.9	980.4	390.163
32	STBG	0.991	-10.213	0.0	0.0	769	564.027
33	4BSR	0.986	-10.558	656.2	249.4	0.0	0.0
Total				10775	4493.4	10851.433	3369.67