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Impact on Long Duration of Overvoltage Due to Back-Feed Restoration of Distribution Network

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ABSTRACT

In power system, power outages can be critical; if the environment and public safety within risk situation. Therefore, restoration power is needed to respond on system distribution to reduce the power restoration time and making the system reliable and efficient. Backfeeding using a nearby feeder in a power system is proposed in this research. When a power outage occurred, the faulted area is isolated from the system and searching available nearby feeders that can restore the outage area without any violation. However, analysing the effects of using a nearby feeder for back feeding is needed to avoid voltage violations. This paper analyses the voltage during the healthy and faulted condition, the impact of using a nearby feeder for backfeeding for a full load, half load and during no-load conditions are examine and also determine the maximum increment limitation of a load during back-feed if a qualified feeder is selected. Newton Raphson method is applied to calculate the power flow in the system and observe the stability of backfeed configuration. The results show the highest voltage supply occur during no load followed by half load and lastly during full load. The maximum voltage increment of load on backfeed is determined to be 0.95pu as an ideal voltage value.

1. Introduction

In power flow study there will be an analysis of the system capability to adequately supply the connected load. Electrical power will be distributed to the loads through the cable line. If there is a fault in a distribution line, certain area will undergo power outage, so feeder system is important to make sure continuous power electrical supply.

When fault happen in a certain area, the power cut- off at the affected area. Avoiding this condition by using nearby feeder is the commonly used by connected the loss supply of substations to an electrical supply through a backfeeding. But the effect on the nearby feeder needs to be analyze before backfeed are applied. Normally affect such as either the nearby feeder can accommodate

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electrical burden of the faulted area or there is overvoltage occur due to the backfeeding. Analysis of overvoltage is highly important because it might damage the power system infrastructure and customer electrical equipment [1,15].

To date, many published studies exist regarding on power restoration in distribution network. Some of them focus on deterministic analysis to achieve back-feed power restoration. Restoration switching analysis (RSA) is used to produces a switching sequence that when executed based on the concept of network tracing [3,14]. This paper use both single-path and multi-path restoration and if the network are too busy and even the multi-path restoration cannot be supported the outage load, the algorithm tries to shed a minimal load while restoring as many other loads as possible.

Some research considers the using of distribution generation (DG) to achieve power restoration because the energy loss can be reduced, reduce the restoration time and improve the reliability of the system. During power outage, islanding occurs which the network is isolated from the main system and supplies by local DG. During islanding mode, DG can maintain the voltage and frequency, follow load changes and also stay stable in large load switching. Genetic algorithm method is used to allocate simultaneously DG and remote controllable switch in electric distribution [2].

There are studies on the effect overvoltage due to current backfeeding and various method to mitigate it [1,16]. The network is studied under 3 different conditions which are at peak load, minimum load and also network at no load. To analyze the overvoltage, time-domain simulation is performed using an Electromagnetic Transient Program and it is assuming as overvoltage when it is above 3pu. To mitigate the overvoltage, shunt reactor which is aimed to reduce the Ferranti effect and to limit or eliminate completely the spike produced by the underdamped behavior of the remaining circuit after the disconnection of the last network protection. However, in this journal only focus on the effect of overvoltage in backfeeding current and the ways to mitigate it without knowing how much the maximum capacity of the load in each feeder can be backfeed to the faulted load.

The main contribution of this paper is to find the feed voltage for 33 bus system and to study the effects of using nearby feeder for backfeeding in 3 conditions which are on full load mode, half load mode and also during no load. To find the feed voltage, the power flow analysis by using Newton Raphson method has been used. To continue with the condition for faulted bus and the connection of possible tie line available for backfeed feeder, the main coding by using MATLAB is created. Other than that, the maximum increment limitation of load on a back-feed also can be determine by setting the limit for backfeed voltage should be ±5% from the reference voltage.

2. Methodology

2.1 Circuit Configuration

Figure 1 shows the circuit diagrams used in this project based on 33-bus system in the distribution network. The distribution network will deliver electrical energy from the transmission line to the load while transforming to a suitable application. Based on the Figure 1, the distribution started with the first level of distribution primary network with a 33kV or 11kV. Then it is followed by Distribution primary substation that distributed power by stepping down 33kV voltage to 11kV voltage as a second level of distribution primary network. The low voltage substation will step down the 11kV voltage to 415V which are the main source of power supply to the consumers.

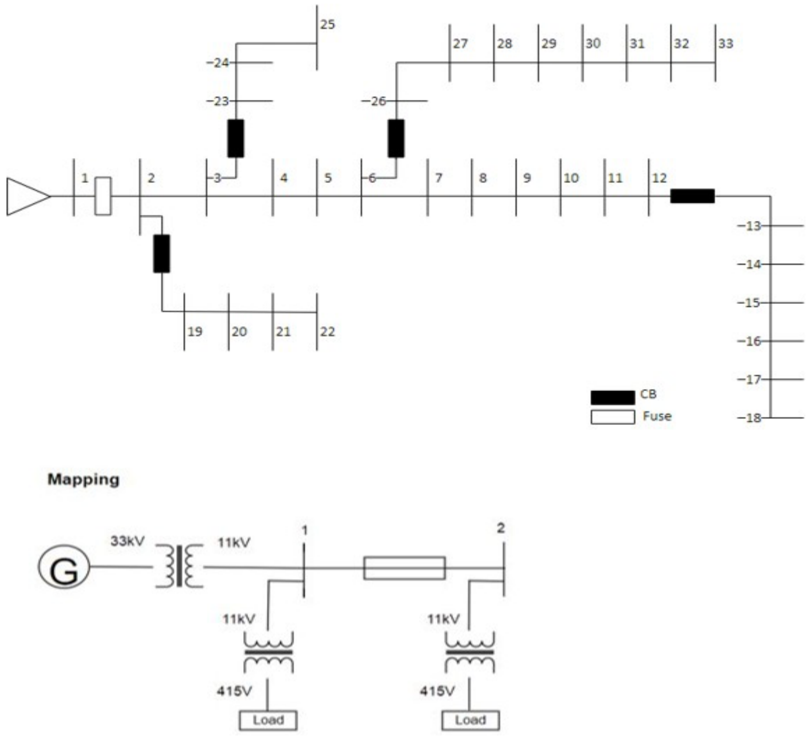

Fig. 1. Circuit diagram for 33-bus system without tie line

Tie line with switches has been inserted in the circuit diagram which act as a possible restoration location during backfeed. The switch on the open mode during healthy condition while if the power outage occur the switch will close for backfeed based on the optimum location of substation.

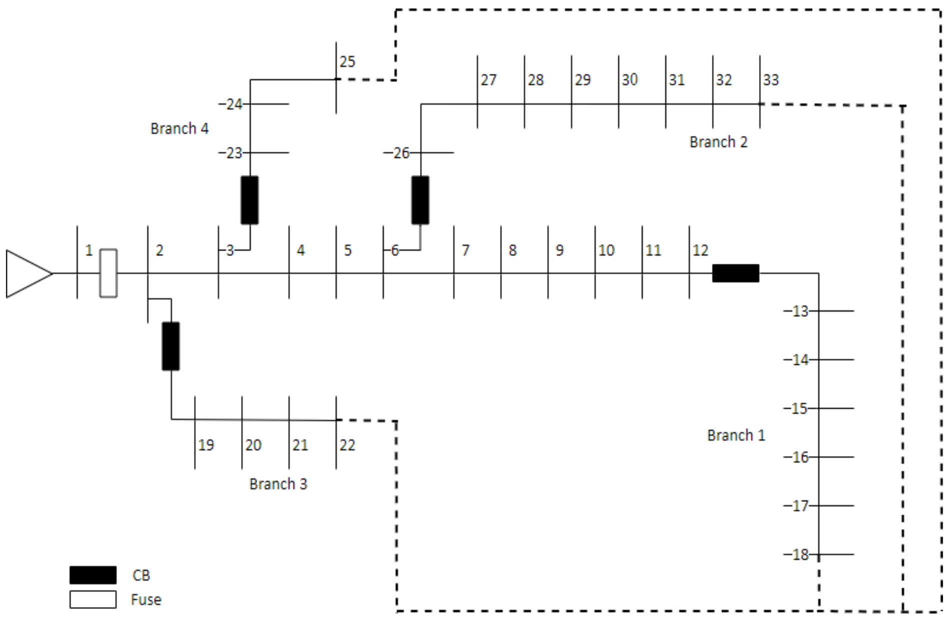

Fig. 2. Circuit diagram for 33-bus system with tie line

2.2 Newton Raphson Power Solution

Newton- Raphson method is the most widely used for solving simultaneous nonlinear algebraic equation. Newton Raphson method is known to be more efficient and practical compare to other method especially for large power systems [12]. The number of iterations required to obtain a solution is dependent on the system size, but more functional evaluations are required at each iteration [12,13]. The first steps, the real and imaginary part need to be separated based on the formula below:

$$P_i = |V_i||V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) \quad (1)$$

$$Q_i = |V_i||V_j||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) \quad (2)$$

The next step, the Jacobian matrix which gives the linearized relationship between small changes in voltage angle $\Delta\delta i^{(k)}$ and voltage magnitude $\Delta| Vi^{(k)} |$ with the small changes in real and reactive power $\Delta Pi^{(k)}$ and $\Delta Qi^{(k)}$ is constructed. Element of the Jacobian matrix are the partial derivatives of (1) and (2), evaluated at $\Delta\delta i^{(k)}$ and $\Delta| Vi^{(k)} |$

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \quad (3)$$

The term $\Delta Pi^{(k)}$ and $\Delta Qi^{(k)}$ are different between the scheduled and calculated value, known as the power residuals, given by:

$$\Delta P_i^{(k)} = P_i^{sch} - P_i^{(k)} \quad (4)$$

$$\Delta Q_i^{(k)} = Q_i^{sch} - Q_i^{(k)} \quad (5)$$

The new estimate for bus voltage is:

$$\delta_i^{(k+1)} = \delta_i^{(k)} - \Delta\delta_i^{(k)} \quad (6)$$

$$V_i^{(k+1)} = V_i^{(k)} - \Delta V_i^{(k)} \quad (7)$$

2.3 Software Programming

MATLAB software has been used as a medium to calculate power flow in 33 bus system. The program starts with created the power flow program by using the data in Table 1 and Table 2 followed by method of solution consists of four programs which are Ifybus, busout, lineflow and Ifnewton.

i. *Ifybus program:* Converts impedances to admittance and obtains the bus admittance matrix.
ii. *Ifnewton program:* To obtain power flow solution by using Newton- Raphson method and it require busdata and linedata.
iii. *Busout program*: Produces the bus output result. The bus output result includes the voltage magnitude and angle, real and reactive power of generators and loads, and the shunt capacitor/reactor Mvar.
iv. *Lineflow program:* Prepares the line output data. It is designed to compute and display the line flow and losses

Busdata program is the information required in a matrix form to facilitate the required data for each bus in a single row. The information required includes bus number, bus code, voltage magnitude in per unit and phase angle in degree, load in MW and Mvar, generation in MW, Mvar, minimum

Mvar and maximum Mvar and lastly shunt capacitor injected in Mvar. The bus code is inserted for identify load, voltage-controlled or slack bus. Code 1 is defined for slack bus while code 0 is for load buses and code 2 is for voltage-controlled buses.

Table 1
Load value (MV)

Bus	Load	Bus	Load	Bus	Load	Bus	Load
2	0.1	10	0.06	18	0.5	26	0.06
3	0.09	11	0.045	19	0.09	27	0.06
4	0.12	12	0.06	20	0.09	28	0.06
5	0.06	13	0.06	21	0.09	29	0.12
6	0.06	14	0.12	22	0.09	30	0.2
7	0.2	15	0.06	23	0.09	31	0.15
8	0.2	16	1	24	0.42	32	0.21
9	0.06	17	1	25	0.42	33	0.06

Table 2
Line data

From	To	$R_1(\Omega)$	$X_1(\Omega)$	λ(f/yr)	r(h)	From	To	$R_1(\Omega)$	$X_1(\Omega)$	λ(f/yr)	r(h)
1	2	0.0922	0.047	0.6	6	3	15	0.591	0.526	0.06	3
2	3	0.493	0.2511	0.6	6	15	16	0.7463	0.545	0.06	3
2	19	0.164	0.1565	0.6	6	16	17	1.289	1.721	0.06	3
3	4	0.366	0.1864	0.06	3	17	18	0.732	0.574	0.06	3
3	23	0.4512	0.3083	0.6	6	19	20	1.5042	1.3554	0.6	6
4	5	0.3811	0.1941	0.06	3	20	21	0.4095	0.4784	0.6	6
5	6	0.819	0.707	0.06	3	21	22	0.7089	0.9373	0.6	6
6	26	0.203	0.1034	0.6	6	23	24	0.898	0.7091	0.6	6
6	7	0.1872	0.6188	0.06	3	24	25	0.896	0.7011	0.6	6
7	8	1.7114	0.12351	0.06	3	26	27	0.2842	0.1447	0.6	6
8	9	1.03	0.74	0.06	3	27	28	1.059	0.9337	0.6	6
9	10	1.044	0.74	0.06	3	28	29	0.8042	0.7006	0.6	6
10	11	0.1966	0.065	0.06	3	29	30	0.5075	0.2585	0.6	6
11	12	0.3744	0.1238	0.06	3	30	31	0.9744	0.963	0.6	6
12	13	1.468	1.155	0.06	3	31	32	0.3105	0.3619	0.6	6
13	14	0.5416	0.7129	0.06	3	32	33	0.341	0.5302	0.6	6

Linedata program are identified by the node-pair method and also required in the matrix form. Line data program include the line bus number, line resistance, reactance and one-half of the total line charging susceptance in per unit on the specified MVA base and the transformer tap setting.

After the voltage in the 33-bus system was obtained via Newton-Raphson method the coding was proceed with the main coding where the fault is insert. During faulted condition, the current for the faulted line and the connected line will become zero. The coding was created based on the circuit design in Figure 1. Any location could be selected as a faulted line setup in MATLAB for testing purposes. Possible option available for backfeed current will be selected by brute force method (testing all possible location and select the optimum location) for restoration [14]. At this stage, tie line will be used as a switch where during healthy condition the switch is in open mode while during the faulted condition one of the available possible switches will be closed to supply the current backfeeding for restoration. So, the faulted area will be restored and will be back to normal condition. The power flow program consists of four programs which are lfybus, busout, lineflow and lfnewton will be calling back to calculate the feed voltage after the system have been restored.

After the restoration power have been done, coding for the effects of using nearby feeder for backfeeding in 3 conditions which are full load mode, half load mode and also during no load has been continue. During full load, the load in the busdata program will be increase to 1 and during no load the load in busdata program will be set to zero. When the value of load data has been changed, power flow program is call again to calculate the feed voltage and the result of 3 different condition of load will be analyse.

3. Results and Discussion

3.1 Healthy Distribution Network

Simulation by MATLAB software has been performed where the power flow program has been used to calculate the 33bus system to obtain the voltage value. The value of voltage during healthy condition shown in Table 3 and has been plot in the Figure 3. The voltage of each the substation from 4 branches of the feeder within the limit. The minimum voltage occurs at substation 13 with 0.9372 p.u.

Table 3
Pre-backfeed restoration (before restoration with healthy condition)

Bus	Voltage (pu)	Bus	Voltage (pu)
1	1.0000 + 0.0000i	18	0.9520 - 0.0114i
2	0.9958 - 0.0002i	19	0.9932 - 0.0008i
3	0.9804 - 0.0017i	20	0.9719 - 0.0051i
4	0.9745 - 0.0021i	21	0.9661 - 0.0069i
5	0.9690 - 0.0027i	22	0.9564 - 0.0104i
6	0.9563 - 0.0070i	23	0.9738 - 0.0033i
7	0.9534 - 0.0103i	24	0.9614 - 0.0074i
8	0.9434 - 0.0124i	25	0.9542 - 0.0103i
9	0.9403 - 0.0132i	26	0.9553 - 0.0071i
10	0.9379 - 0.0139i	27	0.9540 - 0.0074i
11	0.9376 - 0.0139i	28	0.9497 - 0.0094i
12	0.9373 - 0.0139i	29	0.9470 - 0.0106i
13	0.9372 - 0.0144i	30	0.9462 - 0.0110i
14	0.9379 - 0.0144i	31	0.9524 - 0.0161i
15	0.9395 - 0.0144i	32	0.9519 - 0.0145i
16	0.9420 - 0.0144i	33	0.9521- 0.0117i
17	0.9485 - 0.0119i		

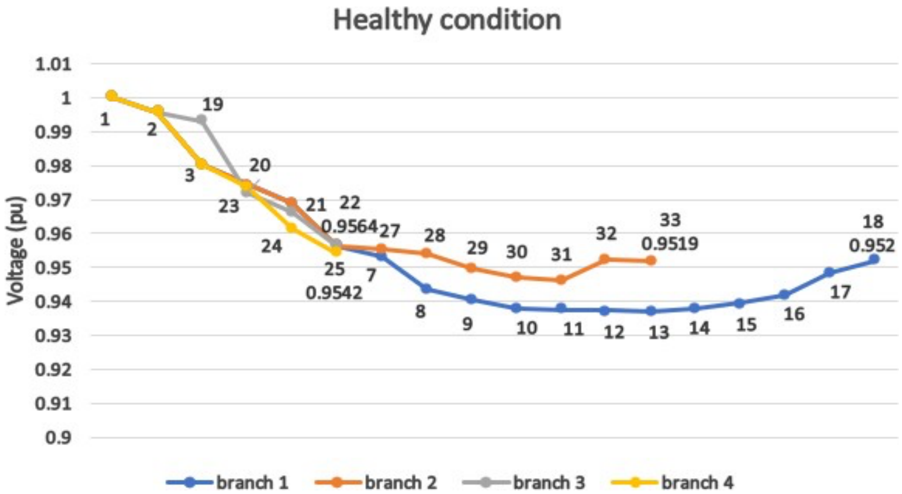

Fig. 3. Output voltage (healthy condition)

3.2 Faulted Distribution Network

The main coding program was created for the faulted condition and to analyze the effect of voltage value due to current backfeeding. User can select the faulted line and any possible option available for backfeed restoration. Table 4 shows the voltage result during backfeeding for each option available and under 3 conditions. When line data number 12 under fault there were 3 possible option available for backfeed which were from branch 2 (Option 1), branch 3 (Option 2) and branch 4 (Option 3). During the faulted condition, one of the available switches will be closed to supply the current backfeeding as the restoration power. For line 12, option 2 was the most stable feeder for backfeed due to the higher voltage stabilities selected compare to the others available branches. The minimum value of voltage during full load, half load and no load if connected to the branch 3 option 2 is 0.8390 p.u, 0.9323 p.u and 0.9442 p.u respectively.

Table 4
Post backfeed restoration

Faulted line		**Voltage at faulted bus during backfeed (pu)**											
		Option 1			**Option 2**			**Option 3**			**Option 4**		
Bus from	**Bus to**	**Full load**	**Half load**	**No load**	**Full load**	**Half load**	**No load**	**Full load**	**Half load**	**No load**	**Full load**	**Half load**	**No load**
1	2	No available feeder											
		connect to branch1			connect to branch 2			connect to branch 4					
2	3	0.9368	0.9782	0.9836	0.9485	0.9786	0.9822	0.9331	0.9768	0.9825	-	-	-
		connect to branch1			connect to branch 2			connect to branch1			connect to branch2		
3	4	0.9034	0.9702	0.9788	0.9239	0.9708	0.9764	0.8935	0.9660	0.9754	0.9028	0.9660	0.9740
4	5	0.8693	0.9624	0.9745	0.8989	0.9633	0.9710	0.8582	0.9577	0.9706	0.8770	0.9577	0.9677
5	6	0.7925	0.9446	0.9639	0.8431	0.9460	0.9582	0.7783	0.9385	0.9588	0.8188	0.9383	0.9527
		connect to branch2			connect to branch 3			connect to branch 4					
6	7	0.7454	0.9239	0.9465	0.7921	0.9420	0.9506	0.7782	0.9239	0.9425	-	-	-
7	8	0.7037	0.9059	0.9320	0.7997	0.9336	0.9506	0.7782	0.9239	0.9425	-	-	-
8	9	0.6823	0.8981	0.9263	0.8077	0.9316	0.9474	0.7828	0.9203	0.9379	-	-	-
9	10	0.6617	0.8912	0.9214	0.8168	0.9303	0.9448	0.7883	0.9175	0.9340	-	-	-
10	11	0.6583	0.8902	0.9208	0.8185	0.9303	0.9445	0.7895	0.9172	0.9335	-	-	-
11	12	0.6522	0.8885	0.9198	0.8220	0.9303	0.9441	0.7920	0.9168	0.9327	-	-	-
12	13	0.6274	0.8823	0.9163	0.8390	0.9323	0.9442	0.8040	0.9164	0.9308	-	-	-
13	14	0.6181	0.8803	0.9154	0.8468	0.9338	0.9450	0.8096	0.9169	0.9307	-	-	-
14	15	0.6102	0.8796	0.9157	0.8557	0.9365	0.9468	0.8165	0.9186	0.9317	-	-	-
15	16	0.6011	0.8793	0.9167	0.8671	0.9401	0.9494	0.8255	0.9211	0.9333	-	-	-
16	17	0.5862	0.8802	0.9199	0.8915	0.9492	0.9567	0.8447	0.9277	0.9384	-	-	-
17	18	0.5789	0.8812	0.9221	0.9040	0.9541	0.9605	0.8550	0.9314	0.9412	-	-	-
		connect to branch1			connect to branch 2			connect to branch 4					
2	19	0.9842	0.9933	0.9945	0.9802	0.9932	0.9950	0.9855	0.9939	0.9949	-	-	-
19	20	0.9494	0.9752	0.9785	0.9082	0.9740	0.9833	0.9625	0.9804	0.9827	-	-	-
20	21	0.9398	0.9703	0.9743	0.8878	0.9688	0.9802	0.9562	0.9769	0.9796	-	-	-
21	22	0.9235	0.9626	0.9676	0.8523	0.9605	0.9756	0.9459	0.9715	0.9748	-	-	-
		connect to branch1			connect to branch 2			connect to branch 3					
3	23	0.9152	0.9660	0.9725	0.9317	0.9732	0.9786	0.9040	0.9660	0.9743	-	-	-
23	24	0.8900	0.9493	0.9570	0.9302	0.9669	0.9717	0.8559	0.9495	0.9622	-	-	-
24	25	0.8707	0.9381	0.9469	0.9342	0.9660	0.9702	0.8136	0.9385	0.9556	-	-	-
		connect to branch1			connect to branch 3			connect to branch 4					
6	26	0.7382	0.9259	0.9496	0.8330	0.9453	0.9585	0.8084	0.9371	0.9525	-	-	-
26	27	0.7184	0.9222	0.9481	0.8220	0.9444	0.9589	0.7969	0.9356	0.9524	-	-	-
27	28	0.6527	0.9079	0.9410	0.7925	0.9420	0.9607	0.7648	0.9305	0.9514	-	-	-
28	29	0.6121	0.8977	0.9358	0.7792	0.9409	0.9622	0.7496	0.9273	0.9507	-	-	-
29	30	0.5943	0.8929	0.9334	0.7765	0.9410	0.9633	0.7462	0.9263	0.9507	-	-	-
30	31	0.5756	0.8907	0.9336	0.7906	0.9498	0.9718	0.7580	0.9326	0.9567	-	-	-
31	32	0.5700	0.8871	0.9303	0.7960	0.9500	0.9715	0.7623	0.9319	0.9554	-	-	-
32	33	0.5680	0.8837	0.9264	0.8070	0.9513	0.9712	0.7718	0.9320	0.9540	-	-	-

The analysis was continuing to study the effect of voltage due to current backfeeding for 3 conditions which are full load, half load and also during no load. The condition is assumed to be full load when the load of the available feeder for backfeed is operated at maximum, half load is when the load of the available feeder for backfeed is operate at medium load and also during no load. Based on the result demonstrates, the largest voltage supply during backfeed occur during no load followed by during half load and lastly during full load. For the maximum increment limitation of load on back-feed was determined by limit the value of voltage to 0.95pu. The system is assumed unstable when the voltage drops below 0.95pu. When the voltage dropped below 0.95pu during back-feed, the other option of available nearby feeder will be considerate to make sure the supply power restoration is stable for the whole power system.

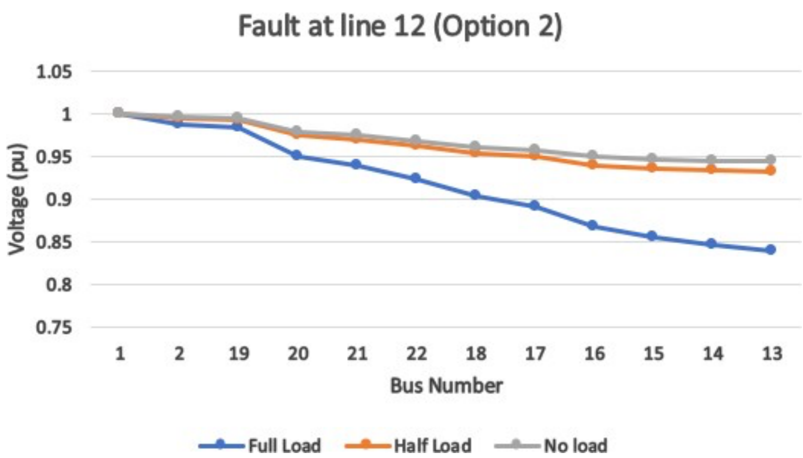

Fig. 4. Output voltage (post-backfeed)

4. Conclusions

To be conclude, all the objectives of this project have been achieved. For the value of voltage during healthy and faulted condition, Newton Raphson method has been used to obtain power flow solution. The effect of voltage due to current backfeeding for 3 conditions which are full load, half load and also during no load also has been successfully analyze. The result shows that, the largest voltage supply during backfeed occur during no load followed by during on off half load and lastly during on off full load. For the third objective, maximum voltage increment of load on backfeed is determined to be 0.95pu as the idea voltage value. The system is assumed unstable when the voltage drops below 0.95pu. When the voltage dropped below 0.95pu during back-feed, the other option of available nearby feeder will be considerate to make sure the supply power restoration is stable for the whole power system. All the program include power flow program and main program is successfully code by using MATLAB software programming. For the future planning, extra load or some internal or external disturbance can be added in the circuit to reach and analyze the overvoltage.

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